Wm. A. Anthony

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

VOL. IX. NEW YORK CITY, JANUARY, 1892. No. 1.

REGULAR MEETING, JAN. 19th, 1892.

The meeting was called to order at 8.15 P. M. by Vice-President Thomas D. Lockwood.

The Secretary read the following list of Associate Members elected by Council, January 19th:

Name.	Address.	Endorsed by
BARBERIE, E. T.	Electrician, Safety Insulated Wire Co., 234 W. 29th St., New York City.	Wm. Maver, Jr. Chas. Cuttriss. G. A. Hamilton.
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McCARTHY, LAWRENCE A.	Western Union Telegraph Co., New York City, 1053 Bedford Ave., Brooklyn, N. Y.	Alfred S. Brown. Geo. H. Stockbridge. Wm. Maver, Jr.
MACFARLANE, ALEXANDER	Professor of Physics, University of Texas, Austin, Texas.	E. L. Nichols. H. J. Ryan. Ernest Merritt.
MOLERA, E. J.	Civil Engineer, 40 California St., San Francisco, Cal.	T. C. Martin. Joseph Wetzler. Ralph W. Pope.
PAGE, A. D.	Assistant Manager, Edison General Electric Co. Lamp Works, Harrison, N. J.	F. R. Upton. John W. Howell. H. Ward Leonard
READ, ROBERT H.	Patent Attorney, with Electrical Review, 13 Park Row, New York City.	S. S. Wheeler. Chas. S. Bradley. Ralph W. Pope.

WEBSTER, DR. ARTHUR G.	Docent in Physics, Clark University, Worcester, Mass.	M. I. Pupin. F. B. Crocker. Louis Bell.
WILLIAMS, WILLIAM PLUMB	Electrical Engineer, Nicholson Electric Hoisting Company, Box 147, Cleveland, Ohio.	T. C. Martin. G. M. Phelps. Franklin L. Pope.
WILSON, HARRY C.	Supt. of P. O. Telegraph, with the Government, Kingston, Jamaica, West Indies.	T. C. Martin. Nikola Tesla. Thos. D. Lockwood.

Total, 12.

THE CHAIRMAN:—[Vice-President Lockwood.] The Institute has every reason to congratulate itself on the accessions to its membership which it is now receiving. It is a matter to be lamented that the weather, which may be properly characterized by the same description that Shakespeare gave to the late lamented Cleopatra, namely that "Age cannot wither, nor custom stale, its infinite variety," has prevented a large audience at the beginning of our proceedings. But what we lack in quantity we must make up in intensity of hearing—if you will pardon the use of the old terms. The subject that we have to-night before us, and which you will find so ably dealt with by Mr. Steinmetz, relates to that phenomenon of molecular friction, which Mr. Ewing has denominated "hysteresis." Mr. Ewing, as we all know, has made the subject so peculiarly his own, that one might at first suppose there was nothing new to be known about it; but I am confident that after this paper is read, those of us who read it with Mr. Steinmetz will find that there is something new under the sun. We will now hear Mr. Steinmetz's paper.

A paper read at the sixty-third meeting of the American Institute of Electrical Engineers, New York, January 19th, 1892. Vice-President Lockwood in the Chair.

ON THE LAW OF HYSTERESIS.

BY CHAS. PROTEUS STEINMETZ.

In the number 137, of December 17th, 1890, of the *Electrical Engineer* I published a short article under the title "Note on the Law of Hysteresis," where I showed that in a set of determinations of the loss of energy due to hysteresis by reversals of magnetism, for different magnetizations, made by Ewing, this loss of energy due to hysteresis can fairly well be expressed by the equation:

$$H = \eta B^{1.6},$$

where H is the energy consumed by hysteresis during one magnetic cycle, in ergs per cubic centimetre, B the magnetization in lines of magnetic force per square centimetre, and η ([1]) a numerical coefficient, in this case = .002.

Considering that even the simple law of magnetism—that is, the dependence of the magnetization B upon the magneto-motive force F (for instance, in ampere turns per centimetre length of the magnetic circuit) has until now defied all attempts of mathematical formulation, it appeared a strange feature that the apparently much more intricate phenomenon of hysteresis, or rather of the consumption of energy by hysteresis, should yield to analyti-

1. If any quantity has a right to be called "magnetic resistance," it is this coefficient η; for η is the *coefficient of conversion of magnetic energy into heat*, while as "electric resistance" we define the *coefficient of conversion of electric energy into heat*.

The term generally denoted "magnetic resistance"—that is, the inverse value of magnetic conductivity, does not deserve this name at all, but is more properly called "reluctance."

cal formulation in such a simple way, to be directly proportional to the 1.6th power of the magnetization. At the same time the coincidence of Ewing's tests with the curve of the 1.6th power was near enough to be considered as something more than a mere incident, but at least as a clue to a law of hysteresis, the more as this law held not only for low and medium magnetization, but even for very high saturation, without showing any kink at that point where the magnetic characteristic goes over the bend or "knee" and thereby entirely changes its shape, nor any marked tendency of deviation of the extremest observed values from the calculated curve.

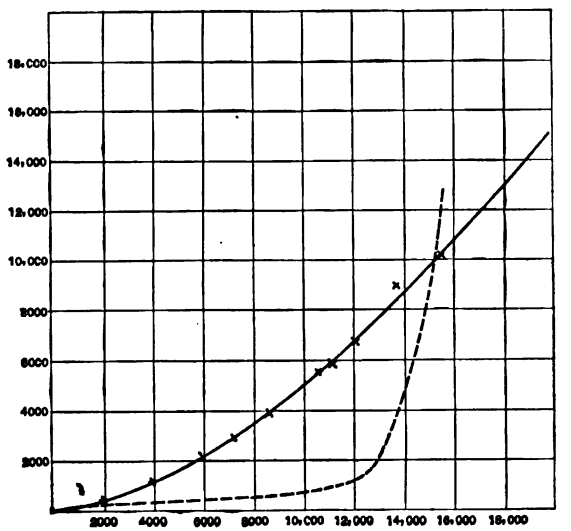

Fig. 1.

In Fig. 1 and Table I, I give from the article referred to, the calculated curve of hysteretic loss, as a drawn line, with Ewing's tests marked as crosses, and in dotted line the curve of magnetomotive force F, corresponding to the different magnetizations, as abscissæ.

In the table, I:

F = the M. M. F., in absolute units,

B = the magnetization, in lines of magnetic force per square centimetre,

H_{obs} = the observed values, and

H_{calc} = the calculated values of hysteretic loss, in ergs per cubic centimetre,

$H_{calc} - H_{obs}$ = the difference between both, in ergs and in percentages.

TABLE I.

F:	B:	H_{obs}:	H_{calc}:	$H_{calc} - H_{obs}$: =	%:
1.50	1,974	410	375	+ 35	+ 8.5
1.95	3,830	1160	1082	+ 58	+ 5.0
2.56	5,950	2190	2190	......	......
3.01	7,180	2940	2956	− 16	− .5
3.76	8,790	3990	4080	− 90	− 2.3
4.96	10,590	5560	5510	+ 50	+ .9
6.62	11,480	6160	6260	−100	− 1.7
7.04	11,960	6590	6690	−100	− 1.5
26.5	13,700	8690	8310	+380	+ 4.4
75.2	15,560	10,040	10,190	−150	− 1.5
				Av: ± 98 =	± 2.6

To study more completely this phenomenon of hysteresis and of the energy consumption caused thereby, I endeavored to make a number of determinations with different magnetic circuits and at different magnetizations.

To be enabled to carry out these experiments, I am highly obliged to Mr. Rudolph Eickemeyer, of Yonkers, N. Y., who, being greatly interested in the laws of the magnetic circuit and having done considerable work himself in this branch of electrical science, not only put the large facilities of his well-known factory at my disposal, but also guided the experiments with his valuable advice. A part of the instruments used in the tests are of Mr. Eickemeyer's invention and covered by his patents.

To be able to deal not only with the small amounts of energy which the reversal of magnetism in a tiny bit of iron wire sends through the ballistic galvanometer, but to reduce the determinations to readings of considerable power-values, and where a much greater exactness can be reached, and at the same time to determine the dependence of the hysteretic loss of energy upon the velocity of the magnetic cycles, I decided to use alternating currents, at least as far as this could be done, whereby the determination of the energy consumed by hysteresis is reduced to a simultaneous wattmeter, voltmeter, ammeter and speed reading.

At the same time this electro-dynamometer method has the advantage that the magnetic cycle is completed in a steady, continuous motion, while in the ballistic method the magnetic cycle is completed by sudden changes in the magnetization, which jumps from point to point, to enable the production of the induced current. This feature introduces an error into the ballistic method, for if a magnetic cycle is gone through by sudden changes, a larger amount of energy may be consumed than if the magnetization varies steadily in harmonic vibration.

Suppose, around a magnetic circuit, an alternating current of N complete periods per second is sent in n convolutions.

Let C = the effective strength of the current,

E = the effective E. M. F. induced in the circuit by self-induction, after subtracting the E. M. F.'s induced by the self-induction of the instruments,

W = the energy consumed in the circuit, after subtracting the energy consumed by the electric resistance,

Then, l being the length and s the cross-section of the magnetic circuit, all in centimetres, amperes, volts, watts, etc.,

Let B = the maximum magnetization in lines of magnetic force per square centimetre,

H = the loss of energy by hysteresis, in ergs per cycle and cubic centimetre; it is

$$W = l\,s\,N\,H \times 10^{-7}$$

hence

$$H = \frac{W}{l\,s\,N} \times 10^{+7}$$

the hysteretic loss of energy, and

$$E = \sqrt{2}\,\pi\,s\,B\,N\,n \times 10^{-8}$$

hence

$$B = \frac{E \times 10^{+8}}{\sqrt{2}\,\pi\,s\,N\,n} \quad (^1)$$

the maximum magnetism.

For higher frequencies, 80 to 200 periods per second, the alternating current was derived from a 1 H. P. 50 volt Westinghouse dynamo. This was driven by a 3 H. P. Eickemeyer continuous current motor. By varying the excitation of the motor field and

1. This formula holds rigidly only for the sine-wave, but as shown in the following, the currents used in the tests were at least very near sine-waves. Besides, a deviation from the sine shape would not alter the results at all, but only slightly change the coefficient η.

varying the E. M. F. supplied to the motor, the speed and therefore the frequency of the alternating current could be varied in wide limits. At the same time, supplied with constant E. M. F. and like all the Eickemeyer motors of unusually small armature reaction, this electromotor kept almost absolutely constant speed under varying load, the more as it never ran with full load.

For low frequencies, this bipolar continuous current motor was used as a bipolar alternating dynamo, as shown in a patent of Mr. Stephen D. Field. On the continuous current commutator two sliding rings were mounted and connected with opposite commutator bars. In the ordinary continuous current brushes a continuous current was sent in, which set the machine in motion as an electromotor, while from the sliding rings by two separate brushes, alternating currents were taken off. By varying the E. M. F. supplied to the motor, the E. M. F. of the alternating current was varied, while a variation of the motor field gave the variations of the frequency. The curve of E. M. F. was very nearly a sine-wave, the ratio of maximum E. M. F. to effective E. M. F. found = 1.415, while the sine-wave requires 1.414—that is, essentially the same.

To determine whether the change of the shape of the alternating current by varying load and varying excitation had any influence upon the readings, the variations of the alternating E. M. F. were produced:

1. By varying the excitation of the field of the Westinghouse dynamo.
2. By running the Westinghouse dynamo fully excited, feeding the secondaries of a bank of converters, feeding from the fine wire coils of these converters the fine wire coils of another bank of converters, and taking current off from the secondaries of these converters, connected from one to six in series.
3. By changing the E. M. F. by means of a Westinghouse converter of variable ratio of transformation.
4. By loading the dynamo when small currents were used for the tests.

But after having found that all these different ways of varying the alternating E. M. F. gave no perceptible difference whatever in the readings, I afterwards used the most convenient way to vary the excitation of the dynamo field and, where higher E. M.

F's were needed, to increase the E. M. F. by an interchangeable converter, which gave the ratios: 1 : 1, 2, 3, 4, 5.

For the determination of the frequency, a direct-reading speed indicator (horizontal ball governor, acting upon a spring) was used, which was carefully calibrated.

For the electric readings, instruments of the electro-dynamometer type were used, zero-reading—that is, the movable coil was carried back by the torsion of a steel spring to zero position.

These instruments were specially built for alternating currents, with very low self-induction and low internal resistance, using bifilar german silver wire as additional resistance.

In the ammeter the range of readings was from 3 to 40 amperes, the internal resistance = .011 ω.

The normal inductance (that is, E. M. F. of self-induction induced by one ampere alternating current, flowing through the instrument with a frequency of 100 complete periods per second): = .045 ω.

In the voltmeter the range of readings was from .5 volts upwards, but to avoid the necessity of corrections for self-induction sufficient additional resistance was used to decrease the correction under 1 per cent., and then the lowest readings were from 3 to 6 volts.

The internal resistance of the voltmeter is = 2.5 ω, its normal inductanee = 4.12 ω.

In the wattmeter the resistance of the coarse wire coil (fixed coil) was = .026 ω, its normal inductance = .073 ω.

The internal resistance of the fine wire coil was = .25 ω, its normal inductance = .33 ω.

In most of the readings sufficient additional resistance was used to make the correction for self-induction of the fine wire coil negligible. Only in a few readings where it exceeded 1 per cent. it was taken in account.

For small currents an Eickemeyer ammeter was used, which, while reading from .7 to 3 amperes, though built originally for continuous currents, had already been used by me for alternating currents and had been checked for its constancy of readings several times, and always found to give no perceptible difference in its readings for continuous currents and for alternating currents up to over 200 complete periods per second, the highest frequency I could reach

Its internal resistance is = 1.1 ω, its normal inductance = 2.03 ω.

Several sets of readings for different frequencies were taken on an old Westinghouse voltmeter converter. The fine wire coil and one of the 50 volt coils were left open. Into the other coarse wire coil an alternating current was sent, in series to ammeter and coarse wire coil of wattmeter, while the voltmeter and the fine wire coil of the wattmeter were connected in shunt around the whole circuit.

Hence a correction had to be applied for the self-induction of ammeter and coarse wire coil of the wattmeter and for the resistance of the circuit. Only in very few readings this correction amounted to somewhat more than 10 per cent. Generally it was much smaller.

The instruments were calibrated several times and their constants found to remain constant.

The speed indicator was calibrated carefully and its corrections added.

Each reading consisted of an ammeter reading, a voltmeter reading, a wattmeter reading and a speed reading.

Before and after each set of readings the zero positions of the instruments were determined, and only those sets of readings used where the zero position had remained constant.

Before and after each set of alternating current readings a continuous current was sent into the circuit and a few readings for different currents taken. Voltmeter and ammeter readings combined gave the resistance of the circuit, and both combined with the wattmeter reading gave a check for the instruments, here being watts = volts $\times$ amperes. Only those sets were used again where an entire agreement was found, and with the alternating current first readings with small currents, then with large currents, and then again with small currents taken, so that I believe every possible care was exercised to avoid any errors in the tests.

As before said, the first sets of tests were made on the magnetic circuit of a small Westinghouse converter.

The constants of this converter, so far as they are of interest here, are:

Mean length of magnetic circuit, 21 cm.
Mean cross-section of magnetic circuit, = 43.67 $cm.^2$
Hence volume of iron, = 917. cm^3.
Resistance of secondary coil, = .2 ω.

Further sets of readings were taken on a magnetic circuit, built up of very thin sheets of iron, alternately 8 in. × 1 in. and 3 in. × 1 in., in rectangular shape, very carefully insulated against eddy currents with layers of thin paper between the sheets. On the two long sides two coils of each 50 turns, very coarse wire (3 No. 10 in parallel), were wound and connected in series, thereby giving $n = 100$ turns of an internal resistance of .048 ω.

Here the mean length of the magnetic circuit was $l = 41$ cm.

The cross-section, $s = 3.784$ cm.^{2}

The circuit consisted of 58 layers of sheet-iron of the thickness $s = .02577$ (1) and the width $w = 2.579$.

The whole volume of iron was $= 155$ cm.^{3}

The sheet-iron pieces were first freed from scales by dipping into dilute sulphuric acid.

In one set of tests an open magnetic circuit was used, by leaving the short end pieces (3 in. × 1 in.) off, and using two piles each of 66 pieces (8 in. × 1 in.) of the same iron, the same pieces as used in the former closed circuit tests.

In these readings, for the determination of the hysteretic loss, only voltmeter and wattmeter, but no ammeter, were used, and the conductivity curve determined separately by voltmeter and ammeter.

The calculation of the readings was done in the following way:

After applying the corrections for self-induction of instruments, resistance and speed, the readings were reduced to lines of magnetic force per square centimetre B and consumption of energy by hysteresis per magnetic cycle H, in ergs.

Then the results were plotted on cross-section paper and if any value was found to be very much out of the curve connecting the other values, it was stricken out as evidently erroneous, not considering it worth while to determine whether it was a wrong reading of any one of the instruments or a mistake in the calculation.

Then from the other values of B and H, under the supposition that H were proportional to any power x of B:

$$H = \eta B^x$$

this exponent x was determined.

1. Calculated from the weight.

This value x will be seen always to be so near to 1.6 that 1.6 can be considered at least as first approximation to x.

Then, under the assumption

$$x = 1.6$$

hence

$$H = \eta \, B^{1.6}$$

the coefficient η was calculated, and now the equation

$$H = \eta \, B^{1.6}$$

plotted in a curve, as given in the figures, and the observed values of H drawn in and marked.

From the curve were taken the calculated values of H, corresponding to the observed values of B, the difference $H_{\text{calc}} - B_{\text{obs}}$ determined, and expressed in per cents. of H_{calc}.

These values are given in the tables and shown in the curves.

I. Magnetic Circuit of the Westinghouse Converter.

Fig. 2; Table II.

MAGNETIC CHARACTERISTIC.

F. = M. M. F., in ampere turns per centimetre length of magnetic circuit.

B. = Magnetization, in lines of magnetic force per square centimetre.

TABLE II. (1)

F.	*B.*	*F.*	*B.*	*F.*	*B.*
2	1500	12	14,750	45	18,150
3	3400	14	15,080	50	18,500
4	6800	16	15,370	55	18,820
5	9600	18	15,630	60	19,140
6	11,750	20	15,880	65	19,440
7	12,850	25	16,450	70	19,740
8	13,600	30	16,950	75	20,020
9	14,100	35	17,370	80	20,300
10	14,350	40	17,780	85	20,560
				90	20,820

HYSTERESIS.

B. = Magnetization, in lines of magnetic force per square centimetre.

H. = Loss of energy by hysteresis, in ergs per cycle, and cubic centimetre, = 10^{-7} watt-second.

TABLE II. (2)

Frequency: $N. = 28$ complete periods per second.

B.	*H.* obs.	*H.*[1]) calc.	*H.* − *H* — calc. obs.	%.
3510	1178	1160	—18	—1.6
10,560	6286	6610	+324	+4.9
13,800	10,286	10,180	—106	—1.0
17,940	15,357	15,600	+243	+1.6
		av:	±173 —	±2.3

Exponent of power, derived from tests:

$$x = 1.6111 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .002410$$

hence, theoretical curve:

$$H = .00241\ B^{1.6}$$

TABLE II. (3)

Frequency: $N = 36$ complete periods per second.

B.	*H.* obs.	*H.* calc.	*H.*—*H.*— calc. obs.	%.
7090	3333	3500	+167	+4.8
10,250	5667	6310	+643	+10.2
13,410	9694	9700	+6	+.1
17,080	14,417	14,400	+17	+.1
19,340	16,111	17,600	+1489	+8.4
		av:	±464 —	±4.4

Exponent of power, derived from tests:

$$x = 1.6476 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .002315$$

hence, theoretical curve:

$$H = .002315\ B^{1.6}$$

TABLE II. (4)

Frequency: $N = 137$ complete periods per second:

B.	*H.* obs.	*H.* calc.	*H.* — *H.* = calc. obs.	%
4000	1490	1410	— 80	—5.7
4670	1818	1800	— 18	—1.0
5510	2358	2350	— 8	— .3
5760	2482	2520	+ 38	—1.5
5840	2540	2580	+ 40	+1.6
6690	3285	3180	— 105	—3.3
6800	3358	3290	— 68	—2.1
6860	3374	3370	— 4	— .1
12,430	8336	8610	+ 274	+3.6
13,750	10,000	10,100	+ 100	+1.0
		av:	±73.5 —	±2.0

Exponent of power, derived from tests:

$$x = 1.5887 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .002438$$

hence, theoretical curve.

$$H = .002438\ B^{1.6}$$

TABLE II. (5)

Frequency. $N = 205$ complete periods per second.

B.	*H.* obs.	*H.* calc.	*H—H.* calc—obs.	%
1790	376	400	+24	+6.0
1990	463	460	− 3	− .7
2380	585	610	+35	+5.7
2620	735	720	−15	−2.1
3060	893	920	+27	+2.9
3390	1054	1100	+46	+4.2
3660	1297	1240	−57	−4.6
3710	1288	1250	−38	−3.0
4620	1822	1800	−22	−1.2
5070	2024	2070	+46	+2.2
4990	2034	2010	−24	−1.2
5910	2693	2620	−73	−2.8
6100	2844	2750	−96	−3.5
6550	3039	3080	+41	+1.3
7290	3673	3640	−33	− .9
8050	4341	4300	−41	−1.0
8320	4410	4530	+120	+2.7
8240	4561	4460	−101	−2.2
		av:	± 47	=±2.7

Exponent of power, derived from tests:

$$x = 1.6012 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .002434$$

hence, theoretical curve.

$$H = .002434\ B^{1.6}$$

From these 4 sets of readings, we get the results:

1.	$N = 28$	4	readings:	$x = 1.6111$	$\eta = .002410$
2.	36	5	"	1.6476	.002315
3.	137	10	"	1.5887	.002438
4.	205	18	"	1.6012	.002434

Therefrom we derive the average, by giving to each value as weight the number of readings, where it is based upon:

$$x = 1.60513 \sim 1.6$$

$$\eta = .0024164$$

Hence:

$$H = .0024164\ B^{1.6}$$

This curve is used for calculating the values given as H_{calc}, and is plotted in Fig. 2 in drawn line.

The observed values of H are drawn in Fig. 2:

1.	For $N = 28$	with the	mark	o
2.	" 36	"	"	*
3.	" 137	"	"	Y
4.	" 205	"	"	+

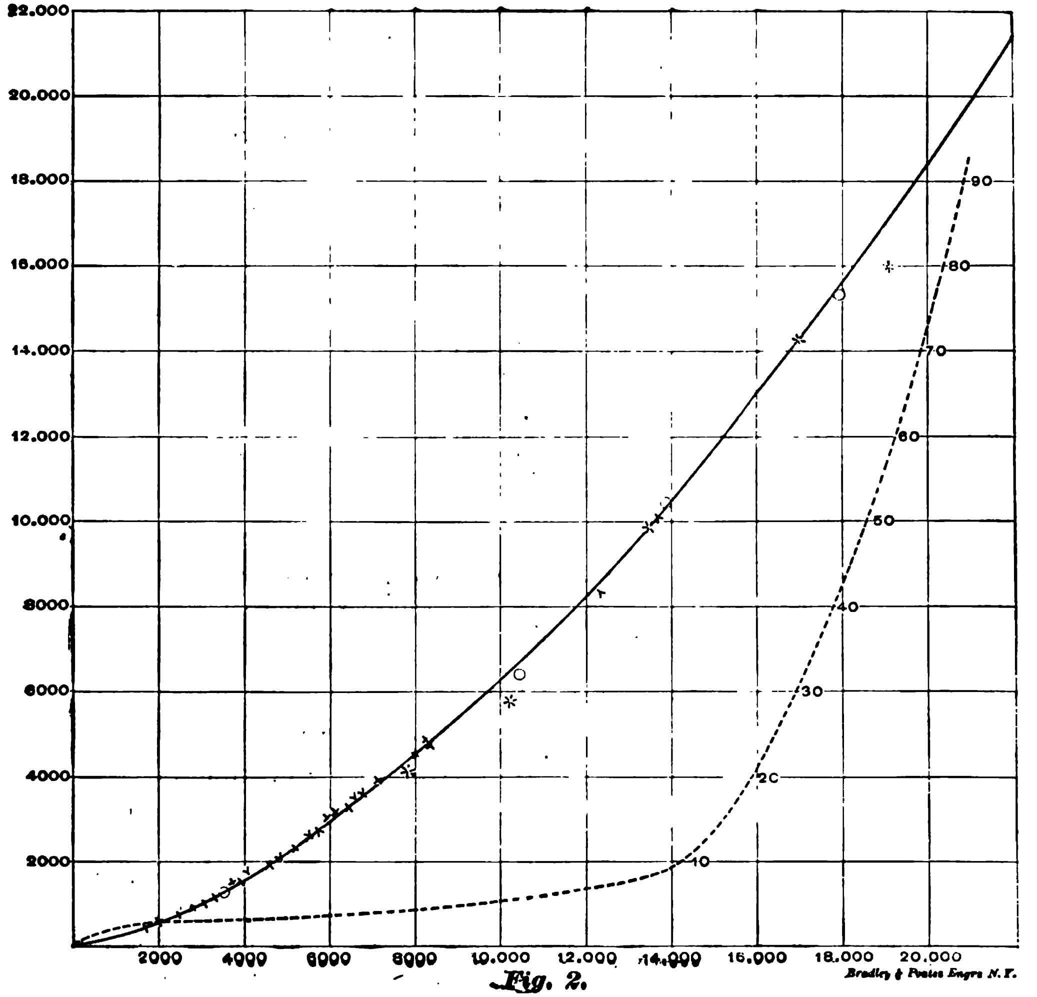

Fig. 2.

Bradley & Poates Engrs N. Y.

The magnetic characteristic is drawn in dotted lines.

From this curve of hysteretic loss

$$H = .0024164\, B^{1.6}$$

we derive the values:

TABLE II. (6.)

B.	H.	B.	H.
1000	152	13,000	9230
2000	462	14,000	10,400
3000	884	15,000	11,610
4000	1400	16,000	12,880
5000	2000	17,000	14,180
6000	2680	18,000	15,550
7000	3430	19,000	16,970
8000	4240	20,000	18,400
9000	5130	25,000	26,290
10,000	6070	30,000	35,210
11,000	7070	35,000	45,060
12,000	8130	40,000	55,800

II.—Magnetic Circuit Built up of Well Insulated Layers of Very Thin Sheet-Iron. Fig. 3; Tables III.

MAGNETIC CHARACTERISTIC.

F = M. M. F. in ampere turns per centimetre length of magnetic circuit.

B = magnetization in lines of magnetic force per square centimetre.

TABLE III. (1.)

F.	B.	F.	B.	F.	B.
2	1700	12	13,750	45	17,500
3	4200	14	14,260	50	17,900
4	7400	16	14,600	55	18,300
5	9200	18	14,900	60	18,650
6	10,400	20	15,200	65	19,030
7	11,160	25	15,700	70	19,380
8	11,850	30	16,200	75	19,730
9	12,470	35	16.680	80	20,080
10	13,070	40	17,050	85	20,400
				90	20,750

HYSTERESIS.

B = magnetization in lines of magnetic force per square centimetre.

H = loss of energy by hysteresis, in ergs per cycle and cubic centimetre, $= 10^{-7}$ watt-seconds.

CLOSED MAGNETIC CIRCUIT.

Frequency: N = 85 complete periods per second.

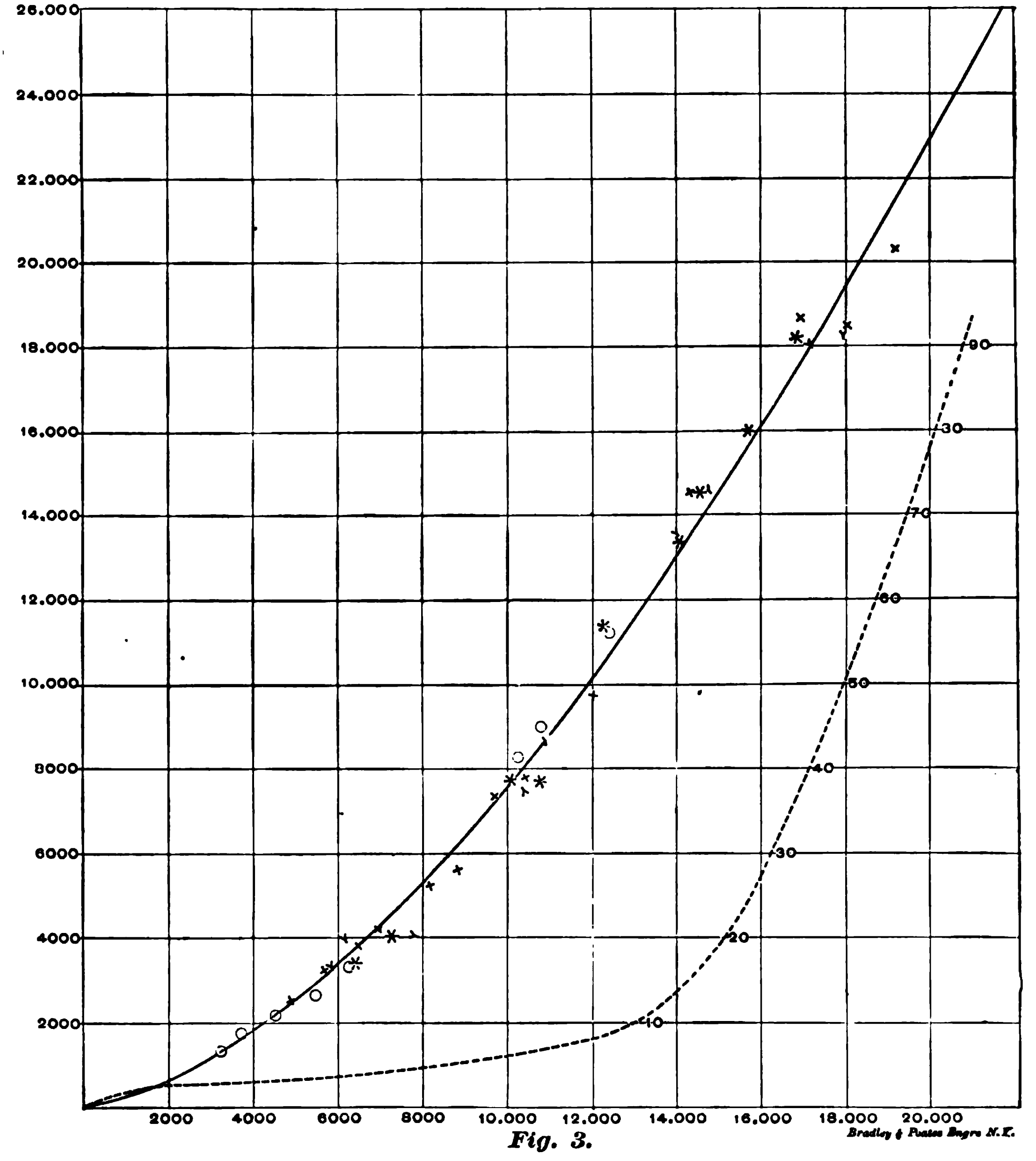
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8000
6000
4000
2000
2000
4000
6000
8000
10,000
12,000
14,000
16,000
18,000
20,000
10
20
30
40
50
60
70
30
90
Bradley & Poates Engrs N.Y.

Fig. 3.

TABLE III. (2.)

B.	*H.* obs.	*H* calc.	*H.* — *H.* = calc. obs	%
5910	3320	3140	— 180	— 5.7
6200	3690	3420	— 270	— 7.9
7690	4220	4700	+ 480	+ 10.2
10,470	7160	7700	+ 540	+ 7.0
11,110	8370	8464	+ 96	+ 1.1
14,030	12,600	12,280	— 320	— 2.6
14,890	13,730	13,540	— 190	— 1.4
17,190	17,040	17,040	.....	...
17,940	17,570	18.240	+ 670	+ 3.7
		av:	± 315 =	± 4.4

Exponent of power, derived from tests:

$$x = 1.6041 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .00285$$

hence, theoretical curve:

$$H = .00285\ B^{1.6}$$

TABLE III. (3.)

Frequency, $N = 138$ complete periods per second.

B.	*H.* obs.	*H.* calc.	*H.* = *H.* = calc. obs.	%
5220	3030	3015	— 15	— .5
5750	3620	3550	— 70	— 1.9
6540	4320	4355	+ 35	+ .8
7070	4830	4890	+ 60	+ 1.2
8210	5950	6160	+ 210	+ 3.4
8520	6090	6530	+ 440	+ 6.7
9570	7850	7840	— 10	— .1
10,450	8780	9040	+ 260	+ 2.9
11,990	11,060	11,230	+ 170	+ 1.5
14,570	15,840	15,340	— 500	— 3.3
14,660	16,160	15,580	— 580	— 3.7
16,770	20,350	19,260	— 1090	— 5.6
17,970	20,620	21,440	+ 820	+ 3.9
19,320	23,180	24,120	+ 940	+ 3.8
		av:	± 371 =	± 2.8

Exponent of power, derived from tests:

$$x = 1.6044 = 1.6$$

Coefficient of hysteresis:

$$\eta = .00335$$

hence theoretical curve:

$$H = .00335\ B^{1.6}$$

TABLE III. (4.)

Frequency, $N = 205$ complete periods per second:

B	H. obs.	H. calc.	H—H.= calc —obs	%
6360	4440	4660	+220	+4.8
7340	5380	5780	+400	+6.9
10,030	9510	9510	......	......
10,860	9980	10,670	+690	+6.5
12,230	13,700	12,940	—760	—5.9
14,600	17,390	17,160	—230	—1.3
14,700	17,830	17,340	—490	—2.8
15,750	19,700	19,360	—340	—1.7
16,700	21,990	21,300	—690	—3.2
		av:	±425	±3.7

Exponent of power, derived from tests:

$$x = 1.697 = 1.6$$

Coefficient of hysteresis:

$$\eta = .00373$$

hence theoretical curve:

$$H = .00373\ B^{1.6}$$

OPEN MAGNETIC CIRCUIT.

Two gaps of $\sim$ 4 cm. length.

TABLE III. (5.)

Frequency, $N = 138$ complete periods per second.

B.	H. obs.	H. calc.	H. — H. = calc. obs.	%
3150	1570	1560	— 10	— .6
3640	2110	2020	— 90	—4.4
4690	2930	2950	+ 20	+ .7
5490	3510	3780	+ 270	+7.7
6270	4380	4690	+ 310	+6.6
10,250	10,450	10,290	— 160	—1.6
11,000	11,810	11,520	— 290	—2.5
12,280	14,250	13,740	— 510	—3.7
		av:	± 208	±3.4

Exponent of power derived from tests:

$$x = 1.6040 \sim 1.6$$

Coefficient of hysteresis:

$$\eta = .00394$$

hence theoretical curve:

$$H = .00394\ B^{1.6}$$

From these four sets of readings we get the results:

CLOSED MAGNETIC CIRCUIT.

N =	85	9 readings:	x = 1.6041	η = .00285
	138	14 "	1.6044	.00335
	205	9 "	1.6970	.00373

OPEN MAGNETIC CIRCUIT.

$N = 138$ 8 readings: $x = 1.6040$ $\eta = .00393$

Herefrom it seems that the consumption of energy by hysteresis per magnetic cycle increases with increasing frequency—that is, with increasing velocity of the magnetic change.

The three values of three coefficients of hysteresis for closed circuit in their dependence upon the frequency N, can be expressed by the *empirical* formula:

$$\eta = (0017 + .000016\, N - .00000003\, N^2)$$

To compare the values of hysteretic loss for different frequencies, in Fig. 3 the curve of hysteretic loss for $N = 100$ complete periods per second is plotted, giving:

$$\eta_{100} = .003$$

hence

$$H = .003\, B^{1.6}$$

and the observed values of H are not directly drawn in, but the observed values of H multiplied with the factor:

$$\frac{\eta_{100}}{\eta_{\text{obs.}}}$$

to compare the different frequencies with each other.

These values are plotted for:

$N = 85$ with the mark v }
138 " " + } Closed magnetic circuit.
205 " " * }

$N = 138$ with the mark o; Open magnetic circuit.

From this curve of hysteretic loss,

$$H = .003\, B^{1.5}$$

we derive the values, for the frequency of $N = 100$ complete periods per second.

TABLE III. (6.)

B.	*H.*	*B.*	*H.*
1000	190	13,000	11.460
2000	570	14,000	12,900
3000	1100	15,000	14.430
4000	1740	16,000	15.990
5000	2490	17,000	17,610
6000	3330	18,000	19,290
7000	4260	19,000	21,060
8000	5280	20,000	22,830
9000	6360	25,000	32,640
10,000	7530	30,000	43.680
11,000	8790	35,000	55,950
12,000	10,080	40,000	69,270

Especially noteworthy is the last set of readings, on open magnetic circuit, in so far as it proves the fallacy of the general opinion that the hysteretic loss of energy in the iron is smaller in the open magnetic circuit than in the closed circuit.

For the coefficient of hysteresis observed on open magnetic circuit

$$\eta = .00393$$

is even greater than that for closed magnetic circuit,

$$\eta = .00335$$

But this discrepancy is easily explained by the fact that in the closed magnetic circuit the magnetization is nearly uniform throughout the whole iron. But in the open magnetic circuit the magnetic field intensity differs considerably from point to point, being a maximum in the middle of the magnetizing coils, a minimum at the ends of the iron sheets. Now, the values of B given in the table, are the average values of the magnetization, and the values H, the average values of hysteretic loss. But the average value of the 1.6th powers of different quantities B is larger than the 1.6th power of the average value of B.

For instance, in a cubic cm. of iron magnetized to $B = 12{,}000$ is $H = 10{,}080$; in a cubic cm. of iron magnetized to $B = 6000$ is $H = 3330$; hence of these 2 cubic centimetres the average magnetization is

$B = 9000$, and the average $H = 6{,}705$ ergs

but to $B = 9000$ corresponds $H = 6360$ ergs; that is, about 5 per cent. less, and the difference becomes still greater, if the values B differ still more.

Taking this into account, it seems that the loss of energy due to hysteresis depends only upon the intensity of magnetization, and perhaps upon the frequency, but is independent of open or closed magnetic circuit, as is to be expected.

III.—Fig. 4. Tables IV.

A third set of determinations of the hysteretic loss of energy is given in the following:

Again a magnetic circuit was built up of 17 layers of a soft

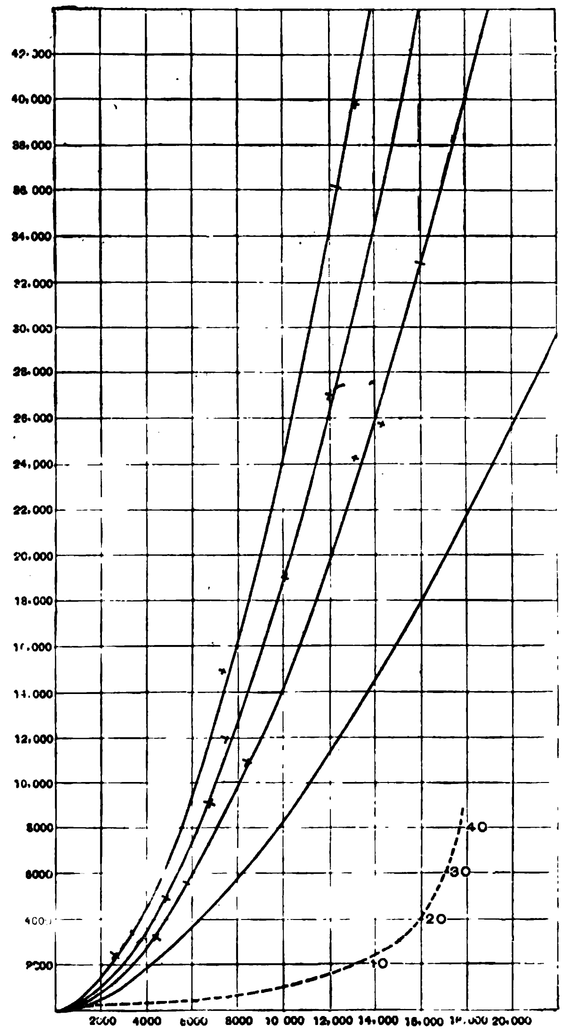

Fig. 4.

kind of sheet-iron, each layer consisting of two pieces of 20 cm. length, 2.54 cm. width, and two pieces of 7.6 cm. length and 2.54 cm. width, of the thickness $\delta = .0686$ cm., that is, of considerably greater thickness than in the former set of tests.

Here evident proof of the induction of eddy-currents in the iron was found. Especially perceptible was a decrease in the watts consumed by the iron, when a larger M. M. F. of high frequency was left acting upon the iron. This decrease must be attributed to the increase of the electric resistance of the iron, caused by its increasing temperature.

To eliminate this source of error as far as possible, before each set of tests an alternating current of high frequency ($N = 200$) and considerable strength was sent through the magnetizing coils and left on for ten to fifteen minutes, and then first readings with low magnetization, then with high, and then again with low magnetization were taken. But, nevertheless, as was to be expected, in these tests the observed values agreed less with each other than in the former readings.

The method of determination, the apparatus, etc., were the same as in the second set of tests, only that ammeter, voltmeter, and wattmeter were used at the same time. In calculating these tests, the law of the 1.6th power was assumed as true, and the loss of energy in the iron expressed by the equation,

$$H = \eta\ B^{1.6} + \varepsilon\ N\ B^2$$

where

$$H_1 = \eta\ B^{1.6}$$

is the true hysteretic loss per cycle and cm³., which is independent of the frequency, and

$$H_2 = \varepsilon\ N\ B^2$$

is the loss of energy by eddy-currents per cycle which is proportional to the frequency N.

From this expression

$$H = H_1 + H_2$$

the coefficients η and ε were calculated and the agreement or disagreement of these coefficients η and ε allow now to check the correctness or incorrectness of the law of the 1.6th power.

These tests gave the following results:

MAGNETIC CHARACTERISTICS.

$F =$ M. M. F., in ampere turns per centimetre length of magnetic circuit.

$B =$ magnetization, in lines of magnetic force per square centimetre.

TABLE IV. (1.)

F.	B.	F.	B.	F.	B.
1.5	2,700	7	11,700	18	15,450
2	4,350	8	12,200	20	15,800
3	7,100	9	12,700	25	16,400
4	8,850	10	13,100	30	16,800
5	10,000	12	13,900	35	17,200
6	10,800	14	14,500	40	17,500
		16	15,000		

HYSTERESIS.

B = magnetization, in lines of magnetic force per square centimetre.

H = loss of energy by hysteresis, in ergs per cycle and cm^3. ($= 10^{-7}$ joules) $= H_1 + H_2$

$H_1 = \eta\ B^{1.6}$ = loss of energy by hysteresis proper, in ergs per cycle and cm^3. ($= 10^{-7}$ joules).

$H_2\ \varepsilon\ N\ B^2$ = loss of energy by eddy-currents, in ergs per cycle and cm^3. ($= 10^{-7}$ joules).

TABLE IV. (2.)

Frequency, $N = 78$.

$\eta = .00331$ $\varepsilon = .751 \times 10^{-6}$

B.	H_1	H_2	H.(1) calc.	H. obs.	Δ	= %
4171	2,060	1,080	3,140	3,060	+ 80	+ 2.6
5850	3,540	2,120	5,660	5,640	+ 20	+ .3
9520	7,740	5,600	13,340	13,440	— 100	— .8
13,160	12,960	10,710	23,670	24,540	— 870	— 3.7
14,320	14,880	12,720	27,600	26,460	+1140	+ 4.0
16,050	17,280	15,900	33,180	33,180	......	
				av:	{+ 6.9 / − 4.5}	± 1.9 (+ .4)

TABLE IV. (3.)

Frequency, $N = 140$.

$\eta = .00331$ $\varepsilon = .730 \times 10^{-6}$

B.	H_1	H_2	H.(1) calc.	H. obs.	Δ	= %
4880	2,650	2,720	5,360	5,280	+ 80	+ 1.5
6780	4,490	5,270	9,760	9,420	+ 340	+ 3.4
7720	5,530	6,830	12,360	12,600	— 240	— 1.9
10,200	8,640	11,940	20,580	20,400	+ 180	+ .9
12,080	11,300	16 700	28,000	29,100	—1100	— 4.0
17,200	19,860	33 840	53,700	53,000	+ 700	+ 1.3
				av:	{+ 7.1 / − 5.9}	± 2.2 (+.2)

TABLE IV. (4.)

Frequency, $N = 207$

$\eta = .00336$ $\epsilon = .757 \times 10^{-6}$

B.	H_1	H_2	H.(1) calc.	H. obs.	Δ	= %
2710	1,030	1,290	2320	2,340	− 20	− .8
4720	2,510	3.910	6,430	6,480	− 50	− .8
7540	5,320	9,970	15,290	15,960	− 670	− 4.4
12,380	11,700	26,800	38,500	38,500	.... .	
13,200	13,000	30,400	43,400	42,600	+ 800	+ 1.8
				av:	{+ 1.8 / − 6.0}	± 1.6 (− .8)

Therefrom we get the results:

$N =$ 78, 6 readings, $\eta = .00331$ $\epsilon = .751 \times 10^{-6}$
140, 6 " .00331 $.730 \times 10^{-6}$
207, 5 " .00336 $.757 \times 10^{-6}$

The values found for η are so nearly alike that we can consider them as constant, and take their mean value

$$\eta = .00333$$

as the coefficient of hysteresis.

Even the values found for ϵ are not much different from each other, not more than was to be expected from the unavoidable differences in the temperature of the iron, which because of the high electric temperature coefficient of iron makes ϵ rather variable.

Taking the average of ϵ, we derive

$$\epsilon = .746 \times 10^{-6}$$

and as formula of iron loss,

$$H = .00333\, B^{1.6} + .746 \times 10^{-6}\, N\, B^2$$

In Fig. 4 are drawn the four curves,

1. True hysteretic loss, $H = .00333\, B^{1.6}$
2. Iron loss for $N = 78$ $.00333\, B^{1.6} + .00005856\, B^2$
3. " " 140 $.0001022\, B^2$
4. " " 209 $.0001567\, B^2$

The observed values are plotted by crosses, +

1. $H_{\text{calc.}}$ is calculated by using for η the mean value $\eta = .00333$, but for ϵ the individual values, corresponding to the particular set of observations.

IV.—Figs. 5 and 6; Tables V and VI.

Two other sets of determinations of the hysteretic loss of energy, for the frequency 170 complete periods per second, were made on two laminated horse shoe magnets, with laminated keeper or armature.

The method of observation and of calculation was the same as in III., and the same precautions were taken.

The dimensions of the horse shoe magnets were:

Mean length of magnetic circuit: 38 cm.
" cross-section: 70 cm.^{2}
" volume of iron: 2660 cm.^{3}
" distance of keeper from magnet, in the first case: .15 cm.
" distance of keeper from magnet, in the second case: .08 cm.

each magnet consisting of 300 sheets well insulated iron, of the thickness .0405 cm.

In the first set of readings, considerable eddy-currents were found; in the second set, only a small amount of eddies.

The magnetic conductivity of the iron was not determined, because the reluctance of the magnetic circuit mainly consisted of that of the air gap between magnet and keeper.

The results were,

B = magnetization, in lines per cm.^{2}
$H_{obs.}$ = observed loss of energy in the iron, in ergs per cycle and cm.^{3}, for $N = 170$.
H_1 = true hysteretic loss of energy.
H_2 = loss of energy by eddy-currents.
$H_{calc.}$ = whole calculated loss of energy, $= H_1 + H_2$

TABLE V.

Frequency, N = 170.

$\eta = .0045$ $\varepsilon = 1.16 \times 10^{-6}$

B.	H_1	H_2	H. calc.	H. obs.	H. — H. calc. obs.	= %
342	51	23	74	70	+ 4	+ 5.3
410	68	34	102	102	......	....
546	108	59	166	166	+ 1	+ .6
620	132	78	210	219	— 9	— 4.3
670	150	90	240	234	+ 6	+ 2.5
746	178	111	289	300	— 11	— 3.7
830	210	138	348	333	+ 15	+ 4.3
1020	293	208	501	524	— 23	— 4.5
1100	345	234	579	549	+ 30	+ 5.3
1200	392	290	682	695	— 13	— 2.0
1310	436	342	779	795	— 16	— 2.1
1400	539	445	984	985	— 1	— .1
1930	820	742	1562	1547	+ 15	+ 1.0
2600	1310	1280	2590	2670	— 80	— 3.1
					+ 71 — 153	+ 19.0 — 19.8
				av:	± 16	± 2.8

Therefore we get the formula for the loss in the iron,

$$H = .0045\, B^{1.6} + 1.16\, N \times 10^{-6}\, B^2$$

In Fig. 5 are shown

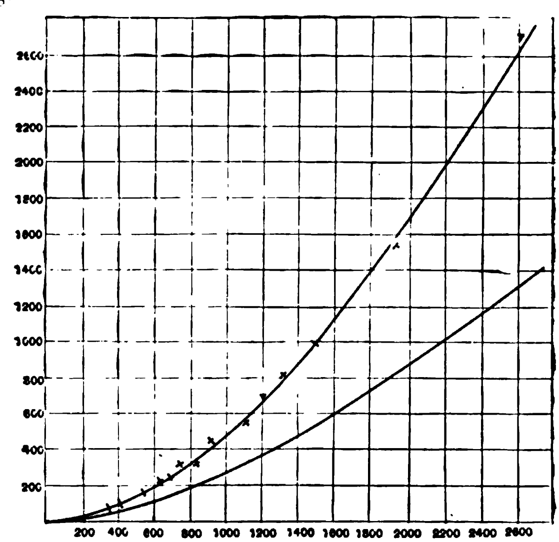

Fig. 5.

1. The curve of true hysteretic loss,

$$H_1 = .0045\, B^{1.6}$$

2. The curve of the whole loss in the iron,

$$H = H_1 + H_2$$

with the observed values marked by crosses +

TABLE VI.

Frequency, $N = 170$

$\eta = .00421$ $\varepsilon = .2083 \times 10^{-6}$

$B.$	H_1	H_2	$H.$ calc.	$H.$ obs.	$H. - H.$ calc. obs.	= %
85	5.2	.3	5.5	5.6	− .1	− 1.8
182	17.3	1.3	18.6	16.9	+ 1.7	+10.0
211	22.0	1.7	23.7	23.5	+ .2	+ .9
560	105	11	116	122	− 6	− 5.0
670	140	15	155	146	+ 9	+ 6.1
685	145	16	161	157	+ 4	+ 2.6
775	176	21	197	202	− 5	− 2.4
800	186	22	208	200	+ 8	+ 4.0
1000	265	35	300	300	......	....
1070	296	41	337	353	− 16	− 4.0
1130	322	47	369	386	− 17	− 4.3
1250	379	56	435	430	+ 5	+ 1.2
1380	445	69	514	514	− 26	− 4.7
2200	940	170	1110	1130	− 20	− 1.8
2420	1090	208	1298	1268	+ 30	+ 2.4
					+ 38 − 90	+27.2 −24.6
				av.	± 10	± 3.4

Therefore we get the formula for the loss in the iron,

$$H = .00421\ B^{1.6} + .2083 \times 10^{-6}\ N\ B^2$$

In Fig. 6 are shown,

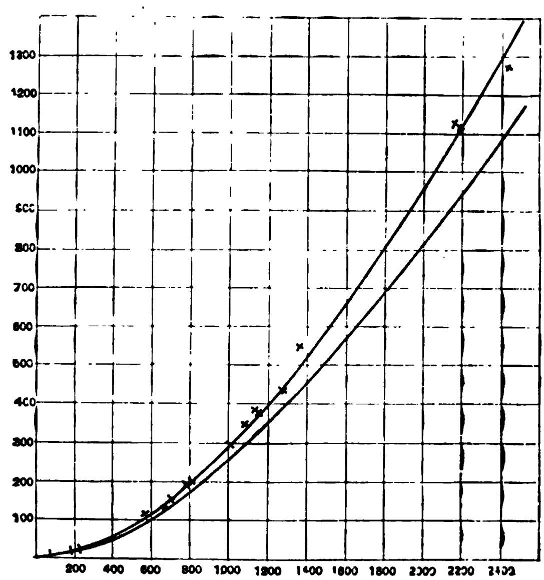

Fig. 6.

1. The curve of true hysteretic loss,

$$H_1 = .00421\ B^{1.6}$$

2. The curve of the whole loss in the iron,

$$H = H_1 + H_2$$

with the observed values marked by crosses +

Especially interesting are these two sets of readings in so far as they cover quite a different range of magnetization as the tests in I. to III.

In I. to III. the tests cover the range from 1790 to 19,340 lines of magnetic force per cm.², that is, for medium magnetization up to high saturation, while the tests in IV. cover the range from 85 to 2600 lines per cm.², that is, from medium down to very low magnetization.

The law is found exactly the same,

$$H = \eta\ B^{1.6} + \varepsilon\ N\ B^2$$

and herewith proved for the full range from 85 lines per cm.² up to 19,340 lines, a ratio from 1 ÷ 230.

This seems not to agree with Ewing's theory of the molecular magnets. According to this theory, for very small magnetization the hysteresis should be expected to disappear, or almost disappear, and the cycle be reversible. Then for medium magnetization, where the chains of molecular magnets break up and rearrange, hysteresis should increase very rapidly, and slowly again for saturation. Nothing of this is the case, but hysteresis seems to follow the same law over the whole range of magnetization, and is certainly not zero for even such a low magnetization as 85 lines per cm.²

Magnetometer Tests.

The method used in the foregoing has the great advantage that

1. It allows the taking of a greater number of readings, over a wide range of magnetization, in a short time, by mere simultaneous instrument readings, and thereby reduces the probable error by increasing the number of observations.
2. It allows the use of electro-dynamometers, as the most reliable electric measuring instruments.

3. It deals with larger amounts of energy, counting by watts or even hundreds of watts, whereby a much greater accuracy can be reached than by the ballistic galvanometer.

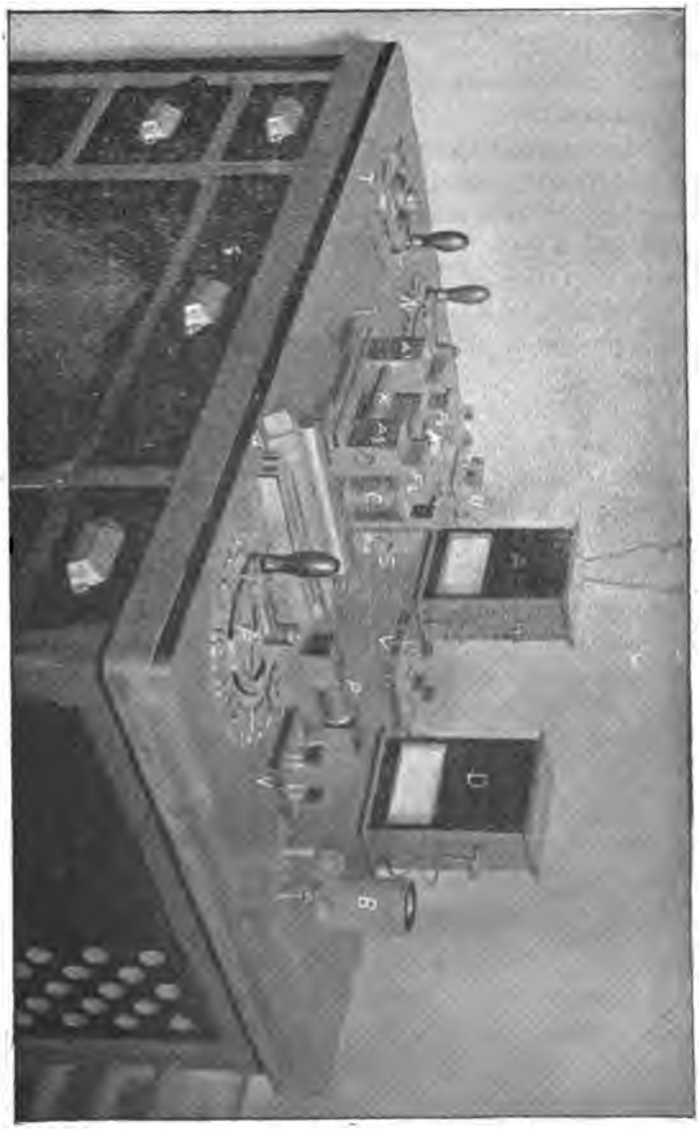

FIG 7.

4. It measures the hysteresis under the influence of an harmonically, and not suddenly varying M. M. F., that is under the

same conditions, where it becomes of importance for practical engineering.

But it has the great disadvantage that it can be used only for testing sheet-iron or other thoroughly laminated iron, where eddies are either inappreciable or can be calculated also. For testing solid iron and steel pieces, this method cannot be used, because of the tremendous amount of eddies which would flow in a solid piece of iron.

To determine the hysteretic loss of energy in steel and cast-iron the Eickemeyer differential magnetometer was used. Complete description of this instrument and its use is to be found in the *Electrical Engineer*, March 25th, 1891, wherefrom is taken a part of the following description. In Fig. 7 is shown this instrument, which I shall be glad to show in our factory to anybody who is interested in it. In Figs. 8 and 9 are diagrams of its action.

The principle of this instrument resembles somewhat the principle of the well-known differential galvanometer, applied to the magnetic circuit. In Fig. 8, suppose F_1 and F_2 were two E. M. F.'s connected in series; for instance, two cells of a battery, x and y the two resistances which we want to compare. Either resistance x and y is shunted respectively by a conductor a and b of equal resistance, which influences a galvanometer needle G in opposite directions but with equal strength.

Then the zero position of the needle G shows that the electric current c_a, flowing in a, is equal to the current c_b in b. But let the current in x be c_x, and in y, c_y; then we must have

$$c_a + c_y = c_b + c_x$$

because the currents c_a and c_y are the two branches of the same integral current as c_b and c_x

Therefore, if $c_a = c_b$, then

$$c_x = c_y$$

But if $c_a = c_b$, and $a = b$, the difference of potential at the ends of a (or, what is the same thing, y) is equal to the difference of potential at the ends of b or x and, therefore, the current in x and y, and the potential differences being the same, it follows that $x = y$.

That is, this method of connection allows us to compare an unknown resistance x with a standard resistance y.

Now, instead of "electric current," say "magnetic current" or "number of lines of magnetic force;" instead of "electromotive force" or "potential difference," say "magneto-motive force;" and instead of "electric resistance," say "reluctance," and we have the principle of this instrument.

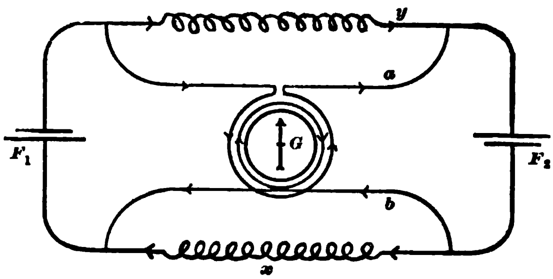

FIG. 8

Its magnetic circuit consists of two pieces of best Norway iron, ⅃⅂ shaped, shown in the illustration of the complete instrument, Fig. 7, and in the diagram Fig. 9, at F_1 and F_2. The middle portion is surrounded by a magnetizing coil c. Therefore if coil c is traversed by an electric current, the front part s_1 of the left iron piece becomes south, and the back part n north polarity.

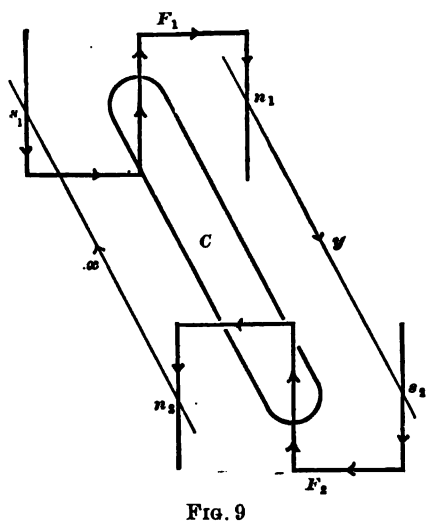

FIG. 9

The front part of the right iron piece n becomes north, and the back part south; and the lines of magnetic force travel in the front from the right to the left, from n_2 to s_1; in the back the opposite way, from the left to the right, or from n_1 to s_2, either through the air or, when n_2 and s_1, or n_1 and s_2, are connected by a piece of magnetizable metal, through this and through the air.

In the middle of the coil C stands a small soft iron needle with an aluminium indicator, which plays over a scale K, and is held in a vertical position by the lines of magnetic force of the coil C itself, deflected to the left by the lines of magnetic force traversing the front part of the instrument from n_2 to s_1, deflected to the right by the lines traversing the back from n_1 to s_2. This needle shows by its zero position that the magnetic flow through the air in front from n_2 to s_1 has the same strength as the magnetic flow in the back from n_1 to s_2 through the air.

Now we put a piece of soft iron x on the front of the instrument. A large number of lines go through x, less through the air from n_2 to s_1, but all these lines go from n_1 to s_2 through the air at the back part of the magnetometer, the front part and back part of the instrument being connected in series in the magnetic circuit. Therefore the needle is deflected to the right by the magnetic flow in the back of the instrument

Now we put another piece of iron, y, on the back part of the instrument. Then equilibrium would be restored as soon as the same number of lines of magnetic force go through x, as through y, because then also the same number of lines go through air in the front as in the back. As will be noted, the air here takes the place of the resistances a and b, influencing the galvanometer needle G, as in the diagram, Fig. 8.

The operation of the instrument is exceedingly simple and is as follows: Into the coil C an electric current is sent which is measured by the ammeter A, and regulated by the resistance-switch R. Then the needle which before had no fixed position, points to zero.

Now the magnetic standard, consisting of a cylindrical piece of Norway iron of 4 cm.^{2} cross-section and 20 cm. length is laid against the back of the instrument, with both ends fitted into holes in large blocks of Norway iron, A_3, A_4, which are laid against the poles S_1 N of the magnetometer, so that the transient resistance from pole-face to iron is eliminated.

The sample of iron that we wish to examine is turned off to exactly the same size, 4 cm.^{2} cross-section and 20 cm. length, and fitted into blocks A_1 A_2 in front of the magnetometer. Then so many fractional standard-pieces of Norway iron are added in front, that the needle of the instrument points to zero. This means that the 4 cm.^{2} Norway iron in the back, carry under the same difference of magnetic potential, the same magnetism as the 4 cm.^{2} of the examined sample plus the x cm.^{2} of fractional standard, added in the front. Hence, 4 cm.^{2} of the examined sample are equal in magnetic conductivity to $(4 - x)$ cm.^{2} of Norway iron, and the magnetic conductivity of this sample is $\frac{4 - x}{4} \times$ 100 per cent of that of Norway iron, for that difference of magnetic potential, viz., magnetization, that corresponds to the magnetometer current.

To get absolute values, the instrument has been calibrated in the following way: In the front and in the back the magnetic circuit of the instrument has been closed by 4 cm.^{2} Norway iron. Then another piece of iron, and of any desired size, has been added in the front. This piece, y, carrying some magnetism also, equilibrium was disturbed. Then through a coil of exactly 110 turns, surrounding this piece y, an electric current i was sent and regulated so that equilibrium was restored. In this case no magnetism passed through y, or in other words, the M. M. F. of the current i 110 i ampere turns, is equal to the differences of magnetic potential between the pole-faces of the instrument. In this way, for any strength of current in the main coil C of the magnetometer, the difference of magnetic potential produced thereby between the pole-faces of the instrument, was determined and plotted in a curve, for convenience in ampere turns per cm. length.

Now, the Norway iron standard was compared on the magnetometer with sheet-iron, of which, from tests with low frequency alternating currents, the magnetization corresponding to any M. M. F. was known, and therefrom derived the magnetic characteristic of the Norway iron standard, and plotted in a curve also.

In the way explained before, the iron sample that was to be determined, was balanced by the magnetometer by Norway iron, thereby giving its magnetic conductivity in per cent. of that of the Norway iron standard, the magnetometer current read, from the curves taking the M. M. F. corresponding thereto—denoted with F— and the magnetization of the Norway iron, corresponding to this M. M. F, F, and from the determined per centage of conductivity of the examined sample, the magnetization B of this sample corresponding to the M. M. F. F.

With this instrument a number of magnetic cycles of different samples of steel and cast-iron were determined.

First, a powerful alternating current was sent through the magnetometer and around all the iron pieces used, to destroy any trace of permanent or remanent magnetism.

Then the examined sample was laid against the front, the standard against the back of the magnetometer, balanced, and a larger number of magnetic cycles completed between given limits, for instance, + 95 and — 95 ampere turns M. M. F. per cm. length. Then readings were taken from maximum M. M. F. + 95 down to zero, and again up to the maximum — 95, down over zero and up to + 95, thereby completing a whole magnetic cycle, and then of a second magnetic cycle, a few readings were taken as check for the first one.

In this way for different M. M. F.'s the curve of hysteresis was found, and by measuring its area the loss by hysteresis determined.

The further calculation was done in a somewhat different way. Generally the number of cycles was not large enough to determine conveniently the exponent by analytical methods.

Therefore the law of the 1.6 M. power:

$$H = \eta B^{1.6}$$

was assumed as true, and for each cycle from the known values of H and B determined the co-efficient η.

If for different cycles the values of η agreed, this would prove the assumption, the correctness of the law of 1.6th power, while a disagreement would disprove it.

In the following for a number of samples the magnetic cycles are given:

$F =$ M. M. F., in ampere turns per cm. length.

B_r and $B_d =$ the intensity of magnetization, in kilolines, corresponding to M. M. F. F, for the rising and the decreasing branch of the magnetic curve.

The area of the looped curve, representing the loss of energy by hysteresis is derived by adding the values of B_d, and subtracting therefrom the sum of the values B_r, B_d and B_r, being given from 5 to 5 ampere turns, or .5 absolute units, the difference of the sums of $B_d - B_r$ just gives the loss by hysteresis, in ergs per cycle.

CAST-STEEL, ANNEALED AND HARDENED. FIG. 10; TABLE VII.

Of one kind of steel, two test pieces were cast, at the same casting, turned off to standard size and, by comparing them in the

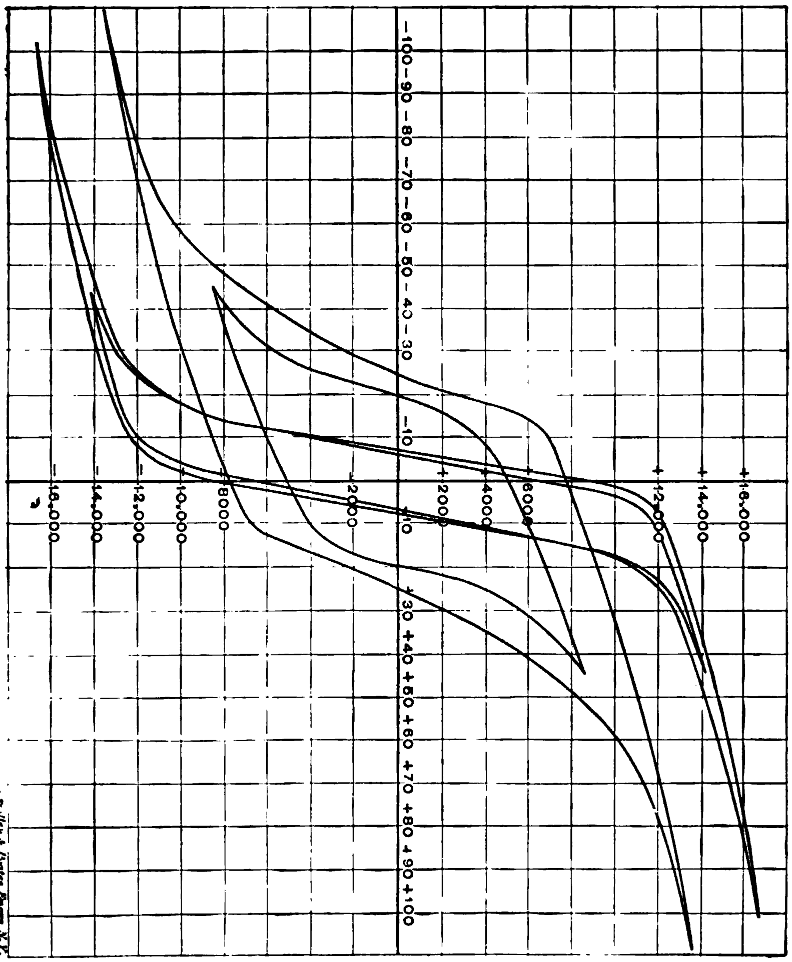

Fig. 10.

magnetometer, found to be exactly alike.

Then the one piece was hardened, the other left annealed.

Magnetometer tests gave the following magnetic cycles :

TABLE VII.

F.	Hardened.						Annealed.			
	B_r	B_d	B_r	B_d	B_r	B_d	B_r	B_d	B_r	B_d
0	± 5.0		± 7.0		± 7.8		± 6.6		± 8.6	
5	−4.4	+5.6	− 6.4	+ 7.5	− 7.3	+ 8.2	− 1.4	+10.7	− 2.6	+11.3
10	−3.7	6.1	− 5.6	7.9	− 6.8	8.6	+ 3.4	11.9	+ 3.7	12.3
15	−2.7	6.5	− 4.4	8.2	− 5.6	8.9	8.4	12.5	8.4	12.7
20	0	6.9	− 1.9	8.6	− 2.3	9.2	10.9	12.8	10.8	13.0
25	+3.9	7.3	+ 1.9	9.0	+ .4	9.5	12 2	13.1	12.0	13.3
30	5.5	7.6	4.2	9.3	2.5	9.8	13.0	13.4	12.7	13.6
35	6.7	8.0	6.2	9.6	4.2	10.1	13.5	13.7	13.2	13.9
40	7.7	8.3	7.6	9.9	5.8	10.4	13.9	14.0	13.5	14.2
45	8.5		8.7	10.2	7.2	10.7	14.1		13.8	14.5
50	(44.5.)		9.6	10.5	8.4	11.0	(44.5.)		14.1	14.7
55			10.4	10.8	9.6	11.2			14.4	15.0
60			10.9	11.1	10.4	11.5			14.7	15.2
65			11.4		10.9	11.8			15.0	15.4
70			(64.5.)		11.4	12.0			15.3	15.6
75					11.9	12.3			15.6	15.8
80					12.2	12.5			15.8	16.0
85					12.5	12.7			16.0	16.1
90					12.8	12.9			16.2	16.3
95					13.0	13.1			16.4	16.5
100					13.2	13.3			16.6	
105					13.4	13.4			(101.0.)	
110					13.5					
					(108.0.)					
$H=$ obs.	48,300		77,800		101,100		34,800		45,000	

Herefrom as coefficient of hysteresis, was found

$$\eta = .02494 \mid .02512 \mid .02490 \mid .007997 \mid .007962$$

Average, $\eta = .024987$ $\sim .025$ $\eta = .007980$ $\sim .0080$

Hence, when *annealed*, the hysteretic loss is

$$H = .008\ B^{1.6}$$

when *hardened*

$$H = .025\ B^{1.6}$$

and calculated by means of these formulas, we derive

$$H_{\text{calc.}} = 48{,}400 \quad 77{,}500 \quad 101{,}500 \quad 34{,}730 \quad 45{,}100$$

and

$$H_{\text{calc.}} - H_{\text{obs.}} = +100 \quad -300 \quad +400 \quad -70 \quad +100$$

= per cent. of

$$H_{\text{calc.}} \quad +.2 \quad -.4 \quad +.4 \quad -.2 \quad +.2$$

In Fig. 10 are drawn some of the magnetic curves for both samples.

It is especially interesting to note that though the chemical constitution of both samples is exactly the same, their magnetic behavior is entirely different, so that the *magnetic* properties of iron seem to be determined much more by its *physical* than its *chemical* constitution.

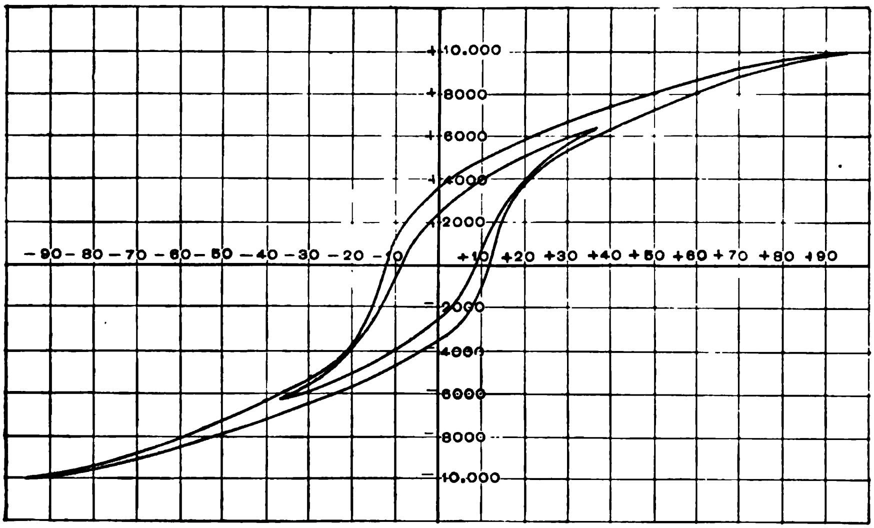

Fig. 11.

ANOTHER SAMPLE OF CAST-STEEL OF LOW MAGNETIC CONDUCTIVITY.

FIG. 11.

TABLE VIII.

F.	B_r	B_d	B_r	B_d	B_r	B_d	B_r	B_d
0	± 2.5		± 2.8		± 3.1		± 3.4	
5	−1.5	+3.4	−1.9	+3.6	−2.1	+3.9	−2.7	+4.2
10	+ .6	4.1	− .4	4.3	− .6	4.6	−1.3	4.8
15	2.7	4.6	+2.7	4.9	+2.2	5.2	+2.3	5.4
20	3.9	5.1	4.0	5.5	4.2	5.8	3.8	5.9
25	4.7	5.6	4.9	6.0	5.1	6.2	4.8	6.4
30	5.5	6.0	5.6	6.4	5.7	6.6	5.5	6.7
35	6.2	6.3	6.2	6.7	6.1	6.9	6.0	7.1
40	6.38		6.6	7.0	6.6	7.2	6.5	7.4
45	(37.0.)		7.0	7.3	7.0	7.5	7.0	7.7
50			7.4	7.5	7.4	7.8	7.4	7.9
55			7.64		7.8	8.1	7.8	8.2
60			(52.0.)		8.1	8.4	8.1	8.5
65					8.4	8.6	8.4	8.8
70					8.7	8.8	8.7	9.0
75					8.95		9.0	9.2
80					(75.0.)		9.3	9.5
85							9.5	9.6
90							9.8	9.8
95							10.0	
							(95.0.)	
H = obs.	14,600		19,900		25.000		29,600	
η =	.0119		.0122		.0119		.0118	

Average, $\eta = .001195$
$\sim .012$

Herefrom,

$$H = .012\ B^{1.6}$$

$\underset{\text{calc.}}{H} =$	14,620	19,520	25,140	30,020
$\underset{\text{calc.}}{H} - \underset{\text{obs.}}{H}$	+ 20	— 380	+ 140	+ 420
= per cent. of $\underset{\text{calc.}}{H}$	+ .1	— 1.9	+ .6	+ 1.4

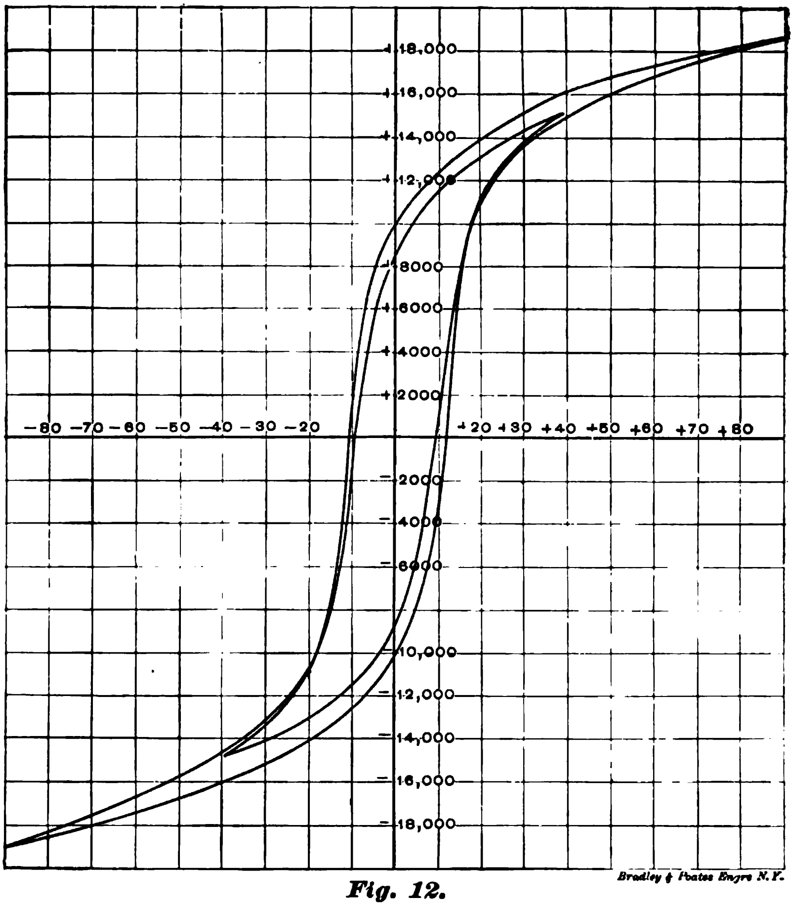

Fig. 12.

With regard to hysteresis, this kind of cast-steel is 50 per cent. worse than the annealed cast-steel No. 1, but still twice as good as the hardened sample. But, magnetically, it is poor—that is, of low conductivity, giving for 40 ampere turns M. M. F. per centimetre length only ∼ 6600 lines of magnetic force per square centimetre, while the annealed steel gives ∼ 14,000—that is, more than twice as many, and even the hardened steel gives more, ∼ 8000.

Soft Machine Steel. Fig. 12.

TABLE IX.

	I.		II.		III.		
F	B_r	B_d	B_r	B_d	F	B_r	B_d
0	± 8.3		± 9.6		50	15.9	16.8
5	− 5.7	+10.2	− 7.5	+11.2	55	16.4	17.0
10	+ 1.2	11 6	− 2 0	12.4	60	16.9	17.4
15	7.4	12.6	+ 7.2	13.5	65	17.3	17.7
20	11.0	13.4	10.9	14.2	70	17.7	18.0
25	12.6	13.8	12.4	14.8	75	18.0	18.2
30	13.5	14.2	13.3	15.3	80	18.3	18.4
35	14.2	14.5	14.0	15.7	85	18.6	18.7
40	14.8		14.7	16.0	90	18.8	
45	(39.0.)		15.3	16.4		(90.0.)	
$H_{obs.} =$	44,400					64,000	
$\eta =$	.00944					.00928	

Average, $\eta =$ .00936

hence

$H_{calc.} =$ 44,000 64,600

$\Delta =$ — 400 + 600

= ± 1.0 per cent.

CAST-IRON. FIG. 13.

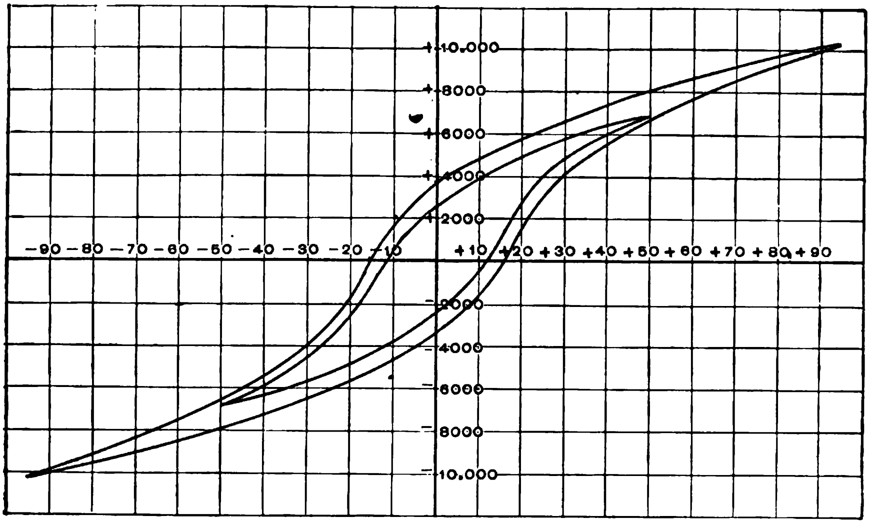

Fig. 13.

TABLE X.

F	I. B_r	I. B_d	II. B_r	II. B_d	F	II. B_r	II. B_d
0	± 2.5		± 3.5		50	6.8	7.9
5	−1.7	+3.2	−2.7	+4.1	55	7.3	8.2
10	− .6	3.9	−1.7	4.7	60	7.8	8.6
15	+ .9	4.4	− .2	5.2	65	8.2	8.9
20	2.6	4.9	+1.6	5.7	70	8.6	9.2
25	3.8	5.4	3.0	6.1	75	9.0	9.4
30	4.6	5.8	4.0	6.5	80	9.4	9.7
35	5.2	6.1	4.9	6.8	85	9.7	9.9
40	5.8	6.4	5.5	7.2	90	10.0	10.1
45	6.3	6.6	6.1	7.6	95	10.3 (95.0.)	
50	6.8 (50.0.)						
$\underset{obs.}{H} =$	22,300 ergs		42,000 ergs				
$\eta =$	.01647		.01589				

Average, $\eta = .01616$

$$\underset{calc.}{H} = \quad 22,000 \qquad 42,800$$

$$\underset{calc.}{H} - \underset{obs.}{H} = \quad -300 \qquad +800$$

$$= \text{per cent.}, \quad -1.5 \qquad +1.9$$

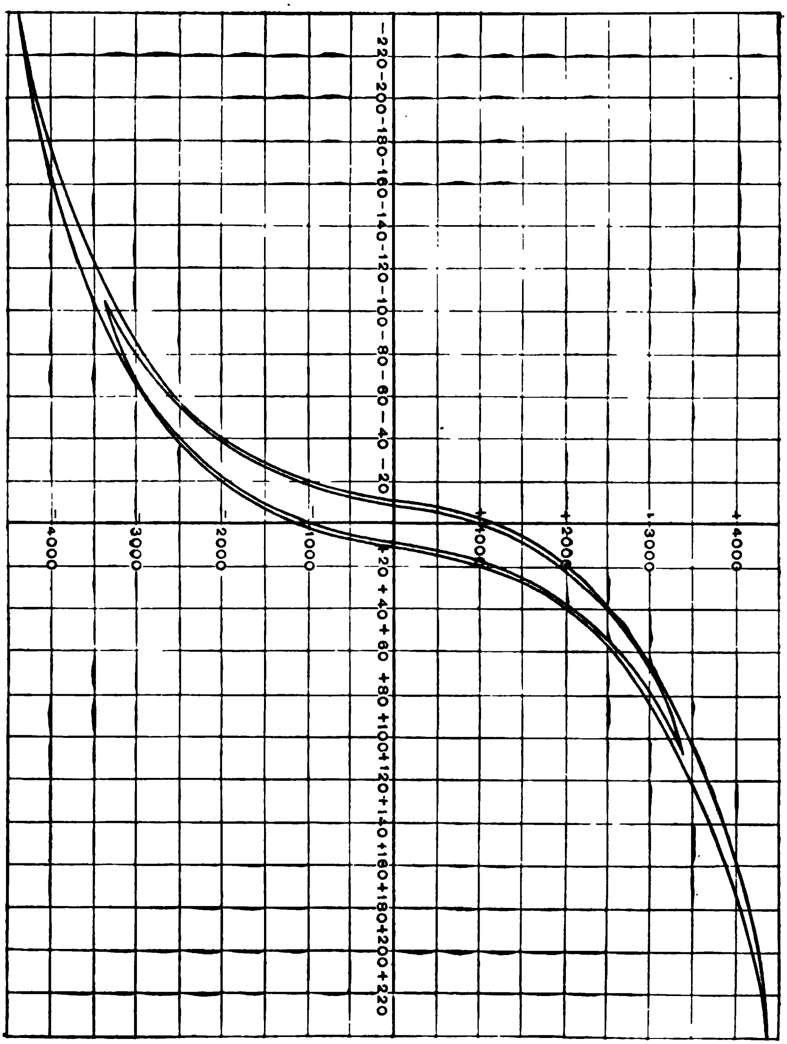

Fig. 14.

MAGNETIC IRON ORE. FIG. 14; TABLE XI.

In the following are given the magnetic curves of a piece of magnetic iron ore, apparently pure Fe_3O_4, of the dimensions, 1 in. × 1 in. × $2\frac{21}{32}$ in.

TABLE XI.

MAGNETIC CHARACTERISTIC.

F = M. M. F., in ampere turns per centimetre length of magnetic circuit.

B = magnetization, in lines of magnetic force per square centimetre.

F	B	F	B	F	B
10	750	70	2930	140	3770
20	1510	80	3080	160	3930
30	2000	90	3220	180	4070
40	2320	100	3350	200	4200
50	2560	110	3470	220	4310
60	2760	120	3580	240	4400

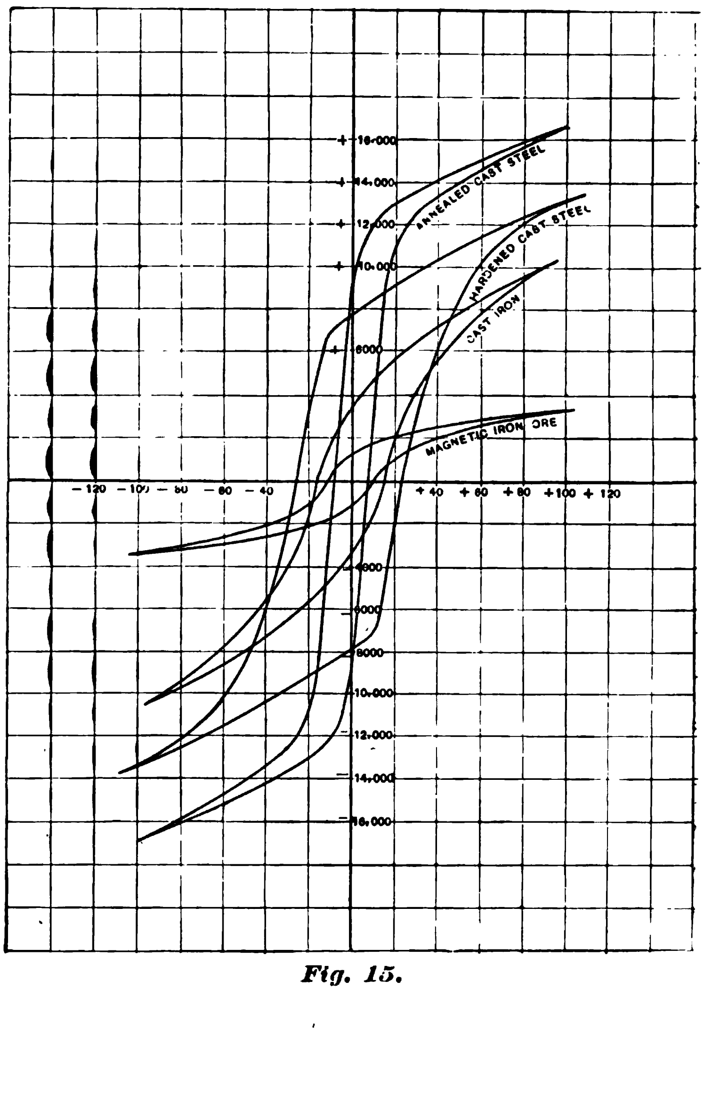

Fig. 15.

TABLE XII.

CYCLIC MAGNETIZATION.

	I.		II.			II.	
F	B_r	B_d	B_r	B_d	F	B_r	B_d
0	± 900		± 1020		130	3640	3740
10	0	+1520	− 200	+1660	140	3730	3820
20	+1200	1920	+1000	2020	150	3820	3900
30	1800	2230	1750	2280	160	3910	3980
40	2160	2500	2150	2520	170	3990	4050
50	2450	2700	2390	2710	180	4050	4110
60	2670	2850	2610	2880	190	4120	4170
70	2850	3000	2800	3020	200	4190	4230
80	3020	3120	2980	3150	210	4250	4280
90	3190	3250	3140	3280	220	4320	4340
100	3340	3360	3280	3410	230	4360	4370
110	3440		3410	3530	240	4400	
120	(106.)		3530	3640		(240.)	

$\underset{\text{obs.}}{H} = 9{,}340$ ergs $\qquad$ 13,780 ergs

$\eta = .02049 \qquad .02041$

Average, $\eta = .02045$

Curve of hysteresis,

$$H = .02045\ B^{1.6}$$

$\underset{\text{calc.}}{H} = 9{,}320$ ergs $\qquad$ 13,810 ergs

$\underset{\text{calc.}}{H} - \underset{\text{obs.}}{H} = -20$ ergs $\qquad +30$ ergs

$= -.2$ per cent. $\qquad + .2$ per cent.

As seen, the coefficient of hysteresis of magnetic iron ore, $\eta = .020$, ranges between that of cast-iron, $\eta = .016$, and of hardened steel, $\eta = .025$.

The magnetic conductivity is approximately 20 per cent. of that of wrought-iron.

In Fig. 15 is given a comparison of the hysteretic curves of

Hardened steel,
Annealed steel,
Cast-iron,
Magnetic iron ore,

in the same size.

This figure shows well the three characteristic forms of hysteretic curves :

TABLE XI.

$$H = \eta B^{1.6} \; [+ \varepsilon N B^2]$$

H in ergs per cycle and cm.^{3}, B in lines of magnetic force per cm.^{2}, F in ampere turns per cm.

Material.	Hysteretic Coefficient. η	Magnetization at the M. M. F. $F = 10$	$= 40$	$= 90$	Residual Magnetism R. For $F = 40$	$= 90$	Coercitive Force C. For $F = 40$	$= 90$	¶ $\frac{\eta}{C}$ For $F = 40$	$= 90$
Very soft iron wire (Ewing)	.0020	12800	14700	16600			(1.5) ¶	(1.9)		
Westinghouse converter, sheet-iron	.0024	14400	17800	20800			(1.8)	(2.0)		
Very thin sheet-iron, standard	.0030 *	13100	17100	20700			(2.3)	(2.8)		
Thick sheet-iron	.00333 †	13100	17500	....			(2.5)	(3.1)		
Sheet-iron	.00421 ‡	....	....	....			(3.2)	(3.9)		
Sheet-iron	.00450 §	....	....	....			(3.4)	(4.2)		
Soft annealed cast-steel	.0080	7800 ‖	14000	16300	5100	8200	6.0	7.0	.00133	.00114
Soft machine steel	.0094	5800	14800	18800	8300	9600	9.1	11.1	.00103 **	.00085 **
Cast-steel of low magnetic conductivity	.0120	2000	6400	9800	2600	3300	9.1	11.6	.00132	.00104
Cast-iron	.0162	1600	6100	10100	2100	3400	10.4	15.2	.00156 **	.00106
Hardened cast-steel	.0250	1200	8000	12900	4500	7500	19.0	23.5	.00132	.00107
Magnetic iron ore	.02045	750	2320	3220		900		10.0		.00204
							Average		.00132	.00108

*, For $N = 100$.

†, $\varepsilon = .746 \times 10^{-6}$.

‡, $\varepsilon = .2083 \times 10^{-6}$.

§, $\varepsilon = 1.16 \times 10^{-6}$.

‖, This, and the following values of this column are derived as average of rising and decreasing branch of the magnetic characteristic, because at $F = 10$ the magnetism is still very unstable.

¶, Computed by means of the average values of $\frac{\eta}{C}$ = .00132 and = .00108.

**, Left out by taking the average of $\frac{\eta}{C}$

1. The hardened steel curve, of high coercitive force, has the bend or "knee" on the *negative* side, so that for zero M. M. F. the "remanent" magnetism is still in the saturation part of the curve—that is, in stable equilibrium; therefore permanently magnetizable.
2. The soft iron curve, with the bend on the *positive* side, so that for zero M. M. F. the "remanent" magnetism, though still very high, is already below the range of saturation, on the branch of unstable equilibre Therefore the remanent magnetism is very unstable and easily destroyed, the more as the coercitive force is very small.
3. The cast-iron curve, which has no marked knee at all, but a steady curvature of low remanent magnetization, but with regard to coercitive force ranging between 1 and 2.

The curve of the magnetic iron ore shows all the characteristics of a cast-iron curve.

Having derived, now, a larger number of values of the hysteretic coefficient η for different kinds of iron and other material, we shall put them together for comparison in Table XI.

It is remarkable, in these results, that for several samples of each set the quotient $\frac{\eta}{C}$ gives almost exactly the same value, while other values disagree therefrom. From this average value of $\frac{\eta}{C}$ are calculated the values of the coercitive force C of sheet-iron, given in the brackets.

For convenience, in the following table are given the values W of consumption of energy in watts per cubic inch, for 100 complete periods (magnetic cycles) per second, and for the magnetization of H lines of force per square inch, giving as coefficient of hysteresis the value $\gamma = 8.3 \times 10^{-6} \eta$

In Table XII., I have given a number of experimental values of the consumption of energy by hysteresis and believe to have shown that this consumption of energy can fairly well be expressed by the empirical formula,

$$H = \eta \, B^{x}$$

where the exponent x is equal, or at least very nearly, to 1.6, and the coefficient η a constant of the material, which ranges from .002 up to .025 and more, and may possibly have a slight

TABLE XII.

$W = \gamma H^{1.6}$

W in watts per cubic inch and 100 complete periods per second.

H in lines of magnetic force per square inch.

	γ	$H =$	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000	110,000	120,000	150,000
Very soft iron wire (Ewing)	166 X 10^{-10}	$W =$	.042	.13	.24	.38	.55	.73	.94	1.16	1.40	1.66	1.94	2.23	3.18
Westinghouse converter, sheet-iron	201		.051	.15	.29	.46	.66	.89	1.14	1.41	1.70	2.01	2.34	2.69	3.84
Very thin sheet-iron	249		.063	.19	.36	.58	.82	1.10	1.41	1.74	2.11	2.49	2.90	3.34	4.77
Thick sheet-iron	277		.070	.21	.40	.64	.91	1.22	1.56	1.94	2.34	2.77	3.22	3.71	5.30
Sheet-iron	350		.089	.27	.50	.81	1.15	1.55	1.98	2.45	2.96	3.50	4.07	4.69	6.69
Sheet-iron	374		.095	.29	.54	.87	1.23	1.66	2.12	2.62	3.17	3.75	4.36	5.02	7.17
Soft annealed cast-steel	663		.17	.51	.97	1.53	2.19	2.93	3.75	4.64	5.60	6.63	7.73	8.88	12.7
Soft machine steel	778		.20	.59	1.14	1.80	2.57	3.44	4.40	5.45	6 57	7.78	9.06	10.4	14.9
Cast-steel of low magnetic conductivity	994		.25	.76	1.45	2.30	3.28	4.39	5.62	6.95	8.39	9.94	11.6	13.3	19.0
Cast-iron	1346		.34	1.02	1.96	3.11	4.44	5.94	7.60	9.41	10.9	13.4	15.7	17.6	25.8
Hardened cast-steel	2077		.52	1.58	3.03	4.80	6.85	9.18	11.7	14.6	17.5	20.7	24.2	27.8	39.8

$H = 25,000$; alternate current transformer, American style (high frequency).

$H = 35,000$; " " " European " low "

Only the values smaller than .25 *W*, can be of practical use; in those larger than 10 the iron gets at least red hot if in larger quantities.

dependence upon the *velocity* wherewith the magnetic cycle is performed, as the second set of alternate-current readings seems to indicate.

In the following table, I give the values of the hysteretic resistance η for some iron samples, subjected to a magnetic cycle between $F = +190$ and -190 ampere turns per centimetre, calculated from Hopkinson's tests[1] by the assumption of the law of hysteresis.

η = the coefficient of hysteresis.

B = the maximum magnetization in lines of magnetic force per square centimetre.

R = the remanent magnetization in lines of magnetic force per square centimetre.

TABLE XIII.

Material.	Condition.	η	B	R
Wrought-iron	Annealed	.00202	18,250	7,250
Soft Bessemer steel..	.045 per cent. C. annealed	.00262	18,200	7.860
Soft Wittworth steel.	.09 " " "	.00257	19,840	7,080
	.32 " " "	.00598	18,740	9,840
	.89 " " "	.00786	16,120	10,740
	.32 " " oil-hard.	.00954	18,800	11,040
	.89 " " "	.01844	16,120	8,740
Silicon steel	3.44 " Si., wrought	.00937	15,150	11.070
	3.44 " " annealed	.00784	14,700	8.150
	3.44 " " oil-hard.	.01282	14,700	8,080
Manganese steel	4.73 " Mn., wrought	.05963	4,620	220
	8.74 " " "	.....	747	....
	12 36 " " "	.....	310	....
	4.73 " " annealed	.04146	10,580	5.850
	8.74 " " "	.08184	1,985	540
	4.73 " " oil-hard.	.06706	4.770	2,160
	8.74 " " "	.....	733	...
Chrome-steel........	.62 " Cr., wrought	.01179	15,780	9,320
	1.2 " " "	.01851	14,680	7,570
	.62 " " annealed	.00897	14,850	7.570
	1.2 " " "	.01638	13.230	6,490
	.62 " " oil-hard.	.03958	13,960	8,600
	1.2 " " "	.04442	12,870	7,890
Tungsten steel	4.65 " Wo., wrought	.01516	15,720	10,140
	4.65 " " annealed	.01435	16,500	11,010
	3.44 " " oil-hard.	.04776	14,480	8,640
	2.35 " " very hard	.05778	12,130	6,820
Grey cast-iron.......	3.45 p. c. C.; .17 p. c. Mn.	.01826	9,150	3,160
White cast-iron......	2.04 " C.; .34 " "	.01616	9,340	5,550
" "	4.5 " C.; 8.0 " "	.....	385	77

These values of the hysteretic resistance vary from .002 up to .082, 41 times the first value.

But especially marked is, that η depends much less upon the chemical constitution of the iron sample, than upon its physical

1. From "Kalender fur Electrotechniker," by Uppenborn, Berlin, Germany.

condition, *annealing decreasing*, and *hardening increasing* the hysteresis very considerably.

So far as the chemical constitution is concerned, the purer the iron the lower is its hysteresis, while any kind of foreign matter increases the hysteresis. Especially manganese increases the hysteretic loss enormously, much less wolfram and chromium, least silicon and carbon. Connected with the increase of hysteresis is always a decrease in magnetic conductivity.

I wish to add a few remarks on two alleged phenomena connected with hysteresis, which have been talked about considerably, without yet being made clear; the decrease of hysteresis for open magnetic circuit, and the decrease of hysteresis of a transformer with increasing load.

With regard to the first, as shown, actual tests do not show a smaller value of hysteresis for open than for closed magnetic circuit.

And it can not be understood how that could be.

For consider an iron molecule of the magnetic circuit exposed to the harmonically varying M. M. F. and performing a magnetic cycle. Evidently it can make no difference for this iron molecule, whether some trillion of molecules distant the magnetic circuit ends in air, or is closed entirely in iron, supposing that the M. M. F. and the magnetism, and therefore also the magnetic reluctivity, are the same in both cases.

Neither can it make any difference whether the M. M. F. is caused only by one sine-wave of electric current, or is the resultant of several M M. F.'s, as in the loaded transformer. It is the same as with the electric current, where the energy converted into heat in each molecule of the conductor does not depend either, whether the material of the conductor on some other point changes, or whether one or more E. M. F.'s are acting upon the circuit.

Hence, until absolutely exact and undoubtable determinations of the hysteretic loss for fully loaded transformers are at hand, the assumption of a decrease of hysteresis with increasing load must be rejected.

That an apparent decrease with increasing load has been observed several times may be conceded, for besides the exceedingly great liability to errors in these tests, where the hysteretic loss comes out as the small difference of two large values, primary energy and secondary energy, and therefore is very much affected by the slightest error in any one of the components, it must be understood that the main possible errors in the determinations on fully loaded transformers all point this way. Neglect of secondary self-induction, decrease of magnetization with increasing load, slowing down of the dynamo-alternator, etc., all cause an apparent decrease in the hysteretic loss for increasing load. At least in one set of tests, those made by Prof. Ryan, at Cornell University, on a small Westinghouse converter, I was able to show in my "Elementary Geometrical Theory of the Alternate Current Transformer"[1] that the observed decrease of the hysteretic loss disappears by reducing the different readings to the same magnetization and the same frequency.[2]

If, indeed, the shape of the wave of M. M. F. varies, then a certain difference in the value of the hysteretic loss can be imagined. Compare it with a mechanical or elastic cycle. A moving pendulum, or an oscillating spring, for instance, continuously converts potential energy into kinetic energy and back; in each oscillation consuming, that is, converting into heat, a part of the energy by internal and external friction. Now, if this motion of spring or pendulum is truly harmonic, less energy is converted into heat than if the motion varies abruptly, is jerking, etc. So, in a magnetic cycle, between the same limits of magnetization the hysteretic loss might be smallest, when the cycle is entirely harmonical, but might be larger if the M. M. F. varies abruptly; for instance, when caused by an intermittent current.

Now, in a transformer with open secondary the M. M. F. acting upon the iron is that of the primary current, and this current is rigidly determined in its shape by the E. M. F. of the dynamo and the E. M. F. of self-induction. But in a fully loaded transformer the secondary current is proportional to the changes of the magnetism, therefore increases very considerably in the moment of a sudden change of magnetism. Hence, if a sudden and abrupt change in the primary current occurs, just as suddenly the secondary current increases in the opposite direction, and thereby makes a sudden change of resulting M. M. F. and magnetism impossible, so that the fully loaded transformer compares with the elastic spring which oscillates freely, while the open-

1. Dec. 1891, *Electrical Engineer*, New York.

2. The latest tests of Ewing prove that, in a fully-loaded transformer the loss by hysteresis is *not* smaller than for open secondary circuit.

circuited transformer compares with a spring, where the motion is determined by a rigidly-acting outside force.

Hence, if the shape of the alternating primary current differs considerably from the sine law, a certain decrease of the hysteretic loss for increasing load can be expected, though certainly not such an enormous decrease as some former tests seemed to point out. These tests must undoubtedly have given erroneous results, perhaps caused by the neglect of the secondary self-induction, which, even if very small and causing only a slight error in the secondary energy, must cause an enormous error in the hysteretic loss, the small difference between the two large values—primary and secondary energy

That an electro-magnet without keeper loses its magnetism quicker than a magnet with keeper, or a closed magnetized iron ring, is a phenomenon. which has nothing whatever to do with this loss of energy by hysteresis, but is merely due to the demagnetizing force of the remanent magnetism. For the remanent magnetism in an open magnetic circuit causes between its poles a certain difference of magnetic potential, which in the moment of breaking the electric circuit acts as demagnetizing M. M. F., and, if the coercitive force is small, as in wrought-iron or annealed steel, almost entirely destroys the remanent magnetism, while in an iron of large coercitive force it affects the permanent magnetism very little. In the closed magnetic circuit the remanent magnetism causes no or very little difference of magnetic potential, and therefore no destruction of the remanent magnetism by its own demagnetizing M. M. F. takes place. But with the hysteretic loss of energy this phenomenon has nothing to do.

To combine the results, what I believe to have proved is that loss of energy in iron caused by reversals of magnetism can be expressed by the analytical formula:

$$H = \eta\, B^{1.6} + \varepsilon\, N\, B^2.$$

where

η = the co-efficient of hysteresis,

ε = the co-efficient of eddy currents,

N = the frequency of the alternations of magnetism,

$\eta\, B^{1.6}$ = the loss of energy by hysteresis proper, or by *molecular friction*, and

$\varepsilon\, N, B^2$ = the loss of energy by eddy currents, per magnetic cycle and per $cm.^3$, proportional to the frequency N.

TABLE XIV.

B	$B^{1.6}$	Increase per 100	B	$B^{1.6}$	Increase per 100	B	$B^{1.6}$	Increase per 100
500	.0208	42	9000	2.122	378	17,000	5.870	55
1000	.0631	85	9500	2.313	389	17.500	6.148	56
1500	.1206	115	10,000	2.511	400	18,000	6.434	57
2000	.1913	142	10,500	2.716	41	18,500	6.722	58
2500	.2732	164	11,000	2.925	42	19.000	7.017	59
3000	.3659	185	11,500	3.141	43	19,500	7.312	59
3500	.4684	205	12,000	3.363	44	20,000	7.613	60
4000	.5800	223	12.500	3.589	45	22.000	8 868	63
4500	.7000	240	13.000	3.821	46	24,000	10.193	66
5000	.8288	258	13,500	4.060	47	26,000	11.59	70
5500	.9662	275	14,000	4.303	48	28,000	13.05	73
6000	1.111	292	14,500	4.580	49	30,000	14.57	76
6500	1.261	308	15,000	4 807	50	35,000	18.65	82
7000	1.420	324	15,500	5.062	51	40,000	23.09	89
7500	1.583	339	16,000	5.329	53	45,000	27.87	96
8000	1.758	353	16.500	5.598	54	50,000	33.00	103
8500	1.936	366						

For convenience, I give in Table XIV., the values of the 1.6th power of the numbers, from 500 to 50,000 with the parts proportional, or the increase of $B^{1.6}$ for 100 lines of magnetic force.

Yonkers, N. Y., December 7th, 1891.

DISCUSSION.[1]

THE CHAIRMAN:—Gentlemen, the poet has informed us that "better fifty years of Europe than a cycle of Cathay." What he would have done had he met a cycle of magnetism, we can but conjecture. The Institute has therefore good reason, I conceive, to congratulate itself that one of its members does not shrink from such a conflict. I am sure I shall but express the sentiments of every member present, when I say that we are much obliged to Mr. Steinmetz for his very elegant and exhaustive treatment of a subject whose title, to say the least, has a most unpromising and uninteresting sound—a subject dealing with the causes of those indispositions of iron to change its magnetic condition which in our old telegraphic days we were wont to sum up by the unscientific term of "residual magnetism."

Before calling for general discussion, I would like to ask Mr. Steinmetz whether, in his experiments and tests, he had determined whether or not there was any real foundation in fact for the distinction which Professor Ewing has drawn between the molecular friction, which he calls "static hysteresis," and the real time-lag, which he denominated "viscous hysteresis."

MR. STEINMETZ:—I really am not yet prepared to answer the question whether viscous or time hysteresis exists or not. My tests in only one set of determinations gave me an increase of hysteretic loss with increasing frequency, which seems to point to

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1. Discussion by Messrs. Bradley, Kennelly, Lockwood and Pupin.

the existence of a viscous hysteresis. For if a viscous hysteresis exists, it would show by an apparent increase of the coefficient of hysteresis, with increasing frequency. But most of the tests do not show this, but give the same coefficient of hysteresis for different frequencies.

At any rate, if there exists such a time-hysteresis—which I shall try to find out—it follows the law of the 1.6th power also.

But I think, only at much higher frequencies than those I have used in my tests, can we hope to meet with viscous hysteresis. I hope to be able at a future meeting to give more detailed information on this and some other phenomena connected with the magnetic hysteresis.

THE CHAIRMAN :—Gentlemen, the subject is before you. While a few of us were in the parlor, prior to the reading of the paper, I heard Mr. Steinmetz condoling with himself in relation to the weather and expressing the hope that there would still be a very considerable discussion. It is therefore to be hoped that any of us who may feel able to grapple with such a subject will not hesitate to do so.

MR. CHARLES S. BRADLEY :—I do not feel able to discuss this paper, but I know it will prove very valuable to us. Our work of late has been upon transformers. I am connected with the Fort Wayne Electric Company, whose transformers now use about 2,000 lines of force to the square centimetre, and we have been trying to increase the lines of force. We encountered the very phenomena treated in this paper, and therefore it is very interesting to me, and I think that we ought to congratulate ourselves upon having a member who can tackle such a subject. It is very seldom that in America, anything of this kind is taken up. We see it very often in Europe, but our commercial age will hardly permit us to devote our time to such experiments and carry them out as they should be.

MR. JOSEPH WETZLER :—A gentleman who is present but who is not a member, has asked me to inquire of the author whether he made any experiments on mitis iron and, if so, what his results were.

MR. STEINMETZ :—I never made any experiments with regard to hysteresis, on mitis iron—only on different kinds of cast-iron.

MR. A. E. KENNELLY :—Mr. President and gentlemen, I think that we have to congratulate ourselves upon a magnetic and physical treat in the paper that we have just listened to. Mr. Steinmetz has been, I think, the first to point out this remarkable law of hysteresis—the variation of the energy consumed per cycle, with the total flux per square centimetre that passes through it. I think that it is perhaps preferable to express the exponent in the equation as a vulgar fraction instead of as a decimal—not that it alters the facts in any way, but merely because it gives us a little more hope of being able to understand what the equation means, if not now, at least let us say in the future. If, instead of writing the energy—Mr. Steinmetz calls it H, as $\eta\ B^{1.6}$, we write it $\eta'\ B^{\frac{8}{5}}$, it gives us some hope of being able to transform that in a simple manner, which will give us the fundamental law concerned. I think there is very little doubt that the law Mr. Steinmetz gives is the true one. It is, first of all, as he showed us some time ago, in accordance with the values observed by Professor Ewing, and so far as my own knowledge goes I am able to corroborate it, for I have observed the same law in the case of one sample of wrought-iron taken by a ballistic method, and another sample of wrought-iron taken by wattmeter method, both giving the $\frac{8}{5}$ power, although I do not know what the exact value of the coefficient η was in those particular instances. It is very puzzling to understand what that peculiar fraction $\frac{8}{5}$ means. It is rather too high and unwieldy a fraction to be understood at a glance. But whatever its inner meaning may be, its outward and visible indications are clear enough, because if you double the flux density in a piece of iron you will treble the energy which is consumed in it per cycle, by hysteresis, independent of the energy that is consumed in it by eddy currents. Of course, if you have any curve which starts from the zero point and rises up in that way, and if you take arbitrary distances like this in the form of a, a^2, a^3, and so on, then if you want to find out whether that curve follows any such law as

$$Y = b\ X^n$$

you have only got to mark off the ordinates corresponding to those abscissæ, and to see if with the powers of a along X you have a constant ratio from one to another in the ordinates. If you do, that ratio will be a^n. In this case, if a is 2, a^n is almost exactly 3. For the 1.6th power of 2 is 3.03, which means that if you double the maximum magnetization in a piece of wrought-iron, you will have 3.03 times the hysteresis loss, and this is a simple way of stating the results which Mr. Steinmetz has pointed out.

Mr. Steinmetz:—As pointed out by Mr. Kennelly, this law of hysteresis gives a very simple numerical meaning. It means that by doubling the magnetization you approximately treble the hysteretic loss and quadruple the eddy loss. So if you make but two tests therefrom, you can find out the amount of energy consumed by eddies and the amount consumed by hysteresis for any magnetization.

And, in general, you will see at once whether the ratio of the iron loss for doubled magnetization is nearer to three, or rather 3.031, or to four, that is, whether hysteresis or eddies consume more energy in the iron.

I would like to add a few remarks regarding the results of the tests given in the paper. This law of hysteresis is of interest from another point of view:

We all know, now, that energy is always the same and indestructible, and merely changes its form and appearance, so that a certain quantity of any kind of energy converted into any other kind of energy always gives an exactly determined amount of the other form of energy, which we call the law of conservation of energy.

But this law of conservation of energy needs a certain restriction or, rather, addition, because every conversion of one form of energy into another is not possible, but only those where the value of a certain integral, called by Clausius the "entropy," is positive or more correctly, is *not negative*, though the case, that the integral of entropy equals zero, hardly exists in nature otherwise but as mathematical fiction, or, in plain English, only those conversions whereby the sum of the latent heat of the universe increases.

According to this law of entropy, if the complete conversion of one form of energy into another is possible, the opposite conversion is not completely possible. Or if we convert a certain amount of one form of energy into another form of energy, and this back again into the first form of energy, which we call a cyclic conversion of energy—we do not get back the original amount of energy, but less, and a part of the energy has been lost; that means, converted into and dissipated as heat.

Therefore no complete cyclic conversion of energy exists, but by any such cycle the amount of available energy has decreased by that fraction that was converted into heat.

Now, these cyclic conversions of energy are of great importance in nature.

For instance, a moving pendulum, an oscillating spring, a discharging condenser completes cyclic processes. In the moving pendulum, continuously kinetic mechanical energy is converted into potential mechanical energy, when it moves from the vertical position into its greatest elongation, while when moving from elongation into vertical position its potential energy is reconverted into kinetic energy, thereby completing a cycle, so that in vertical position all the energy is kinetic, in elongation all the energy potential.

In the same way, in the oscillating spring, a cycle is performed between potential energy of elasticity and kinetic energy of motion, in the discharging condenser between electrostatic and electrodynamic energy, and that the pendulum and the spring come to rest, and the condenser discharges, is due to the continuous loss of energy by dissipation as heat, caused by the law of entropy.

Now, in none of these cyclic conversions of energy, so far as I know, was the law known, which determines and analytically formulates the loss of energy by conversion into heat. The electromagnetic cycle is the first one where in the law of hysteresis, this law of dissipation of energy by heat, finds an analytical formulation.

In the alternating electromagnetism we have such a cyclic conversion of energy from electric into magnetic energy and back. Magnetism represents a certain amount of stored up or potential energy determined by the integral

$$\int F \, d \, B$$

Now, as long as the magnetism increases, electric energy is transferred from the electric current and converted into potential magnetic energy. While the magnetism decreases, potential magnetic energy is reconverted into electric energy, and appears in the electric circuit as E. M. F.

But the full amount of energy is not given back to the electric circuit, but less. Less by that amount that has been converted into heat by hysteresis.

Hence the law of hysteresis is the dependence of the integral of entropy in the electromagnetic cycle, upon the intensity of magnetization, and therefore of interest.

DR. M. I. PUPIN:—I agree fully with Mr. Steinmetz's last remarks that no process in nature is perfectly reversible and that the phenomenon of magnetic hysteresis is only a special case of the irreversibility of natural processes. It is only a special case of the general law which was first announced by the late Professor Clausius, the law namely that the entropy of the universe is tending toward a maximum, that is, that there is a certain function of the properties of matter of the universe which increases as the amount of heat energy increases in the universe. Now, as in every process there is a certain amount of energy converted into heat, the amount of heat in the universe is continually increasing. Therefore the entropy is continually increasing and therefore steadily approaching its maximum. Professor Rankine made a guess as to how many years would elapse before the whole energy of the universe will be converted into heat, when there will be no life, no natural phenomena excepting heat vibrations. It is very far off yet

Closely connected with this magnetic hysteresis is, I think, the so called electro-static hysteresis. Of course experimental researches in this field have not been carried on far enough yet, to enable us to speak with any definiteness, but still it is beyond all doubt that if you polarize a dielectric and depolarize it again, a certain amount of heat is developed. I think one of the obstacles to the commercial introduction of the condenser, is its getting hot. Now some think it gets hot on account of the convection currents which are passing between the plates of the condenser by means of the air currents and the dust that is in the air; but if you use paraffine so that it will prevent those convection currents, even then you will observe heat developed in the paraffine which must be attributed to the same cause which develops heat when iron is magnetized and demagnetized; that is hysteresis.

Polarization and depolarization of paraffine, and in fact any other dielectric, is not a perfectly reversible process.

Allow me now to comment upon a few points brought up in Mr. Steinmetz's paper. I always believed thoroughly in Professor Ewing's views with regard to the following experimentally well supported assumption, namely that in very low magnetizations the act of magnetizing and demagnetizing is practically reversible, and that when a high point of saturation, say 24,000 or 25,000 lines per square centimetre is reached, that after that the loss due to hysteresis does not increase. I do not see why it should increase, because after that the iron does not receive any stronger magnetization. The additional lines of force after passing the saturation point are due to the increased magnetization of the air itself, and that magnetization is practically reversible.[1] I see that Mr. Steinmetz has found out an increase, independent of the degree of saturation. There is a discrepancy, and I am inclined to side with Professor Ewing, until I am convinced by Mr. Steinmetz that his method of measurement and observation could not be objected to in any particular whatever. Unfortunately, Mr. Steinmetz has not discussed his method so that one can examine it critically. He has given the general idea, the instruments employed, etc., but there is no discussion of the theory of the method, and also of the probable percentage of his errors of observation. I am sure that Mr. Steinmetz will do that at some future time. It would be very interesting and very important indeed to know whether that disagreement is in favor of Mr. Steinmetz or of Professor Ewing.

There is on page 49 a discussion of the variation of the hysteresis loss with the load. In that discussion Mr. Steinmetz says as long as the secondary current is open, the form of the wave of the primary current may not be a sine curve; but that when the secondary current is started, the wave of the magneto-motive force is forced into the shape of the sine curve on account of the reaction of the secondary current. Now I would beg to disagree with Mr. Steinmetz; I think it is just the opposite. It does not make any difference what the electromotive force is, as long as there is a very large self-induction in the circuit,—as there certainly is in the primary circuit as long as the secondary is open, the wave of the primary circuit is independent of the wave of the impressed electromotive force and is practically a sine wave. But when the secondary circuit is closed, then the impressed electromotive force, being assisted by the electromotive forces in the secondary circuit, asserts itself and gives the primary current its own shape, and the stronger the secondary current, the larger assistance the primary impressed electromotive force gets from it. The secondary current aids the primary impressed

1. A. E. Kennelly, on "Magnetic Reluctance" TRANSACTIONS, vol. viii. No. 11, p. 500.

E. M. F. to assert itself and force the primary current into its shape, that is, the shape of of the impressed E. M. F. That can be proved very easily both from theoretical and practical standpoints. So that I do not see the force of Mr. Steinmetz's argument.

MR. STEINMETZ:—The method used in my tests was the well-known electro-dynamometer method, as explained in the paper, with some slight modifications to insure the greatest possible exactness in the results.

With regard to the difference between open circuited and fully loaded transformers, I think Professor Pupin misunderstood me. I did not say that the wave of the primary *current* in the transformer under *full load* resembles the sine wave more than with *open circuit*, for that would have been wrong. What I said was that the wave of the *magnetism* and of the *resulting* M. M. F. in the transformer under full load resembles more the sine wave than it does in the open circuited transformer.

Suppose the impressed E. M. F. at the terminals of the transformer differs from the sine shape, differs even considerably. Then the primary current, which at open circuit represents the resulting M. M. F., will differ much less from the sine shape than the impressed E. M. F., being smoothed out and rounded off to a very great extent by the heavy self-induction of the open circuit transformer. For in the moment of any sudden rise of the impressed E. M. F., already a small rise of the primary current and, therefore, of the magnetism, will induce sufficient counter E. M. F. to make a rapid increase of the primary current impossible.

Hence, in the open circuited transformer, the wave of the magnetism will resemble the sine wave more than the wave of impressed E. M. F. But, nevertheless, it must differ from the sine wave if the impressed E. M. F. differs from sine shape. For, as before said, the resulting or current producing E. M. F. and, therefore, the current, is rigidly determined by the small difference of impressed and induced E. M. F., and the induced E. M. F. must therefore have a shape very similar to the impressed E. M. F., hence differing from sine shape the more the impressed E. M. F. differs therefrom.

Now, the induced E. M. F. is the differential quotient of the magnetism. Hence, if the magnetism is a sine wave its differential quotient, the induced E. M. F, has to be a sine wave also and, on the other hand, the more the induced E. M. F. differs from sine shape, the more its integral function, the magnetism, is forced to differ. Indeed, the magnetism may apparently differ, in its absolute value, less from sinusoidal form than the impressed E. M. F., for it is not the instantaneous values of the magnetism which are directly influenced by the shape of impressed E. M. F., but the greater steepness or flatness of the curve of magnetism which is directly caused by the impressed E. M. F. But it is just this difference in the *velocity* of change that is, in the *quickness* of rise or decrease of the magnetism, and not the magnetism itself, which would have to account for an increased loss by hysteresis. Hence, it is really *not* the difference of the curve of magnetism, from sine shape, but that of the curve of induced and, therefore of impressed E. M. F., which may possibly cause an increase in the loss by hysteresis.

Quite different in the transformer at full load. Indeed, its apparent self-induction is essentially decreased and the primary current will therefore resemble the shape of the impressed E. M. F., and differ from the sinusoidal form, much more than for open circuit.

But at full load the wave of magnetism and of resulting M. M. F. is much more independent of that of primary current and primary E. M. F. It is caused by the combined action of the instantaneous values of primary and of secondary current, and the secondary current, again, is induced by the magnetism. Hence the result will be, if a sudden change of impressed E. M. F. occurs and produces a sudden change of primary current, just as suddenly as the opposite change of the secondary currents will take place, so that the resultant M. M. F. of both combined currents will not change perceptibly, but practically independent of either current, will alternate freely in sinusoidal waves, in spite of any difference in the wave shape of primary and secondary current from the sine law.

And, indeed, a glance over the curves of instantaneous values of the electric quantities in the transformer, as they have been determined, for instance, by Professor Ryan, at Cornell University, and communicated to this Institute some time ago[1], shows a considerable discrepancy at open circuit between the primary current and the sine wave, while in the loaded transformer the secondary E. M. F. and, therefore, the magnetism, almost universally resembles sine shape.

With regard to Ewing's theory of the molecular magnets, I do not say that I disbelieve in it, neither that I believe in it. At the first view, this theory did not seem to agree with the results of my tests, as I said in my paper, but I did not take the time to think it over more completely whether this theory could be made to agree with the tests; my aim was to gather *facts*, being convinced that based upon a large number of facts, a theory will be found in due time to explain them. [See appendix, p. 64.]

DR. PUPIN :—Magnetic force is certainly a resultant of the primary and secondary currents. As long as the secondary is open, the primary current will be a sine wave, practically. It does not make any difference what the impressed electromotive force is of the alternator, and therefore the magneto-motive force will be a sine wave and the magnetic induction will vary like a sine wave If you close the secondary circuit, the self-induction

1. TRANSACTIONS, vol. vii, p. 1 *et seq.*

in the primary is reduced, and therefore the back electromotive force in the primary is smaller and the impressed electromotive force begins to assert itself more and more and gives to the primary current its own shape. The shape of the secondary current, as long as the secondary's resistance is very large and the secondary current is small—that, too, is practically a sine wave, the primary current being also practically a sine wave, the resultant of the two—that is, the magneto-motive force—must also be a sine wave. But now, if you diminish the resistance in the secondary circuit, that is, increase the load, then the shape of the primary current begins to correspond to the shape of the impressed electromotive force, and also the shape of the secondary current begins to correspond to the impressed electromotive force, and the resultant of the two, the magnetizing current, must also begin to correspond more and more in shape to the impressed electromotive force—that is, the magneto-motive force begins to correspond to the shape of the impressed electromotive force. The same is true of the magnetic induction. We are not to forget that the secondary current does not depend on the rate of change of the primary current only. The relation is a little more complicated. There is a difference in phase between the primary and secondary, varying anywhere between 90 degrees and 180 degrees. When the difference in phase is nearly 180 degrees, that is, at full load, then the primary current and the secondary current correspond to each other almost exactly in shape, and have the same shape as the impressed electromotive force.

MR. STEINMETZ:—I can not yet quite agree with Dr. Pupin. The resultant of two M. M. F.'s of equal shape, but different phase, need not have the same shape, but can have an entirely different form. So for instance the resultant of two very ragged-looking waves can be a complete sine wave. Let us come down to numerical values. Take for instance a 1000 volt alternator, feeding into the primary coil of a transformer. The internal resistance of the primary coil is 20 ω. The current flowing through the primary, at open secondary circuit, a small fraction of an ampere. Hence, what I call the "resulting E. M. F.," that is the E. M. F. which sends the current through the resistance, is only a few volts.

But this "resulting E. M. F.," is the difference of this instantaneous values of primary impressed, and primary induced E. M. F. The difference is only a few volts, the primary impressed E. M. F. = 1000 volts, hence the primary induced E. M. F. must be almost like the impressed E. M. F., and must differ from sine-shape, therefore, if the impressed E. M. F. differs; and if the differential quotient of magnetism, the induced E. M. F., is non-sinusoidal, the curve of magnetism is non-sinusoidal also.

In the transformer at full load the current and therefore the difference between induced and impressed E. M. F. is much greater, the induced E. M. F. is therefore much more independent of the impressed E. M. F., the more, the greater the load is, hence the curve of magnetism alternating freer than at open circuit, and therefore more approximating the harmonic vibration of the sine-wave

DR. PUPIN:—It does not by any means follow that at every moment the difference between the impressed E. M. F. and the back E. M. F. is small when average value of the current is small, and that is the point in your argument. And even if it is I do not see how that can prove that the shape of the current and the impressed E. M. F. are the same.

MR. STEINMETZ:—We have seen that the effective value of the current, and therefore the effective or average value of the difference of primary impressed and primary induced E. M. F. must be small. This indeed does not prove that some of the instantaneous values of this difference may not be considerable. But first, this could be only the case with very few values, because, if for any great length of time the current were considerable, this would show in the average or effective value, the more, as this is the average of the squares of instantaneous values.

On the other hand, to make the current considerable only for a moment, while immediately before and after it is small, either the induced E. M. F. must suddenly decrease enormously, and the next moment increase just as suddenly—which is impossible, because it is the differential quotient of magnetism—or the primary E. M. F. had to rise and decrease again very suddenly, and such a sudden rise, and immediately afterwards decrease of primary impressed E. M. F., not only is an electro dynamic alternator unable to produce, but no electric circuit would permit a current of such enormously large value and short duration to pass. Hence we can from the small value of effective primary current, conclude that also its instantaneous values without exception must be small.

DR. PUPIN:—I do not suppose that a wave which is not a sine, must necessarily be a wave that goes up and down with sudden variations. I think that every good commercial machine is constructed in such a way that the electromotive force is a perfectly smooth curve. There may be small corners, but even those corners are very nicely rounded. Generally speaking it is a sign of good construction of the machine when the impressed electromotive force is a smooth curve—certainly not a curve that has kinks in it. Kinks in the current curve are produced by a harmonically varying resistance. It would be almost impossible to construct a machine so badly as to give kinks in the electromotive force curve. The current may run smoothly, but still be very far from a sine wave. A sine wave is not the only smoothly running wave. There are many other waves that are nice and smooth. The only possibility of having such a current as Mr. Steinmetz described, would be simply to introduce into the circuit a harmonically variable resistance. An arc light circuit represents a harmonically variable resistance, and introduces those complications, the kinks. An arc light machine violates most of the well established rules in dynamo construction, but it does the work of the arc light circuit admirably, and it does it because it encourages kinks and other irregularities in the current wave.

MR. STEINMETZ :—I entirely agree with Professor Pupin, that there is really nowadays almost no possibility of getting such sharp pointed waves of alternating E. M. F. that a difference of the hysteretic loss between open circuit and closed circuit could be expected. And I did not believe myself in this cause of the discrepancy of former tests on transformers under full load and with open secondary circuit. I made this remark only to be absolutely just, and not entirely to reject as erroneous, determinations made by others, but at least to point out a cause which might produce, though not at all likely, a slight difference between the values found under full load and with open circuit.

Indeed, all our modern alternators produce waves very much resembling sine curves, and the only way to get from them such rapidly changing E. M. F's is, as Dr. Pupin pointed out, the introduction of variable resistances, as arc lamps, into the circuit.

But some of the older types of alternators. as, for instance, the Klimenko alternator at the Vienna exhibition, 1882,[1] gave evidently sharp pointed E. M. F.'s, as I found by drawing the curve of instantaneous values of E. M. F. of an alternator of a similar type, where induction was produced by making and breaking the magnetic circuit. As you see, this is a very similar case to that referred to by Dr. Pupin, only that in this case a variable magnetic reluctance and not a variable electrical resistance was introduced into the circuit.

MR. KENNELLY :—It is unfair, perhaps, when we have such a good paper, to offer criticisms upon it, but when it is as likely as this is to become classical I think that in self defense we ought to try to keep it as free from all imperfections as possible. I am taking the liberty of making a criticism on one term Mr. Steinmetz has used. He has spoken of the normal inductance of the coil of his ammeter as so many ohms, and I would suggest that it would be preferable to employ the word impedance, instead of inductance, because an inductance is a henry and an impedance is an ohm, and I think it is a pity to confuse the two ideas.

MR. STEINMETZ :—I did not use the term *inductance* as synonymous with coefficient of self-induction, where it would be expressed in henrys, but I used inductance in the very sense that Mr. Kennelly means with *impedance*.

I intentionally used the term *inductance*, following a proposition which I read once, I do not remember where. but which seemed to me so highly commendable, that I should like to see it introduced in practical engineering.

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1. A remarkable feature was that it consumed 4 H. P. when running under full load, but almost 6 H. P. when running fully excited but without taking current off, that is, without load.

Indeed, the "coefficient of self-induction" gives all the information needed for determining the electric phenomena in inductive circuits. But everybody will concede that it is a tedious, cumbersome work, from the "coefficient of self-induction" to calculate, for instance, the instrument corrections for a whole set of tests made with somewhat differing frequencies. Besides, I think it will be some time before the "practical electrician" will handle the "coefficient of self-induction" just as easily as he now does ohms and amperes.

Let us consider somewhat closer the phenomena in an inductive circuit. If a sine wave of alternating current flows through an inductive circuit, a certain E. M. F. is consumed by opposing E. M. F.'s.

First, by the electric resistance of the circuit, an E.M.F. E_1 is consumed, which is proportional to the current C, with a coefficient of proportionality, R, which is called the true or ohmic resistance, or, in short, the *Resistance* of the circuit.

This E. M. F. is of *equal* (but opposite) phase with the current C:

$$E_1 = R\ C$$

Then by the action of the changing magnetic field of the circuit an E. M. F., E_2 is consumed, which lags one-quarter of a phase, or 90 degrees, behind the current, and is proportional to the current C, with a coefficient of proportionality I, which I call the *Inductance* of the circuit:

$$E_2 = I\ C$$

This inductance, I, is of equal dimension with the resistance R, hence measured in ohms also.

This inductance, I, is proportional also to the frequency of the alternating current. Hence, if I call the inductance for 100 complete periods per second the *Normal inductance* I_0, for any other frequency N the inductance is simply

$$I = \frac{N}{100}\ I_0$$

Now, the "normal inductance" is a constant of the circuit just as well as the "resistance" or the "coefficient of self-induction," and only depends upon the latter by the equation,

$$I_0 = 200\ \pi\ L$$

only that "inductance" is measured in ohms also, therefore most easily combined with the resistance.

The combination of the *resistance*—which determines the E M. F. of equal phase with the current—with the inductance, which determines the E. M F. lagging one-quarter phase behind the current, is the "impedance," or "apparent resistance."

Hence,

$$\text{Impedance} = \sqrt{(\text{Resistance})^2 + (\text{Inductance})^2}$$

The quotient of inductance and resistance is the angle of difference of phase between current and impressed E. M. F.

$$\tan \varphi = \frac{\text{Inductance}}{\text{Resistance}}$$

You see, it is easy to make a person understand that he has in an alternating current circuit two kinds of resistances. a "resistance" which consumes energy and an "inductance" which does not consume energy, and make him calculate the apparent resistance or "impedance" as the hypothenuse of a right-angled triangle, with resistance and inductance as catheti; while the coefficient of self-induction will frighten the "practical man" still for quite a while.

On the other hand, "inductance" is more convenient than "coefficient of self-induction," because expressed in the same dimensions as resistance, in ohms.

I used the term "normal inductance," because in reducing the readings I found it much more convenient than the use of the "coefficient of self-induction," and therefore recommend its use.

MR. WETZLER:—Before moving to adjourn, I would like to move a vote of thanks to Mr. Steinmetz for his admirable and interesting paper this evening.

THE CHAIRMAN:—Gentlemen, it is with feelings of peculiar gratification that I put this motion. I was very glad indeed to hear Mr. Bradley, in his initiatory remarks speak of the marked excellences of the paper we have heard read, and I was pleased also to hear him remark upon the rarity of such papers in Amica. Mr. Bradley, I think, did our sister societies of Europe more than justice, because it is in but few of the societies over there, and I am speaking of English-speaking countries of course, that we find such papers as this—leaving out the Physical Society and that other in which the most distinguished member of our own profession now presides so ably (I mean the Royal Society), there is none in which papers of this character are of high frequency.

[A vote of thanks was carried and the meeting adjourned.]

APPENDIX:

[COMMUNICATED BY MR. STEINMETZ AFTER ADJOURNMENT.]

Having had time in the last few days to consider more deeply the relation of this law of hysteresis to Ewing's theory of magnetism, I found that this law of hysteresis agrees very nicely with Ewing's theory, giving just the phenomena this theory leads us to expect.

According to Ewing's Theory, for very low M. M. F.'s, forces too small to affect the chains of molecular magnets, the magnetic cycle should be almost reversible, that is, the hysteresis very small or almost nil.

For medium M. M. F.'s, that is M. M. F.'s large enough to break up the chains of molecular magnets, the magnetic cycles must become markedly irreversible, and the hysteresis as function of the M. M. F., must rapidly increase.

For high M. M. F.'s, where the chains of molecular magnets are mostly broken by the superior outside M. M. F., the hysteretic loss, as function of the M. M. F., should be expected to increase slower again and always slower.

This is exactly the case, when the hysteretic loss, follows the law of the 1.6th of the *magnetization* B, as shown best by the affixed curve Fig. 16.

In Fig. 16 the *dotted curve* gives the magnetization B, in lines of magnetic force per cm², as function of the M. M. F. F, in ampere turns per cm.

The *drawn curve* gives the hysteretic loss, in ergs per cm.³ and cycle, calculated by the equation:

$$H = .003507\ B^{1.6}$$ [1]

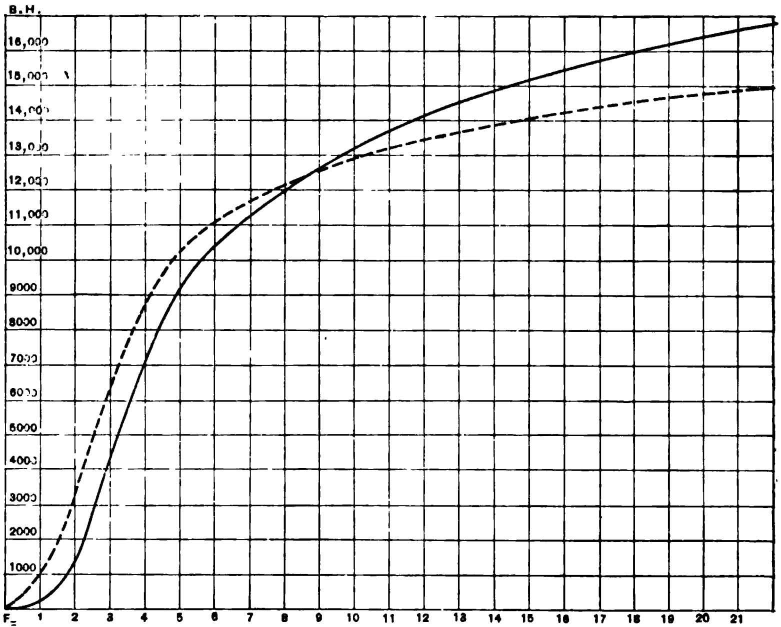


Fig. 16.

but not plotted, as in the former curves, with the magnetizations B as abscissæ, but with the M. M. F.'s: F as abscissæ, that is in the form:

$$H = f(F).$$

As seen, the hysteresis H for low M. M. F.'s, $F = 0 \sim 1$, is very low and almost nil, increases very rapidly for medium M. M. F., $F = 2 \sim 5$, and then increases slower again and always slower, just as Ewing's theory leads us to expect.

Yonkers, N. Y., February 7th, 1892.

1. This curve corresponds to a set of tests not contained in the paper, being made after its completion. I chose this particular set of tests, because it covers a larger range of magnetization than any set of tests given in the paper.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 16, 1892.

The 64th meeting of the American Institute of Electrical Engineers was held this date, at No. 12 West Thirty-first Street. The meeting was called to order by Vice-President Francis B. Crocker.

THE CHAIRMAN:—We have two papers for this evening's meeting. The subject of the first one, although not at all familiar, is nevertheless very interesting and sooner or later will be a matter of importance. In fact I doubt not that a great many inventors are now working on this very problem, and although it now strikes us as peculiar, this combination of alternating and direct currents, each of which we are used to consider separately, nevertheless it is merely a question of a few months, I think, when systems of this sort will often be the subject of discussion. Without any further delay, therefore, I will announce the paper of the evening on "A Proposed System of Alternating Direct Current Transformation," and introduce Lieutenant F. Jarvis Patten, as the author.

A paper read at the 64th Meeting of the American Institute of Electrical Engineers, New York, February 16th, 1892, Vice-President Crocker in the Chair.

A PROPOSED SYSTEM OF ALTERNATING-DIRECT CURRENT TRANSFORMATION.

BY LIEUTENANT F. JARVIS PATTEN.

Recent German practice has given unforeseen importance to all devices for transforming and rectifying alternating currents. The year just passed has been fruitful in the development of multiphase systems, and the new departures are marked by novelty and ingenuity. I have followed these steps with close attention, for they open to the electrical engineer a comparatively new and very interesting field.

The system of transformation which it is the purpose of this paper to lay before you, has arisen mainly from my study of multiphase current developments, and I style it a proposed system, because I have not yet had an opportunity to test it in the completed form and can therefore give no data as to efficiency.

Quoting an author who has written interesting descriptions of multiphased apparatus for the *Electrical Review* of London, after describing the Shuckert motor transformer, which you will remember was brought to your notice by Mr. Carl Hering, in his interesting reminiscences of the Frankfort Exhibition, the author in closing sums up as follows:

" The present importance of these currents (multiphased) may " be greatly diminished by the discovery of an apparatus capable " of transforming a single alternating current economically into " a continuous current. It is also possible and even probable that " multiphased currents will constitute merely a transitory sys- " tem, as the Jablochkoff candle constituted a transitory system " between the arc and incandescent lamp."

While it is not my desire to detract in any way from the known merits and beauty of multiphase systems, I have always maintained that two wires ought to be sufficient for all purposes, and the system here presented is simply offered as a solution of the problem of obtaining electrical energy in any desired form from a single high tension alternating current.

To merely reverse all the positive or negative impulses of a single alternating current would evidently not be a solution of this problem. The resulting current and the magnetism it produces are pulsating in character, having zero periods at each re-

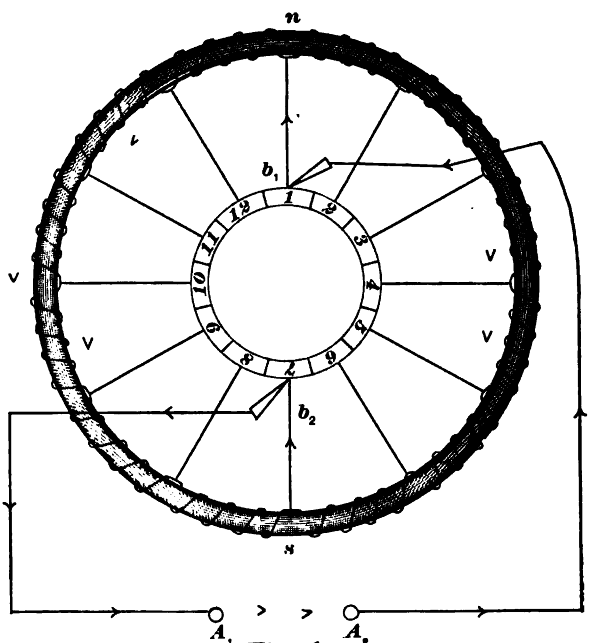


Fig. 1.

versal of current. A useful direct current must be obtained, or one having a practically uniform electromotive force.

To explain the methods used, I must direct your attention briefly to a former paper, read about two years ago, describing an alternating motor which was new at that time, as well as to the Shuckert machine before referred to.

A combination of the functions of these two machines renders possible a number of singular and interesting transformations, which, if they are not entirely novel, any description they may have received has escaped my notice.

The essential features of what for convenience I will style the

"Patten motor," are shown in Figs. 1 to 3 of the drawings, and the Shuckert machine is shown by diagram in Fig. 6.

To explain the former, Fig. 1 is an ordinary Gramme winding and collector, in which a direct current applied to the brushes would make, say, the poles indicated *n* and *s*. A source of alternating current connected to the brushes, however, would reverse the polarities of the ring at each reversal of current, and the tendency to motion would of course be reversed if the fields remained

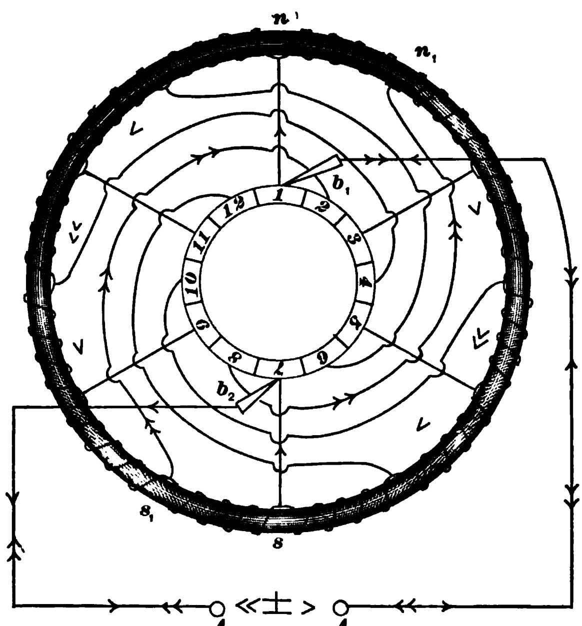


Fig. 2.

the same, but would continue in the same direction if the fields were also reversed by the same alternations of current. If, however, the fields N and S were maintained constant, and by some device the brushes b_1 and b_2, Fig. 1, could be made to change places at each reversal of current, then with an alternating current the polarities *n* and *s* of the ring would remain unchanged, and in a constant field the tendency to motion would still be continuously in the same direction.

It is not practicable to move the brushes mechanically, but the same effect is obtained by the system of armature connections shown in Fig. 2, where the odd numbered bars of the collector are connected to the winding in the usual way, but the intermediate even numbered segments are connected to points of the winding diametrically opposite to them.

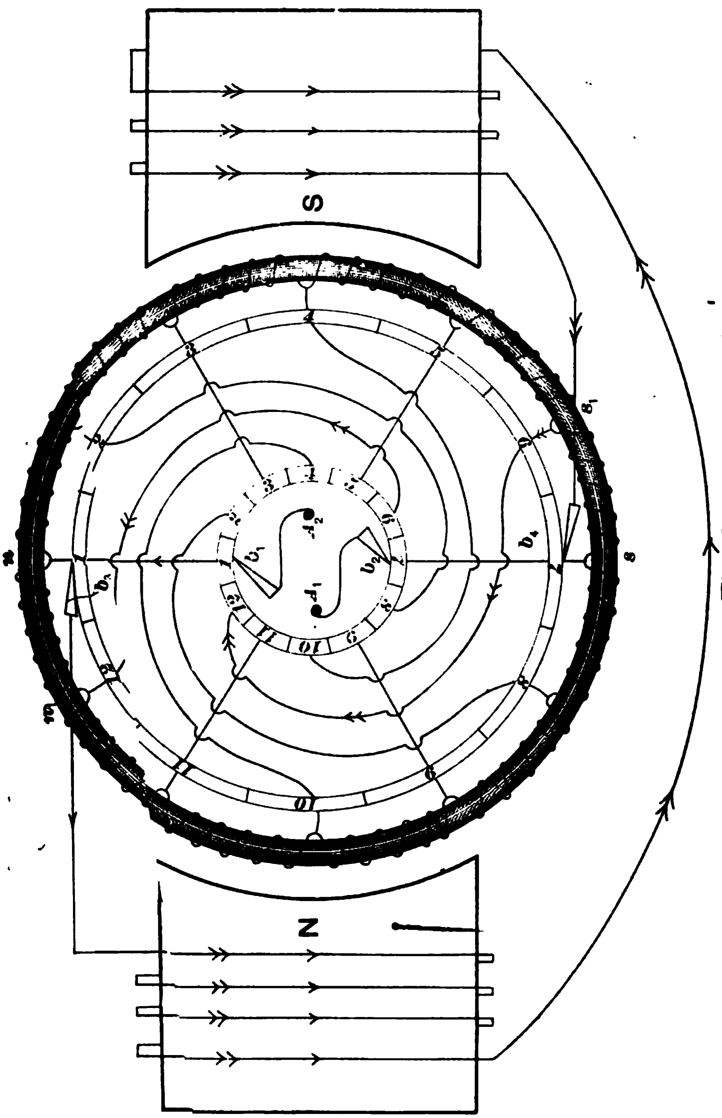


Fig. 3.

Such an armaure, supplied with an alternating current and placed in a two pe field, will turn through the arc covered by one collector bar aeach reversal of current, the polarity of the ring remaining unchanged, as will be seen by tracing two successive impulses, shown respectively by the single and double arrows.

If, besides the collector just described, another be connected to the winding in the ordinary way, like the outer one in Fig. 3,

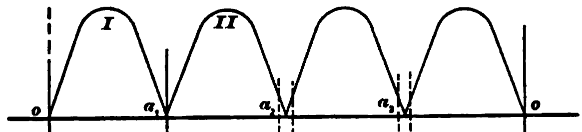


Fig. 4.

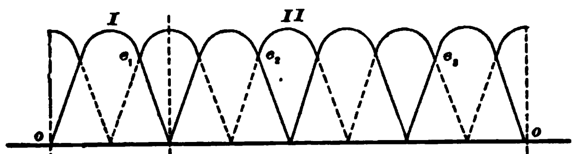


Fig. 5.

where, to avoid confusing the drawing, the source of alternating current is shown inside the collector, then evidently brushes bearing on the outer collector will give, as indicated, a current of one direction to any circuit connected to them, as that used for exciting the fields, N. S, Fig. 3. Thus connected, the machine starts itself as would a direct current motor, both fields and armature reversing, but it will continue gaining in speed until one seg-

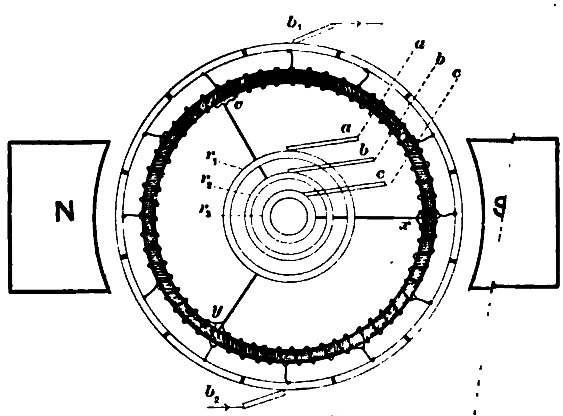


Fig. 6.

ment of the collectors pass their brushes at each reversal of current, when it becomes a synchronous alternating motor, having a fixed and uniform speed—that of commutation. And it may be given almost any speed as compared to that of the generator and yet be in synchronism, by suitably altering the winding and giving the motor commutator a greater or less number of segments.

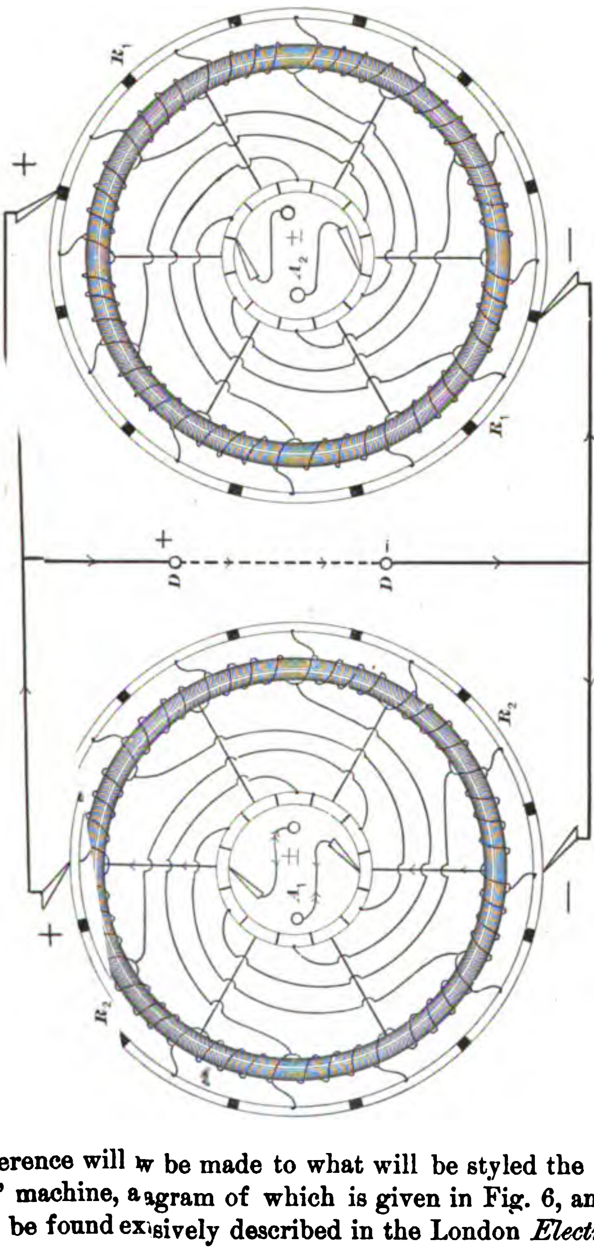


Fig. 7.

Reference will now be made to what will be styled the "Shuckert" machine, a diagram of which is given in Fig. 6, and which will be found extensively described in the London *Electrical Re-*

view of November 20th and December 25th, 1891. It consists of an ordinary Gramme winding and collector, the latter shown for convenience outside the ring. There are also three separate

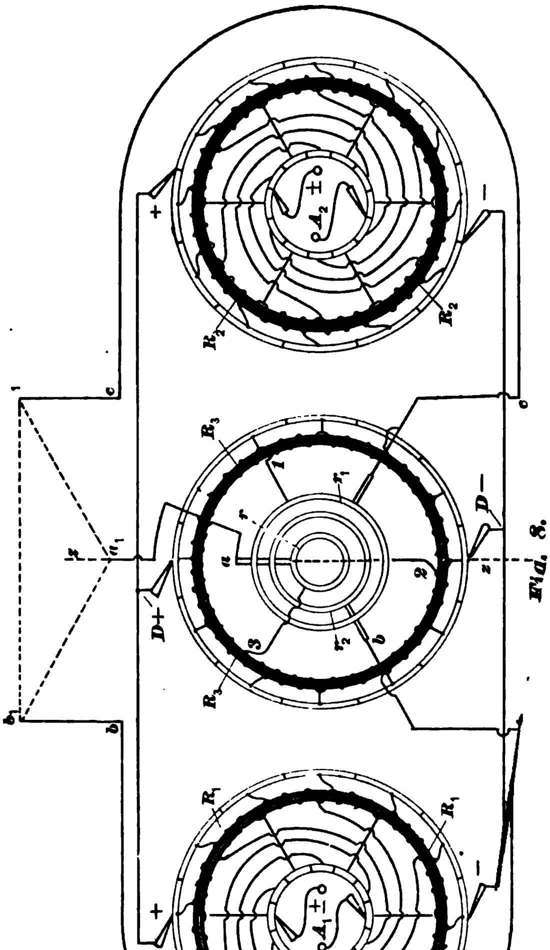


Fig. 8.

ring contacts, r_1, r_2, r_3, provided with brushes a, b, c, and the rings are connected each to one of three equidistant points of the armature winding, x, v, y.

Such a system admits of two important transformations, namely—

A direct current applied at the brushes b_1, b_2, bearing on the collector, causes the armature to turn, and triphased alternating currents can be collected in circuits connected to the brushes *a*, *b*, *c*. It may be noted here in passing, that these latter will reverse at each half revolution.

Or conversely triphased alternating currents supplied at the rings through the circuits connected to the brushes *a*, *b*, *c*, will cause the armature to turn and (when in synchronism) a uniform direct current will flow in any circuit connected to the brushes b_1

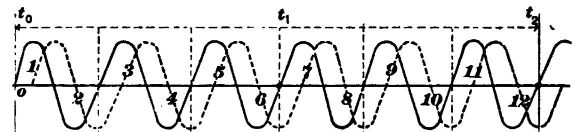


Fig. 9.

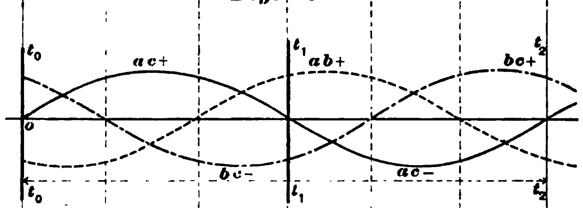


Fig. 10.

and b_2, bearing on the collector. The machine thus transforms triphased alternating currents into a uniform direct current or the reverse. If the functions of this machine and that previously described be combined, other novel transformations will result, as it is evidently only necessary to supply a current of approximately uniform E. M. F. to the collector brushes in Fig. 6 to obtain triphased alternating currents in circuits connected to the brushes *a*, *b*, *c*, or the rings.

Returning now to Fig. 3, the current in a circuit connected to the brushes bearing on the outer collector will be a single alternating current, rectified like that shown in Fig. 4, and will have zero values corresponding to each reversal.

But if two alternating currents, having a quarter phase difference, be rectified and superposed, a comparatively uniform direct current like that shown in Fig. 5 will result. To obtain this, two armatures like that shown in Fig. 3, secured to a common spindle, are placed in the same field and are supplied with independent alternating currents differing in phase by a quarter period. This arrangement is shown by diagram in Fig. 7, where the fields are

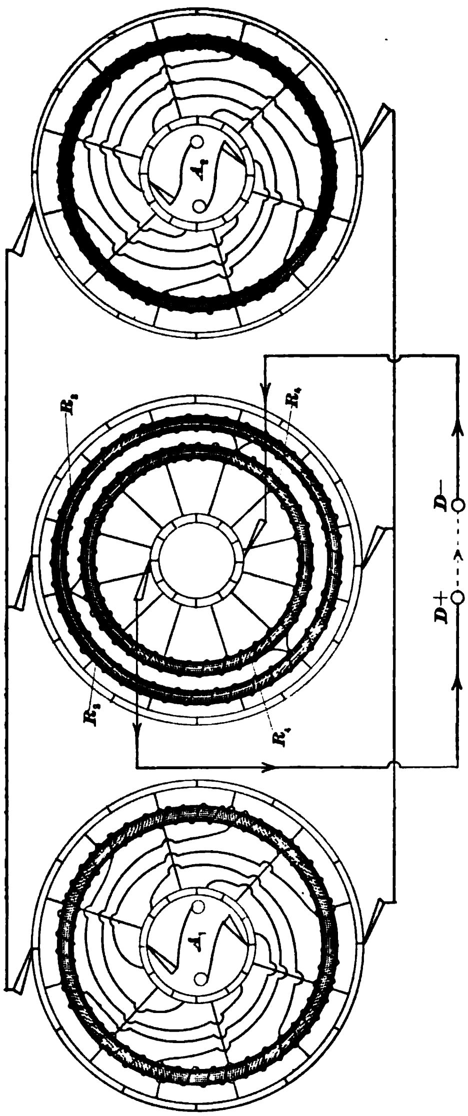


Fig. 11.

omitted, alternating currents differing by a quarter period being supplied at A_1 and A_2, a comparatively uniform direct current like that pictured in Fig. 5, will flow in the circuit D+ D—. If, now, these terminals be connected to the brushes of an armature like that shown in Fig. 6, we will have the combination referred to, shown in Fig. 8, in which the middle armature has an ordinary collector shown outside the winding, and three rings with brushes connected to three equidistant points of the winding. The fields are omitted as before and all three windings will be supposed fixed to the same spindle and external circuits, a_1, b_1, c_1, are connected to the brushes bearing on the rings r_1, r_2, r_3 of the middle armature.

A singular transformation is made possible by this device. Thus single alternating currents differing a quarter phase, supplied at A_1 and A_2, are transformed in the ring R_3 to triphased alternating currents, but a peculiar feature is here introduced which results from the fact that the triphased currents are only reversed at each half revolution of the ring R_3, the same as in Fig. 6, while the alternating currents supplied at A_1 and A_2, as we have seen, are reversed as many times in a single revolution of the rings R_1 and R_2 as there are collector segments, or say, 12 times per revolution, as indicated by the diagrams Fig. 8 and Fig. 3. As the currents differing a quarter period, supplied at A_1 and A_2, can be obtained on known methods from a single alternating current, we have then here presented *the means of transforming a single alternating current of short wave length or high frequency into triphased alternating currents of long wave length or low frequency.*

Thus a single alternating current like that represented by the unbroken line 1 to 12, in Fig. 9, making 12 reversals in the time t_0, to t_2, is transformed to triphased alternating currents, making but two reversals in the same time, these latter curves representing as they do the currents in the circuits a_1, b_1, c_1, Fig. 8, during one revolution of the armature.

The next step consists in changing these triphased currents to a uniform direct current on the plan used in the Shuckert machine, Fig. 6.

Thus, referring to Fig. 11, the winding of the ring R_3, instead of having three equidistant points connected to rings as before, has them connected to corresponding points of another winding, R_1, placed on the same core and provided with a separate collector, but to avoid confusion of the drawing the two windings are here shown separately, one inside the other.

Here, as in Fig. 6, a circuit connected to the brushes bearing on the collector of the ring R_4 will be supplied with a direct current of uniform E. M. F., resulting from the conversion to a direct

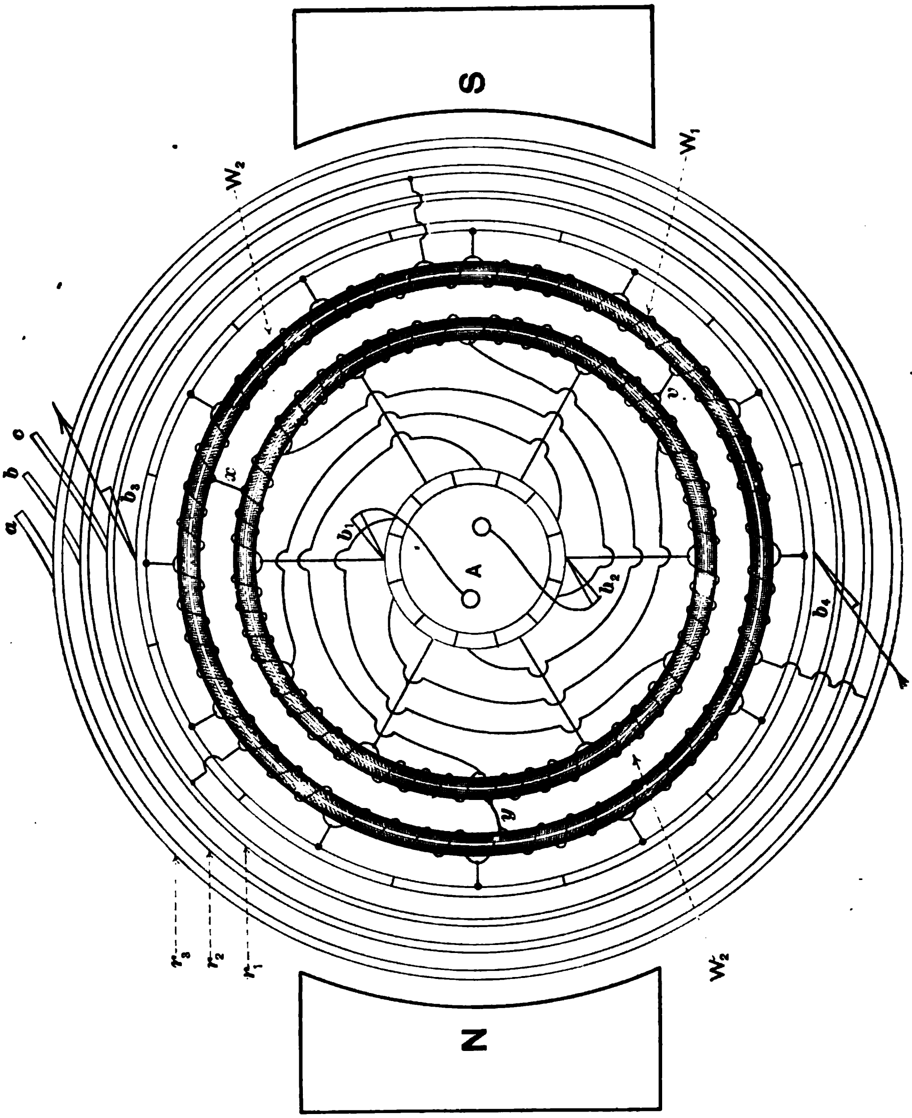


Fig. 12.

current of the triphased currents delivered from the winding R_3 to the winding R_4.

Here, then, is the means of transforming a single alternating current to a continuous direct current of uniform E. M. F.

Machines like the last two described seem complicated, but approximate if not quite as good results can be obtained from simpler devices. The preceding details were necessary to explain the consecutive steps taken.

As simple a form as that shown in Fig. 12, will probably meet

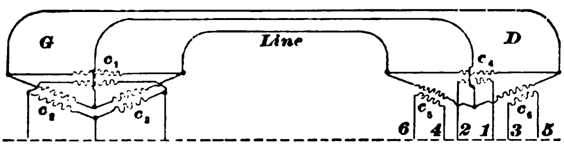


Fig. 13.

the requirements of practice. It represents two independent armature windings carried on the same core, but here shown apart for clearness of illustration. The inner winding, which has a collector directly and reversely connected, as in Fig. 2, is supplied with a single alternating current through the brushes at A. This winding is also connected to the outer one at three equidistant points, as shown, and the outer winding is provided with an ordinary Gramme collector, and if desired, three rings that are connected to three intermediate equidistant points of this winding.

This reduces the machine to a single armature with two windings and two collectors, or at least to two separate armatures and collectors, which form will doubtless be found preferable. The consumption circuit will be connected either to the brushes bearing on the collector or the rings of the secondary winding, according to which function of the machine it is desired to render operative.

Thus a single alternating current of ordinary period may be transformed either to triphased alternating currents of low period or to a direct current of comparatively uniform E. M. F.

If a three wire system, like that shown in Fig. 13, is used throughout, giving triphased currents at the delivery end *D*, from the secondaries of the three converters, the transformation of these triphased currents to a single direct current of uniform E. M. F., or to triphased currents of a much lower frequency of alternation, can be accomplished on similar lines. It is well known that multiphase motors give better results with currents of comparatively low frequency, 40 to 80 per second being the reported practice abroad.

On the other hand, the converters for reducing potential increase rapidly in size as the frequency of alternation decreases, consequently very large converters are required for such systems. These features are antagonistic and render the conversion apparatus costly if low frequencies are essential to the proper working of rotary field machines.

The system shown in Fig. 14 admits of using high frequencies on the line and in the conversion apparatus at G and D, for raising and lowering potential, while the transformer, Fig. 14, changes these triphased currents of high frequency either to a uniform direct current or to triphased currents of a lower rate of alternation.

At the delivery end D, Fig. 13, separate converters c_4, c_5, c_6, are used, the secondaries not interlinked having free terminals, as shown, which are taken to the brushes 1, 5, 4 and 2, 3, 6, bearing on the commutator of the ring R_2, the winding of which is connected at three equidistant points x, v, y of the ordinary Gramme ring and collector R_3, or to three ring contacts, as may

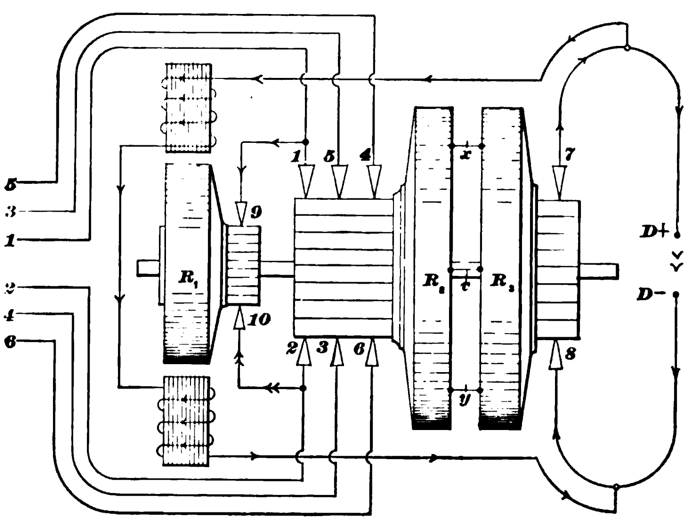


Fig. 14.

be desired, according to whether a direct current or triphased currents is required, as a result of the transformation. The machine R_1 is simply a synchroniser, requiring only sufficient power to drive the apparatus and is supplied with one of the triphased currents only. This machine keeps the whole apparatus in synchronism, and the currents from all the secondaries are taken to

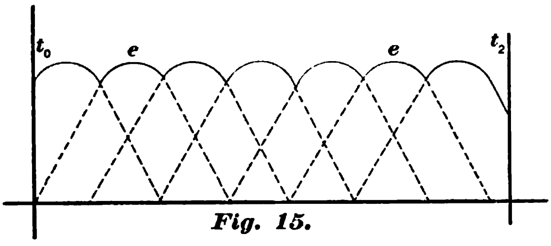


Fig. 15.

the winding R_2, Fig. 14, which is direct and reversely connected as before explained.

The resultant current, flowing in the winding of this armature, R_2, will be like that shown in Fig. 15, which represents a triphased alternating current, rectified, and is already a very close approximation to a uniform direct current, so that if the leads x, v, y, Fig. 14, connected to three equidistant points of the winding R_2, be taken through rings and rubbing contacts to three external in-

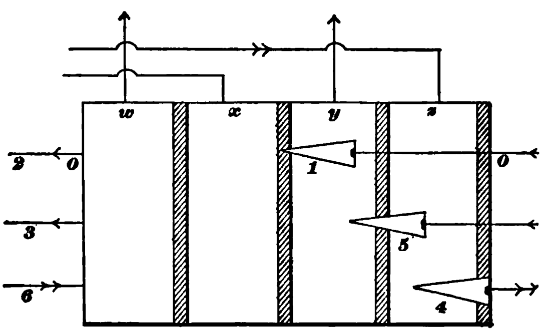


Fig. 16.

terlinked circuits, as before explained, these circuits will be supplied with perfect triphased alternating currents, but of a lower frequency than those supplied to the brushes of the ring R_2. Thus, if the frequency throughout the system in Fig. 13 were 288 reversals per second, and there be, say, 12 segments in the commutator of the ring R_2, there would then be developed in the circuits connected to x, v, y, triphased alternating currents having 48 reversals per second.

We have, then, here a means of changing at a single transformation multiphase currents of high frequency to similar multiphase currents of low frequency.

This system admits of using high frequencies on the line, and in the conversion apparatus at both ends of the line, and low frequencies in rotary motors at the delivery end. If, instead of being connected to three rings, the leads x, v, y are connected, as shown in the figure, to another winding, a direct current of uniform E. M. F. will flow in the circuit D+ D—. This transformer requires no further explanation here.

Fig. 16 shows a developed view of a part of the commutator of the ring R_2 and the relative positions of the brushes.

To prevent short-circuiting, the segments are separated, as shown, so that a brush will not bear simultaneously on adjacent segments, and for obvious reasons, the brushes have a lag behind each other of two-thirds of a segment. The arrows show how the currents are flowing at the time being. Brush 1 has no current; brush 5 has a positive, and brush 4 a negative impulse.

If these transformations can be made on a large scale economically, it will be possible to supply not only alternating current apparatus of every description, including multiphase devices, but direct current apparatus as well, from a single high tension alternating current. When the original source of supply is a water power, and the distance is not too great the losses of conversion may well be brought within commercial limits.

DISCUSSION.[1]

THE CHAIRMAN, [Vice-President Crocker]:—Gentlemen, you have heard this paper which shows great ingenuity, as we should expect from the fact that its author has given us several times before equally ingenious devices. This subject is particularly difficult. You will notice that he has clearly indicated methods of accomplishing four very difficult problems, any one of which would be a sufficient subject for an ordinary paper, I think. In fact some of them would appear to be almost impossible. But I notice one point—he speaks of the fact that low frequency is objectionable in tri-phase transmission, because it requires large converters. That is a fact of course. But I think that the static capacity of the line may be more objectionable than the large transformers, so I would therefore suggest that possibly the line itself may require low frequency. The possibility of transform-

1. By Messrs. Crocker, Carl Hering, Birdsall, Pupin, Louis Bell, Kennelly, Mailloux, Hutchinson, and Hewitt.

ing alternating currents into direct, is certainly novel, and sooner or later bound to be useful. He also suggests how to transform high frequency currents into low frequency currents and *vice versa.* That also is very important, and, will sooner or later probably be a matter of utility in electrical engineering. It is not many years from the time an idea is suggested until it becomes an every day matter and in fact a necessity. This matter is certainly worthy of discussion, and therefore I would suggest that any members who have any comments to make do so.

There is a communication, I believe, from Prof. Dolbear to be considered this evening, in place of the paper of Mr. Sperry. Mr. Sperry is unable to give his paper for various reasons, and Prof. Dolbear has sent an interesting communication in connection with some experiments of his on the molecular effects of currents in wires. Therefore although Lieut. Patten's paper is well worthy of discussion, I would suggest that speakers make their comments as brief as possible.

Mr. Carl Hering:—I would like to ask whether such machines have been built and have been run, or whether it is only a proposed system. If they have been run, I would like to ask if there is not considerable sparking at the commutator brushes; it seems to me that at the commutator the current would either be short-circuited, or else the circuit would be opened, either of which would produce sparks.

Lieut. Patten:—I have not put the whole apparatus as described, to a trial, but practically the whole of it, so far as the conversion is concerned, and I think that I see the point that seems difficult to Mr. Hering The armature soon reaches synchronism, if it is properly constructed, and then the sparking practically disappears. The conversion to a direct current of the form shown in Fig. 4 is I think practically perfect, and I will explain at the board how the short-circuiting is avoided. If the armature is not properly built, and the machine does not acquire synchronism readily, the sparking is bad indeed, no question about that. As to short-circuiting, suppose the brushes instead of being as indicated in the figures, are at a point where they bear on two segments at the same time, [referring to black-board] then of course the current coming in could go either way, and would have a short-circuit. To prevent that, a large insulation is placed between segments, broader than the brush contact, so that we practically get a current broken at nearly zero potential, and we have the sparking due to that potential only. When the machine is in synchronism it is very slight. I have only tried it with a machine supplied with about 2,000 watts, and less, but the results were quite satisfactory.

Mr. Birdsall:—I would like to ask Lieut. Patten if a motor like Fig. 3 has been built?

Lieut. Patten:—Yes sir; many of them.

Mr. Birdsall:—And the current taken from the outside commutator charged the field magnets?

Lieut. Patten:—Yes, and this rectified current makes to all appearances a perfect field, but really it is not so. It seems to be a constant field, and will hold a heavy piece of iron very nicely; but it is not a constant field as we know by experiments made by others in a more delicate manner.

Mr. Birdsall:—But it makes a sufficient field to run the machine?

Lieut. Patten:—Oh yes. I have taken a five H. P. Perret motor and turned it into the form shown in Fig. 3, and while it does not give the power that it would on a direct current of uniform E. M. F., still to all appearances the field magnetism seems to be perfect. Take the armature out and the field magnet seems almost as perfect as with the ordinary direct current.

Dr. M. I. Pupin:—I wish to make a few remarks about a machine that I constructed myself for the purpose of transforming alternating currents, that is alternating polyphasal currents. If we have two armatures—ring armatures, say, and we send a three phase current through the coils of one armature, we create a rotating field. Now, say that between the outside and the inside armature there is a piece of iron which has a smaller magnetic resistance in one direction—serves as it were, to bridge over the lines of force from the outside armature to the inside; and if this iron bridge, as I may call it, is rigidly attached to a shaft which carries brushes, the result will be that if the inside armature is stationary and the outside armature is stationary and the field rotates, that it will carry this iron piece with it and with the iron piece it will carry the brushes, and therefore if the inside armature is connected to a commutator we shall be able, as soon as the brushes are in synchronism with the rotating field, to take off the direct current from the commutator.

It is understood, of course, that the brush-carrying iron bridge must be provided with a reaction coil which will start it and bring it into synchronism with the rotating field.

The arrangement can also be made to have the outside and inside armature in contact and provide a small three phase motor to carry the brushes and bring them into synchronism with the rotating field. The three phase motor will be capable of getting into synchronism with the rotating field if the reluctance of its armature is very small in one particular direction as compared to its reluctance in any other direction.

Lieut. Patten:—I will explain the difficulty. Among many different forms in which I have tried these experiments, I have explained only a few, thinking that it would make too long a paper anyhow. I have tried the one just explained. It is perfectly feasible, if you can get the speed. But I think I can make it plain where the trouble comes in. If that were a solution, the Shuckert machine would end the whole matter. [Illustrating.] I have indicated here briefly, a Gramme ring. Instead of drawing all the coils, I have indicated the three equal parts of the entire winding, and A, B, C are the terminals of three equal coils or parts of the entire winding. Now, as this armature turns through space, the currents in these different coils will reverse as they pass the neutral line of the field only, consequently we must look for an alternation of current in each coil corresponding to each half revolution. Take an alternating current that has 288 reversals per second. For that machine to get into synchronism, what has to happen? Its armature must turn at such a speed that each coil will pass the neutral line of the field 288 times a second or—you can easily figure it out—something like 8,000 revolutions a minute. Now, there is the whole difficulty with this machine, and if you make multipolar machines you are not much better off, for the reason that, first, the connections become very complex and then we must divide the ring into a number of multiple magnets, and the rotary field effect which causes the armature to turn, loses its power in a great measure. It does not produce the same starting power that you can get out of a device like this, and this constitutes the main difference between the plan suggested by the gentleman who just spoke and the one which I have described.

DR. PUPIN:—These two objections, I think, are very easily overcome. In the first place, the alternation of the polyphasal current which is transmitted to this transformer, should not be too high, and the static capacity should not be too high, because these machines are called upon to transmit energy to a very long distance, and as soon as you transmit energy over a long distance you have to take into account the line capacity, and the line capacity prevents high frequency. The armature may rotate twenty times per second or 1,200 times per minute in the case of a bipolar three phasal machine.

LIEUT. PATTEN:—I admit that with low frequencies there is very little difference between the two.

DR. PUPIN:—Secondly, with regard to the formation of the poles. A three phase machine does not necessarily imply that the ring armature is to have three coils. In fact, it must have six coils. Then the ampere turns are perfectly symmetrical, and therefore the magnetization is perfectly symmetrical.

MR. CARL HERING:—I think one of the points made is not well taken. I understood Lieut. Patten to say that three phase current motors are confined to two pole motors. This is a mistake, as the largest one ever built was the one at Lauffen, which had eight poles.

LIEUT. PATTEN:—I am well aware of that fact, but I understood with low frequencies, and not with high frequencies. I do not know that it would make any difference.

DR. LOUIS BELL:—I am very much interested in this discussion of the possible means of transforming currents in some rather unusual ways. But I would, as a matter of engineering practice, like to know whether there are special advantages to be gained from using these unusual forms of machines over what would be obtained by using one straightforward direct current, or synchronous alternating, or polyphase machine, and then using two receiving machines coupled together, one of them for the purpose of handling the current as a motor, the other to give out whatever sort of current might be desired. For instance, you might go back to so old and simple a form of machine as the spherical armature T-H arc machines, with which all are perfectly familiar. Machine No. 1 would operate very well as a generator, machine No. 2 as a direct current motor to furnish by machine No. 3 either direct currents or by putting on collecting rings, a drehstrom current, which could be utilized in any form of motor which might seem desirable. In the next place, by putting collecting rings on both generating and receiving machines it would operate fairly well as a drehstrom system, and by using one of the collector rings on the second receiving machine you would be able to get an ordinary alternating current of low frequency. I simply mention that form of machine as a type. The point I want to get at is the advantage to be gained by these unusual though very interesting windings over a straightforward combination of generator at one end of the line and motor generator at the other, consisting perhaps of two machines coupled together in a way that would immediately suggest itself in ordinary engineering. The alternating current lends itself to being played with in a most interesting fashion. You can secure from it almost anything that may seem desirable to use in reference to any particular problem. But as a matter of straightforward engineering practice, I would like to know whether there is a material advantage in efficiency or convenience to be gained from employing unusual forms of machines instead of the ordinary dynamo at one end and the motor and generator at the other.

THE CHAIRMAN [Vice President Crocker]:—I have heard Prof. Thomson himself, I think in this very room, say that his arc dynamo can be used as a motor, but I think it is of rather low efficiency. But I understand Dr. Bell to suggest it merely as a possible apparatus. I myself think that direct current motors can be worked on a direct current line of even as high voltage as 30,000 to 50,000, which is supposed to be only within the range of alternating current apparatus. The only difficulty, of course, is to obtain direct current machines that are capable of working at that high voltage. I do not think it is at all impossible. We now have dynamos that will generate 5,000 volts of direct current. That was true five or six years ago. I think that now, or perhaps a few years hence, we may be able to produce direct current machines of 30,000 to 50,000 volts, which is high enough for transmission over one or more miles of line. As Dr. Bell says, this elimininates many complications, especially the static capacity of the line, which is almost as great a difficulty in long-distance power transmission by alternating currents as it is in cable telegraphy, and we all know that in that case it is one of the greatest obstacles that has ever been encountered in electrical engineering, and I believe it is almost an equally insurmountable difficulty in very long-distance transmission of power with alternating currents. With the direct current, the static capacity is of no consequence whatever, because it simply charges up the line once or twice per day which amounts to nothing, but if we charge and discharge the line a hundred times, or even thirty and forty times per second with the alternating current, it will require a large part of the current generated by the dynamo. To be sure, this does not consume energy necessarily, but it uses up the capacity of the generating plant, and that is nearly as bad. Having the energy playing in and out of the line, although it may not be consumed, is almost as objectionable as having it consumed, if we get little at the receiving end. If a plan intended to transmit three hundred horse power, transmits but fifty or one hundred, the plant is practically useless.

MR. E. T. BIRDSALL:—I hardly agree with Dr. Bell and your self, Mr. Chairman, in regard to there being no reason for the use of these multiphase currents, as I have had a little experience in that direction. I had, some time ago, the problem submitted to me of transmitting 5,000 horse power ten miles. I reasoned as the last speaker reasoned—why use alternating currents with the losses in the transformer and the static capacity of the line, and all that sort of thing—why not use one large ordinary continuous current dynamo and a large motor at the other end with a line of shafting, and then put railway generators or anything you please on that shafting? But when I tried to get estimates for direct current dynamos for 5,000 or 10,000 volts pressure from the various companies, they did not appear to be disposed to build them, and much less to make any guarantee as to insulation and whether they would stand, and after a while I found that I must either build this direct current machine myself or else put in an alternating system. That, I think, is the reason why so much attention has recently been given to these multiphase currents and the direct current dynamos have been let alone in this work. Of course, direct current dynamos of high voltage can be figured out on paper. They can be built and they can be run, but the question is, can they be run commercially? If you have to put in a new armature every night, the stockholders are going to be heard from, and everything comes down to that basis after a while. So that, I think, is what has given rise to all the multiphase current work that has been done recently.

DR. BELL:—I want to put myself right before the assembly, on one point. I did not intend to state, nor did I state, I think, that I was a foe of the alternating current, either taken straight or diluted with three phases. I have not anything against it at all. The only point I raised was the relative usefulness of three straightforward machines of any approved type, either synchronous alternating, drehstrom or direct current, as compared with the somewhat complicated, although beautifully ingenious apparatus which has been suggested to-night, for use in general engineering practice. I would not like to put myself on record as believing unreservedly in the use of direct currents at very high tensions. We might find it easier to use the synchronous motor requiring two wires, starting it either by a two-phase motor or some extraneous power, or the drehstrom system, as well as the direct current. The only point is that having a sending dynamo and a receiving motor and dynamo, we can so change the current with which we start as to utilize them most conveniently with practical apparatus that is in everyday use. It is not at all a question of drehstrom against the field, or direct current against continuous. It is simply a question of using three ordinary machines such as we all are familiar with, for transmitting energy, instead of turning to exquisitely ingenious apparatus of at present somewhat uncertain efficiency.

LIEUT. PATTEN:—I wish to answer Dr. Bell on one point. Though apparently complicated, these machines are self-starters, as you will readily see by examining the circuits of Fig. 3, and they do not require multiphase currents or an auxiliary motor to start them, as all other synchronous machines do. If the current is coming, say, in one direction, it makes a certain polarity in the armature, and the shunt circuit makes a corresponding polarity in the field. Of course, when the current reverses, it reverses both field and armature alike, and the machine is thus a self-starter and has that great advantage. It starts the same as a direct current motor would under the same conditions

MR. A E. KENNELLY:—This interesting description of ingenious combinations brings us face to face once more with the problem which threatens to be as vital a one in electrical engineering as ever has been the problem of naval defense and offense in quite another sphere. Of course, as has been mentioned to-night, it would be very nice to take an ordinary straightforward direct current dynamo and a similar straightforward direct current motor and couple them together for long-distance transmission, if the cost of the intervening conductor were not a matter of considerable importance, and so, as soon as the length of the line becomes such that the cost of copper is a determining factor, it becomes necessary to raise the pressure. There is now a point where the pressure has to stop, not, as Prof. Crocker has pointed out, that it is essentially obliged to stop, but because it is with the present skill and present knowledge in construction, a matter of necessity for the moment to stop. To overcome the difficulty, therefore, and to enable us to work with high pressures conveniently and safely, the alternating current system has given us the means, for the present time at least, of climbing up to high pressures and climbing down from them with advantage and success. But I look forward to the struggle for supremacy in systems of long-distance transmission with a certain degree of hope that the difficulties of maintaining and operating high tension, continuous machinery, is a difficulty which will disappear with time, and I see no essential reason why we should not be able, as the Chairman has said to-night, to use in the future, perhaps not in the near future, direct current high pressure machines, without considerable loss in hysteresis, without the large difficulty of overcoming the static capacity of a long line entailing its large amount of dynamo capacity, and with all the direct advantages which a direct system, has in its power to bestow. I can only say, then, that while I think we are all interested in whatever tends to overcome this very noble problem of distributing energy within a radius of fifty miles, that the balance of advantage is not wholly, it seems to me, in the direction of alternating current transmission.

THE CHAIRMAN [Vice-President Crocker]:—I would like an opportunity also to explain my meaning to Mr. Birdsall, because I think he misunderstood not only Dr. Bell, but myself also. In the first place, I said nothing that would indicate that the alternating current had no sphere of action whatever, nor did I say that you could buy direct current dynamos of 30,000 or 50,000 volts to-day; nor could you buy any dynamos at all thirty years ago. The fact that makers will not bid on 5,000 or 10,000, still less on 30,000 volt machines, is because they have no demand for them. But I would call Mr. Birdsall's attention to the fact that we have 5,000 volt direct current machines in arc lighting of the ordinary closed coil Gramme-Wood type. As soon as there is a demand for them we will have them. A few years ago, a test with a magneto which failed to show a current through 5,000 ohms was considered high insulation. Now we have 5,000 megohms, and 500 000 megohms for that matter, in some cases. I agree thoroughly with Mr. Kennelly in saying that there is no insurmountable difficulty whatever. It is purely a matter of degree. If we can make 5,000 volt generators, as we can to-day, we can make 10,000 volt generators next month, and 50,000 volt generators in a few years.

MR. BIRDSALL:—I think it only remains for me to agree with the previous speakers to render this discussion harmonious. Of course, I do not pretend to say what will be done in the future any more than I think what was done in the very remote past is of much use to-day The questions that we have to meet are the problems which come up to-day. That method which promises a solution to morrow is the one that we work at the most. At the present day, the alternating multiphase current promises more for to-morrow than the direct high pressure current To-morrow it may be reversed.

MR. C. O. MAILLOUX:—While I admire the beautiful ability of the alternating current to go through the act of "presto, change!" and transmutation, and while I think that it has a sphere of wide and extended usefulness, yet I am not prepared to believe, as one gentleman said this evening, that it will do everything. It is not as well adapted to cases of transmission and distribution of power on a large scale at constant potential, as it might be. The alternating current has great ability to "get there," but it has not ability to "stay there," or "brace up," because it has not thus far succeeded in solving a very important problem—that of compounding. We can compound a dynamo, so as to make it automatically raise its potential to cover and compensate for any "drop" in the circuit which it feeds. Not so with the transformer, unfortunately. I have a case at present where it is necessary to operate a thousand lights by the alternating current system, though it is impossible to locate the transformers nearer the house than 1,500 or 1,800 feet. The difficulty is complicated by the great distance at which the transformers are situated from the supply station. The loss from the station to the lamps is likely to be anywhere from one to twenty-five per cent., simply because in addition to the large loss on the line (primary), which can not be absolutely compensated for, there will be a large loss in the secondary mains themselves. Now, if it were possible to provide means by which the secondary could compound itself and automatically raise itself as the occasion demanded, when the load increased upon the secondary, I would feel that the transformer was a first class thing for that purpose. But in this case the solution is one far from completely satisfactory. In cases of transformations like those which have been proposed and discussed this evening, this difficulty is emphasized because it is quite evident (and easily demonstrated mathematically) that the greater the loss in the transmission the greater that discrepancy or drop would be between the potential on the primary and the secondary sides of the transforming apparatus, no matter of what kind, if using alternating currents as the primary source. If we have an efficiency of 98 per cent., the "drop" may be quite small, but if our efficiency falls down 40 or 50 per cent., then the inability to "stay there" will be all the more emphasized on the secondary side. That is a point of great importance and which has thus far limited the scope of the alternating current system more than would have otherwise been the case. I understand that many have been at work on this problem, but thus far without very satisfactory results. The best that we can do is to use a higher potential than normally required, and then compound negatively, so to speak, by using so-called "dimmers" or "boosters"

DR. CARY T HUTCHINSON:—I would like to ask, what are we here for? I thought it was to discuss the Patten motor. But it does not seem to be so at present.

THE CHAIRMAN [Vice-President Crocker]:—I do not know that there is anything in our Constitution or By-laws that limits us to the Patten motor this evening. But still, there is a certain amount of relevancy in that remark, and the Patten motor is open for discussion. Possibly the Patten motor needs no discussion. It is very well explained by the author. Moreover, it does involve the question of long distance transmission and distribution. In that connection, I would say that Mr. Birdsall's idea of ten miles for long-distance transmission is rather short, I think.

MR. BIRDSALL:—No, not when you have to figure dividends for the stockholders.

THE CHAIRMAN [Vice-President Crocker]:—The pace has been set by the Frankfort-Lauffen transmission at 50 or 100 miles. Ten miles is for ordinary arc lighting or power circuits.

MR. CHAS. HEWITT:—Dr. Bell has asked what advantages such an arrangement as is under discussion to-night has over the direct current transformation. There is one point which, by the way, is not electrical, that I would suggest, although I may seem heretical for doing so. It is the danger to the operator. When the distance to be covered reaches, say 10 miles, and the power to be transmitted is of sufficient amount, higher potentials have to be used than men are accustomed to handle. If we generate such pressures with direct current dynamos, which must be handled, it becomes exceedingly dangerous. We cannot count on the first honor man of some university to run such a machine, but must rely on men of but moderate intelligence.

These multiphase motors and generators lend themselves beautifully to this practical and serious question. The current can be generated at low pressure, say 100 to 500 volts. All apparatus that must be handled can be placed in the low pressure circuits, while all wires and apparatus carrying the high pressure, dangerous current can be placed entirely out of reach. I think this is a point which we certainly should not lose sight of, and I know that none of us would wish to feel responsible for the life of some poor fellow who had to operate a 50,000 volt direct current generator.

THE CHAIRMAN [Vice-President Crocker]:—I do not personally consider that a 50,000 volt generator is much more dangerous than a 5,000 or even 2,000 volt generator. I think it has been demonstrated that 1,000 volts will kill. If that is the case, I do not see that 50,000 is much worse than 2,000. Either will kill, and it is like a man falling off a house 50 feet high, and falling off one 500 feet high.

MR. BIRDSALL:—Yes, Mr. Chairman, but the house that is 50 feet high has rubber on the roof and the one that is 5,000 feet high has ice on the roof. That is the difference. The 50,000 volt current will leak, break down the insulation and offer many more opportunities for accidents than the one of 5,000 volts.

MR. HEWITT:—The Chairman fails to catch the point I am making. In one case the high pressure can be put absolutely out of reach, in the other it can not. It is comparatively easy to make apparatus for handling and controlling 2,000 volt currents, but when it comes to controlling 50,000 volt or even 15,000 volt currents by means of switches and other appliances, the difficulties are almost insurmountable.

MR. MAILLOUX :—To come back to the Patten motor, I would like to ask Lieut. Patten whether there would not be considerable difficulty in producing machines capable of developing such high potentials as have been considered here this evening—say 15,000 or 20,000 volts. I speak of this because, owing to the relative complication and multiplicity of circuits in the machines, it appears to me that it would be difficult to produce machines capable of giving that voltage without unduly increasing the number of commutator segments, so as to get the necessary insulation between the point of high and low potential.

LIEUT. PATTEN :—The machines described are intended only for the low tension circuit after the reduction of potential has taken place. The entire system contemplates a closed high tension circuit like that used in the Lauffen-Frankfort tests, where there was no break whatever in the high tension circuit.

The Secretary read the following list of Associate Members elected at Council meeting, Feb. 16th, 1892:

Name.	Address.	Endorsed by
DELAND, FRED,	Western Manager. The Electrical World 465 The Rookery, Chicago, Ill.	Edw. Caldwell. Louis Bell. Wm. A. Rosenbaum.
GRAY, ELISHA	Highland Park, Ill.	George M. Phelps. Ralph W. Pope. Thos. D. Lockwood.
GRANER, ADOLF	Electrical Patent Agent, 529 North 35th St., Philadelphia, Pa.	Carl Hering. Geo. M. Phelps. Jos. Wetzler.
JAMES, JOHN N.	Electrician, Naval Observatory, Washington, D. C.	Geo. C. Maynard. T. C. Martin. E. G. Willyoung.
MCKISSICK, A. F.	Professor of Electrical Engineering, The A. & M. College of Ala., Auburn, Ala.	Ernest Merritt. Harris J. Ryan. Edw. L. Nichols.
SUMMERS, LELAND L.	Assistant Electrician, Western Union Telegraph Co., 18 W. U. Telegraph Bldg., Chicago, Ill.	Edw. Caldwell. W. A. Rosenbaum. Louis Bell.
Total, 6.		

Transfers from Associate to Full Membership; approved by Board of Examiners, Jan. 12th, 1892:

BURLEIGH, CHARLES B.	Electrician, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.
DUNSTON, ROBERT EDWARD.	President, The Connecticut Motor Co., Plantsville, Conn.
HIBBARD, ANGUS S.	General Superintendent, American Telephone and Telegraph Co., 18 Cortlandt St., New York City.
WILSON, CHARLES H.	General Superintendent, Chicago Telephone Co., 203 Washington St., Chicago, Ill.
BENJAMIN, PARK	Electrical Expert and Engineer, 32 Park Place, New York City.

Correspondence.

Mr. Chas. Proteus Steinmetz :—When reading Mr. Patten's highly interesting paper on a proposed system of alternating direct current transformation, I noticed again one thing which had occurred to me on a former occasion, namely, that the danger of getting fluctuating currents and fluctuating magnetism by the use of rectified alternating E. M. F.'s is generally highly overestimated. Even in an incandescent lighting circuit, the current caused by a rectified alternating E. M. F. can never approach zero, but as soon as there is any amount of self-induction in the circuit the rectified alternating current and still more the magnetism produced thereby, is practically constant.

How far self-induction and hysteresis suppress fluctuations, I had occasion to observe a short time ago on a pulsating E. M. F., which varied not only between 0 and maximum, but which *reversed.*

A pulsating E. M. F. of 15.8 volts effective, which varied between +26.5 volts and —14.5 volts (so that the negative maximum was somewhat more than one-half the positive maximum), was acting upon a magnetic circuit of 4.5 $cm.^2$ cross-section and 41 cm. length, thoroughly laminated against eddies, and surrounded by 100 convolutions of wire.

The frequency was 170. Then the current amounted to 14.5 amperes [1] effective, and fluctuated between +24.8 amperes and —6.0 amperes, that is, was still reversing, but its negative maximum being less than one-fourth the positive maximum.

The magnetism produced by this current fluctuated between +15,500 and +7,400 lines of magnetic force. That is, even a pulsating E. M. F.. which reverses in direction to as high a degree as this is not able to reverse magnetism. A non-reversing E. M. F., then, will hardly cause perceptible fluctuations of magnetism. Hence rectified alternating currents are much steadier than generally assumed. But in the alternating part of the line, the current must pass through zero. In the rectified part it never does Hence, at the synchronizing commutator, there must be a discontinuity, causing a tremendous sparking, if no special precautions are taken against it. This can be done by a short-circuiting arrangement at the brushes, as explained on another occasion.

The method of transforming proposed by Lieut. Patten, is entirely different from this synchronizing device. I do not think it even necessary to use two armature windings. As the simplest form of such a transforming instrumentality I should consider an armature winding, connected to such a cross-connected commutator as Lieut. Patten proposes for receiving

1. It is interesting to note that while 15.8 volts effective pulsating E. M. F. sent 14.5 amperes through the circuit, 15.8 volts effective alternating E. M. F. sent a current of only 1.6 amperes through the same circuit with the same frequency

high-frequency alternating currents, and at the same time connected to an ordinary continuous current commutator, to receive or to deliver continuous currents, while this commutator is tapped at several points and connected to sliding rings, wherefrom low frequency alternating or polyphase currents can be taken off or sent in.

If, then, for instance, a high frequency alternating current enters the Patten commutator, it sets the machine in motion as an alternating motor, while the same machine as a continuous current dynamo delivers a steady continuous current at the other commutator. But this continuous current is not to be considered as the rectified alternating current, and therefore is not pulsating, but is the steady current of a continuous current dynamo, a dynamo, indeed, which is not set in motion by a belt, but by using the same machine as an alternating motor.

I have used such a machine a long time, especially for transforming continuous currents into low frequency alternating or

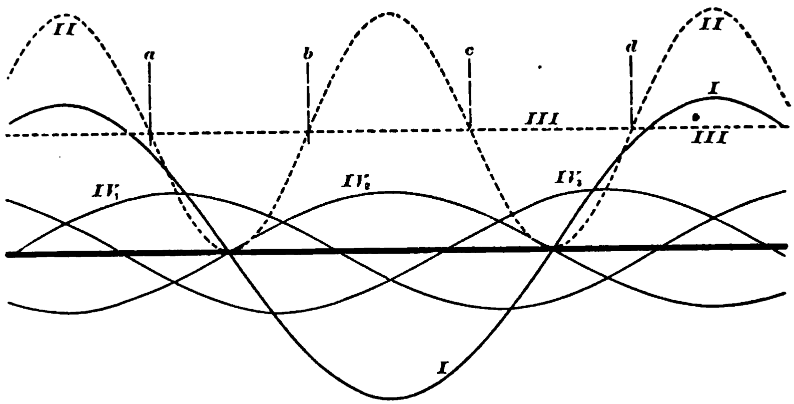


FIG. 17.

pulsating currents, as explained in my paper on hysteresis. Several times I connected the alternating brushes of this machine with the alternating brushes of another such machine, and so derived a power transmission, where the current in both stations is continuous, while the live current is alternating. Let us consider the general principle of such a conversion of alternating into continuous currents, etc.

In Fig. 17, curve I represents an alternating current, curve II the power or the effect of this current, straight line III the power of a continuous current of equal power. As seen, the instantaneous power values of the alternating current fluctuate between zero and maximum, are larger than those of the continuous current from *b* to *c*, smaller from *a* to *b*, *c* to *d*. Hence to convert the alternating current I, II into the steady current III, an instrumentality is necessary which is able to take up during the time *b* — *c* the surplus amount of alternating current energy, to store this up and deliver it back to the circuit during the time $c - d$ Therefore a simple synchronizing device is not sufficient to straighten alternating currents.

In Patten's proposition this electric energy is stored up as mechanical momentum. During $b - c$ the transformer accelerates, during $c - d$ its speed slows down. But the consequence thereof is that the transformer has to be of sufficient size to give this momentum.

By the use of self-induction for straightening the commutated alternating current, this surplus energy is stored as magnetic potential, by the use of condensers as electrostatic charge; by the use of storage battery as chemical affinity—all these ways can be made to answer the purpose of straightening a commutated alternating current so as to make it practically steady or constant.

I wish to direct attention to one remarkable fact with regard to the polyphasal system. If we have, for instance, three polyphasal currents, IV_1, IV_2, IV_3, and add their power curves together we get the *straight line* III. That means,

"*While in an alternating current system the instantaneous power values fluctuate twice during each period between zero and a maximum, in a polyphasal system the instantaneous power values of the system remain constant just as in a continuous current system.*"

The consequence thereof is that in transforming from polyphasal to continuous currents and back, there is neither storing up of energy nor armature reaction present, and therefore the transformer can be made as small and with as much wire on the armature as wanted, while when transforming between alternating and polyphasal or continuous current, energy has to be stored up, armature reactions will take place, etc., and the transformer must have a certain size to answer the purpose.

Feb. 21st, 1892.

PROF. ELIHU THOMSON:—The proposed system of Lieut. Patten is based on the *commutation* of alternating currents. This appears to be the fundamental idea, out of which he develops his various figures and methods. These are very pretty in theory, but not very practicable, in my opinion. To commute an alternating current of any considerable potential is not practicable by any means such as Lieut. Patten shows. There would need to be an absolute fixedness of phase, and a theoretically perfect commutation. Neither of these are attainable in practice. Short circuits and burning at the commutators would be inevitable, except in small models Even if the potential of the currents to be commutated is made very low, the difficulties of commutation do not disappear, and much larger commutators would be needed. When Lieut. Patten succeeds, *practically*, in commutating alternating currents representing, say, 10 to 20 H. P., by the plan shown in Figs. 1 and 2, the consideration of his other plans or figures based thereon, would seem to be in order. The difficulty is that electrical currents will not always do what has been marked out for them on paper, and Lieut. Patten falls into the error of presenting as solutions of various problems and even emphasizing them in italics, merely diagrams on paper, which might represent actual conditions if the currents dealt with had only a small potential and at the same time small strength. In practice, the facts of self-induction and distortions, and the fact that a commutator of alternate positive and negative segments with brushes which *ought to be* exactly on the *line* between the segments when the current is *zero* is not a very easy thing to work, and keep in order, are rather against such systems as are proposed in the paper before us.

Feb. 29, 1892.

Read at the sixty-fourth meeting of the American Institute of Electrical Engineers, New York, February 16th, 1892, Vice-President Crocker in the Chair.

NOTE ON THE

MOLECULAR MOVEMENT IN A CONDUCTOR.

BY PROF. A. E. DOLBEAR.

Maxwell and others have made experiments to discover whether there was any evidence of momentum in a conductor carrying an electric current. So far as I know all the experimenters looked for a *longitudinal* momentum, that is, one in the direction of the current in the conductor, but no evidence appears to have been discovered that the molecules are thus moved. Still it is as near certain as anything can be and not be demonstrated, that the molecules in a conductor are moved in some way by an electric current. If they be thus moved then there must be momentum in some direction. If it be not longitudinal it may be transverse. If there should be movement in the transverse direction, what kind of experiments would be needed to show it? This is the way the question presented itself to me. When a current is sent through an *iron* wire the latter is twisted, to the right or the left according to the direction of the current. This is interpreted as due to the specific magnetic quality of the conductor, for it does not occur in a copper or other conductor.

Suppose the molecules of a conductor to be *rotated*, each upon its own axis, the axis being longitudinal with the wire, what evidence of such motion would be externally exhibited by the conductor as a whole. Evidently it would be masked altogether in a common wire, for the momentum of any one molecule in one direction would be just balanced by that of the contiguous one in the opposite direction—a condition of things mechanically propagated through the diameter of the wire. In order to discover it, it would be necessary to prevent such mechanical transference of the movement, and this can be done by making the conductor a hollow cylinder. I therefore made a cylinder of gilt paper about 20 inches long and four inches in diameter, this I provided at each end with a bail for suspension, thus: The suspending wire being eight or ten feet long, the lower end of a short wire dipping into a mercury cup as shown. [Fig. 1] With this arrangement a decided evidence of twist could be noticed, but on account of the resistance of the gilt paper, a strong current could not be used without so high a voltage, that the paper took fire several times. I then had a thin copper cylinder made of nearly the same dimensions and suspended in a similar manner, and could use a current of thirty or forty amperes. The rotary motions were in the same directions as before, namely—when the current was going down, the twist was always right handed as indicated by

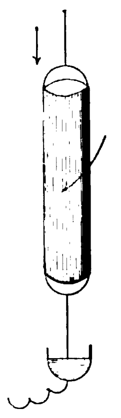


FIG. 1.

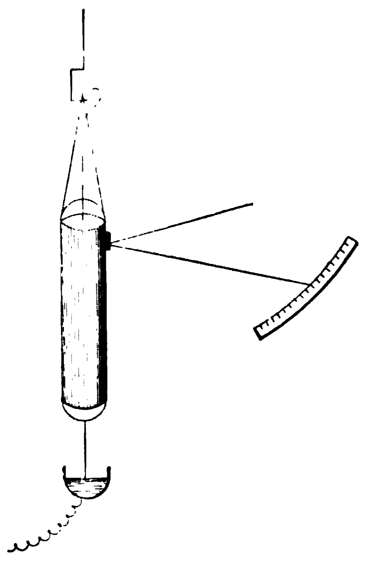


FIG. 2.

the arrow, and of course opposite when the current was reversed. While there was no doubt about the rotary movement, the weight of the apparatus was so great, I concluded to see if one made of lighter material—aluminium, would not give greater amplitude with same current. A similar cylinder of aluminium foil was prepared and so hung that all tangential movement would be due solely to itself and not at all to any other part of the apparatus, that is, it was mounted with bi-filar suspension. The weight of the foil with its connections was 1.85 oz. 55.6 grams. A bit of mirror was fastened to the upper end, and a beam of sunlight reflected from it upon a scale 16 feet distant, and 25 feet long. [See Fig. 2.] With this arrangement, the twist produced by the current was such that it was not difficult by timing the swings and changing the direction of the current, to make the cylinder swing through 90°. A current of fifteen amperes swung it through a foot and a half of the scale. It would come to rest at about half the distance of the greatest amplitude of the swing, for each different current employed, and *therefore showed the continuous action of the torsional force for a constant current.* If this be the interpretation of the phenomenon, then the molecules are rotating when there is a constant current, and thus the explanation of the heating effect of the current, is brought back to dynamical and mechanical principles. Adjacent molecules must be rotating in opposite directions at their point of contact, but this vibrating or heat motion, necessitates more or less separation, when such rotation goes on; on impact it is arrested so there must be impact and slip, impact and slip. The arrest of motion being the immediate antecedent of the heat, as is friction in any case. These experiments have not been carried out quantitatively for lack of facilities. May be the interpretation is wrong, and some wise one who knows all about it, can point out its inadequacy. I think the experiments are new, and may lead to an understanding of what goes on in a conductor when a current of electricity traverses it, if this be not the whole of it.

DISCUSSION[1].

MR. MAILLOUX:—I do not want to have it thought that I am that wise one, who knows all about it. Yet, while the paper was being read I could not help surmise that the horizontal component of the earth's magnetism may have had a great deal to do with the rotation. It does not seem to me that the experiment is conclusive until it shall have been tried in different relations with respect to the earth's magnetism, and the effect of different magnetic fields in its neighborhood has been tested. Since the current travels in a vertical direction and the lines of force form circles concentric with its line of motion, it is quite evident that any magnetic field, however feeble, must have some effect upon the conductor. The difference of magnetic potential on two sides of that tube has a different relation to the magnetomotive force of the earth's magnetic circuit. One side would tend to add such portions or elements of its force as are of the same magnetic polarity or direction, while those on the other side being of

1. By Messrs. Mailloux, Wolcott, Kennelly, Pupin, Binney, Crocker, Sheldon and Kintner.

contrary direction would interpose a contrary magnetomotive force. The effect of that might be to tend to rotate the wire slightly, as well as to translate it laterally.

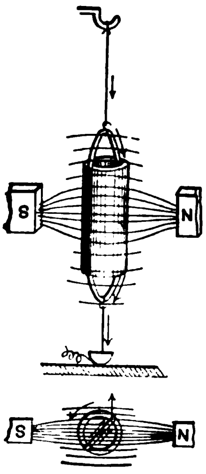
MR. TOWNSEND WOLCOTT :—Mr. Mailloux's remarks, I think, would hardly apply to continuous rotation. If that tube is perfectly straight and perfectly uniform in resistance, there is no reason for a continuous rotation, but if that tube is crooked it might revolve partially. The reason I take this view of it is that somewhat more than a year ago I saw an experiment tried which was supposed to upset one of Maxwell's experiments, that is, a current going through a straight vertical wire, and when I examined the apparatus I found the wire was not straight. In the experiment of Maxwell it was proved that there is no tendency to rotate magnets—if you place two or more magnets with the similar poles towards the vertical wire and pass a current through it, there is no rotation, that is, on the assumption that the wire is straight. The gentleman who tried the experiment, in order to show that there was some rotation kept commutating the current, just as Prof. Dolbear mentioned. In that way he succeeded in amplifying the swing, so that it showed a very considerable amount. It seems there was not a complete revolution in this experiment. With the very long suspension mentioned in the paper, it seems to me you ought to get at least one revolution if the torque was of any account whatever.

MR. KENNELLY :—Without pretending to make any remarks as to whether this action observed was really due to the cause that Prof. Dolbear has suggested, I merely desire to point out that if that particular cylinder did turn, it is reasonable to suppose that another cylinder inside, concentric with it, would also independently turn, a third one within that would also turn, and so on. Now, if they would each and all separately turn, surely when they were united in one solid mass the whole mass would revolve and I think it is very strange that if such an action would take place, a solid rod of copper pivoted upon its axis should not have been observed to rotate when a current passes through it independent of all magnetic forces.

DR. PUPIN :—I would like to call attention to an experiment made some years ago by Prof. Braun, of the University of Tubingen (Braun, F., Deformationsstrome, Wiedemann's Annalen, vol. 37, p. 97, 107; vol. 38, p. 53; vol. 39, p. 130). He found that a wire made of a magnetizable substance, when twisted one way will generate an electromotive force acting in one direction, and if twisted the opposite way it will produce an E. M. F. acting in the opposite direction. Prof. Rowland called my attention to a current interrupter constructed on that principle, where a twisted wire is made to untwist by sending a current through it. Perhaps the phenomenon observed in Prof. Dolbear's interesting experiment may be due to a similar cause.

MR. HAROLD BINNEY :—I think there is a third point not brought out, and that is the effect of the bails. It seems his (Prof. Dolbear's) experiments were not conclusive, as he used currents first in one direction and then in the other. It is clear that the current in passing downwards would go more in one bail than in another, owing to its tendency to lateral shifting in the magnetic field. In that case, in starting to go downward, it would, let us say, go more in the right hand bail, and if that bail were not exactly perpendicular to the lines of force it would tend to shift it across the field of force and so cause rotation. Then when the current was turned in the opposite direction, if properly timed to the period of the apparatus, the twist would be in the *same direction* as the swing, although it would flow through the other bail, and these infinitesimal impulses properly timed might well cause appreciable rotary oscillations. This may have something to do with the phenomenon observed and is not based on the supposition that there was lack of symmetry in the apparatus. See Fig. 3.

THE CHAIRMAN [Vice-President Crocker]:—I should expect a lack of symmetry there, as Mr. Wolcott suggests. If one side



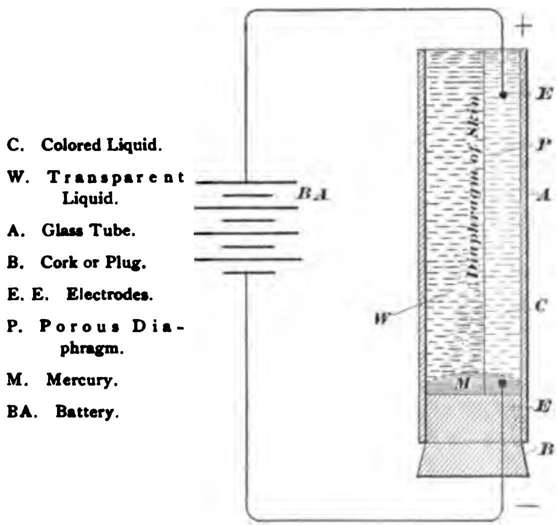


FIG. 3. FIG. 4.

was a little thicker than the other, the current would be stronger on that side. That would throw it out of balance and cause rotation, but if it were perfectly symmetrical, according to our present knowledge of electric currents, there would be no tendency to rotate.

MR. MAILLOUX:—I think it would be well to call attention to the fact that a wire or a cylinder situated as that is in the earth's magnetism, would have present in it Hall's phenomenon, that is to say, the current would not be distributed equally throughout the mass of that cylinder. It would be unequally distributed by the very fact that it was placed in the magnetic field not symmetrically related to the flow of current. That effect, though it might be slight, would further complicate the case and might be in itself a partial explanation of the peculiar actions observed.

MR. WOLCOTT:—I think the whole effect is entirely too small to be noticed there. It will be remembered that Mr. Hall looked for the effect some time before he found it himself, with the very best apparatus.

DR. SAMUEL SHELDON:—Prof. Hall used, I think, between forty and fifty amperes, passing through an ordinary university pattern of the Ruhmkorff magnet, and then used a Thomson reflecting galvanometer of the ordinary pattern and even then obtained a very small deflection.

MR. CARL HERING:—Some interesting results might be obtained if that conducting cylinder were surrounded by a fixed iron cylinder. This would shield it from the earth's field, and if the motion was due to the magnetic lines circulating around that conductor, the effect should be increased, because of the iron cylinder which increases these magnetic lines.

THE CHAIRMAN [Vice-President Crocker]:—It certainly can be said that this experiment is only suggestive and not at all conclusive. There are a great many possible things that might cause this rotation other than any molecular action, such as Prof. Dolbear suggests. He evidently thinks that it is open to suspicion, and I think it would have to be carried very much farther before it could be accepted as one of the phenomena of nature.

MR. CHAS. J. KINTNER:—I suggest a modified form of the apparatus which perhaps might bring about the results that Prof. Dolbear seeks. Instead of a metallic cylinder, suppose we take a light glass cylinder, Fig. 4, and attach in some way a porous diaphragm through the centre thereof, with mercury at the bottom and a wire running upwards into the mercury, connected at one pole of the generator, and with a conductor running from above into two liquids, a colored liquid on one side of the diaphragm and a perfectly transparent liquid on the other. If there be any tendency to molecular movement there, I think it is possible the colored liquid would be forced to rotate through the diaphragm and mix with the transparent liquid.

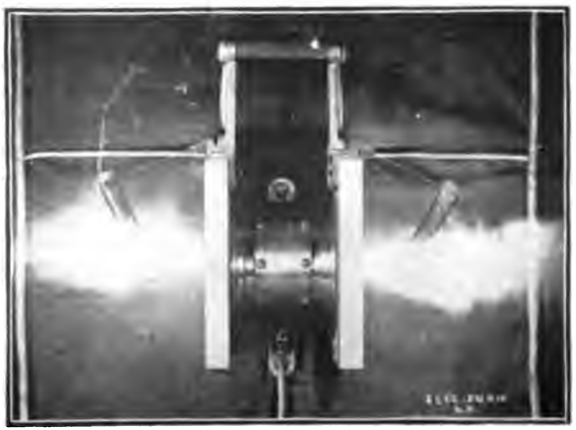
[Adjourned.]

WURTS ON LIGHTNING ARRESTERS, AND THE DISCOVERY OF NON-ARCING METALS.

[March 15, 1892.]

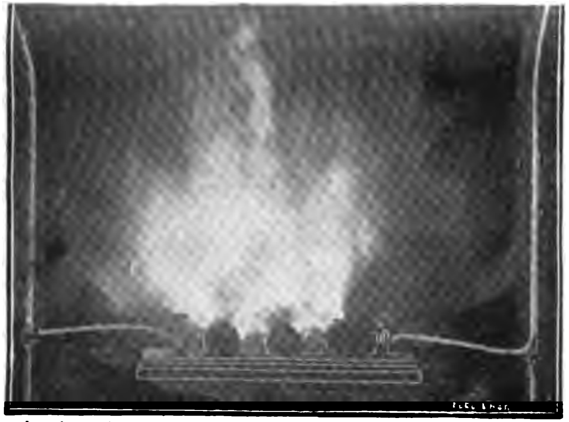
Photographs illustrating 1,000 *volt short-circuits, and the different effects obtained with arcing and non-arcing metal electrodes, and with large and small air-gaps.*

Interruption of short-circuit between non-arcing metal electrodes, with two $\frac{1}{16}''$ air-gaps.

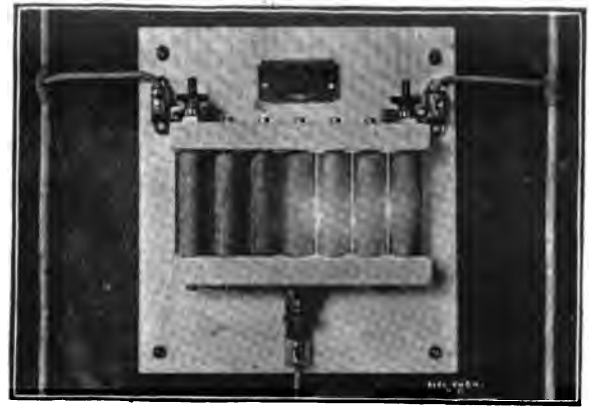


Automatic Air Blast Double Pole Lightning Arrester. This arrester was first exposed with the electrodes fixed in the position shown, and the flash taken subsequently.

Double Pole Non-arcing Metal Lightning Arrester. Interruptions of short-circuit between poles, $\frac{1}{3}''$ air-gap



Short-circuit maintained between non-arcing electrodes, with two $\frac{5}{8}''$ air-gaps.



Double Pole Non-arcing Metal Lightning Arrester. Interruption of short-circuit between Line and Ground.

Short-circuit maintained between non-arcing electrodes, with two $\frac{5}{8}''$ air-gaps same conditions as above.

1,000 volt short-circuit maintained between copper electrodes (arcing metal), with two $\frac{1}{32}''$ air-gaps.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 15th, 1892.

The Sixty-fifth meeting of the American Institute of Electrical Engineers, was held this date at No. 12 West Thirty-first Street. The meeting was called to order by Vice-president Thomas D. Lockwood, who said,

Gentlemen: Recently looking over the proceedings of a British institution, I found the following statement made by a well known man; that about 150 years ago, Franklin made the first useful application of electricity. When one considers the subject, it seems rather odd to regard a rod devised to prevent the destructive effects of electricity, as being a useful application of the agent it is intended to counteract. However that may be, I am very glad to have the opportunity of introducing to you one who has done his best to follow up the same line of work as was initiated by Franklin. I have much pleasure in introducing Mr. Alexander J. Wurts, who will read his paper on Lightning Arresters and the Discovery of Non-Arcing Metals.

[Mr. Wurts read the following paper.]

A paper read at the 65th Meeting of the American Institute of Electrical Engineers, New York, March 15th, 1892, Vice-President Lockwood in the Chair.

LIGHTNING ARRESTERS, AND THE DISCOVERY OF NON-ARCING METALS.

BY ALEXANDER J. WURTS.

During thunder-storms electric wires become charged from the atmosphere with an electric potential, different from that of the earth; there is then a tendency to establish an equilibrium, that is, for a discharge to or from the earth as the case may be. If this discharge be left to choose its own path, it will select one or many of the weaker points, usually the most vital part of the system, and there rupture the insulation. It therefore becomes necessary to rid the line of this charge in some suitable manner, and without allowing it to damage any portion of the system. This is usually accomplished by the well-known air-gap lightning arrester. Benjamin Franklin nearly one hundred and fifty years ago, drew sparks across an air gap from a charged conductor very much as we do it to-day. He, however, did this to demonstrate the presence of the charge, while we do it for good riddance.

Shortly after the erection of the first telegraph line by Morse in 1844, it was found necessary to provide means for discharging the line during thunder-storms, and numerous devices were brought out and patented for this purpose. The main features of lightning arresters from that time till recently have been the "spark gap" and the "kicking coil," the latter being interposed between the discharge circuit and the apparatus to be protected. The spark gap arrester on telegraph lines answers the purpose admirably as far as lighting and atmospheric induced charges are concerned. When, however, electric lighting was introduced, the lightning arrester problem became more difficult in consequence of the dynamo short-circuit that invariably follows the discharge. It then became necessary to provide means for promptly interrupting this short-circuit, and so the fuse was added, and then there followed all kinds of automatic devices for interrupting the short-circuit and restoring the arrester to its normal condition. But most of these devices have been more or less defective and unsatisfactory, and now that high potentials are used, the proper interruption of the short-circuit becomes more difficult than ever. A very interesting method of interrupting the electric arc, is that which is commonly called the "magnetic blow out." The action of a magnet upon the voltaic arc was first observed by Davy, and afterwards carefully studied by De la Rive, who, in describing the various phenomena connected with this subject, mentions the fact that an electric arc cannot be

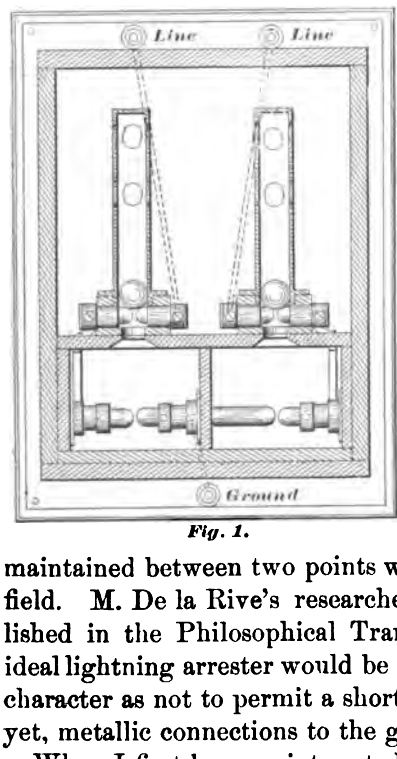


Fig. 1.

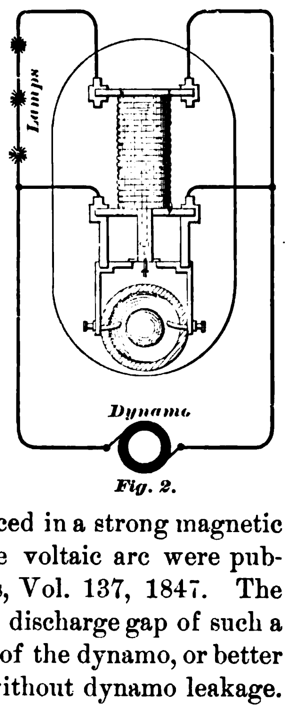


Fig. 2.

maintained between two points when placed in a strong magnetic field. M. De la Rive's researches on the voltaic arc were published in the Philosophical Transactions, Vol. 137, 1847. The ideal lightning arrester would be a simple discharge gap of such a character as not to permit a short-circuit of the dynamo, or better yet, metallic connections to the ground without dynamo leakage.

When I first became interested in this subject, I was naturally guided somewhat by previous practice, which had been to provide with each arrester and discharge circuit, an automatic circuit interrupter. Fig. 1 illustrates my first practical step in this direction, and represents the Winsor-Wurts lightning arrester, the fundamental idea of which emanated from Mr. Paul Winsor, who proposed that a discharge gap be placed in the neck of a bottle, the idea being that the heat of the arc formed by the short-circuit would sufficiently expand the air in the body of the bottle to blow out the arc. With this idea as a nucleus, the arrester depicted in Fig. 1 was evolved. Referring to the figure, it will be noticed, without going into detail, that the arrester is double-pole and that each discharge gap is placed in the centre of an air chamber. In the upper part of each of these there is a slotted passage, which might correspond to the neck of a bottle, and in which there is placed a second air-gap in series with each of the others. The second air-gap is bridged with a carbon ball, the latter being held in place by tubes having vent holes in the sides and rubber bumpers at the top. The action which takes place when a discharge to ground is made with a resulting short-circuit is as follows: The arc at either or both of the jumping spaces instantly heats and expands the air in the respective air chamber, which, rushing up through the slotted passages, blows either or both carbon balls to the top of the tubes. The arc formed where the circuit has been broken by the projected carbon ball is, at the same time instantly blown out, thus completely rupturing the circuit. The only demonstration is a quick puff as the air rushes out of the holes near the upper ends of the tubes. The object of the holes is obvious. As the balls are confined in the tubes they at once drop back to their former positions, and thus automatically place the apparatus in a condition ready for another discharge and short-circuit. In testing this arrester the terminals are connected to the circuit of a thousand-volt generator. The air spaces are bridged ever with a fine wire to take the place of an actual discharge. Then, by the throw of a switch the full pressure of the machine is placed on the arrester. There is an enormous rush of current, the temporary wire bridges fuse, arcs are formed, the air expands with an explosion, the balls fly up, more arcs are formed, tongues of fire shoot out of the holes in the tubes, the upper arcs are blown out, the balls drop back to their normal positions, and all this happens like a pistol shot, without causing more than insignificant flicker in the lamps. It is very curious to notice that if this short-circuit is made, as I suppose it often is, on the crest of a wave of an alternating current, the report of the explosion is much sharper and louder than when the circuit is closed at the instant the wave is at or near the neutral point. I might add here, that, after short-circuiting a thousand-volt 3,000 light machine through such an arrester about 400 times, there was not the slightest deterioration to be noticed anywhere. Those who are not familiar with this kind of work will hardly appreciate this last fact, or realize what is accomplished each time the arrester "goes off."

Soon after this arrester was completed, steps were taken to adapt the same principle to an arc circuit lightning arrester, which resulted in the one illustrated in Fig. 2. By referring to the figure, you will notice that a vertical solenoid provided with an iron core is connected in the main circuit beyond the point of contact with the discharge circuit. The discharge electrodes are curved arms which swing freely through the sides of a cylindrical

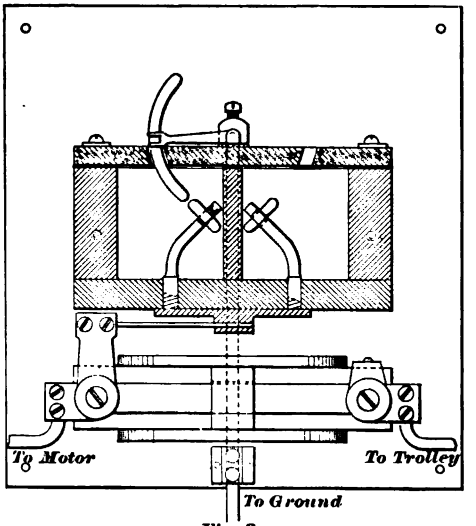


Fig. 3.

air chamber, and the construction is such that when the core falls, the discharge electrodes will be forced out. The action is then as follows: Under normal running conditions the core is held up in the solenoid, but if a discharge occurs from both sides at once short-circuiting the machine through the discharge points, the solenoid will at once lose its power, the core will fall and force the discharge arms out through the holes in the walls of the chamber. This action would draw out arcs three inches long, and the heat thus generated is sufficient to cause a sudden expansion of air in the air chamber and thus blow out the arcs even though the current be but ten amperes and the pressure 3,000 volts. Without the device just described for lengthening the arc, the heat developed would have been insufficient. In short-circuiting a 50-light machine through this arrester, there is a scarcely perceptible flicker in the lamps, the core drops, the short-circuit is opened and the core drawn back into its normal position ready for further action, all in an instant of time. Although I have used an electromagnetic device in the construction of this type of arrester, it will be noticed that the placing of a coil in the lightning arrester circuit has been avoided, so that even though every discharge has to pass through this coil to reach the discharge points, yet from this point on, the discharge has a non-inductive path to earth through the arrester in preference to the dynamo.

Neither of these arresters would interrupt a short-circuit on a 500-volt direct current generator, so after some further experi-

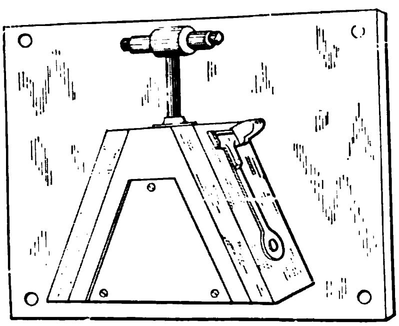


Fig. 4.

menting the arrester shown in Fig. 3 was evolved. Referring to Fig. 3, it will be noticed that there are two air chambers, in each of which is a fixed carbon discharge point. Above these chambers is a curved carbon swinging freely from one chamber to the other through suitable openings, so that either end of the curved carbon, as the case may be, shall come into close proximity to either of the fixed discharge points. The action is as follows: When a discharge takes place, it passes to one of the fixed discharge points, depending upon the position of the curved carbon, then across the air space to the curved carbon, and from there to the ground as shown in the figure. The dynamo current then following, causes an arc to be established between the curved carbon and one of the fixed points, and the heat generated by this arc expands the air in its respective chamber, increasing the pressure therein, and causing the curved carbon to be instantly blown from one chamber to the other. This ruptures the arc and adjusts the arrester for the next discharge. In testing this arrester, 500-volt and 1,000-volt generators have been repeatedly short-circuited through it, and in every case the circuit has been instantly broken without injury to the dynamo, and the arrester has as quickly reset itself in readiness for future use. In one of the tests made to demonstrate its promptness and reliability, the fixed points were so adjusted as to touch the curved carbon in either of its two normal positions. A 1,000-volt generator was then short-circuited through the arrester, which resulted in the circuit being repeatedly opened and closed without injury to either dynamo or arrester. This power circuit arrester was afterwards much improved, and finally took the form shown in Fig. 4,

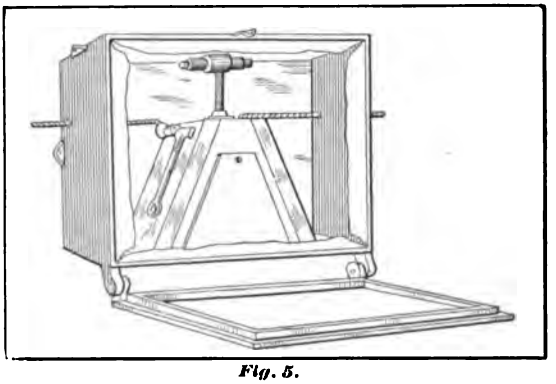


Fig. 5.

and the arrester shown in Fig. 1 was also finally changed to this form. This arrester is made of iron and marble, and its advantages over the others are its non-combustibility and the double break in connection with the air blast. Fig. 5 illustrates the same arrester, fitted into an iron box lined with asbestos, and in this shape is adapted to either car or pole use.

So far you will observe that my one object had been to provide a simple, reliable and non-inductive circuit interrupter. In this I had succeeded as far as immediate wants were concerned, but with the prospects of higher voltages in the near future the problem seemed but imperfectly solved. The experiments of Lodge, Hughes, and others were carefully studied, and I finally decided that it might be well to repeat some of them. So, one day, while casting about for some suitable means of experimenting, I happened to be passing under a driving belt; my hair stood on end, and my body became charged. Of course somebody had to touch my ear (that seems to be the proper thing to do under the circumstances), and my body became discharged. That evening, while thinking over the events of the day, my thoughts rested on this belt, the electrified atmosphere around it, and the charging and discharging of my body, and I wondered whether the phenomena observed were not very similar to those experienced during thunder storms. On the following day I stretched about four feet of No. 14 insulated wire under a belt, parallel to it, and about two inches below it. I then brought the ends to a convenient place where I could ground the wire or not as I chose. The room was then darkened, the belt set in motion, and a most beautiful sight presented itself. Between the belt and the wire were seen soft purple streamers, giving the appearance of a film connecting the belt and wire. In some places these streamers were more dense than others, and in this were suggestive of the Northern Lights. There was no disruptive discharge at all between the belt and wire. On bringing the bare end of the wire within one quarter of an inch of a ground a continuous discharge took place. When one end was well grounded no spark could be drawn from the other end. When one end was grounded through a choke coil consisting of about 40 turns of No. 14 wire, small sparks could be drawn from the other end, showing the impedance offered by the coils to the discharge. When neither end was grounded both ends showed "side flash" every two or three seconds. So far, these results seemed to correspond with the experience met with in electric systems when exposed to the influence of thunder-storms. The conditions also seemed to be very similar. Here was a wire stretched through an electrically disturbed atmosphere; the wire became charged, and the charge passed readily to ground through a metallic discharge circuit containing an air-gap. An induction coil impeded the discharge, and when there was no ground connection there was side flash. All these results seemed to correspond with practice.

The thought then occurred to me, "What would happen if I were to string a second wire near and parallel to the first, and ground it, leaving the first wire insulated?" A second wire was quickly strung, but before making the ground connection the following observations were made. The purple streamers seemed equally divided between the first and second wires, and either would give about equal sparks. On grounding the second wire no indication of a charge on the other could be obtained. The streamers were now all directed to the second wire, and the first was as inert as a block of stone would have been. If, now, in these laboratory experiments, there were reproduced the conditions existing between electric wires and the atmosphere during thunder-storms, then, to prevent wires from becoming charged, all that would be necessary would be to stretch a grounded wire near and parallel with the wire to be protected, and, in fact, it would seem as though one such grounded wire would protect all the wires that could be strung on any one line of poles. An explanation of these phenomena is not far to seek. An insulated wire lying on the surface of the earth cannot become charged from the atmosphere, because the latter is at the same potential as the earth; but an insulated pole line can be, and is charged

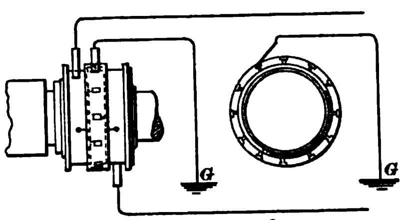


Fig. 6.

when exposed to the influence of thunder-storms, because the atmosphere surrounding the wire is at a different potential from the earth; therefore with an insulated pole line, and an adjacent grounded parallel wire, the grounded wire in effect transfers the earth to the level of such wires, but if a grounded wire near and parallel to an insulated wire in effect causes the earth to be transferred to the level of the insulated wire, then the insulated wire cannot become charged. The grounded wire running over the poles will relieve the atmosphere in its neighborhood of any difference of electric potential that would otherwise exist between that neighboring atmosphere and the earth, and the insulated line would then fail to become charged. Soon after performing this experiment, I learned that such an overhead grounded wire had been used to great advantage, and that being the case was greatly surprised that it was not in more general use.

I next replaced the wire I was using, which was much battered and bruised, with a new wire, and found the charge much diminished by the superior insulation. The latter was then replaced by bare wire insulated with a glass tube. The spark now was scarcely perceptible, being about the size of the spark obtained from a Leclanche cell, and even this could be obtained only after several minutes of charging. These results seemed to indicate a gradual charging of the wire by more or less perfect contact with an atmosphere having a different potential from that of the earth. With the idea of gradual charging in mind, the following plan was hit upon for a lightning arrester. The first conception was to alternately ground both poles of a generator over a very small air-gap, and at rapidly recurring intervals. The improved plan, however, was to alternately dead ground the poles of an alternator at every neutral point in the electromotive force wave, the

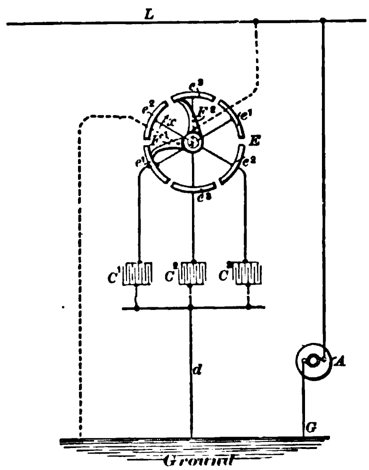


Fig. 7.

idea being to so constantly discharge the line in this manner, as to effectually prevent a charge from attaining any considerable intensity, and at the same time avoid the short-circuit which now invariably follows the discharge over the air-gap of our present arresters. The method of carrying out this plan will be understood by a glance at Fig. 6, which represents an elevation and end view of the collector rings of an alternator, also the ground brush which alternately grounds the poles of the generator at every neutral point in the E. M. F. wave. Upon experimenting, I found that an alternator could be short-circuited at the neutral point without a spark. If the short-circuit occurred a little before the neutral point, that is, on a decreasing electromotive force, there was slight sparking, but no tendency to hold on. If the short-circuit occurred at all after the neutral point, a furious arc was established which would hold on indefinitely.

This form of arrester has not yet been tested in actual practice, but it will be during the coming season, and I have great hopes that it will not only successfully discharge the line, but effectually prevent any considerable accumulation of the charge. Of course this form of arrester is only adapted to alternators.

For direct current use I have devised something quite similar, the principle of which will be understood by reference to Fig. 7. Referring to the figure, A is a generator, one pole of which is grounded at G, the other being connected to the trolley line L; E is a circuit controlling device consisting of fixed commutator like metal pieces e^1, e^2, e^3, opposite pieces being electrically connected; F^1, F^2, are brushes insulated from each other and revolving at a

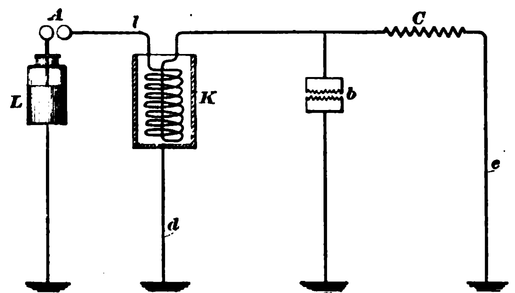


Fig. 8.

high speed in a direction indicated by the arrow, F^1 is connected to earth, and F^2 to the line: e^1, e^2, e^3, are connected respectively to three condensers, C^1, C^2, C^3, the latter being grounded as indicated at *d*. The action is as follows:—With the brushes in their present positions, the line is connected through F^2 and e^3 to condenser C^3. This condenser is therefore being charged while condenser C^1 is being discharged to earth through e^1 F^1 When F^2 passes to e^1, condenser C^1 will be connected to the line, and become charged while condenser C^3 will be discharging through e^2 and F^1. Thus by the continued rotation of these two brushes, it will be seen that the trolley line is being constantly discharged into a fresh condenser.

This arrester has also not been tested in actual practice, but if my hopes are fulfilled it will accomplish for direct current circuits what the neutral point arrester is intended to accomplish for alternating circuits, the idea being in either case to take off the charge bit by bit, but at such rapidly recurring intervals that the line will be kept practically free from charge, or, at least prevent the charge from attaining sufficient intensity to damage any portion of the system. Personally I am much interested in these two arresters, which practically afford direct connection to earth without dynamo leakage, and would like to dwell on them more in detail, but time will not permit.

Referring once more to my experiments with charged wires, I would say that they were nearly all repetitions of experiments quite familiar to all of you. Let me, however, call your attention to one of them which I am confident is not old in detail. Referring to Fig. 8, L is a Leyden jar, *l* is a bare line wire, a portion of which is coiled and immersed in a tank K of water. This tank is well grounded. Line *l* is continued through induction coil C and then grounded as shown; *b* is a gap discharge circuit. Now with a spark at A there was a small spark at *b*; with a gap at *d* there was sparking at *d* and *b*, spark *d* being larger than *b*. With a gap at *e* sparks were obtained simultaneously at *d*, *b*, and *e*. Induction coil C was either a primary or a secondary of a 40-light converter. When C was primary, spark *e* was very small. When C was secondary, *e* was larger, but still small when compared with *d* and *b*. These results led me to what I call the tank arrester, which consists practically of the coil and tank of water represented in Figure 8. Its use, however, is limited to comparatively low potential circuits. In practice I propose to immerse in a tank of well grounded running water a coil consisting of about fifteen feet of No. 0000 bare wire, and connect this coil in series with the trolley circuit. The apparatus as I have designed it will give a leakage current of 3.7 amperes at 500 volts, which, however, is inconsiderable if adequate protection is provided. Of course with suitable means for cutting out this arrester, the leakage need only occur during stormy weather. The prominent features of this arrester are: First. the comparatively large portion of the line exposed to ground connection; second, the opportunity for constant leakage of the charge, that is, the intensity of the charge need not rise to the striking electromotive force of an air gap before beginning to discharge; third, the fact that whatever charge may be induced on the line will be forced to pass through this tank before reaching the generator; and fourth, the impedance of the coil, which will tend to force the charge from every point on its surface into the water and therefore to earth.

From my experience with charged wires I learned two lessons, both of them old, but in books they had not impressed me as they did in practice. The first lesson was, that I must not expect one or two discharge circuits to discharge the many miles of wire that we have in our lighting and power circuits. The second was that a "kicking coil," no matter how great its impedance, would still take a portion of the discharge. My final conclusions then were; that in order to afford the best possible protection for electric plants, the wires must fairly bristle with discharge points properly located in discharge circuits. With this idea in mind a cheap and effective pole arrester seemed to be the proper thing to look for. My experiments from this time on led me to a discovery so remarkable, and so contrary to all previous ideas, that I am going to read you a description of them.

In designing the arresters already described, I had followed closely the rut of previous practice, which had always been to provide with each discharge circuit, a circuit interrupting device. Upon reflection, however, it was evident that one circuit interrupter placed in the main circuit would interrupt the arc on any discharge circuit. For a moment the problem of a simple pole arrester seemed solved, but on second thought the difficulties and inconveniences inseparable from any automatic main circuit interrupter appeared to be insurmountable, and the idea was no sooner conceived than it was abandoned. And yet, poor as it was for practical purposes, it proved a good stepping stone, and led to the following plan, viz.: To provide the line with ordinary discharge circuits, that is, with the well known saw-tooth protectors, made of carbon so that they would not easily burn away; and then in the station, between the generator and the first discharge circuit, provide an automatic device which, upon the passage of an abnormal current from the generator, would instantly short-circuit the dynamo and as quickly open again, the intention being that should a short-circuit occur out on the line through any of the discharge circuits, a short-circuit at the dynamo would so reduce the pressure on the line as to render it impossible for an arc to maintain itself. Then, any such arc having been extinguished, the short-circuit at the generator could be interrupted, and the service would continue as before. This idea meeting with general approval, steps were at once taken to put it to a test in the following manner: To a 1,000-volt alternator there was connected a circuit consisting of about 100 yards of line wire, and in this circuit there was placed a pair of carbon dischargers having saw-tooth edges, and a $\frac{1}{16}$ in. air-gap, also a switch. In shunt with this circuit, that is, directly across the terminals of the generator, there was connected a simple device (it will not be necessary to explain its construction) which, upon the passage of an abnormal current in the circuit containing the dischargers, would instantly short-circuit the generator and as quickly open again. All the connections being made, the air-gap was bridged with a bit of tinfoil to start the arc, and the switch thrown. The actions that followed in an inconceivably short space of time were these:—The tinfoil burst with a snap, an arc was formed, the automatic short-circuiting device operated, the arc was extinguished and the short-circuiting device opened. So far, this was exactly what was anticipated, but no sooner had the short-circuiting device opened, and the electromotive force returned to the line and the dischargers, than the dynamo pressure forced an arc across the air-gap once more, and the whole operation was repeated. This repetition was found to be due to the fact that when the arc was first established between the carbon saw-tooth plates, the carbons were heated to a white heat which not having time to dissipate itself before the pressure returned, the dynamo current found a sufficiently easy path over the heated air-gap to re-establish an arc. However, the test being otherwise satisfactory, success seemed assured, for all that was necessary now was to use solid metal dischargers that would readily conduct the heat away, and the trouble above cited would no doubt be avoided. So the test was repeated, using the same apparatus as before, except the dischargers, which now consisted of three solid, round, brass rods, 1 in. in diameter and $1\frac{1}{4}$ in. long, placed side by side with their axes parallel to each other, and having air gaps of $\frac{1}{16}$ in. That is, the line was connected to the two outside bars, leaving the middle one idle to be connected to ground, as would be the case in a double pole lightning arrester. The air-gaps were bridged as before with tinfoil to start the arc, and the switch thrown. The test was successful in the highest degree—too successful, in fact, not to arouse suspicion. So I thought I would repeat the experiment, and see how the dischargers would behave without the short-circuiting device. The result was an overwhelming surprise, for at the dischargers there was merely an insignificant spark scarcely larger than a pea. The experiment was tried again and again, with the same result. Any electrician would have predicted a brilliant display of fireworks. The most plausible theory advanced to explain this action was that the electric motor driving the dynamo being small, its speed was probably reduced to such an extent by the overload suddenly thrown upon it, that the electric pressure was at once reduced below that which would be necessary to maintain an arc across the air-gaps. On second thought, this theory would have seemed improbable, but at the time it was accepted without a question. In a few days a test was again made, this time a small engine being used for motive power, and the same results were obtained as before. The afternoon of the same day both engine and generator were changed, with like results. In the meantime a little reflection seemed to indicate that perhaps this strange action was not, after all, due to the slowing down of the motor, but to the possible cooling effect of the metal dischargers on the arc. With this idea in mind, I had constructed, a set of three dischargers similar to the first, but much larger, 2½″ diameter x 3″ long, thinking that if a little metal was good, more would be better, and that perhaps with a large generator the mass of metal would have to be greatly increased to produce the results already obtained. This large discharger was connected to a 3,000-light, 1000-volt alternator; the air spaces were bridged as before; and the scene which followed beggars discription. The large metal bars were melted like beeswax in a great ball of fire. My disappointment was keen for I thought I was on the verge of making a discovery, and that in the previous cases the comparatively feeble engine had not been the cause of the action. Thinking, however, there could be no harm in melting up the smaller discharger, I connected it in where the larger one had been, bridged the air space, and threw in the switch. Imagine my astonishment on hearing an insignificant snap like the crack of a toy pistol, and seeing an arc as before no larger than a pea. I then pushed a nickel down into one of the air-gaps to short-circuit it, and leaving only one air-gap for the arc, and tested again, with the same results. Two questions now presented themselves: viz., what were the differences between the large and small dischargers other than size, and why did the small discharger behave in this altogether unlooked for manner? The answer to the first question was readily found by tracing the two dischargers back to their source, and there learning that the larger one of the two was made of cast brass, containing certain proportions of tin and copper, and that the smaller one was made of hard-drawn brass, containing certain proportions of zinc and copper. These facts at once established two differences between the dischargers other than mere size; one was, their physical structure, the other their composition. Which of these two differences caused the difference in their actions? A discharger composed of cast brass containing the same proportions of zinc and copper as the hard-drawn brass discharger was made and tested, and found to work perfectly. It was thus determined that the physical structure of the metal had no influence in suppressing the arc. The important difference between the two dischargers then lay probably in their composition, and I was now rapidly becoming convinced that in brass, consisting of certain proportions of copper and zinc, there must exist certain properties which do not permit of an arc being maintained between two dischargers, even with the high pressures of 1,000 volts. It also occurred to me that possibly the shape of the dischargers had something to do with the results obtained. So the next step taken was to have a number of dischargers made up in different shapes and sizes, such as spheres, ovals, solid half cylinders, tubes and cubes; all worked well with the exception of the cubes. The cubes were placed so that their faces were separated by $\frac{1}{16}''$. Now when the tinfoil was placed over their edges, the action was favorable, but if the tinfoil were pushed down between the faces, the arc would hold on indefinitely, and yet without any demonstration whatever, thus, even when the arc did hold on, showing a very different action from the other metals. The size of the dischargers did not seem to affect the results so long as there was sufficient metal to prevent actual melting—$\frac{1}{4}$ in. brass rod melted on the third trial. It was next decided to make dischargers of other metals, and thus learn whether there were any other substances that would give these results, and if so, perhaps some light would be thrown on the real cause of the action. The metals first tested were hard steel, hard-drawn copper, phosphor-bronze, aluminium-bronze, and aluminium, all of which failed utterly. The next metal tested was zinc, and with this, most successful results were obtained. Perhaps you will now think the experimenter very slow to put two and two together, but who is there who is at all familiar with the properties of zinc, that would have suggested this metal as one likely to resist an electric arc and 1,000 volts in this manner? With such results before me, I was ready to try anything. The next metals were tin and nickel. Both of these failed. Tin made the most brilliant display of all the metals. The next tried was antimony, and it worked perfectly. The theory now advanced to explain the phenomena was that with the metals that do not allow the arc to be maintained, there is formed at the instant the arc is started, an oxide of the metal which, becoming instantly volatilized in the intense heat of the arc, chokes up the air-gap with vapors of high resistance, and so presents an effective barrier to the further passage of the current. With metals that do maintain the arc, instead of the vapor of the oxide of the metal, there is formed a pure vapor of the metal itself, and this offers comparatively no resistance to the passage of the current. When tests similar to the above were made on a 500-volt direct current generator, every one of the metals failed. The arc, however, was small and quiet with the special metals, thus even with the direct current showing a very peculiar action. Another curious phenomenon connected with zinc and antimony is this: The smaller the air-gap the less tendency there is to maintain an arc when using an alternating current at 1,000 volts pressure. In fact, when the air-gap is two inches long the arc, when once started, will be maintained, while at ½ in. or ¼ in. the arc will not give up without a struggle, and at $\frac{1}{32}$ in. there is only a small spark caused by the fusing of the tinfoil, and the circuit is instantly interrupted.

The next step taken was to try higher pressures. A short circuit on a 2,000-volt generator, through the double air-gap discharger, failed to be interrupted; four and five air spaces also failed. Six air spaces of $\frac{1}{32}$ in. each, interrupted the short-circuit instantly, but six air spaces, which would make three on each side of the circuit for the lightning charge to jump through, were strongly objected to as offering too great a resistance. A test was then made to determine the pressure needed to strike an arc across three air-gaps, and was found to be 3,500 volts, measured with a Cardew on an alternating current generator. The experimenter then procured a lightning arrester well known in the market, and one which is known to take the lightning discharge successfully, and tested it for the striking electromotive force, which was found to be between 8,000 and 9,000 volts. In order, however, to avoid any prejudice that a series of air-gaps might arouse, the following plan was hit upon: Pairs of non-arcing dischargers, Fig. 9, were mounted upon thermostatic supports in such a manner that the pairs would normally rest in contact with each other, and so that any current traversing the system would be forced to pass through the thermostats and dischargers in series. The thermostats were so arranged as to cause the two dischargers in each pair to open a way from each other upon the passage of the current. If then, a single and permanent air-gap were connected in series with this system, that is, an air-gap just sufficient to prevent the normal pressure of the line from striking any arc, and if an arc were started across it, the sudden rush of current through the thermostats would instantly introduce a number of air-gaps in the circuit corresponding to the number of pairs of thermostatic dischargers, and thus automatically open the short-circuit. This

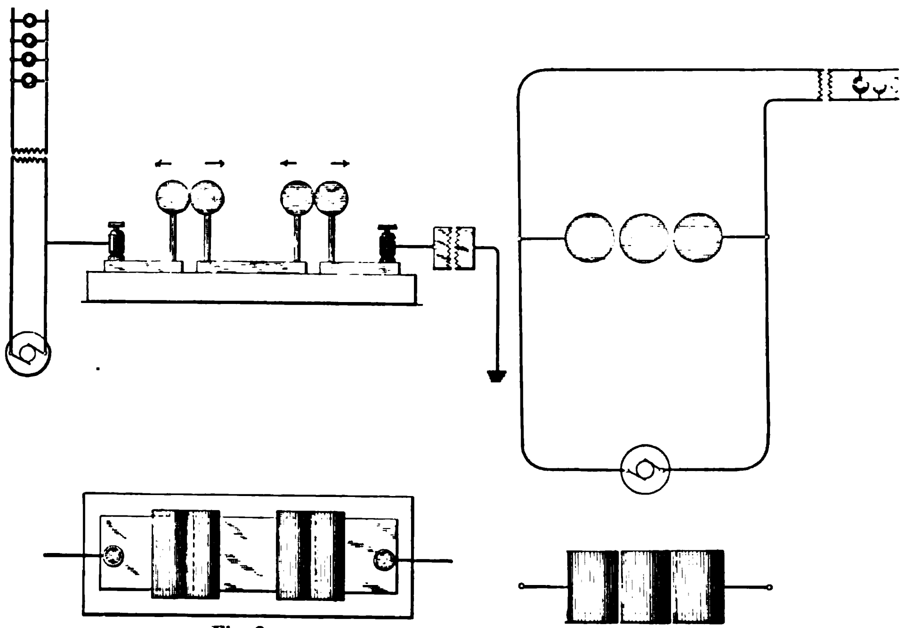


Fig. 9. *Fig. 10.*

device was tested and found to work admirably. Of course after the circuit has been interrupted, the thermostatic dischargers at once return to their normal positions. In fact, this action is so rapid that if a series of these dischargers be connected in a short-circuit without a permanent air-gap, the circuit will be automatically opened and closed every two or three seconds. In order to appreciate the very remarkable action of this thermostatic device it must be well borne in mind that a very small air-gap is all that is necessary for the interruption of the circuit.

Thus far, although I had tested a number of metals, my selection had been quite at random, so that by this time I was desirous of making a more thorough and systematic investigation of this new property. The chemical properties of zinc, and antimony were carefully compared without any new light. The various groups of metals were examined, and then it occurred to me that, of all the metals tested, not one of them belonged to the two groups in which zinc and antimony are found, according to Mendelejeff's grouping. The metals of the zinc group are,—

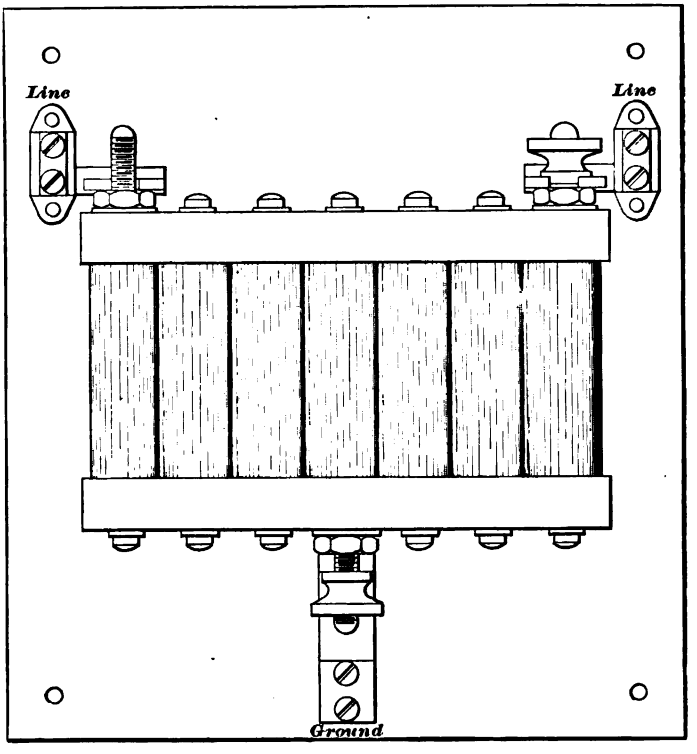


FIG. 11.

Zinc, cadmium, mercury and magnesium, and of the antimony group are,—antimony, bismuth, phosphorus, and arsenic. I first tested cadmium, and found it non-arcing. Then magnesium,—more, however, from a sense of duty than because I had hopes of anything but negative results. Fortunately I made this test on much lower E. M. F.'s, and found it non-arcing at 100 volts over two air-gaps of $\frac{1}{32}$ in. each. On 250 volts the magnesium caught fire, which was, of course anticipated. I then wanted to try mercury, but for the moment, not seeing how to make such a test with a liquid, I was diverted to the antimony group, and upon testing bismuth found it to be non-arcing. Phosphorus and arsenic were not tested. A final attack was now made upon the zinc group by testing mercury in the form of a copper amalgam. This test was the most successful one of all, for after a number of short-circuits on a 1000-volt alternator, I found the surface of my dischargers had not been disturbed in the slightest degree. It will thus be seen that all available metals in these two groups are non-arcing. In searching for the non-arcing metals each test was made with two air-gaps and the E. M. F. at the time of the short-circuit was, with the exception of the test on magnesium, 1000 volts. Figure 10 illustrates the connections and general method of testing these metals.

Figure 11 represents a double pole lightning arrester made of non-arcing metal, and in connection with this paper will be readily understood without further explanation.

Discussion.[1]

The Chairman, [Vice-President Lockwood] :—We have had the pleasure of listening to a most instructive and interesting and, at the same time, a most intensely practical paper—perhaps one of the most practical that we have had this season. Many of us are old telegraph men, and we all recollect our early and our persistent struggles with lightning arresters. Some of the most successful lightning arresters gave us the most trouble. The paper we have heard is worthy of exhaustive discussion, and as the lightning arrester, like the poor, is always with us, and as the history of the lightning arrester is the history of applied electricity, I trust we shall have a most exhaustive and full discussion, and I am sure that Mr. Wurts will be willing to answer any questions that may be asked.

Dr. Chas. E. Emery :—I would like to ask the speaker a question with reference to the statement on page 15, that the tests failed for a direct current of 500 volts (that is practically the same as used on railroad work), whether or not this apparatus as finally constructed will protect direct current apparatus operating with high voltage.

Mr. Wurts :—This metal, which I have called "non-arcing," will not of itself interrupt direct current circuits from street car generators. This action, however, of the direct current on non-arcing metal is very peculiar, thus distinguishing it from other

1. By Messrs. Birdsall, Emery, Kennelly, Lockwood, Prescott, Sullivan, E. P. Thompson and Wetzler.

metals even though the arc be maintained. When short-circuiting a street car generator through these air-gaps, the arc is very small and quiet; but I have not been able to interrupt such circuits by the simple use of this metal. The arresters which have been described (Figs. 3, 4 and 5,) and which are on the floor, are used on direct current circuits. Fig. 4 illustrates the arrester used on 500 volt trolley circuits. These arms which are the discharge electrodes, fly out by the expansion of the air in this air chamber, and thus rupture the circuit, and the arms falling back to their normal position, instantly and automatically place the arrester in a proper condition to repeat the operation. In testing these arresters the arc is started by placing a bit of tinfoil in the

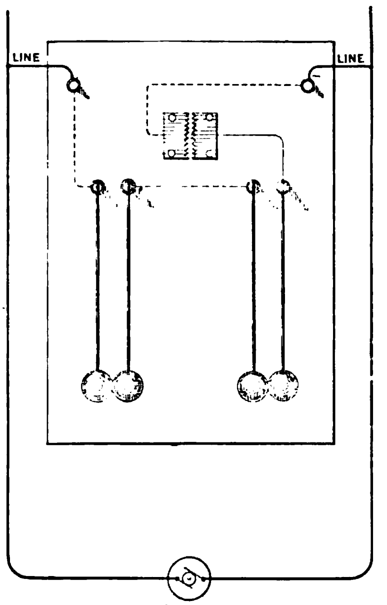


FIG. 12.

air-gap and the short-circuit is thus established on a large street car generator. This same arrester placed in an iron box, as illustrated in Fig. 5, is adapted to either car or pole use. Before this arrester was designed, the one shown in Fig. 3 was used. Here is a photograph of the flash as the arrester operates.

I have a curious device here, Fig. 12, but do not know that it has any practical value. You will notice that here are four brass posts extending horizontally from this back-board and from which are suspended, by means of copper ribbons, two pairs of non-arcing metal balls, the balls being about an inch in diameter. The two balls in each pair normally rest in contact with each other. Just above these you will notice an ordinary lightning arrester discharge gap. Now the arrangement is such that the copper ribbons, the ball, and the discharge gap are connected in series with each other, so that if an arc be established across the air-gap, the current will follow down one copper ribbon to the metal ball, then across to the next ball, up that ribbon, across to the next ribbon, down and across the next two balls, and finally up the last copper ribbon. The action then with an alternating current is this: the amount of heat generated between the metal balls resting in contact with each other is sufficient to expand the air and thus force the balls apart, and as a very small air-gap is all that is necessary to interrupt the circuit when using a non-arcing metal, the circuit is instantly interrupted. This device, which I hold in my hand, has been tested a number of times on a thousand volt short-circuit, and if you will examine it, you will find the metal balls but slightly scarred. One very curious fact is, that the metal balls do not fuse together.

This sample here, which consists of three cylindrical rods, has undergone eight short-circuits on a thousand volt generator, and I have reversed the rods, so that you may see the action of the current on the metal. The scars cannot be felt with the hand, and each spot is no larger than an ordinary sized pinhead.

In short-circuiting through this sample, which is a commercial non-arcing lightning arrester, I connected the terminals of my generator to either of the outside bars, giving me three air-gaps, in each of which I placed a small piece of tinfoil not larger than the head of the pin, and closed the short-circuit, which was then instantly interrupted. On examining the air-gaps I found that only one of the bits of tinfoil had been fused. The tinfoils in the other two spaces were still intact. To interrupt a 3,000 volt short-circuit I connected ten air-gaps in series, short-circuiting each one of them with a drop of water, and upon examining the gaps after the short-circuit had been interrupted I found three or four of the gaps still short-circuited by the drops.

MR. GEO. B. PRESCOTT, JR:—Mr. Wurts attributes the peculiar action of these metals to the non-conducting property of their vapor. I would like to ask him if he considered the possibility of its arising from a peculiar polarizing effect, due to the small air space and proximity and shape of the poles, on the molecules of the intervening atmosphere?

I came here to-night not expecting to hear very much that was new on a subject so old and apparently exhausted, but have been very agreeably disappointed. Mr. Howell's remark that it is a research, I think describes the paper.

THE CHAIRMAN:—I think by an attentive reading of the paper it will be seen that Mr. Wurts ascribed the success of the non-arcing metals to the non-conducting vapor of an oxide which was formed there.

MR. WURTS:—That is my present theory, that there is a non-conducting vapor formed in the air-gap which chokes the further passage of the current. A fact which seems to lend strength to this theory is, that in order to obtain the non-arcing property, the air-gaps must be very small, and it seems as though under such circumstances the non-conducting vapors might be somewhat concentrated, but if the air-gaps be large, allowing plenty of fresh air to circulate, the vapors may be scattered, and thus allow the free passage of the current. I have also thought that perhaps there might be something in the nature of a counter-electromotive force hindering the passage of the current, or that perhaps the dischargers themselves were coated with a non-conducting film; but I do not think the latter is the case, as a bit of tinfoil dropped into the air-gaps will instantly re-establish the circuit Of course this is only a theory that I have, and I am in hopes that some ideas will be brought out here which will aid me in further researches.

MR. JOSEPH WETZLER:—I would like to inquire of Mr. Wurts if he has ever considered the possibility of his non-arcing metal being used in the construction of safety fuses, as we might expect that if this metal were non-arcing, much of the danger now attending the maintenance of an arc when a fuse is blown would be obviated by using fuses of such non-arcing metals.

MR. WURTS:—I have some very interesting data on that point. As zinc is one of the non-arcing metals, I thought that if a zinc fuse were made, I would have one that would not establish an arc when "blown," but at that time I did not fully appreciate the necessity of a small air-gap for the immediate interruption of the circuit. I first made a fuse of pure zinc, and, upon short-circuiting, an arc was established very much as in the blowing of a lead fuse. I then made a fuse of about 50 per cent. zinc and 50 per cent. antimony, which, however, worked no better; but I have here a fuse block which permits of the use of lead fuses, and which when blown on a thousand volt short-circuit will not maintain an arc. You will notice that on this wooden block there are two sets of small non-arcing metal cylinders, there being three cylinders in each set. Over each set I stretched a lead fuse, and then connected the two fuses in series. In testing this fuse block on thousand volt short-circuits, I placed the block in a converter primary fuse box without lining; then when the fuses melted, the arc was instantly taken up by the small air-gaps between the non-arcing metal cylinders and a circuit immediately interrupted without the slightest tendency to flash to the walls of the iron chamber; in fact, the stumps of the lead fuse, you will notice are still in the block.

The fuse block that I now hold in my hand is the only one I have made for higher potentials, and you will notice that I have arranged seven non-arcing metal cylinders in the shape of a semi-circle, thus giving me six air-gaps, and over these I extend my fuse.

MR. WETZLER:—Of what metal is your fuse?

MR. WURTS:—I have used lead fuses, also copper and aluminium fuses. I connected the terminals of a self-regulating 2,000 volt alternator to the terminals of this fuse block and threw the switch, having first raised the E. M. F. of the generator to 2,500 volts. Please bear in mind that this was a self-regulating generator. The fuse was blown on the short-circuit and the arc immediately interrupted, whereas in short-circuiting through a similar fuse without the non-arcing metal cylinders, I was forced to separate the terminals of the fuse about a foot, before the arc would let go. This being the case it seems to me that this metal might properly be called "non-arcing." In testing without the metal cylinders, not only did I have to widely separate the terminals of the fuse, but I also passed the fuse, which was a copper wire, through a $\frac{1}{16}''$ hole in marble slabs, the slabs being placed next the fuse terminals for protection, thinking that in this way, I could bring the terminals of the fuse closer together, and at the same time extinguish the arc; but it was not until I had, even under these circumstances, separated the fuse terminals about a foot, that the arc would "let go."

MR. EDWARD P. THOMPSON:—In view of the great importance which the discovery of non-arcing metals by high potential alternating electric currents may have in other departments of the electrical industry besides that of lightning arresters, it becomes desirable, that every phase of the subject should become known. From the systematic manner in which Mr. Wurts has investigated the matter, I should judge that there is not one stone left unturned. I would ask therefore, as to any tests he may have made to show the necessary thickness the non-arcing metal should have in order to exhibit the peculiar property. For instance, suppose he employed as electric terminals, *arcing* metals such as copper, lead or any member of the same chemical class, coated each with a layer of *non-arcing* metal such as hard brass, zinc or mercury. The question is, how thick should the coating be, and what is the effect upon the metals?

MR. WURTS:—In answer to that question I will show you some copper amalgam dischargers which I made by electrolytically depositing copper into mercury. This process gave me a paste which I pressed into cylinders as you see, and then allowed to set. Mercury being one of the non-arcing metals the arc was not maintained. An amalgam, however, made in this manner is soft and readily crumbles away; but the amount of non-arcing metal that is necessary for instant interruption of the circuit is very small, and this fact is well illustrated by the following experiment:

I made three copper dischargers similar to those I have just shown you, and which I knew, under conditions of a short-circuit would maintain the arc. These discharges I first washed with acid and then dipped into mercury, thus slightly amalgamating the surface of the copper dischargers. The coating of mercury was so thin that I could scrape it off with my penknife. I connected the terminals of the generator as before and caused eight short-circuits to be established one after the other across the air-gaps. The first time that I closed the short-circuit I did not notice a flash or any movement of the voltmeter and concluded that I must have had an open circuit, but upon examination found that the tinfoils had been fused. I presume I must have used exceedingly small pieces of tinfoil. I performed this experiment eight times, and then, upon examining the discharges, found them not to be burned or burred in the slightest degree, In fact I never would have known that they had been tested in this manner except for a little blackening caused by the fusing of the tinfoil. This form of non-arcing metal is, however, not practical, for upon repeating the test an indefinite number of times, the mercury was finally driven off, leaving the copper exposed and then the arc was maintained. So long, however as this thin film of mercury was present there was not the slightest tendency to arcing.

DR. WM. E. GEYER:—I should like to ask Mr. Wurts in those cases where the arc is not absolutely stopped but where the little arc is maintained, whether it keeps to one place or keeps running about between the rods?

MR. WURTS:—The arc maintains a fixed position and is very quiet. On 3,000 volt short-circuits I have used six air spaces, which are not sufficient to interrupt the circuit and the arc was quietly maintained. There was no demonstration at all, but the current passing, judging from the temperature of the metal bars, must have been very great. The metal, however, does not burn even when the arc is maintained. When I say does not burn, I mean comparatively speaking, for after long continued arcing, the metal does show some signs of the arc.

Here is a single-pole line arrester consisting of four non-arcing metal cylinders and three air-gaps. I have used this in connection with high potentials, and have maintained the arc for one or two minutes at a time, and if you will examine it, you will notice that there is no roughening at all.

Here is a double pole line arrester which has seven non-arcing metal cylinders and six air-gaps, that is, three air-gaps from line to ground for the discharge to jump through. This arrester is similar to the station arrester represented in Fig. 11, except that it is conveniently mounted in an iron box.

When the pure non-arcing metals are used, the dischargers are considerably burned by the arc, for instance, here is pure antimony, which you will notice is somewhat melted away. It is the same with this sample of cadmium, which you will also notice is somewhat burned. The addition, however, of 50 per cent. of copper seems to give toughness to the metal or some similar property which does not permit the arc to burr or burn, and yet there is still a sufficient quantity of non-arcing metal present to prevent the maintenance of the arc. In commercial brass rod there is about 35 per cent. of zinc and 64 per cent. of copper, also a small quantity of lead. I made a set of non-arcing dischargers consisting of about 50 per cent. of zinc and 50 per cent. of copper, but could not notice any perceptible difference between this and the commercial brass rod; 90 per cent. zinc and 10 per cent. copper burred very much like the pure zinc, and 90 per cent. copper with 10 per cent. zinc failed to interrupt a thousand volt short-circuit.

Here are some non-arcing metal dischargers enclosed in a small wooden box. If you will examine this box you will notice that there is not the sign of an arc on the cover or sides. There is no blackening.

Mr. E. T. Birdsall:—In that part of Mr. Wurts's paper where he speaks of the belt and the second parallel wire, he makes the remark that it is a very good lightning arrester, and also in another part of the paper he says that all we would need for a perfect arrester would be a line which was bristling with points to conduct the current to the ground. In this connection I would like to say, as a matter of history and record, that four and five years ago, in all the specifications for line work for outside pole lines which were gotten up by the old Edison Electric Light Company, we always included barbed iron fence wire; this was run along on the poles the whole length of the pole line and grounded at every two or three poles. Here we had the parallel wire bristling with points and also connected with the ground at frequent intervals It made as far as I know a good lightning arrester, as I do not remember of any station that was struck where this plan was used, but as soon as somebody with influence in the company got out something else, we had to use that.

Mr. M. C. Sullivan:—I note that Mr. Wurts cites cases where the arc is reliable to hold on, and when this is so there is more or less fusion. I would like to ask Mr. Wurts how different this effect appears in the non-arcing from what would be considered arcing metals or the different bars he uses.

Mr. Wurts:—In experimenting with these non-arcing metal bars, I have not been able to re-establish the arc rapidly enough to raise their temperature. It is only when I use an insufficient number of air-gaps to interrupt the short-circuit and thus allow the arcs to be maintained, that the metal bars become heated. In repeatedly short-circuiting a thousand volt generator through the arrester illustrated in Fig. 11, the metal bars did not apparently change their temperature. The circuit is interrupted so instantaneously that there is no time for heating. I mentioned the heating in connection with circumstances where the arc was maintained. that is, where I used a current of higher electromotive force than could be interrupted by the number of air-gaps under test.

Mr. E. P. Thompson:—When one bar is arcing and the other non-arcing, it might be impossible to determine just what would take place, by theoretical consideration. Have you tested this feature?

MR. WURTS:—In connection with that point I have only made this one test, namely to insert a carbon bar in between two non-arcing metal bars; but when the short-circuit was once established the arc held on most persistently.

THE CHAIRMAN:—If there is any one thing more instructive than another in what has been brought before us this evening, it is the exhaustive way Mr. Wurts has prosecuted his experiments. Whenever any gentleman has asked a question, Mr. Wurts has had his answer ready—an experiment to describe, and a sample to show.

MR. A. E. KENNELLY:—While I think it is impossible to doubt that these experiments are very novel and interesting, perhaps the most interesting of all is that one which has been elicited in discussion where a short-circuit fuse has failed to arc when shunted by a series of these air-gaps. I would like to ask Mr. Wurts whether in any of the experiments of that nature that he conducted, the electrical pressure which he used on that fuse, or the pressure of the generator which he short-circuited, was, so far as he knows, less than the pressure which would have independently forced its passage across the air-gaps that were in shunt, because if so, it would seem to indicate that the bursting of the safety catch had either raised the pressure above that of the generator, or else that it had produced locally some very unusual effect.

MR. WURTS:—Using this fuse block with the seven non-arcing metal bars arranged in a semi-circle, I connected the terminals to a 2000 volt generator, having first raised the E.M.F. to 2700 volts. That E.M.F., if I am understanding the question, would not strike an arc across these six air-spaces; but had I used ordinary metal for these bars, and once established the arc across the air-spaces, then the arc would have been maintained. It is a very different thing to establish an arc by external means, and to cause an arc to establish itself. In the non-arcing metal arrester described, the air-gaps are always sufficient to prevent the dynamo from starting an arc by its own E. M. F.

MR. KENNELLY:—Then, if I understand Mr. Wurts, had those bars been ordinary metal, say copper, the same pressure would have started an arc across the air-gap?

MR. WURTS:—No, it would not have started an arc, but it would have maintained the arc when started.

MR. KENNELLY:—I think that is a very remarkable fact and one which calls for further explanation, an explanation that does not appear to be immediately upon the surface. That is a point that I confess I am unable to understand for the moment, and it is not the only point in the paper that I have been unable to understand. But there has been one case mentioned by Mr. Wurts which I would like to have a little further elucidation upon, and that is not in connection with the particular metal which he had employed so successfully. I think I could explain my meaning best on the blackboard. The very interesting experimental case is mentioned by Mr. Wurts in which he actually grounds a line along which power is being delivered at every pulsation of the dynamo, and right at the neutral point, or immediately before the neutral point he grounds the line. But I have not understood the exact method of protection which Mr. Wurts expects to obtain by that device, however interesting it may be in itself. We will take the case of an electrified cloud floating above the earth's surface. The pressure in the cloud may be enormously high. Let us suppose it to be a million volts, for want of better knowledge; and then suppose that we have a wire which is connected with a ground, either by direct communication, in the manner suggested by Mr. Wurts, at each pulsation, or by gradual leakage, or in any other way that you please This cloud, let us suppose, is negatively charged at a very high pressure, and then the wire will become positively charged and its original neutral charge will have been decomposed, the negative electricity will have passed into the ground, will have gone beyond the limits of this cloud, and the whole region here will be positively charged, not only the wire but all the surface of the earth in this vicinity. Now that would be the condition of affairs prior to the lightning flash. There will be a static strain all across this insulator, and there will be a positive charge, but one which is not evident, owing to the opposite influence of this negative electrification. Now suppose that a lightning discharge takes place at some point. There will now be an enormous development of apparent electrification, and that will constitute a "return stroke," or lightning stroke on a minor scale. It will not have the same power that a lightning stroke delivered here would have. But it may have a powerful local effect, and will depend for its suddenness on the suddenness of the lightning discharge. Now if this is measured in millionths of a second, the secondary electrification will be up and over in the same interval of time. But the momentary grounding of the circuit through the dynamo can only take place at definite intervals, let us say in two or three per cent. of the total time; and if the lightning discharge occupies only one or two millionths of a second, it seems to me that this device will be inoperative; but if the discharge should happen at the exact moment when the line is grounded, then of course it is possible that this might carry away the discharge. If, however, I have not understood the action of the device I desire to be enlightened.

Mr. Wurts:—I think you fully understand the action of the device, but I believe I began my description of it with these words, "with the idea of gradual charging in mind." From my experiments with charged wires I had conceived the idea that possibly electric lines were gradually charged up to a high potential and not suddenly, as you have there described upon the blackboard. I am rather inclined to think, however, that they are often charged suddenly; but may it not be that although the primary cause of the charge is sudden, the time of wave propagation is considerable; for example, if I have my neutral point arrester connected at one end of a line and suddenly have a charge induced at the other end, may not the time of wave propogation from one end of the line to the other be considerable and by grounding the far end of the line at rapidly recurring intervals, may it not be possible to help matters considerably? I do not think we can have too many lightning arresters, or too many different kinds of lightning arresters connected to the line. I would recommend an overhead grounded wire, a leakage arrester such as I have described and called a "tank arrester," also some reliable type of discharge-gap arrester in the station and at frequent intervals along the line. I know of a case where a dynamo tender, wishing to determine the best lightning arrester on the market, procured four or five different kinds and connected them to the line in parallel. When the first discharge occurred, every lightning arrester operated at the same time. And this suggests a question which I would like to ask. I would like to know if anybody has noticed, when several lightning arresters are connected in parallel and fairly close together, say, three or four feet apart, whether the charge will ever skip one of these discharge circuits and apparently make a selection. I have noticed this repeatedly, and know of a case where there are about twenty lightning arresters on one switch-board all connected to the same ground wire, and one of which has never been known to take a discharge. The air-gaps in the arresters are all one-sixteenth of an inch, and in fact all the connections and surrounding conditions seem to be the same for each arrester except that of position. It occurred to me then that perhaps the failure of this one arrester might be due to nodal points.

My question then is: Are there nodes formed by the line discharge such that it is possible to connect an arrester to a nodal point on the line, in which case there would, of course, be no tendency to discharge?

MR. LOCKWOOD:—Although the subject is perhaps, from the telephone and telegraph man's point of view, rather an over-estimated one, if I may judge by the remark with which Mr. Wurts turned off the subject on the first page—"The spark gap arrester on telegraph lines answer the purpose admirably"—still I think I will venture a word or two on that part of the subject. As I understand the paper, the first part of it addressed itself largely to lightning arresters *per se*, without regard to whether the generators exciting the circuit were alternators or continuous current generators, while the latter part, in which the non-arcing metals were described, related more particularly to alternating circuits. Now, as Mr. Prescott very pertinently observed, there has been a great deal said about lightning arresters, and I think he meant there has been a great deal said which might just as well have been left unsaid. It is one of those things which nearly every electrician from 1840 down, has felt himself at liberty to theorize about, and I do not know that the habit has quite left the race. While speaking of theories I should like to say that the theory which the speaker of the evening has developed concerning the reason that some metals under an alternating electromotive force of very high voltage, will not arc while others will, seems to me to be at least a plausible one. We know now that the useful arc which is displayed between the carbon points of an electric arc lamp is produced first by a spark, and then by the extremely hot vapor, carbon vapor which exists between the points, and I do not think it is very unfair reasoning to say that inasmuch as a conducting vapor will maintain an arc, that a non-conducting vapor won't.

In a work on telegraphy, called the Telegraph Manual, by Taliaferro P. Shaffner, which was published in New York in 1859, there is a very good chapter on lightning arresters, at pages 564 and 586, and the first time I read that chapter I was very much interested to observe that the spark gap arrester which answers the purpose so admirably for telegraph work, even so far back as 1859 and before that, was not considered on the French railway lines and by French railway electricians to be "all that was required," and a very good picture is found there of not only the saw-tooth air gap, but closely associated therewith is a long wire evidently intended to be fused and to open the circuit. Such a combination has, to my certain knowledge, been attempted at least to be patented some half dozen times in the last half a dozen years, but I do not know whether that has been cited as a reference to any of them. Shortly after the telegraph was industrially started in this country by Mr. Morse, a gentleman whom many of us know personally. Mr. J. D. Reid, whom we are in the habit sometimes of calling the nestor of telegraphy, invented the first electro-magnetic "lightning protector," as he called it, although I never could see why lightning needed any protection—like a good many other things we protect in this country. Perhaps "apparatus protector" would have been a better name. It consisted of a very coarse wire magnet, provided with an armature and a pivoted lever; a strong counteracting spring pulled one end of this lever over to one side, and held the lever which was in contact with the line against a contact leading to the instrument (the circuit coming first to the magnet, then to the lever, then from a platinum point on the lever to the contact post which led through the instrument to be protected, thence either to earth or to the next station.) There was a ground post just under the other end of the lever, and an air-gap of about one-eighth of an inch between the lever point and the ground post, and the idea was that when the lightning discharge came, this magnet would be energized, and would pull away temporarily the armature from the old position against the force of the counter-spring, and would discharge it to earth and then the counter-spring would at once pull it back, and in this same Shaffner's Manual there is a picture showing the very experiment which the protective apparatus enthusiast always shows, to prove how successful and efficient his protector is. That is, there were a couple of pieces of fine copper wire which were to be saved, and in the experiment which Mr. Reid carried out they were saved; and his machine was considered in its day such an important device, that the Franklin Institute gave its silver medal to Mr. Reid for the meritorious invention. But he very soon found out that it was not necessary, and as he has himself said, he found out that a very much better protector was to put a lightning rod on each pole, and run this wire we have heard about this evening from pole to pole, grounding it where necessary on the pole rods. This expedient has been used in this country and England for a great many years. But in telephony, although the telephonic current is, speaking from the point of view of strength, the weaker vessel, it perhaps makes up for the slenderness of its current, by the number of telephone lines there are in the United States compared with other electrical wires. If it was only lightning that telephone apparatus had to be protected from, there would not be much trouble in protecting it successfully and easily. When Mr. Sargent, whom many of you know very well, and who is General Manager of the telephone company in Brooklyn, was in Philadelphia, so little was he troubled by lightning that he never found it necessary to put a lightning arrester on any line whatever, and he never had any instrument destroyed by lightuing. Since, however, the advent of the arc light with its 30 to 40 or 50 lamps upon a circuit, and since the second advent, if I may so call it, of the electric railway, the telephone has not possessed a complete immunity from destructive influences; and one of the worst troubles about contacts between telephone lines and lines carrying heavy currents is this very tendency—a discharge once having passed—for a perpetuation of the arc which we have heard about this evening, which tendency has been found in larger electrical installations to be so destructive; and therefore telephone men have found it necessary now not only to put on air-gaps to discharge dangerous potentials - and this with metallic circuits I should say—they have also found it necessary to put on something, and preferably a thermal protector, which will first break the circuit and then either ground it or short-circuit it, so as to avert the dangerous results of what we have learned to call "sneak currents," for we have found in our business where we have so many wires massed together, that it is not the very heaviest currents which are the most dangerous, but those which creep in and smolder in the insulation for some time and finally break out into a blaze, after the smoldering has gone so far that when the blaze breaks out it is almost impossible to save anything within a radius of perhaps two hundred feet.

The third form of dangerous current we have to protect ourselves against, is that which comes on in values of from five amperes upwards, which is not a sneak current by any means but which makes its onslaught boldly. However, as I have said, the sneak current we have found the most dangerous, all things considered, and during the last three or four years a great many devices have been invented to circumvent it. One very interesting one which has recently been called to my notice was gotten up in Colorado. It consists of a little box of hard rubber with a cylindrical perforation through it, closed by a hard rubber plug on the lower side. There is a chamber of about three-quarters of an inch long and from half an inch to five eighths of an inch in diameter in the centre of this plug, and within the chamber is coiled up about twenty-five feet of very fine german silver covered, wire. While its resistance considered by itself is not great, still on a heating current coming on, the resistance of the circuit is pretty well concentrated into that little chamber; a great portion of the heat at all events is so concentrated. Through a small pin hole in the upper part of the rubber box are dropped a couple of globules of mercury, which of course penetrates into the chamber and gets all around this little coil of wire. The pin hole is then covered up with a very thin membrane of say thin sheet rubber, which is cemented down by bicycle tire cement, or some similar substance so that the aperture is perfectly light. Fixed to the metal post on one side and having one end in contact with the line circuit, is a thin spring which carries at its front end a contact point and which lies at its free end in contact or right on the top of this thin rubber membrane. Immediately above the contact point is an earth contact, or a contact which may lead to the other side of the curcuit in the case of a metallic circuit. In addition to this, there is a fuse which perhaps will disappear with a current of four, five, six or seven amperes. After passing through the fine wire the circuit leads to the instrument. When a dangerous current comes in, it heats up this fine wire coil, and causes the mercury to expand, and if the heat goes on, it causes the mercury to vaporize. The rubber sheet is bulged out and presses the free end of the contact spring against the rough points, short-circuits the circuit, cuts the instrument out and either blows out the fuse or works like a vibrating contact. It short-circuits the fine wire coil, I should also say, at the same time. The heat goes down, the mercury condenses and the rubber sheet contracts.

I would like before sitting down to express the great pleasure I have experienced in hearing the paper of the evening and especially in listening to the very prompt and instructive way in which every question has been answered, by Mr. Wurts.

The Secretary:—Mr. Wurts, who is with us this evening and who has presented this paper, has not yet become a member of Institute, but his application is in, and if it had been a little earlier it would have been favorably acted upon. I desire before we close to offer a vote of thanks to him, for the care and trouble he has taken to prepare this paper and bring it before us in such good shape, and also in having given it to the Secretary in time to have it printed in advance.

[The motion was carried.]

THE SECRETARY:—At the February meeting of the Council, it was decided to hold the General Meeting this year in Chicago. It has not been the usual practice of the Institute to hold its general meetings outside of New York City, but two years ago a meeting was held in Boston, and the Council has felt that the time has now come when we can obtain a sufficient attendance in any city that we may care to visit, to hold a successful meeting. At the Council meeting to-day it was decided to hold that meeting in Chicago on Monday and Tuesday, the 6th and 7th days of June. The Annual Meeting for the election of officers and the reception of yearly reports, and the transaction of business will be held in this house on the third Tuesday in May; that is fixed by the rules. This meeting has heretofore been held in conjunction with the General Meeting, but this year it has been thought wise to postpone the General Meeting a little later, and it is also proposed in connection with the Annual Meeting in this city to have a dinner. The meeting will convene at about four o'clock in the afternoon and adjourn for dinner at 7 o'clock. It has been felt by a good many that it has been some time since we got together in a social way, and that this would be a fitting occasion for such an event.

At the Council meeting this afternoon, the following Associate Members were elected.

Name.	Address.	Endorsed by
ALDRICH, WILLIAM S.,	Associate in Mechanical Engineering in the Department of Electrical Engineering. Johns Hopkins University, Baltimore Md.	Louis Duncan. C T. Hutchinson. H. S. Hering.
BLAKENEY, W. H.,	Firm of Blakeney and Rennie, Mechanical and Electrical Engineers, 33 Bath St., Glasgow, Scotland.	Geo. M. Phelps. Francis R. Upton. Ralph W. Pope
CARROLL, DWIGHT F.	Instructor in Electrical Engineering, Lehigh University, South Bethlehem, Pa.	R. O. Heinrich. Ralph W. Pope. T. C. Martin.
LENZ, CHARLES OTTO,	Draughtsman (Electrical), Edison General Electric Co., Box 3067, New York City.	J. H. Vail. Charles Hewitt. Robert T. Lozier. J. Stanford Brown.
MARTIN A. J.	General Supt., West End Electric Co., 1310 N. 29th St., Philadelphia, Pa.	H. A Reed. G. A. Hamilton. H. A. Foster.
PEROT, L. KNOWLES,	Consulting Electrical Engineer 308 Walnut St., Philadelphia, Pa.	H. G. Reist. J. B. Cahoon. Franklin Sheble.

SACHS, JOSEPH,	Electrician, The American Engineering Co., 109 World Building: residence, 1839 Lexington Ave., New York City.	Joseph Wetzler. T. C. Martin. Ralph W. Pope.
WESSELS, EDWARD J.,	New York Agent, The Short Electric Railway Co., 121 World Building, New York City.	E. P. Thompson. Edw. E Higgins. T. C. Martin.

Total, 8.

The following named gentlemen were transferred from Associate to Full Membership:

AYRES, BROWN,	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.
ROBB, WM. LISPENARD,	Professor of Physics, Trinity College, Hartford, Conn.
UPTON, FRANCIS R.	Treasurer and General Manager, Edison General Electric Co., Lamp Works, Harrison, N. J.

Total, 3.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, April 19th, 1892.

The 66th meeting was held this date at No. 12 West Thirty-first Street. The meeting was called to order at 8 P. M. by Vice-President Lockwood.

THE SECRETARY:—Mr Chairman. At the meeting of the Council this afternoon, it was decided in accordance with the report of the Committee to have the dinner, that was mentioned in the notices, at "The Arena," No 41 West 31st Street. The business meeting of the Institute will be held on the 17th of May, in this room, at 4 P. M., and the adjournment will be at about 7 P. M. There will be no paper read, the meeting being devoted strictly to the reception of the annual reports, the election of officers, and matters of that kind.

The Council at its meeting this afternoon elected the following associate members:

Name.	Address.	Endorsed by
BADT, FRANCIS B.	Manager, Mining Dep't, T.-H. Electric Co., 6506 Lafayette Ave., Englewood, Ill.	George Cutter. W. A. Kreidler. Joseph Wetzler.
BLADES, HARRY H.	General Sup't, The Detroit Motor Co., 1343-55 Cass Ave., Detroit, Mich.	A. L. Rohrer. H. A. Kinney. J. C. Hatzel.
COOLIDGE, CHARLES A.	Sup't and Electrician, Northern Improvement Co., Centralia, Wash.	Leo Daft. Ralph W. Pope. T. C. Martin.
CORY, CLARENCE L.	Professor of Electrical Engineering, Highland Park College, Des Moines, Ia.	Edwd. L. Nichols. Harris J. Ryan Ernest Merritt.
EDWARDS, JAMES P.	Firm of W. A. & J P. Edwards, Electrical Contractors and Engineers, Graniteville, S. C.	G. H. Stockbridge. Ralph W. Pope. Alexander S. Brown.
FLATHER, JOHN J.	Professor of Mechanical Engineering, Purdue University, Lafayette, Ind	James E. Denton. Jas. A. Vandergrift. R. O. Heinrich.
HIGGINS, EUGENE	Assistant Electrical Engineer, with Frank B. Rae, 302 Hammond Building, Detroit, Mich.	Frank B. Rae. Wm. A. Anthony, Ralph W. Pope.
HILL, GEORGE	Chief Engineer and General Manager, Carrere and Hastings, 44 Broadway, New York City.	Montgomery Waddell. A. St. Clair Vance. J. T. Marshall.

HOOPES, ARTHUR	Experimenter, Edison Laboratory, Orange, N. J.	A. E. Kennelly. T. C Martin. Ralph W. Pope.
MARVIN, HARRY N.	Secretary and Expert, Marvin Electric Drill Co, Schenectady, N. Y.	Frank J. Sprague. Nikola Tesla. Chas. L. Clarke.
METCALFE, GEORGE R.	Electrical Engineer, with C. O. Mailloux, 45 William and 404 West 22d Streets, New York City.	Wm. E. Geyer. C. J. Field. C. O. Mailloux.
PARKER, HERSCHEL C.	Assistant in Physics, Columbia College, 21 Fort Greene Place, Brooklyn, N. Y.	M. I. Pupin. Holbrook Cushman. F. B. Crocker.
SCOTT, CHARLES F.,	Assistant Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Chas. A Terry. O. B. Shallenberger. W. J. Jenks.
SMITH, T. JARRARD	Manager Electrical Dep't., The E. S. Greeley & Co., 5 and 7 Dey St., New York City.	W. M. Miner. Ralph W. Pope. F. Jarvis Patten
SPERRY, ELMER A.	Electrical Engineer, Sperry Electric Mining Machine Co., Chicago, Ill.	T. C. Martin. Joseph Wetzler. Ralph W. Pope.
STILLWELL, LEWIS B.	Electrical Engineer, Westinghouse Electric and M'f'g Co., Pittsburg, Pa.	Chas. A. Terry. Ralph W. Pope. Joseph Wetzler.
TISCHENDOERFER, FRED. W.	Electrical Engineer, Eickemeyer & Osterheld M'f'g. Co, Yonkers, N. Y.	Chas. P. Steinmetz. Joseph Wetzler. T. C. Martin.
WATERHOUSE, LAWRENCE MAXWELL,	Consulting and Practical Electrical Engineer, 16 St. Michael's Place, Brighton, Eng.	Geo. A. Hamilton. T. C. Martin. Ralph W. Pope.
WURTS, ALEXANDER JAY,	Electrical Expert, Westinghouse Electric & Mfg. Co, Pittsburg, Pa.	Chas. A. Terry. Wm. E. Geyer. O. B. Shallenberger.

Total, 19.

THE FOLLOWING ASSOCIATE MEMBERS WERE TRANSFERRED TO FULL MEMBERSHIP.

AYER, JAMES I.	General Manager, Municipal Electric Light and Power Co., 322 Pine St., St Louis, Mo
EMERY, CHARLES EDWARD	Consulting Engineer, Bennett Building, New York City.

Total, 2.

THE CHAIRMAN:—[Vice-President Lockwood.] The Institute is to be congratulated upon these accessions and especially upon the fact that, as you will have observed, they are not confined to New York alone, and the tendency to centralize is in this case at least departed from, so many of the new associate members hailing from different parts of the United States and some from foreign countries.

The subject for our consideration this evening, as you will see by the papers before you, is "Methods of Electrically Controlling Street Car Motors." Unfortunately the author of the paper is not with us this evening.

[The following paper was then read by Mr. R. W. Ryan.]

A paper read at the sixty-sixth meeting of the American Institute of Electrical Engineers, New York, April 19th, 1892. Vice-President Lockwood in the Chair.

METHODS OF ELECTRICALLY CONTROLLING STREET CAR MOTORS.

BY H. F. PARSHALL

While in many respects the controlling apparatus for street car motors and the general requirements of the same do not differ greatly from some other cases, there are some features that demand the closest attention if the car is to be handled either efficiently or comfortably so far as the passengers are concerned. While the number of methods proposed and tried in times past has been great, at the present time there seems to be sufficient agreement between the principal designers and sufficient data at hand to warrant the writing of a fairly comprehensive paper on the subject.

The problem of controlling the motors is probably the most difficult one in the whole range of street car work, and in no small degree determines the electrical design of the motors, or to be more specific, to start a car under any given conditions of track a certain torque is required. Beyond a certain limit, fixed largely by the convenience of passengers, this torque cannot be exceeded. The smaller the current with which the motor is able to develop this torque, the smaller the rheostat or other starting devices may be and the more efficient the car equipment. Should the motor, therefore, be incapable of developing a comparatively powerful torque per ampere, the amount of energy dissipated either in the magnetic windings, armature windings, or rheostat becomes excessive, the results being the more or less rapid deterioration of these parts.

It may not be out of order just here to discuss the design of the motor with reference to getting this torque most efficiently. The average H. P. exerted by a street car motor at the car wheel probably does not exceed 20 per cent. of the maximum it is expected to do in starting the car under the various conditions encountered. Now to get the highest efficiency from a motor run under these conditions, it is necessary to get the highest possible efficiency at that H. P. at which the greatest amount of work is to be done, and inasmuch as the loss in the conductors for this average H. P. is necessarily low, (otherwise the motors would burn out in doing the maximum work to which they are subjected), the question does not resolve itself into how to get the least possible motor resistance of armature and magnets, but rather, how to minimize the constant loss of hysteresis, eddy currents and friction. While all of these losses vary somewhat with the speed in series wound motors, the variation of these losses is not great, since for an increased speed there is in general a diminished intensity of magnetization and pressure. To render these losses a minimum, and at the same time to get the requisite torque to handle the car efficiently, there is but one solution, that is, to put the maximum number of turns on the armature compatible with good running as to heating and sparking.

While the truth of these statements may be more or less apparent to all when stated in plain terms, but little attention was paid to this matter in the earlier motors designed. The numerous measurements made, however, have so uniformly been in favor of motors with a comparatively large number of conductors on the armatures, that the importance of this matter is now pretty generally understood. This agreement as to the general design of motors has in no small way been influential in bringing electricians into agreement as to how the motor should be controlled, since with an armature of a comparatively large number of turns, less turns are required in the field magnets to produce a given torque with a given number of amperes. The function of the magnets, therefore, has become of less importance. It is always, however, to be borne in mind, that other things being equal, the motor with the greatest number of turns in the magnets will develop the greatest torque for small currents. With a given electromotive force acting on the armature circuit, and a given torque developed by the armature per ampere, it does not matter, so far as efficiency is concerned, whether the difference in electromotive force at the armature terminals and the line is due to drop in external resistance, or to drop in the magnets. This point determines once for all, that motors with commutated fields are not necessarily more efficient than other motors.

The particular advantages of the commutated field method are, that with a limited number of pounds of copper, or in the case of street car motors, with the limited space available for field magnet windings, it is possible to adjust the magnetizing force of the field coils so that the rate of doing work of the motors may be made to correspond with the rate this work is required by the car for the various speeds and conditions of track. This adjustment may be made for any size of motor, with any required degree of precision by varying the number of magnet coils. To increase the range or precision it is only necessary to increase the number of coils. In practice it has been found that this number could not be very great, otherwise the car wiring becomes too complicated and too expensive. This same holds true of the controlling switch. Three magnet coils or sets of magnet coils seem to be the practical limit, since there is a general agreement between street railway managers that the present number of magnet connections (6) should not be increased, and even with this number there is occasional trouble with broken wires or terminals. With a 15 H. P. motor it is possible with three sets of coils to run under most conditions met with in practice without employing external resistance. It is occasionally necessary, however, when the car is to be run at two or three miles an hour, to make use of the resistance coil that is ordinarily used only when starting. With 25 H. P. motors it is necessary, with three sets of magnet windings, to make use of this resistance coil very considerably in ordinary practice, since without this it is not possible to get a speed of less than one-third the maximum speed of the car, which is generally taken to be about 18 miles an hour.

The range of speeds without the use of a rheostat is determined by the limit to which it is safe to heat the magnets. The temperature of the magnets should not in any case exceed 65°C. This would put the increase of temperature at about 30°C. This increase corresponds to an average loss in the magnets of about 0.3 of a watt per square inch of radiating surface. For the few seconds generally taken to start the car the loss may be as high as two watts per square inch without dangerous heating. Experience, however, has demonstrated that to exceed this limit, even for very short periods, there is considerable risk. Having the maximum number of watts that may be dissipated in the magnets, the series resistance of same may be calculated from the properties of the motor on the supposition that each ampere taken by the motor produces a certain number of pounds pull at the periphery of the car wheel. In a well designed motor with commutated fields, it is easy to get from 35 to 40 pounds pull at the periphery of a 30″ car wheel with the coils in the series position. These coils are either wound side by side, or one on top of the other, according to the necessities of the case as determined by the general design of the motor. Experience has shown the advisability of winding these coils in independent spools whenever the general design will permit, since in case of trouble it is cheaper and easier to replace the damaged coil, and there is less liability of crosses between the coils. As an example of a design, that has been found to give general satisfaction in practice, I give the following figures from a series of tests made on a Sprague No. 6, S. C. Motor, the magnetic data of which has already been published by myself:[1]

EFFICIENCY OF STREET CAR MOTOR NO. 6.

[Reduction 11.7 to 1,—30″ Wheels.]

Brake H. P.	Efficiency.	Speed.	Remarks.	Res.
14.3	87 Per Cent.	1110	3 coils in parallel	0.8
11.8	87 "	1174	3 " "	.8
11.4	86 "	1184	2 " "	1.4
9	84 "	1309	2 " "	1.4
8.25	82 "	955	2 in parallel, 1 in series......	3.24
6.35	79 "	1040	2 " 1 "	3.24
4.9	72 "	1070	2 coils in series......	4.86
3.9	70 "	1014	3 " "	7.42

It is to be noted especially that it is possible to get an approximately constant speed with a wide range of loads, and yet have the energy dissipated in the magnets remain approximately constant, and that it is possible to get a torque corresponding very approximately over a wide range, to that required to propel a car under conditions met with. This is the solution of the question, how to get the highest efficiency. For instance, suppose a car is to be run between two points in a given space of time, and this is not an infrequent requirement, and that the magnet windings of the motor are such that either the car runs the distance in too short a time or in too long a time, it will be necessary then to

1. TRANSACTIONS, vol vii, p. 218.

accelerate the car for a time beyond the limit required, then to allow it to slow down, then to accelerate it again, or go through some such cycle of operations to get the required results. More power will be required with such windings than when such a torque can be had at the motor, that will produce the required speed by an approximately uniform acceleration. To get the same results given above for the No. 6 motor, with the magnet coils arranged in loops instead of separate coils would require upwards of three times as many pounds of copper as was used in the present case (110 lbs.) This motor was designed to give a maximum car speed under ordinary conditions of from 12 to 15 miles an hour. At present it is thought advisable to have a maximum car speed of from 18 to 20 miles an hour,[1] since numerous measurements have shown the economy of running street cars at as high a speed as the conditions of track, etc., will permit. In a series of measurements made by myself, it was found that the watt hours per car mile decreased very considerably with the speed of the car up to 30 miles an hour. To get this high speed, (20 miles per hour) it has been found necessary to vary the proportions of the magnet coils from that given in the above for the No. 6 motor. Thus for a single reduction 15 H. P motor the resistance of the last coil to be turned from series to parallel is only 15 per cent. of the total resistance of the magnets, and the turns of this coil only 20 per cent. of the turns in the other two coils. The reason for putting this low resistance coil inside, is to get the greatest number of turns when the coils are all in series and the least resistance when the coils are all in parallel. Further, under ordinary conditions this coil has the least expenditure of energy in it and the least radiating surface. With a winding of this proportion, it is necessary with 15 H. P. motors to use an external resistance of 6 or 8 ohms. With 25 H. P. motors an external resistance of from 10 to 12 ohms is required. This resistance should be so sub-divided that there is not more then 20 volts E. M. F. between adjacent contact pieces, and so proportioned that the increase of temperature is not in any case above 150°C.

A method that is receiving a great deal of attention now is that known as the "Series Parallel Method." While it has not

1. All car speeds are quoted for straight and level tracks. These when calculated for a new motor are determined from the speed and H. P. curve of the motor, assuming the resistance to be 30 lbs. per ton. The methods of measuring these speeds are in general such, that the probable error is too great to determine the percentage slip of the wheels.

yet been introduced very largely in practice, numerous experiments have indicated the desirability of doing this as soon as some of the troublesome features of the switch have been overcome. The method of operating is as follows:

In starting, a rheostat of from 8 to 20 ohms is used, according to circumstances, in series with the motors, which are in series with each other. After this resistance is thrown out of circuit the magnet coils of one of the motors are short-circuited, a section at a time. To make the start smooth, 3 or 4 coils at least are required. The magnet coils being short-circuited, the armature is then short-circuited, and the magnet coils thrown in circuit simultaneously with the armatures being thrown in parallel. It is just at this point where the difficulty with the switch has been encountered, since either the switch has to be operated with great rapidity, or the contacts act in perfect unison, otherwise unpleasant results as to short-circuiting occur.

The advantages of the method are that a very wide range of speeds is obtainable at a comparatively high efficiency, and that the energy required to be dissipated by the rheostat is small for the low speeds frequently required in city practice. This lessening the duty of the rheostat is a very important point, since as yet it has been found exceedingly difficult to construct a cheap rheostat that could be placed under the car in the small space available and dissipate so large an amount of energy as is required when the car is to be run for a considerable time at a speed as low as 2 or 3 miles an hour. Any method of control that has lessened the energy to be dissipated in the rheostat has in general been considered with favor, since there has been a corresponding diminution of trouble in each case that the energy to be dissipated has been lessened.[1]

Having now given a general discussion of the problem a brief description of some of the apparatus recently devised may prove of interest.

Figure 1, shows the general design and arrangement of an improved form of platform switch, which combines both the "field commutation" and the "series resistance" methods of starting

1. Since writing the above concerning the series parallel method of control, some months ago, I have had an opportunity of inspecting the apparatus very recently put in operation by the Thomson-Houston Electric Company. The trouble from arcing at the switch has been overcome by a novel and ingenious construction. It is gratifying to learn that the results of a practical trial recently made on the West End road show that the expectation in regard to better efficiency is fully realized, a gain of 39 per cent. having been obtained in actual practice.

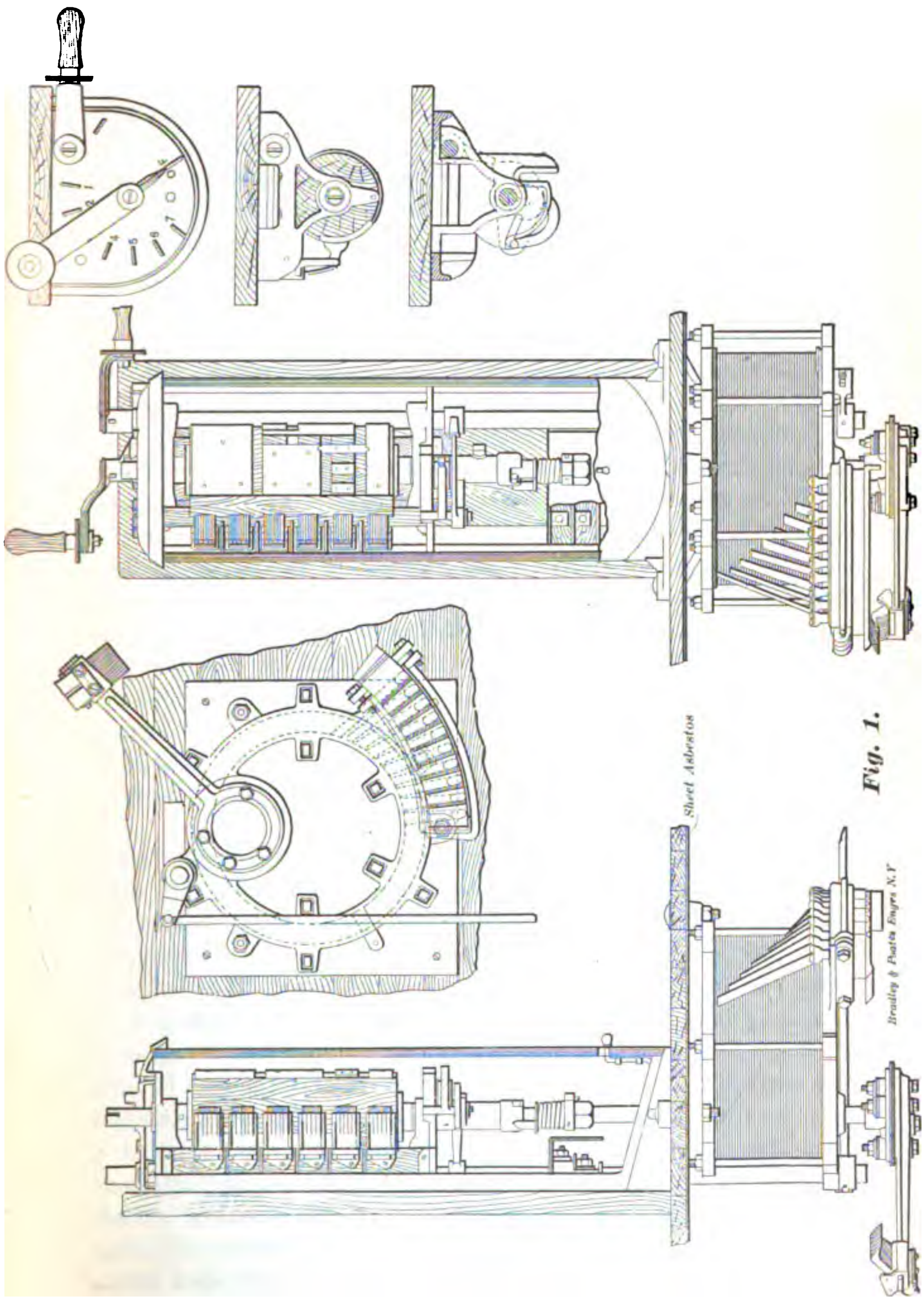
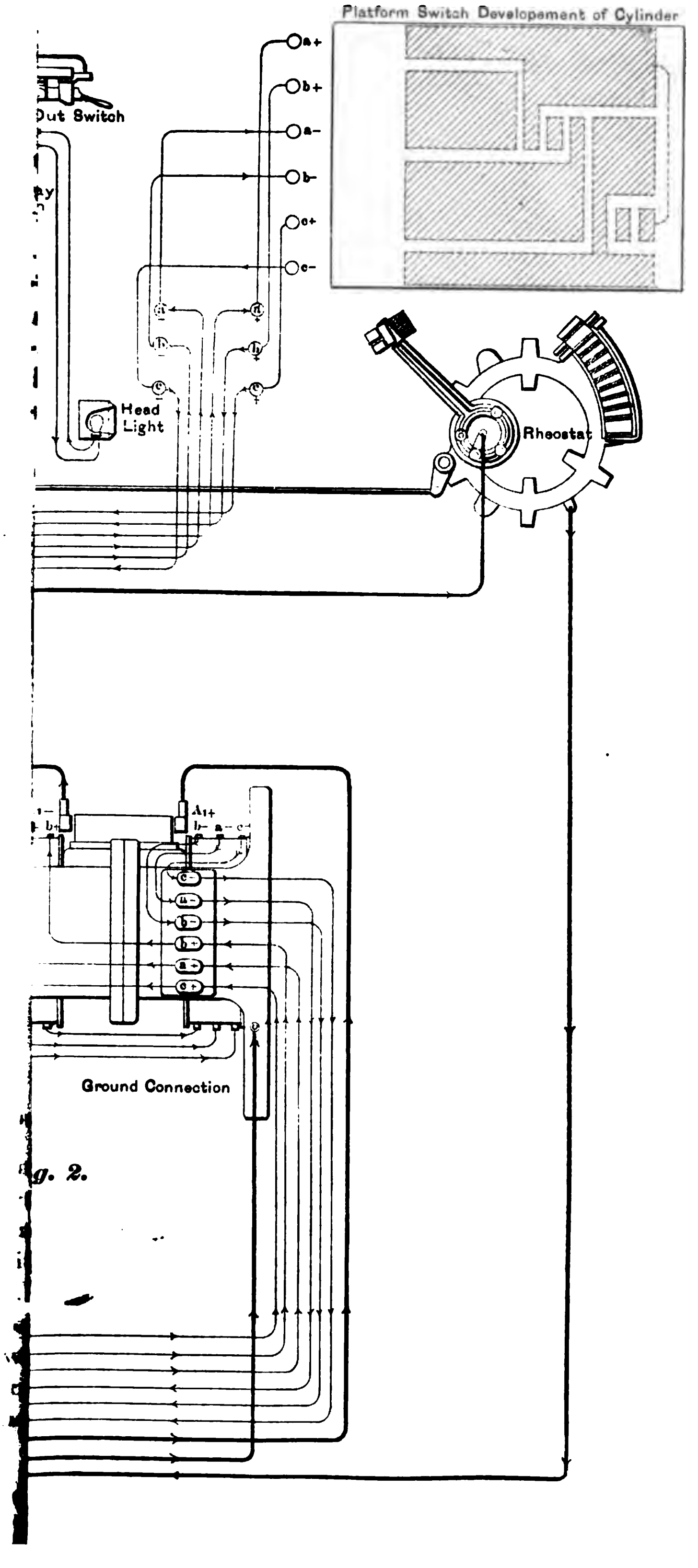


Fig. 1.

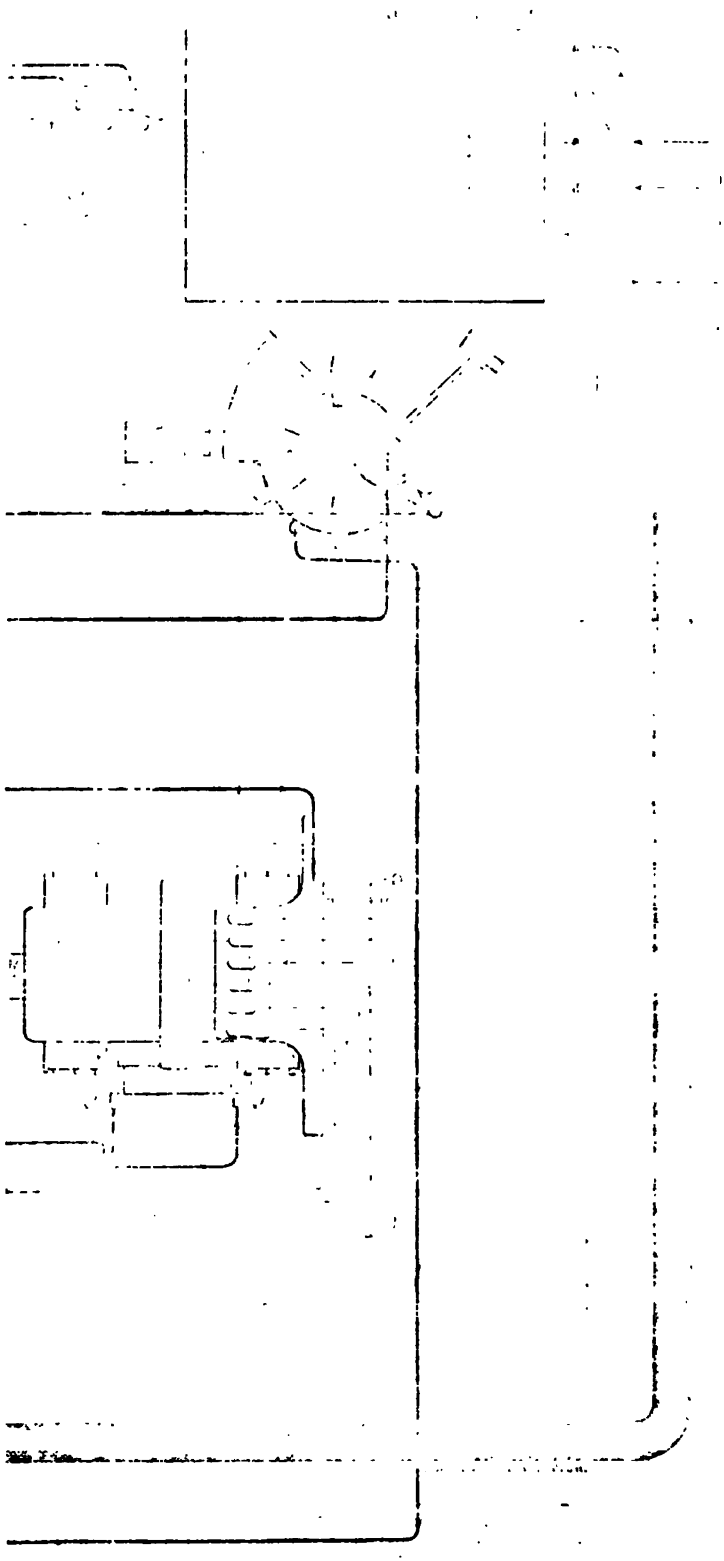
COMBINED REHOSTAT AND PLATFORM SWITCH.

cars. To start the car, the switch handle is turned from the position marked "off" with a counter clockwise movement; this movement carries the arm of the rheostat, which is placed under the switch, around and over the contact segments, so that the resistance is gradually cut out of circuit. After the contact arm has been carried around to 135 degrees and all the resistance has been cut out, it is released from the cylinder shaft and left locked in this position. A further movement of the switch handle then affects only the cylinder, and commutates the sectional windings of the field magnets of the motor from series to parallel in the usual way. In stopping the car the field coils are turned from parallel to series, the resistance coil is then again put into circuit and the circuit broken when the contact lever leaves the last segment of the resistance coil, and not, as hitherto, upon the cylinder contacts. The only caution to be observed in stopping is to see that the switch handle shall be turned to the position marked "off," for the motors are reversed by means of a separate reversing switch placed under the car and operated by a lever connecting with a separate shaft in the controlling switch case. The shaft of the platform switch interlocks with this reversing shaft in such a manner that it is impossible to reverse the motors until the cylinder is in the "off" position. The use of this separate controlling switch has been objected to, but to combine both the advantages of the rheostat and commutated fields the switch mechanism becomes too complicated and the switch too large to have the reversing performed by a reverse movement of the controlling switch handle.

The cylinder plates and contacts are made of thick iron stampings, as experience has shown that iron is more durable than brass for this purpose. The burning, due to the formation of arcs, does not have so much effect upon iron as it does upon brass, and there is more certainty of good contact. The contacts on the cylinder consists of a number of stampings arranged in a brass frame, each stamping making an independent spring contact with the switch cylinder. The rheostat employed is built up in a circular form from a large number of flat rings stamped from thin iron sheets. The rings are built up in the form of a cylinder, each ring of iron being separated from the adjacent rings by a ring of mica, except at point where it makes contact with the ring on other side of it. Instead, however, of being arranged in a continuous spiral circuit, the coil is divided into a


Platform Switch Developement of Cylinder
Out Switch
Head Light
Rheostat
a+
b+
a-
b-
c+
c-
A1+
Ground Connection

g. 2.



number of parts so arranged that the direction of rotation of the adjacent spirals is reversed, this being done to make the inductance of the coil as small as possible. A coil wound up in a continuous spiral having a mean diameter of 12″ and a radial depth of 1″, 6″ long, and composed of 400 plates, was found to have an inductance of 40 milli-henrys. The coil was then wound up in 12 sections, the direction of each section being reversed, and the inductance in this case was found to be 8.5 milli-henrys. These sections are stamped from different thicknesses of metal, so that those coils which are in circuit the shortest time and have

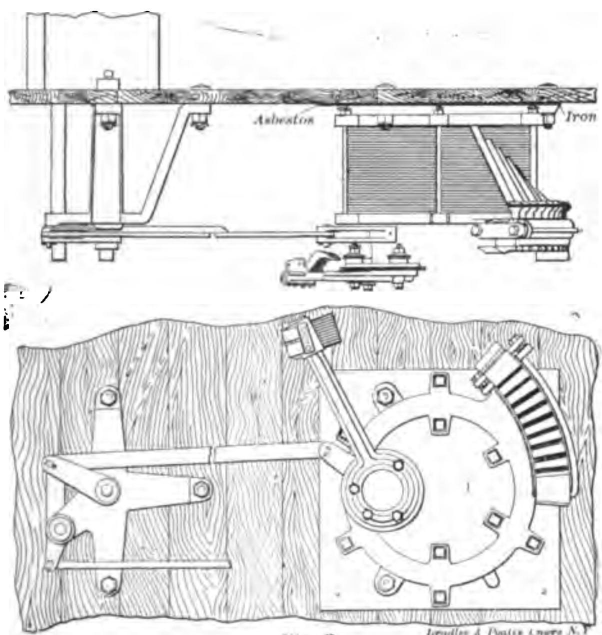
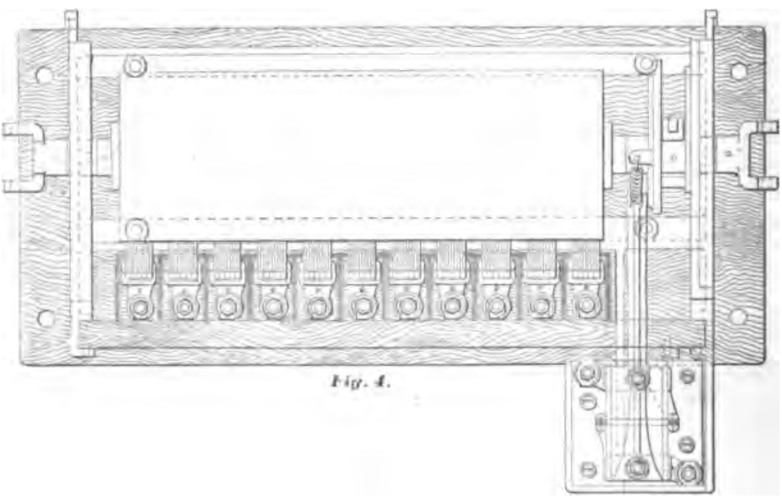


Fig. 3.
DETACHABLE RHEOSTAT FOR COMBINED RHEOSTAT AND PLATFORM SWITCH.

the least current to carry are of highest resistance and least ampere capacity, and those that are liable to be in circuit for some time are thicker and have less resistance and greater ampere capacity. Copper connections are made at different points in the coil, all these connections being brought to a number of small iron contact pieces fitted in a spiral form and arranged so that the switch contact lever can slide over them. The contact pieces are insulated from the frame with sheet mica and from one another with small slate slabs. The rheostat is entirely fireproof and can expel with safety the heat evolved within it under all ordinary conditions. As a point of practical importance it is, however, advisable to place a sheet of metal and a layer of asbestos paper between the rheostat frame and the car floor. This will prevent any danger from fire, either from heating or sparking, should such occur. It is to be noted that the general design of this rheostat is such that those parts having mechanical functions and energy dissipating functions have been separated as much as possible. Of course the mechanical functions of a rheostat are more or less limited; it is evident, however, this effort is in the right direction. It is with respect to this particular point that the rheostat has a decided advantage over any form



CYLINDER CAR SWITCH, GENERAL ARRANGEMENT

of mechanical clutch in starting a car. The clutch, of course, has its advantage in starting quickly bodies that have a great amount of inertia. In ordinary practice, however, the amount of energy dissipated in a clutch is approximately equal to that necessary to dissipate in a rheostat, but the clutch has in addition to its energy dissipating function, a very exact mechanical function, and these two functions are interdependent on the same wearing parts. For this reason, if no other, clutches have not yet been made to compete favorably with rheostats.

Figure 2 gives a diagram of the car connections for this switch. It will be seen that the current from the trolley wire first goes through the field coils and switch cylinder for commutation, then through the armature and reversing switch, and thence through the switch contact lever and resistance coil (in starting) to ground. It will be noticed that by use of the separate reversing switch the armature wires and field wires are each kept separate and distinct from one another. Formerly there was considerable trouble from the breaking of these wires, especially where the wire entered the brass terminals at the various terminal boards. This has been almost entirely obviated by using 49 strand cable wherever wire was subjected to bending.

In some cases the construction at the platform ends is such as to make it inconvenient to place the rheostat used with this form of switch immediately underneath the cylinder. This is the case when certain kinds of draw bar or step constructions are used. In these cases a modification of the switch arrangements is made that is shown in Fig. 3. Instead of the rheostat a light frame is placed directly under the cylinder. This frame serves to support the switch shaft, upon which is placed a crank connecting with a bar, which is carried off to the rheostat contact lever. With this arrangement the rheostat can be placed under any convenient part of the car flooring and operated as well as when directly under the platform.

Figures 4, 4A and 4B show general plans of a car switch designed to be placed under the car and about half way between the motors, when the car construction permits. This design, while open to the criticism that the switch is somewhat inaccessible for inspection, meets the demand that has sometimes been made when it has been thought the space ordinarily occupied by the platform switch could not be sacrificed. The principle is the same as the platform switch already described, but it is modified in form and shape to suit the particular condition under which it is to work, and it is to be noted that the mechanical adjustments required are much more exact, otherwise there would be considerable burning of the contacts, since the motorman would be unable to tell whether or not the switch contacts were on proper positions.

The rheostat is arranged in sections and connections brought from them directly to cylinder contacts. A cylinder is used to commutate both resistance and field magnet coils.

An important point that has been attended to in this switch is the breaking of the circuit on a separate switch instead of on the cylinder. A snap switch, of the knife blade pattern, is employed to break the circuit at four points. It operates in connection with the cylinder shaft, to which it is connected with a special locking and releasing gear of similar design to that shown in Figure 1. The first movement of the cylinder shaft closes the snap switch and completes the circuit through the coil. Further movement then disengages the snap switch from the shaft

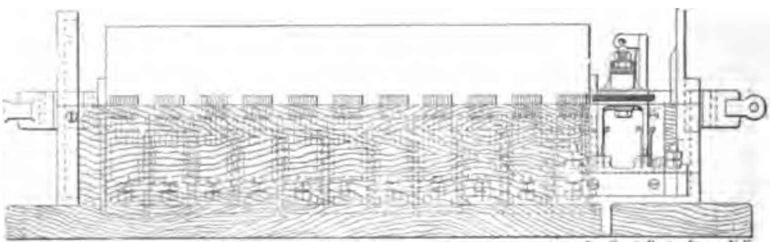


Fig. 4. A

(leaving it closed) and the different commutations are affected. joints makes connection between the platform lever and the When breaking the circuit the snap switch is again brought into action.

When this form of car controlling switch is used, the platform lever is fitted at its lower end with a bevel gear wheel meshing into another gear wheel placed on the cylinder shaft. When necessary an extension shaft fitted with one or more universal

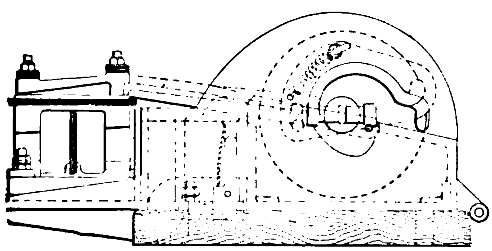


Fig. 4. B

cylinder shaft. When this switch is placed in the middle of the car, the amount of car wiring is materially lessened and the car inspection made more easy.

With reference to controlling switches in general, it is evident that a great number of designs may be prepared that will give approximately the same electrical results in point of efficiency. In deciding then upon the merits of a new design of switch, the commercial factor relating to repairs has therefore to be very largely considered, and had designers been able to guide their work more closely from the balance sheets of railroad companies, when such had been properly kept, instead of conforming to popular notions, very much more progress would have been made in this line during the last few years.

In closing this paper it might be well that I should remark that my experience has been largely confined to what is known as the commutated field method of control, and that I have naturally expressed many of the qualities of other methods in terms of this method. If these expressions are not judged satisfactory, I leave it for those who have had a similar experience with other systems to express in their criticisms the qualities of the commutated field system in their own terms.

Discussion.

The Chairman [Vice-President Lockwood]:—It is to be regretted that the author of the paper is not present this evening, as he might very likely have been able to add very largely to the interest which its perusal no doubt inspires. This paper, as you will have observed, is of the most intensely practical type, and I may say also rather paradoxically perhaps, that its brevity is something of an improvement in length on some of the best which have been before us—even those of the most classic and able character which we have had. From experience I can myself say that it is much easier to write a long paper than a short one, and it seems to me that Mr. Parshall is greatly to be commended for the terseness and shortness of his paper and especially in that he has left a reasonable time for a fair discussion of the points he has enumerated. When we recollect that it is hardly four years since our first paper on electric street railways was brought out, and hardly five since the first papers on the electrical transmission of power were placed before us, I consider it most remarkable that this paper is as practical, as definite, and as positive as it is. These, indeed, are its most prominent characteristics. We should note especially, I think, the exact tone of every statement made and the sharp transition in this respect between it and some of the earlier papers which we had upon the subject, which necessarily dwelt upon the phenomena concerned from a general point of view, and as necessarily contained generalizations, some of which experience has proved to be without foundation in fact. The paper of itself merits a full and free discussion, and although we are, as I have intimated, deprived of the opportunity to put questions to the author, yet I conceive that every point which is necessary and useful will be fully elicited.

While the paper itself and the diagrams accompanying it modestly style themselves, virtually a "Parshall" paper and "Parshall diagrams," we cannot fail to observe that both the paper and the diagrams are very complete. The subject is now open for the discussion of the Institute.

While it is possible that street railroads may not be a subject with which many of us are conversant, yet I may suggest that the fullest and freest discussion is always in order, and that it is not perhaps necessary for us to confine ourselves to street railroads—that the matter deals with motors and that we should be glad to hear from any one who can instruct us, or even entertain us, upon the subject.

Mr. Chas. Hewitt: — In order to start the discussion, I would call attention to the statement on the last part of the second page and top of the third page, not so much with the idea of disputing what is said as because it seems to me slightly misleading. It says: "With a given electromotive force acting on the armature circuit and a given torque developed by the armature per ampere, it does not matter,so far as efficiency is concerned, whether the difference in electromotive force at the armature terminals and the line is due to drop in external resistance, or to drop in the magnets." When I first read that, it certainly gave me the impression that Mr. Parshall was saying that there was no difference in efficiency whether we regulated our motors by commutated fields or whether we used an external resistance. But in reading it more closely, I notice that he does not say that exactly, but that seems to me to be a question which is certainly open to debate and a very interesting point to discuss. Is it possible to operate two cars, say in the same city or under the same conditions—I mean to get the same results from the car as far as the railway company is concerned—in one case by commutating the fields and in the other case by using a rheostat or any external resistance. My experience has been mostly with the commutated fields, but at the same time I have had the privilege of examining a good many cars using the external rheostat, and in every case, whether a double reduction motor or a single reduction motor or a gearless motor is used it takes more watts to accomplish the same result with a car using an external resistance than with a car which uses simply the commutated fields. Whether that is inherent in the method, I am not prepared to say, but I merely state that as a fact, and I would like to throw that out as a matter for discussion—as to whether in the opinion of the members here it is possible to build motors —no matter what the ratio of reduction is—that they may be operated with a rheostat with the same efficiency as with the commutated fields. Mechanically there is much to be said in favor of the rheostat, but electrically there is much to be said against it, so far as we have seen.

Another point that I would also like to draw out in discussion is the apparent loss of efficiency in the departure from the old double reduction motors. Every departure which has been made from the high efficiency double reduction motors—for instance, from the No. 6 motor which Mr. Parshall refers to—if we start with that, every type of motor which has been made since then has been a step backward, so far as efficiency is concerned, until we get to the gearless motor, which I believe takes the most energy of all to accomplish the same result. The single reduction motor comes in between, and the high speed motors are the most efficient of all. Now is this lack of efficiency inherent in the motors or not? Will it be possible in the future to build single reduction or gearless motors which will be as efficient as the double reduction motors? I think these two points might make an interesting discussion.

MR. TOWNSEND WOLCOTT :—In regard to Mr. Parshall's statement here, it seems to me very plain that he means simply you can design a motor so that the resistance will be in the coils themselves. A certain number of volts has got to be wasted, whether inside the magnet or outside. It is possible to design a motor so that you would not use any outside resistance at all, but it does not follow that it will be any more efficient. There are plenty of stationary motors on the market running on incandescent circuits—small sizes—that have such high armature resistance that you can turn on the current without any rheostat whatever. But the efficiency of motors of course is low when it gets up to its normal speed. It is not possible to run a motor from the constant potential circuit and put the current with full voltage right on to the armature when the armature is standing still. Of course you get burn-outs, unless the resistance is enormously high. But even if the armature was made with such resistance that is would start without burning out, the efficiency would be the same, as though that was an external resistance while it was running at that speed, which would require such resistance in the rheostat.

In regard to the efficiency of double, single reduction and gearless motors, as I understand it, the efficiency measured at the car wheel does not show the discrepancy the gentleman spoke of. Of course the power delivering at the end of the motor shaft would be greater and the efficiency would be greater on a high speed motor, but when we consider all the gear friction, as far as I have been able to ascertain, the efficiency is not so greatly different. In fact the gearless motor people claim that they run with the highest efficiency in some cases, which they do not claim for all work, but under certain conditions they claim to run with as good an efficiency as with double reduction motors.

MR. CHAS. P. STEINMETZ : — If we wish to speak about the efficiency of motors, we should decide first what we mean by this term, for although electrical engineering has very exact methods of determination, there are so many meanings for efficiency that the term usually means nothing. The one measures the resistance of the motor, and finds say one ohm. With 15 amperes current this means a loss of 15 volts, or three per cent. at 500 volts line potential. Then he begins to say what a beautiful motor he has of 97 per cent. efficiency. But he does not take into account that he loses perhaps 20 per cent. by hysteresis and Foucault current, loses 10 per cent. by friction in the bearings, and wastes 30 per cent. besides by grinding the gears to dust, and gets then only a mere nothing to the wheel axle. Another one desires to proceed more correctly, and measures the "mechanical efficiency" of the motor. That is, he applies a brake to the armature shaft, measures the electric power sent into the motor, and the mechanical power taken off from the motor shaft, and finds 87 per cent. "a very good motor." Whether in practical service under the strain of the gear thrust, the friction is the same, and how much he loses in the high speed gearing; nobody knows.

I have no exact data of the losses in the high speed gears of the street car motors used here; I remember only one data on an English system of geared street car motors, very carefully cut zig-zag gears, which certainly do not waste much more power than the usual spur gears; there the loss amounted to about 40 per cent. In the data given on the efficiency of street car motors this loss is generally *not* included. And especially street car gears must be very wasteful, not only because of the rough usage they are exposed to when going through rain and dirt or over dusty roads, but from the fact, that the transmission of power by gearing is at its best only when the height of the gear teeth is negligibly small compared with the radius of the gear. But in this high speed gearing the pinion must necessarily be small, and then the height of the teeth is very perceptible compared with the radius of the pinion.

In this case the gearing does not transmit with a fixed, but with a varying ratio; the teeth touch each other first with their heads, slide over each other and come out of impact when touching each other with their feet. That means, that the ratio of transmission for each tooth which passes another, varies between the ratio of the maximum, and the ratio of minimum radii of impact.

Suppose the pinion has 16 teeth, the motor revolves with 1,200 revolutions. Then 19,200 times per minute the leverage of the transmission goes up and down. Either the speed must vary, fluctuate as often—which is out of the question because of the momentum—or as many times per minute the gears come out of impact and in again, alternately the one or the other leading. Every time they come in impact again—19,200 times per minute—it gives a blow against the teeth. This is what causes the rattling and hissing noise of high speed gearings, and their rapid destruction.

That the loss of energy in the gearing is considerable, we can see without any tests, if we consider in what very quick time steel and phosphor-bronze pinions are ground to dust and raw-hide gears torn to fibres. For the law of conservation of energy teaches us that where a display of energy takes place, a corresponding consumption of energy exists, and if such a tremendous energy is set free as to grind steel and bronze to dust, and to chop raw-hide pinions rapidly to fibres, the consumption of energy must be correspondingly large, and the only source of energy is the motor. With regard to gearless motors, I have seen a number of test curves of such a motor, which showed an efficiency of 80 per cent., and considering the absence of the loss of energy in the gearing, I really cannot see, how the double geared motor can possibly be more efficient.

MR. THORBURN REID:—The practical street car man has an exceedingly simple method of getting the efficiency of the street car motor. He does not bother his head very much about the resistance of either the armature or the field. He does not know how much friction there is in the gear, but he runs his car and he sees how much current it takes to drive and how many volts E. M. F. there are on the terminals. He multiplies the two together and gets the number of watts to drive his car on the road. He gets another car and tries that and sees that the one that takes the smallest number of watts has the best efficiency. That is all that is necessary for his purpose, and I think that for our purposes that is all that is necessary. If a motor draws a car with the least amount of energy, that is the best motor we can get for the work. Mr. Hewitt told us that the double reduction motor appeared to be the most efficient, the single reduction the next, and the gearless motor the least efficient. I suppose that he means by that just what the practical street car man would mean—that it takes the most current to drive a gearless motor, less for a single reduction and less for a double reduction. If I remember Mr. Short's paper, read, I have forgotten where now, he gave three curves, as I remember it, for efficiency of street car motors in which he put the gearless motor as using the smallest amount of energy of the three, the single reduction motor next and the double reduction motor as using the most. That is my recollection of it and I won't be certain that I am right. I would like to know really which motor is the most efficient of the three as a practical street car man looks at it.

THE CHAIRMAN:—In justice to Mr. Parshall, I perhaps should show this plate and read a note which he has sent about it which has only recently been received. I do not know whether you can see it, but at all events it will be printed in the proceedings:

"The three curves in Figure 5, are for single reduction motors with commutated fields. No. 1 is for a 25 H. P., No. 2 for a 15 H. P., and No. 3 for a 20 H. P. motor. The pull at the car wheel for the more important points is given, since without this such curves of efficiency and horse power of street car motors are of but very little value. It may be well to state that it has been found possible to increase the limits of the high efficiency part of the curve by modifying the construction of the armature core so as to diminish the losses by hysteresis and Foucault currents."

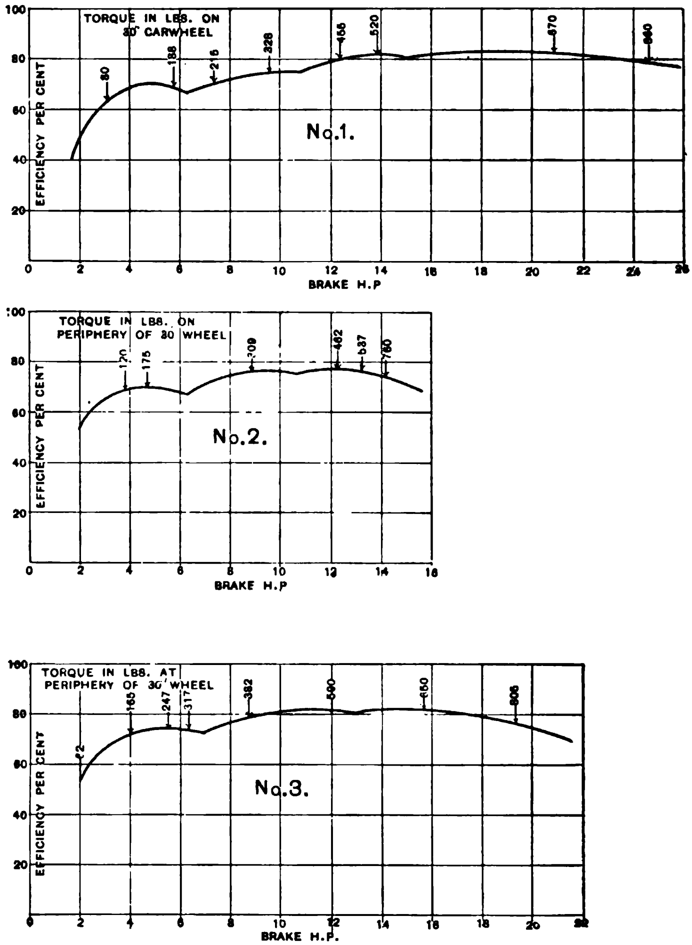


Fig. 5.

Mr. Hewitt:—I think the paper Mr. Reid referred to was read by Mr. Short before the Chicago Electric Club and the portion of the paper that misled Mr. Reid and perhaps others is the fact that Mr. Short started with his double reduction motor, whose maximum efficiency is no higher than the maximum efficiency of his gearless, viz.: 70 per cent. He first tested the motor without gears. He then put on a single reduction of gears and tested again. Of course he got a lower efficiency.

Then he put on another reduction and tested again and of course he got a lower efficiency still. Now we all know that every reduction in gears gives a loss in power. The misleading portion is that he uses a motor of very low maximum efficiency. A well designed double reduction motor with commutated fields starts off with an average efficiency of 85 per cent. and a maximum efficiency of 88 per cent. to 90 per cent. Allowing 15 per cent. loss in gears as shown by Mr. Short we get an *average* efficiency at the car axle of 70 per cent, which is as high as the *maximum* efficiency of Mr. Short's gearless motor. We can discuss here theoretical efficiencies of motors, but so far as the street railway is concerned, the commercial efficiency is the only one to be considered. Any road which is worthy of the name of an electric road has definite routes and puts cars on those routes to run on schedule time. It will not let its motormen race or run ahead of time or behind time. So that no matter what system a car belongs to, it has given to it a certain service and it is the car which does that service with the least expenditure of energy (repairs being equal) which is the most efficient to the railroad company. Crosby and Bell in their recent book show that the coal consumption is comparatively a small part of the operating expenses of a road, but there is another point which is not stated, I believe, in connection with this extra energy required to drive the single reduction and the gearless motor, and that is the vastly larger power plant required to be operated. I know very well that with the No. 6 motor on an average road we could easily run twelve cars with a 100 kilo-watt dynamo, whereas with single reduction motors we can run only 8 and with some motors only 5 or 6 cars Now it makes a great difference whether you have got to install two 100 kilo-dynamos to do a certain duty or one. It is not only the actual cost of the coal pile and the actual cost of attendance but it is the increased cost of the plant. Power plants have got to be built of almost double the size now, that they were two years ago with the No. 6 motor. That, I think is a serious item and one which designers of apparatus ought to consider and one which I think the railway companies will consider seriously before very long A prominent engineer of a railroad syndicate told me, after testing thirty-five roads, that they actually could not afford to build the stations to provide current for the motors now made.

Mr. Wolcott:—In regard to the power consumed by gear, Mr. Hewitt correctly stated Mr. Short's method But, as I remember, the Franklin Institute made some tests some years ago with refereence to the efficiency of gearing The best possible spur gear gave 90 per cent —this is a laboratory test. With two reductions, that is 81 per cent. Now if the motor has 85 per cent. efficiency as Mr. Hewitt mentions, that gives us 68.85 per cent.—call it 69 per cent. efficiency, and the gearless motor started with about the same—about 70 per cent.

Mr. Hewitt:—That was the highest efficiency, not the average. The double reduction motor will average about 85 per cent.

Mr. Wolcott:—Now the chief difficulty with the gearless motor, to my mind, is a mechanical one. I have not seen any gearless motor that suits me all around for mechanical reasons. The Short motor drives cars with a sort of a lathe dog arrangement. It always seemed to me that there would be considerable loss on that. Some of the motors drive with side-rods like a locomotive. Of course one difficulty in putting an armature right on the shaft is the trouble of getting it out in case anything is the matter with it. With side-rods you have got to have a truck much more rigid. One of the greatest improvements of street cars of late years is what is called flexible gearing. Four wheels are always resting on the track. If you connect up with side-rods, it is all right on the straight track; but when you come to curves I think you will find there is a great deal of the power wasted in that way. It does not seem to me so much an electrical problem as a mechanical problem.

Mr. Hewitt:—I beg to differ from the gentleman on that very last statement. If you will notice the curve published by Mr. Short, you will see that it falls off very gradually, so that the average efficiency in the gearless motor is very low—somewhere about 45 per cent. We can get with the double reduction an efficiency of 60 to 70 per cent. for the whole car equipment. With the gearless we go down to 45 or 50 per cent.

Mr. Steinmetz:—I have not read Mr. Short's paper, but I am of the feeling that the gearless motor which gives an average efficiency of 35 per cent as stated must be a very poor motor. I know that the average efficiency of a well-designed gearless motor can be brought to as high as 75 per cent. Tests made by an independent railroad company on such a gearless motor showed that the highest efficiency reached is a little over 80 per cent., and compared with other single reduction motors what struck me as most remarkable was that the efficiency curve was just very flat and over a wide range beyond 70 per cent.[1] But I think that this falling off of the efficiency curve in the geared motor is due more to some defect in the design of the motor and is not essential in the principle of double reduction or single reduction or gearless motor. But 35 per cent. efficiency—that is a very poor motor, no question about that, and entirely drops out of consideration. Then there was another point. What was the objection against the transmission of the power by connecting rods?

Mr. Wolcott:—Requiring the truck to be less flexible. In the modern street car gear the two axles can move.

Mr. Steinmetz:—Yes, but in the gearless motor with connecting rods they can move just as well, or even more freely.

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1. See correspondence, p. 166, for diagram showing these curves.

MR WOLCOTT:—The best street car gears have several improvements. They will move to and from each other. That certainly cannot take place with side-bars and they can be twisted.

MR. STEINMETZ: —Locomotives have been built in that manner so that there is no mechanical hindrance to be provided for, and it has not been found necessary in practice.

MR. WOLCOTT: —It seems to me that even that would interfere somewhat with the flexibility of the arrangement. You certainly would require the dissipation of some energy there.

MR. STEINMETZ: —I cannot see that. Suppose the motor to be rigidly connected with the car body, but resting together with the car body on springs. Then the motor shaft can go up and down and oscillate freely with the car body, while the wheel axles can twist and come out of parallelism with each other and with the motor shaft just as they like, or rather as the condition of track and car causes it, without interfering with the action of the connecting rods, hence without dissipation of energy, all three axles moving in parallel vertical planes.

MR. WOLCOTT: —If the motor shaft and the car axle are in parallel plane how can they move out of parallel?

MR. STEINMETZ:—Motor shaft and car axle can take any inclined position against each other, and nevertheless remain in parallel vertical planes, moving up and down and twisting with regard to each other. The fact is, there is no dissipation of energy, because there is no wearing out, for after a year's continuous and daily running I found a pair of such connecting rods not worn at all. Besides, it is exactly the same method of transmitting the power, to which steam railroading has been led by 70 years practical experience.

MR. HEWITT:—I would like to ask Mr. Steinmetz if the test he refers to was made on a car in actual service and whether that car was operated by a rheostat. I feel confident in saying that if we can furnish gearless motors that will operate with an *average* efficiency of 75 per cent. in actual practice, there never will be another geared motor sold. I think there is another point in Mr. Parshall's paper here which gives an inkling of the cause of this low efficiency. At the top of the second page he says: "The average H. P. exerted by a street car motor at the car wheel probably does not exceed 20 per cent. of the maximum it is expected to do in starting the car under the various conditions encountered." I am prepared to say that that is rather overstating than understating the fact If we examine the dynamo curve, a good dynamo will give a high efficiency from half load to full load, but when it gets below half load it drops very suddenly. The trouble in street car work is to get a high efficiency under average conditions.

MR. STEINMETZ:—The tests were made by the West End Street Railway company in Boston and the motor was working with a commutated field—not with a rheostat—the gearless motor that I referred to.

Mr. Chas. G. Curtis:—I am rather surprised to hear those who have evidently had a good deal of experience with railway motors express themselves so strongly against gearless motors. There seems to be an idea that it is impossible even by the use of enough copper and iron, without reference to the weight of the machine, to accomplish the same result at a slow speed that is accomplished at a high speed. Now why should not a gearless motor, which revolves at one-tenth of the speed of the old style double reduction machine, be made to give the same power as the double reduction machine, provided enough copper and iron is put into it, provided the cross-section of the iron is increased and provided the number of turns of the armature is sufficiently increased? Now I know of a gearless motor which was operated for several months, and tested by some experts who were not interested in any way and who found by comparison that it took 16 amperes to make 18 miles an hour, while one of the regular Thomson-Houston cars required 28 amperes to make 17 miles an hour. The Thomson-Houston car was one that had been in use about six weeks without any renewal of the gear and therefore the gears were probably more than half worn out. Then the test was made with another car where the gears had been used about two weeks and it was found that the car required about 25 amperes. Some Stevens Institute young men made some tests on the same road—a long series of tests—and they found that the cars required about 26 amperes on an average, while this car that I speak of that was operated by a gearless motor ran along invariably with as low as 16 or 17 amperes and the average of a long series of tests made it 16 amperes as against 28; which is a saving of about 40 per cent I do not see any reason why it should not be so, and when the characteristics of the machine are known, it is perfectly evident that it must be so. It is simply a question of having enough iron and enough turns on the armature. Now the increased turns on the armature would result in an increased resistance were it not for the fact that a larger wire is used. The same is true of the field. But it must be remembered that with the old double reduction machine the field required a good many ampere turns to bring it up to saturation, and in the new machines such as those made by the Thomson-Houston company to-day the ampere turns are less. The resistance of this machine was about $2\frac{1}{10}$ ohms and my impression is that the resistance of the Thomson-Houston double reduction machine is about two ohms. I know that the armature is half an ohm. I think there are about 40 lbs. of No. 12 wire on each of the field spools and that I figure is about two ohms. The weight of this machine was 2.400 pounds, and the armature had no objectionable heating at 22 H. P. We never ran it 22 H. P. running a car alone, but we dragged trailers with it and tried it up grades and it would stand 22 H. P. easily enough. Probably 300 or 400 pounds could be knocked off that weight by a judicious re-arrangement of the metal. As I say the diminution in efficiency is purely a question of increasing resistance. All the other factors must be better in the gearless motor than in the geared motor. Hysteresis and Foucault currents, which are the only other losses that amount to anything are reduced by the diminution of the speed and in direction proportion to the reduced speed, except for the fact that the number of poles is increased. In regard to the difficulty of communicating the rotation of the armature to the wheels which Mr. Wolcott speaks of, we did not notice any difficulty of that kind at all. On the other hand we rather smiled at the perfection with which the mechanical part of it worked. The power was transmitted by a face plate carrying flat pins and those pins stood between rubber cushions and the torque of the motor operated to compress one set of cushions, or the other set, according to which way it was going. Of course when the two pins were in a vertical position, if you should pass over a rut in the track the motor would descend and the face plate with its pins of course would slide down between the cushions—probably never exceeding half an inch. The cushions had cast-iron caps which protected their ends and after their motor had been in use several weeks there appeared some wear on those caps. Of course any question as to loss of efficiency was disposed of by the speed and by the amperes and volts. As Prof. Short was saying in his last paper, the efficiency of gearing seems to increase enormously with the speed. That is shown in the peculiar phenomenon which takes place in the Thomson-Houston double geared cars. They operate their cars on what they call a loop. In order to get the maximum speed they throw out some of the field winding. Now when they do that, it is done with one throw, that is to say there is only one section of the field that is thrown out. The power comes on suddenly and the car jumps ahead, but there seems to be very little difference in the speed whether there are trailers on or not. In other words the gearing seems to be the limited element. Beyond a certain limit the gearing consumes an enormous amount of power. Below that speed it consumes about 30 per cent. My experience is that those gears, with the usual amount of dirt will consume 30 to 40 per cent. at a speed not over 15 miles an hour. I have seen two 15 H. P. Thomson-Houston motors with passengers hanging on to the steps and making within two miles an hour of the same speed that it would make with no trailing cars on and no passengers in. I should think there was a difference of two miles an hour out of 17. My experience is that the main difficulty with the whole problem is to get a mode of running at a slow speed or a half speed which is reasonably efficient and at the same time be enabled to run at full speed. The only method which has been devised which is at all practical is that pursued by the Thomson-Houston company which I have referred to which consists in cutting out some of the field winding and diminishing the strength of the field. But that is open to the objection that you cannot carry it beyond a certain point, because you get self-induction in the armature. I should like to ask some gentleman here whether the new Thomson-Houston waterproof motor, as it is called which has a slotted armature, is operated in that way with a divided field coil or "loop," as they call it. If it is, I should think that the comparative strength of the loop must be very little because otherwise they would have sparking at the commutator.

MR. HEWITT:—The last gentleman seemed to infer that I was arguing against the gearless motor *per se*, which is not the case. I merely tried to bring out facts as they actually exist on roads as they are running. I spoke of the gearless motor as shown in Mr. Short's paper because it is to be inferred that he has choson a fair example to illustrate that paper, and he shows an average consumption of 24.5 amperes including zero readings. It is very misleading for us to compare the consumption of amperes alone, because of the variation in electromotive force. The last gentleman said he tested one motor with something like 16 amperes, another one 25 amperes; but the difference in electromotive force may be very great. With 16 amperes you may have 500 volts; with the 28 amperes you may have 320 volts. The watts are the same in each case. The only safe comparison we can make is the actual watts which the car consumes in doing its work. Mr. Short's paper shows that the motor he refers to gives an average consumption of 13.8 electrical horse power. That is an actual test and I know of no other gearless motors in actual street railroad practice that have done any better. I do not think anybody is prepared to say that the Westinghouse motors have exceeded that in economy. In fact, at Pittsburg I am told that they have shown a much larger consumption of power. I do not know what motor the gentlemen are referring to; therefore I cannot speak intelligently about the test he refers to, but certainly no published tests show the efficiency he speaks of. If he has a motor that will show that efficiency in actual operation it is as good as any single reduction motor on the market. But even at that figure, it cannot compare with the efficiency of the double reduction motor.

MR. C. G. CURTIS:—I only meant to speak of this motor as a matter of general interest, not as a result that has been accomplished, which is remarkable, or anything of that kind. When I spoke of the amperes required, a comparison of 16 to 28, I of course took into consideration the volts. I mean that there was not enough difference in the volts to affect that One was 480 and the other 465 or nearly 470, so that it made a difference of about 2½ per cent., whereas the total difference in the amperes was 43 per cent., I think, so that the net result was about 40 per cent. gain.

As regards Prof. Short's gearless motor I was not speaking of it in comparison with that, nor do I see why the question should be judged scientifically by a consideration of any particular motor. From the theoretical point of view there is no reason why the gearless motor should not be just as efficient as any other kind of motor provided you can get on enough copper to make the resistance as low. Now if Prof. Short's motor is as inefficient as he says, it may be due to bad construction of the armature which results in very high Foucault currents. But it is more likely due to too high resistance. He has got a large amount of wire on the field and a large amount of wire on the armature and those two things combined make a considerable loss. But even then I do not see why he should get such a loss as he states. It takes an immense resistance there to make a very much greater resistance than they have in the old style machines. It must be borne in mind that in this new machine the field which consumes more energy than the armature due to its resistance is very much reduced. The field in the new Thomson-Houston machine is operated with one coil. This coil has a cross-section which is about square, and the machine weighs 2,300 pounds. I saw one the other day in operation in Pittsburg. The superintendent told me he had it operating a snow-plow with over 100 amperes on the two motors steadily and there was no injurious heating, and he was under the impression that he had had it operating as high as 130 amperes for over an hour. That of course is an enormous current for the 25 H. P. machines. But as I say, by adopting the slotted form of armature which reduces the resistance of the magnetic circuit, they have succeeded in reducing the amount of ampere turns on the field, so that they can get along with much less resistance. If there is any other cause of efficiency in a motor, I should like to hear it mentioned. Certainly the loss from friction on the bearing is not worth speaking of. A gearless motor has an advantage in that respect over any other form of motor for the simple reason that the torque is transmitted to the wheels symmetrically with respect to the axle. There is no thrust tending to throw the armature shaft out of its position Whereas in the ordinary geared motor there is a tremendous thrust. But even with that thrust the friction is so little with the oil bearing that it is hardly worth speaking of.

Another point, where you have a hollow shaft which necessitates a shaft probably from 5 to 6 inches in diameter, it makes a very large bearing and the distance that the bearing surface travels is very great compared with the ordinary bearing. But when you come to compare it you find the ratio is about two to one in diameter. Now your speed has come down to one-tenth, so you are five times as well off as you were before. It is only a question of keeping the bearing oiled. That can no doubt be accomplished by using a saddle bearing brass such as that in an ordinary car-box. I do not suppose the loss due to friction on the bearings is 1 per cent. There is no reason why that the resistance should not be reduced to a sufficiently low point. It is simply a question of copper. In this machine No. 10 wire was used instead of No. 12. No. 10 is pretty nearly twice the cross-section of No. 12, and the turns were about 2½ times as many. The consequence was that the resistance of this armature was about 1½ times that of the old Thomson-Houston machine. But the Thomson-Houston is very low indeed; it is one-half an ohm, and that is one reason why the Thomson-Houston machine has been so successful. It has got a margin there. I have seen two of those 15 H. P. Thomson-Houston machines drag 3 trail cars and do it hour in and hour out in summer with the thermometer up to 90, at a speed of 16 miles an hour, and that is half again as good as any other kind of motor I have seen working on a car.

MR. CHARLES P. STEINMETZ:—I cannot see that the resistance of a gearless motor must be any larger than that of a high speed motor. For a slight increase in the size of the armature wire easily brings the armature resistance down. For instance the gearless motor I referred to, had an armature resistance of ¾ ohm, using wire No. 9 B & S gauge. The field was commutated, and, when in parallel, had a little less than ½ ohm resistance, giving a total motor resistance of somewhat less than 1¼ ohms. The Foucault currents in the armature amounted to some 20 watts. Hysteresis was considerably larger because of the high magnetization used, and reached a maximum of 124 watts. The loss by the resistance of the motor depends upon the current and can easily be calculated by the figures given above.

The system I referred to was the Eickemeyer-Field system, as used in Toledo, Lynchburg, Yonkers, etc.

In Toledo they had these gearless motors, and double reduction motors running at the same time, on the Consolidated Electric Railway Company, and there the station superintendent found that if he ran only gearless motors he consumed less coal under the boiler of the steam engine than when he ran double reduction motors.

THE CHAIRMAN:—Were not the motors that you referred to that were tried at Toledo, those in which it is said that the inside helix excites the armature direct instead of being excited by the field magnet polarity?

MR STEINMETZ:—Yes, sir. The magnetizing helix directly and closely surrounds the armature and consequently there is not only no magnetic leakage, but the length of the magnetic circuit the least possible. In consequence thereof with a given weight of material, the cross-section of the magnetic circuit and therefore the magnetization can be as much higher. For instance the motor I referred to, with the field fully excited, drives 24 million lines of magnetic force through the armature. Besides, if the field coil surrounds the armature, the height of the whole motor is very little more than the diameter of the armature.

This has the advantage again, that the lowest part of the motor is still 4½ inches above the ground, and nevertheless only 26 inch car wheels—the ordinary horse car wheel size—is used.

Mr. C. G. Curtis :—What speed do you run at?

Mr. Steinmetz :—Well, the lowest speed is about six to seven miles; that is with commutated fields.

Mr. Curtis :—What speed was this loss of a hundred and some odd watts?

Mr. Steinmetz :—I did not measure it for a certain speed, but I followed it over the whole range of speeds; this loss by Foucault currents and by hysteresis depends upon the speed, decreasing for slow speed because of the smaller number of reversals, and decreasing for high speed also, because of the decreasing magnetization. The figures I gave correspond to that speed, where the loss is maximum. Indeed, it can never be 24+124=148 watts, because the maximum of Foucault current does not take place at the same speed as that of the hysteresis loss, the one varying directly proportional to speed and to the 1.6th power of the magnetization, the other following the square law.

Mr. Hewitt :—What Mr. Steinmetz said and what the Chairman said about the magnetization of the armature on the Eickemeyer motor is true also in large measure of the Edison motor and the Thomson-Houston motor. The field coils overlap the armature and form the pole piece, but still they are not as efficient as the double reduction motors. I do not pretend to deny that the gearless motor can be made as efficient as any other motor, provided we have unlimited space and can put unlimited iron and unlimited copper in it. On a street car we have got a limited space and we have to conform to that space and that is the reason why perhaps more iron and more copper are not used. Another thing if we use more iron and more copper we would have a more expensive machine. That is another very serious point Mr. Short's motor I believe runs about three inches from the ground, two or three inches; I am speaking from memory and am not positive. But we certainly should not run a motor nearer than three inches to the ground because we are liable to strike something—a loose paving stone or piece of iron. Three inches is complained of by railway companies. And when we start with 30 inch wheels or even 36 inch wheels we have very little space, but when we come to locomotives for high speed, 100 or 120 miles an hour and can use 40 inch wheels and larger, we have all the space needed. It seems to me that so far as street railways are concerned we have reached our limit with the single reduction motor and with them I would like to see a better efficiency than we are now getting.

Prof. F. B. Crocker :—This question of the relative efficiency of single and double reduction gear motors is really a question of the relative efficiency of motors at different speeds, and is an old problem. Take a given motor; of course the lower the speed the less the losses are. I have made a list of them—Foucault currents, hysteresis, friction and air resistance are all reduced at lower speeds. The only losses that are increased are the $C^2 R$ effects; that is the heat due to the electrical resistance. There seems to be a great confusion as to whether we can run a motor at slow speed and get a reasonable efficiency. Now as I say the only losses that are increased at low speeds, other things being equal, are the resistance losses and as Mr. Curtis says it does not require any great increase in the size of the wire to make up for this. For instance, No. 12 wire increased to No. 10. A machine wound with a No. 10 wire does not occupy much more space than one wound with No. 12 and that yet makes enough difference to materially reduce the resistance, and in the case Mr. Curtis spoke of it almost made up for the increased length of wire. The facts that the Foucault currents and hysteresis are materially reduced at low speed is quite a saving. Another point Mr. Curtis spoke of—the reduction in the thrust on the bearings in gearless motors—is also quite important. Unfortunately, as Mr. Hewitt says, we have to have some means of allowing the car to go at slow speed. We are supplied with 500 volts whether we are running at fast or slow speed. Therefore we have to introduce external resistance or resort to some peculiar method of overcoming this difficulty. But the single reduction gear or double reduction gear motors when standing still or running at low speed, require practically the same resistance in series as gearless motors. It would be simply a question whether the rheostat had 20 ohms or 22 ohms. In other words the rheostat would actually require a little more resistance in the case of high speed motors on account of these motors having a little less resistance than low speed ones. Any motor running at less than its *normal* speed whether that be high or low requires regulation which probably reduces its efficiency. But a motor can be designed to run at 200 revolutions almost as well as at a thousand. I agree with the remark of Mr. Steinmetz that the man who cannot design a motor of better than 35 per cent. efficiency had better not try to apply it to street car work. Any one can design a motor to run with better efficiency than that—at any reasonable speed.

THE CHAIRMAN:—We have a very good illustration of the solution of the question: What will happen when an irresistible force meets an immovable body? I have not any doubt that the irresistible force would keep on backing and obtaining new and fresh headway and that the immovable body would remain immovable. I think therefore that as the evening is far advanced we should let Professor Crocker's remarks stand as the last word of science this evening, and unless there is a strongly evidenced desire for a debate a motion to adjourn will be in order.

[Adjourned.]

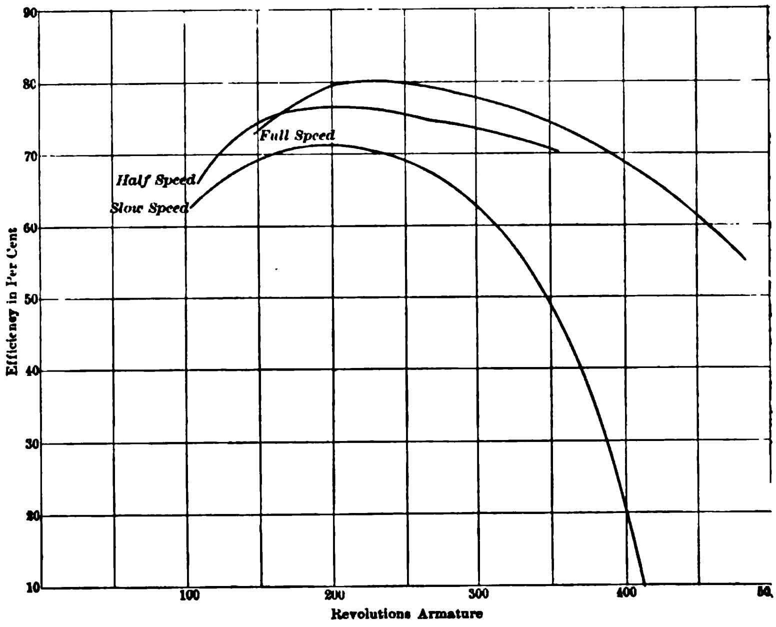
PROF. DUGALD C. JACKSON:—[Communicated.] The able paper by Mr. Parshall on controlling street car motors is sufficient in itself to demand attention. Moreover, the whole subject of electric railway motors has been given too little careful attention, except by a small number of manufacturers and street railway managers. It is therefore to be hoped Mr. Parshall's lead will be followed by others equally competent. There is much in Mr. Parshall's paper that has been felt by careful designers and users of street car motors but that has not before been reduced to words, and Mr. Parshall deserves the thanks of all interested for laying views resulting from his wide experience before the Institute.

One side of the subject that is an eminently practical one to the street railway manager has not been touched by Mr. Parshall. As it often determines the receipts of the electric car, its demands upon methods of motor control are worthy of full discussion. In the smaller cities and towns and in suburban places it is possible to run street railway cars at a high rate of speed and with a considerable interval between them. These cars can be placed on wheels of large diameter (33 in. and 36 in.) without detriment to the traffic. The motors can, therefore, occupy considerable vertical space, armatures of large diameter can be used, and the magnets can have four poles. The development of this type of machine has apparently led to the controlling device described by Mr. Parshall. Such motors admit of placing a large number of turns of wire on the armature and of using each turn to its greatest advantage.

In some of our large cities quite different conditions exist. Speed is limited to a maximum not exceeding 10 to 15 miles per hour, and much of the traffic is carried for short distances; in other words, it is shopping or pleasure traffic. This demands cars on close headway and *easy of access*. The floors must not be raised far above the street level, and the motors must therefore take up little vertical space, hence requiring armatures of small diameter. This limits the number of turns of wire on the armature, makes the utility of four pole magnets doubtful, and requires the field turns to be increased. To do their work properly, such motors when mounted on 26 in. wheels should give satisfaction equal to that given by 15 H. P. or 20 H. P. motors of the latest types placed on 33 in. wheels. I think nearly all who have studied the matter will agree that the conditions here defined must be met in New York City and Chicago before the electric car can compete with the grip car. In many of the smaller cities now operating electric cars the same conditions are felt with greater or less force, and meeting the requirements means considerably increased traffic (receipts per car).

It is questionable whether it is not best to permanently connect the motor armatures in series with each other and with their fields for such work. The starting and speed regulation can be very satisfactorily effected by a rheostat, while it is possible to put the fields of the two motors in parallel for fastest speeds. Practically this method of connecting has been used with excellent success. It retains the principal advantages maintained for two motors on each car, *i. e.*, added traction and decreased chances of trouble due to lack of harmony between the motors, and introduces no unnecessary complications.

While the magnetic and parasitic armature losses should be reduced with special care in street railway motors, at the same time the electrical resistances of armatures and field should with equal care be made the least that is consistent with meeting other requirements. Reducing the energy used in the rheostat by increasing the losses in the fields is not likely to meet universal favor, as it merely transfers the seat of trouble to a point



more expensive to repair. Hence *rheostat* regulation, with or without auxiliary commutation of fields seems likely to prevail with the majority. With proper design, such as Mr. Parshall would give us, the auxiliary commutation of the fields may serve an excellent purpose in economizing weight of copper.

Mr. Chas. P Steinmetz [Communicated]:—To prove the statement I made in the discussion, with regard to the efficiency of the Eickemeyer-Field gearless street car motor, I give herewith a reproduction of the efficiency curves found in the tests made by the West End Street Railway Company in Boston.

In this 20-H. P motor, the car wheels are 24 inches in diameter, and the distance from lowest part of the motor to the ground is 4 inches. The motor is one of the first of its class ever built.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

ANNUAL MEETING.

The Annual Meeting of the American Institute of Electrical Engineers, was held at 12 West 31st street, New York City, May 17th, 1892. The meeting was called to order at 4 P. M. by Vice-President Lockwood. The following annual reports of the Institute were read:

REPORT OF COUNCIL FOR THE YEAR ENDING APRIL 30TH, 1892.

Your Council takes pleasure in submitting for your information, in accordance with the Rules of the Institute, the following report, showing the growth in membership, receipts and disbursements and a brief review of the work of the year ending April 30th. It has been the practice heretofore to bring this report down to the date of the annual meeting, but it is more convenient to end the fiscal year with the calendar month, which gives more time to prepare the reports for presentation, and if there appears to be no objection to this practice, the yearly accounts will be closed hereafter on April 30th.

Ten regular meetings and one special meeting of the Council have been held during the year, at which the average attendance has been 11. The largest number present having been 13 and the smallest 7.

The general meeting of the Institute was held in New York City, May 20th and 21st, and occupied two days. Eight other meetings have been held. At these various meetings, 24 papers and reports were read and discussed, and have since been printed and distributed to the members.

The Institute was invited to unite with other engineering societies in the establishment of Engineering Headquarters at Chicago during the Columbian Exposition As the plans of the Exposition developed, however, it appeared that the proposed Electrical Congress would require the undivided support of all electrical organizations, and for this reason your Council deemed it wise to decline entering into the proposed arrangement. It was subsequently decided that the Institute should support the action of the World's Congress Auxiliary in making preparations for the World's Electrical Congress in order to do its share in making the Congress a success.

In accordance with the instructions of a meeting of the Institute, the following delegates were appointed by Council to represent the Institute at the Frankfort Electrical Congress in 1891: Messrs. Carl Hering, Nikola Tesla, Prof. Richard O. Heinrich and Dr. Edward L. Nichols With the exception of Mr. Tesla, all the delegates were in attendance, and their report was duly submitted to Council and printed in the Transactions.

At the meeting of February 16th, it was decided that the general meeting of 1892 be held at Chicago in order that an opportunity might be offered the western members of the Institute to participate in its proceedings. It was believed that the standing of the Institute as a national body would be enhanced by the holding of its meetings in other cities than New York, provided experience proved that this might be successfully done. The date was subsequently fixed for June 6th, 7th and 8th.

The total membership at the close of last year's report was 541, as follows:

Honorary	3
Members	161
Associate Members	377
Total	541
Associate Members elected during the year	111
Making a total of	652

The following have resigned during the year:

HENRY S. ISELIN, W. S. BELDING.
THOS. B. KERR, B. C. BATCHELLER,
J. HOWARD PRATT, Jr., H. C. ROOME,
A. H. HENDERSON, W. P. TROWBRIDGE,
GRAHAM D. FITCH.

Total.... 9.

We have lost by death:

GEORGE WORTHINGTON, of New York City,
CHARLES J. VAN DEPOELE, of Lynn, Mass.

Total.... 2.

Elections cancelled by reason of failure to qualify	4
Suspended for non-payment of dues	5
Dropped from the list for non-payment of dues	17
Loss of membership	37

Deducting this loss of membership as stated leaves a remainder of 615, (a net gain of 74,) classified as follows:

Honorary Members	3
Members	179
Associate Members	433
Total membership May 1st, 1892	615

SECRETARY'S BALANCE SHEET.

FOR THE YEAR ENDING APRIL 30TH, 1892.

RALPH W. POPE, SECRETARY, in account with the
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.			*Cr.*
1892.			
To balance from 1891........ ....$	10 51	By Cash to Treasurer..... ....$	6,717 48
Sundry receipts	6 00		
Entrance fees......	500 00		
Life Members	100 00		
Past dues.......................	278 76		
Current dues	4,618 85		
Advance dues..........	144 17		
Electrotypes sold....	528 31		
Typewriting and Stenography.......	217 14		
Transactions sold...	223 15		
Subscriptions for Transactions.......	95 50		
For Binding...................	20 65	Secretary's Balance on hand.........	25 59
	$6,743 04		$6,743 04

DISBURSEMENTS DURING THE YEAR.

The Treasurer has disbursed upon warrants drawn by the Secretary, approved by Council and Finance Committee the amount of $7,224.89 classified as follows:

Special Deposit Mercantile Trust Co.................... .. ..$	500 00
Stenography and Typewriting..	556 41
Stationery and Miscellaneous Printing..	505 45
Postage	299 95
Messenger Service	40 27
Salaries	1,441 67
Engraving and Electrotyping...	649 14
Meeting Expenses...........	480 10
Rent.	600 00
Printing Transactions	1,801 08
Express	4 60
Telegrams	3 61
Binding	170 52
Office Fittings	15 38
Office Expenses....	75 46
Copyright	4 50
Duties	3 00
Extra Clerical Work	50 00
Library..........	3 75
Engrossing	20 00
	$7,224 89

This amount should be credited with the following items:

Special Deposit....... ... .$	500 00	
Electrotypes Sold.	528 31	
Received for Typewriting and Stenography...........	217 74	
Received for Binding..........................	20 65	
Sundry Receipts........	6 00	
	$1,272 70	1,272 70

Showing the net expenses of the year to have been............	$5,952 19
And the net receipts for fees, dues, sales and subscription on account of Transactions	5,960 43
Showing an excess of net receipts over net expenses of.........	8 24
The outstanding current bills against the Institution amount to	491 17
And the amount of uncollected bills from other than members	$ 305 94

The arrearages of dues for the past year amount to $480.00 most of which is probably collectible.

In accordance with the instructions of the last annual meeting, the Secretary and the Treasurer acting as Trustees, made a special deposit of the $350.00 previously reported as a building fund, also $500.00 surplus from the General Fund making a total of $850.00 which has drawn interest at the rate of 3 per cent. This rate was reduced to 2 per cent., May 14th. The Treasurer's cash balance on April 30th was $245.53, and the Secretary's cash balance the same date $25.56, making the current balance carried forward to the next year $271 09. Special deposit $850.00.

Respectfully submitted by direction of Council,

RALPH W. POPE, *Secretary.*

New York, May 1, 1892.

TREASURER'S REPORT,

FROM MAY 15 1891 TO APRIL 30, 1892.

GEORGE M. PHELPS, TREASURER, in account with

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance May 16, 1891, from previous year	$ 752 94	
Received from Secretary, May 16, 1891 to April 30. 1892	6,717 48	$7,470 42

Cr.

Payments, from May 16, 1994 to April 30, 1892, on warrants from Secretary, Nos. 267 to 352, inclusive	$7,224 89	
Balance to new account	245 53	$7,470 42
Balance on hand, General Fund, May 1, 1892	$ 245 53	

BUILDING FUND.

Balance on hand, May 16, 1891	$ 350 00
Transferred from General Fund, July 1, 1892	500 00
	$ 850 00
Total General Fund and Building Fund	$1,095 53

N. B.—Warrant No. 286, for the transfer of Building Fund to the Mercantile Trust Company on certificate of deposit, was for $850.00, including $350.00 already entered in Special Account, and $500,00 from General Fund. The General Fund is therefore credited with $500 00 only—on Warrant No 286.

Respectfully submitted,

GEORGE M. PHELPS, *Treasurer.*

The Auditing Committee after examining the accounts and vouchers, and comparing them with the above statements, reported that they had found them correct, and it was voted that they be accepted and placed on file.

The Chair appointed Messrs. Francis R. Upton, George H. Stockbridge and Dr. Cary T. Hutchinson an Auditing Committee to examine the books and reports.

The following officers were elected to fill vacancies occurring under the Rules:

President,
FRANK J. SPRAGUE.
Term Expires, 1898.

Vice-Presidents,
(Terms Expire 1894.)
A E. KENNELLY,
NIKOLA TESLA,
OSCAR T. CROSBY.

Managers,
(Terms Expire 1895.)
CHARLES WIRT,
ANGUS S. HIBBARD,
MICHAEL I. PUPIN,
CHARLES P. STEINMETZ.

Treasurer,
GEORGE M. PHELPS.

Secretary,
RALPH W. POPE.

Terms Expire 1893

On motion of Mr. Upton, it was voted that the Trustees be authorized to set aside $150 from the General Fund during the coming year at their discretion adding it to the present building fund of $1000, and investing it at a more remunerative rate if possible.

On motion of Mr. T. C. Martin, a committee of three was appointed to revise the present method of electing officers, and to report at the General Meeting at Chicago in June.

The Chair appointed Messrs. T. C. Martin and P. V. R. Van Wyck, Jr., a committee to escort the President elect to the Chair. On assuming the Chair, President Sprague said:

Gentlemen of the Institute,—As you have already been informed, this honor has come to me suddenly, and I presume I may say, following the dictates of political practice, entirely unsought. I have to thank you very much for the confidence which you have expressed by the vote. I feel, however, with Mr. Martin that the method of casting the vote which was employed to-day is not one which necessarily shows the real sentiments of this association. We have an organization which is truly representative of the electrical engineers of the United States. Not over a quarter of them are residents of this city, and not more than a quarter, and in fact much less than that can ordinarily be present at these meetings, hence I am heartily in accord with the suggestion that has been made that there should be a more representative method of ascertaining who is really the choice, not only of those present but who shall be the representative of the more sober and carefully considered judgment of this association. However, having been elected, I shall try to do all in my power for the benefit of the Institute of Electrical Engineers. We have a year before us which is going to mark the inauguration of the greatest electrical exhibition which has ever been held and which probably will be held for a number of years. It is one in which the intelligence and skill and all that has made American electrical engineering a success, are going to be brought in competition with the best that the old country can bring us. There is now an Advisory Council whose duty is to aid the World's Fair authorities in getting together a representative congress of the electricians of the world. The officers and members of this Institute will have much to do in making that a representative body. Before this year closes it is probable that there will be advances in electrical engineering which are now merely suggested. I believe I am justified in saying that the year will be marked perhaps, as no year in the past has ever been by great works, and on that account, it gives me great pleasure to preside over the deliberations of this Institute.

In thanking the Institute for the confidence shown by my election, I wish to move a vote of thanks to the Vice-President who has just vacated his Chair, for the very able manner in which he has performed the duties of the office, and especially in view of the great amount of work which has fallen to his particular sphere in the absence of the Past-President. I am sure all those who are acquainted with Mr. Lockwood, with his intimate connection with one of the greatest industries, and also with his independent position as an electrical engineer, all in fact who know his ability, energy and honesty of purpose, will heartily agree with me that we can do no more graceful thing than to extend a vote of thanks to him for his past services.

MR. MARTIN:—I move that we make that a rising vote.

Mr. Sprague's motion was carried by a rising vote.

MR. LOCKWOOD:—Mr. President and Gentlemen of the Institute: I am already, what I hardly expected to be until I had finished dinner, too full for utterance. I feel deeply the appreciative vote which has just been tendered to me. I am very glad indeed if I have been able to be of any service to the Institute. It has been my fortune, as I said at the beginning of the past year, to have in some measure to stand in the boots of another man, and I have endeavored, although my understanding is perhaps not as great as his, to fill them. But whatever success I may have had by the aid of the Council, to whom collectively I wish to express my hearty thanks—whatever good I have been enabled to do by the very efficient aid of the Secretary, I can only say has been due to hard work, for I am a most thorough believer in the phrase which is frequently, and erroneously I believe, attributed to Talleyrand, that genius is simply an infinite capacity for taking pains. At a very early stage in my history, which has been somewhat of a vareigated character, I made up my mind that the only genius I possessed, was that kind of genius, and I endeavored to make it as available as possible to myself and to others. I have believed all my life that whatever is worth doing is worth doing as well as may be, and therefore I have endeavored to serve the Institute to the best of my power. I thank you for your very kind vote.

The Secretary read the following list of Associate Members elected and transferred at Council Meeting this date:

Name.	Address.	Endorsed by.
BEALS, PASCAL P.	Electrical Contractor and Agent for the Waddell-Entz Electric Co., 50 Terrace, Buffalo, N. Y.	Justus B. Entz. Montgomery Waddell. Thos. H. Foote.
BERTHOLD, VICTOR M.	With T. D. Lockwood in Patent Department of American Bell Telephone Co., 16 Upton Street, Cambridgeport, Mass.	Chas. R. Cross. Thos. D. Lockwood. I. H. Farnham.
BOSSON, FREDERICK N.	Electrician, Calumet and Hecla Mining Co., Calumet, Mich.	H. Ward Leonard. George Cutter. R. W. Pope.
FLOY, HENRY	Graduate Student in Electrical Engineering, Cornell University, Barnes Hall, Ithaca, N. Y.	Ernest Merritt. Edw. L. Nichols. Harris J. Ryan.
GROSS, S. ROSS	Electrician, Tennessee Coal, Iron & R. R. Co., Ensley, Ala.	Henry B. Cram. Walter C. Fish. S. C. Peck.
LITTLE, FRANKLIN P.	Manager, F. P. Little & Co., 141 East Seneca St., Buffalo, N. Y.	H. A. Foster. S. S. Wheeler. Geo. M. Phelps.
MCRAE, AUSTIN LEE	Professor of Physics, Missouri School of Mines, Rolla, Mo.	Edwin H. Hall. H. V. Hayes. Brown Ayres.
PERRY, NELSON W., E. M.	Editor, *Electricity*, 6 Park Place, New York City, Residence, 40 Sidney Place, Brooklyn, N. Y.	H. L. Webb. H. Ward Leonard. R. W. Pope.
SHAW, EDWIN C.	General Superintendent, T omson-Houston E. L. and P. Co., 40 Court St, Buffalo, N. Y.	H. A. Foster, A. E. Woolf. A. E. Winchester.
VERLEY, HORACE S. L.	With Dr. Wm. E. Geyer, as Laboratory Assistant, Stevens Institute, Hoboken, N. J.	Wm. E. Geyer. J. H. Cuntz Joseph Wetzler.

Total 10.

Elected to Honorary Membership, by Council, May 17th, 1892.

FIELD, CYRUS W. Gramercy Park, New York City.

KELVIN, *Lord*, LL.D., F.R.SS. L. and E. The University, Glasgow, Scotland.

SIEMENS, DR., WERNER VON, Berlinerstrasse 36, Charlottenburg, Germany.

Transferred from associate to full membership.

Approved by Board of Examiners, March 14th, 1892.

BAYLES, ROBERT N.	Electrician, The "C & C" Electric Motor Co., New York City.
GRAY, ELISHA	Highland Park, Ill.
HEWITT, CHARLES	The Edison General Electric Co., New York City.
INRIG, ALEC. G.	Electrical Engineer, Antwerp, Belgium.
MACFARLANE, ALEXANDER	Professor of Physics, University of Texas, Austin, Texas.

Total, 5.

The President appointed Messrs. F. B. Herzog, Francis R. Upton and T. C. Martin as a committee on revision of the method of electing officers to report at the General Meeting at Chicago.

The annual meeting then adjourned and the members re-assembled at "The Arena," No. 41 West 31st street, where a dinner was served, at which 65 members and guests were present. President Sprague presided, and remarks were made by Thos. D. Lockwood, Oscar T. Crosby, Charles E. Emery, Oberlin Smith, Prof. George Forbes, Dr. Louis Duncan and Past-Presidents T. C. Martin and Franklin L. Pope.

This was the first purely social gathering of the Institute, and was so thoroughly enjoyed that it was voted to organize a similar event annually hereafter.

OBITUARY.

Charles Joseph Van Depoele was born in the Province of West Flanders, Belgium, in the year 1846. His birthplace was the small place of Litchervelde, situated about sixty miles northwest of the city of Brussels. He died in Lynn, Massachusetts, March 18th, 1892. His death occurred after a sickness of four months, and it was, primarily, due to heart failure. Mr. Van Depoele was elected an Associate Member of the Institute, June 5th, 1888, and transferred to full membership September 7th, 1889.

When about ten years old young Van Depoele saw the telegraph system of the East Flanders railway installed, and as his father was master mechanic of the road he had an opportunity of studying into the mysteries of the working of the telegraph, which he was not slow in doing as he had early acquired a taste for natural philosophy, and read with avidity all works within reach. His taste for machinery was, undoubtedly, inherited from his father and his familiarity with the use of tools was of great advantage to him in his early work. We find him at the age of fifteen or sixteen years building telegraph instruments, Ruhmkorff coils, and going so far as to construct a Bunsen battery of forty cells. In this work he did not receive the encouragement of his father. who was very much opposed to his son spending his spare time in this way. His father apprenticed him to a cabinet-maker and he mastered the trade in a remarkably short time.

In 1864 his father moved to Lille, France, where young Van Depoele became interested in sculpture and worked for some time in the works of Buisine–Rigot, where more than two hundred sculptors were employed. He distinguished himself by making an immense piece of carved work some eighty feet in height, an altar-piece for a large cathedral. During this time, however, his spare moments were spent either reading electrical books or building and experimenting with electrical apparatus. His father strongly disapproved, and thought his time and labor might be better spent.

When about twenty-three years old he decided to come to America, and he arrived in Detroit in the summer of 1869. He immediately engaged in the church furniture business, but the success of this venture did not make him forget or lose interest in his electrical experiments, but the income allowed him to begin experiments of greater magnitude than he had hitherto attempted. By the aid of a large Bunsen battery he began experiments with arc lamps, and later when the description of the Gramme. machine was published he built a model of it. Outside of lighting his workshop, his first commercial work was done in 1878 when he furnished arc lights for Forepaugh's Circus, at Campas Park, using for this purpose a three light dynamo. The front of the Detroit Opera House was lighted by him during the same year. This practical work led directly to the organization of a stock company with a capital of $125,000. The company immediately started the manufacture of electric light apparatus at Nos. 29 and 31 Atwater street, and they soon had a number of successful plants in operation on excursion boats running on the Detroit River.

About this time he began to pay attention to electricity as a motive power, and during the year 1880 did a great deal of experimenting. He experimented with pieces of carbon for collecting the current from the commutator of dynamos. During the latter part of the year 1880 the company was reorganized with a capital stock of $500,000, and the works moved to Chicago where large arc lighting machines were built and his first experiments were made in the propulsion of street cars. His work in this direction at the Chicago Exposition and at the Exposition at Toronto, Canada, are familiar to all, and although the courts have not yet decided on the patent situation as to who the pioneer in electric matters was, yet it would seem that Mr. Van Depoele's claim can be substantiated.

Mr. Van Depoele had a most wonderful capacity for hard work, and no matter what reverses came he was always hopeful, always ready and willing to carry on his work at all hours of the day or night. Perhaps the best measure of his industry can be made by referring to his record in the Patent Office. We find that his first electrical patent was for an arc lamp and was granted April 27th, 1880, the application being filed September 20th, 1879, and from that time until August, 1887, he secured ninety-one patents of which the majority related to electric lighting apparatus, arc and incandescent lamps, dynamo electric generators, motors, converters and current controlling apparatus, together with a large number of patents relating to electric railways, and also to reciprocating electric engines and that form of elevated railways known as "telpher systems."

In 1883 he received one of the earliest patents on electric railway underground conduit systems, and in February of 1886 he patented the overhead trolley switch now in use all over the country. During the years 1888 and 1890 (after he had become associated with the Thomson–Houson Electric Company) Mr. Van Depoele applied for and received fifty-three patents beginning with the universally used carbon commutator brush and including five different systems of underground conduit transmission together with the numerous devices entering into the now well-known overhead trolley system construction. In addition to these the list includes the pioneer patents on the closed circuit reciprocating electric percussion drill. During the year 1890, forty-six patents were granted him, including overhead electric systems, systems employing converters for modifying the current to be employed in electric railway circuits, contact devices for electric systems, telpher systems; several forms of electric railway underground conduits in which the conduit is entirely closed, and a number of methods of adapting electric currents to the propulsion of reciprocating engines, also several patents for alternating current motors.

During the year 1891, thirty patents were granted, including electric railway systems, with overhead and underground conductors, several patents relating to alternating current motors, and a number relating to reciprocating electric engines. In the early part of the year 1892 a patent was granted for electric railways, the filing date of which was June, 1885, and which contains broad claims for the upward pressure overhead electric railway system. The last patent granted during his lifetime was filed in the early part of 1887 and was for a railway power station system which, although not thought much of by others in that year, has since been demonstrated to be most important. The entire number of patents granted to Chas. J. Van Depoele is 225, and at the time of his death there were seventy-one applications pending before the U. S. Patent Office in his name.

The list is a long one and represents many years of diligent study and earnest effort to promote electrical science in all its branches. Whilst it is impracticable to enumerate in detail, it may be said that the patent record left by Mr. Van Depoele has been equalled by only a few of his competitors and excelled by none in the scope and variety of the subjects treated by him. His range of vision, quickness of perception, and fertility of resource, were something marvellous, and when it is considered that he began experimenting in a small private laboratory in the city of Detroit in 1872, when, to obtain insulated wire of any description was a matter of personal effort, and when it is considered that in the summer of 1883 he had actually tested and for sale a dynamo electric machine operating 60 lights, it will be seen that he did pioneer work in everything which he undertook, and that in all probability he contributed as much to the development of the electric industry as any other one man.

The Ninth General Meeting of the Institute was held at Chicago, Ill., June 6th, 7th and 8th. The opening session was held at the Grand Pacific Hotel, the meeting being called to order by President Sprague, who then relinquished the Chair to Vice-President Lockwood. In the absence of the authors the following paper was read by Vice-President Hering:

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 6th, 1892, Vice-President Lockwood in the Chair.

NOTE ON SOME EXPERIMENTS WITH ALTERNATING CURRENTS.

BY DR. LOUIS DUNCAN,

Assisted by Mr. E. R. Carichoff and Messrs. R. H. and G. E Hutton.

I must apologize for the brevity and scope of this paper, not because I sympathize with long papers, but because I had intended to embody in this the results of a considerable amount of work done during the year, and I find that the rush of work at the last of our term has made it impossible for me to do more than write a note descriptive of the methods used, and to give a few illustrations of its use. Last fall I published a preliminary statement of a method for obtaining alternating current curves, and it has proved so satisfactory that we have used it in a number of investigations of alternating current phenomena.

The first real representation of an alternating current curve was made by Joubert, who employed a contact piece rotating with the armature of a dynamo, touching a fixed brush at a point of the revolution determined by the position of the brush with relation to the dynamo poles. He obtained a curve for current which was approximately a sine curve. Later, in 1888, Messrs Wilkes, Hutchinson and myself modified the method to obtain the curves for E. M. F. and current in the primaries and secondaries of induction coils. This modification was used afterward at Cornell, where Professor Ryan and others made valuable experiments, and it has been more or less generally employed. The principal difficulties lie in the fact that with a single commutating arrangement but one curve can be taken at a time, and as an experiment involving four curves takes something like 45 minutes, the condition may seriously change; while the whole voltage of the dynamo is at times on the commutator. It is at best rather a tedious method. In our work referred to above, and in the work at Cornell, E. M. F's. were measured by an electrometer, and currents were obtained by getting potential differences at the terminals of a non-inductive resistance through which the current passed. Lately, in France, two commutating arrangements have been used to give two curves at once, with a condenser charged through the contact and discharged through a d'Arsonval galvanometer.

By the method which I described last fall, any number of curves may be obtained simultaneously, with only a few volts on

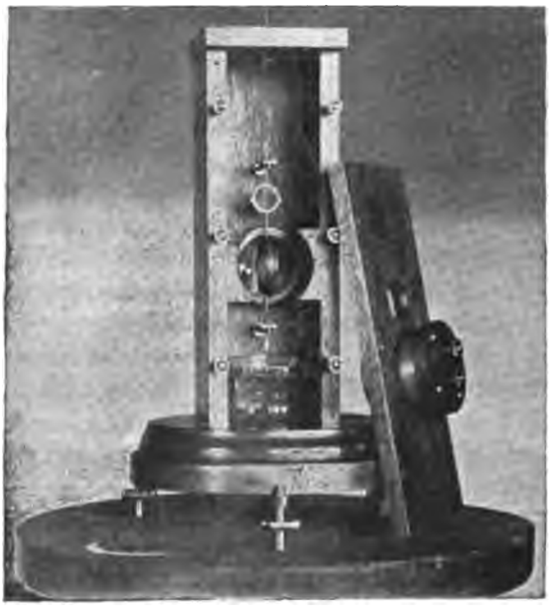


Fig. 1.

the commutator and with a rapidity and accuracy much greater than by the other methods. Briefly, a number of dynamometers are used, equal to the number of simultaneous curves to be obtained. These dynamometers are very cheap and convenient. The first ones used were made by Mr. Carichoff and myself, and were quite satisfactory, but experience having suggested some improvement, and our time being fully occupied, Messrs. E. S. Ritchie and Sons made four of them, such as are shown in the picture [Fig. 1.] I will describe them more minutely below.

The four dynamometers have their stationary coils wound

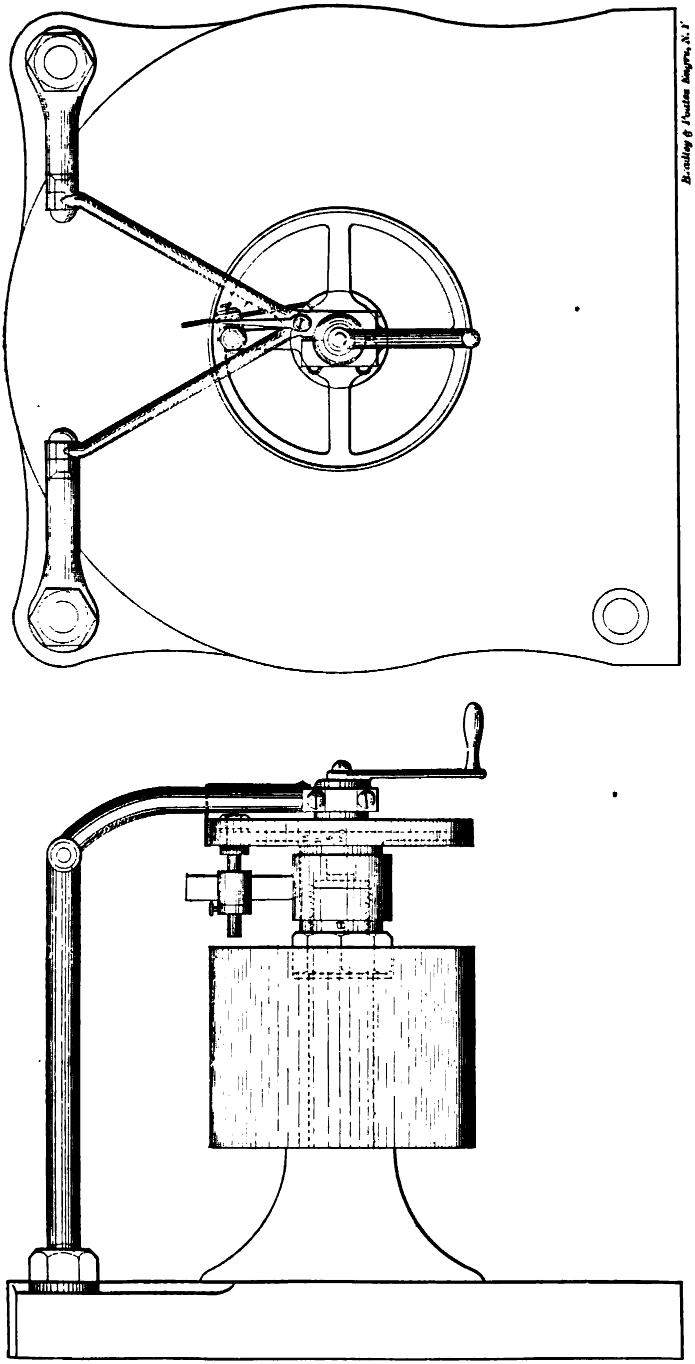


FIG. 2.

for,—say—primary current, primary E. M. F., secondary current and secondary E. M. F. The movable coils are wound with fine wire, and are all connected in series. The E. M. F. instruments are made exceedingly sensitive so their self-induction may be made a minimum, and in series with them is placed a large non-inductive resistance, the relation of the self-induction and resistance being made such that the former may be neglected. The circuit of the movable coils is through a battery of a few storage cells to a brush which may be moved by hand through the arc of a circle, and which touches a contact piece on the dynamo shaft once every revolution. The other end of the circuit being joined by a sliding connection with the contact piece, the circuit is closed through the cells and coils for a short period once every revolution. The instant of closing this circuit is determined by the position of the movable brush with respect to the dynamo poles. Now suppose an alternating current is sent through the stationary coil of one of the dynamometers. If an instantaneous current be sent through the movable coil, an impulse will be given it dependent on the value of its current and on the instantaneous value of the current in the stationary coil; as the period of the coil is great compared with the period of the dynamo, we will get a steady deflection dependent on this product. If now we move our contact brush, the instantaneous current will pass at some other point on the alternating current wave, and our deflection will be proportional to the value of the current at this point; by moving the brush through an angle corresponding to a complete wave we can plot the wave exactly, providing we have properly calibrated our dynamometer.

It is apparent that in order to attain accuracy our instantaneous current must be very brief and very steady, and its value must be the same in actual work as in calibrating. A d'Arsonval galvonometer in the circuit allows us to judge the two last points, and we found that when a high resistance was used in the circuit so that any variation in the contact resistance was eliminated, almost absolute steadiness was obtained. It was also assured by using a condenser charged during part of the revolution and then discharged by the contact brush through the circuit. To give an idea of the current in this circuit, an ordinary arrangement, when the condenser was not used, was 12 volts through 1000 ohms, and it must be remembered that this current only passes an exceedingly small part of the time.

Dynamometers:—The dynamometers were made of wood, mounted on a revolving base, so they could be adjusted with respect to the meridian. It will be seen on looking at the picture that one side is made removable to facilitate adjustments. The fixed coils are wound in two cylinders which move in and out through holes in the sides, and whose distance apart is adjusted when the instrument is calibrated, so the scale divisions read directly in volts or amperes, or fractions of them. The movable coil is suspended by a silk fibre, which gives it no directive force but which sustains it. Directive force is given the coil and current is introduced to it through two palladium hair springs which

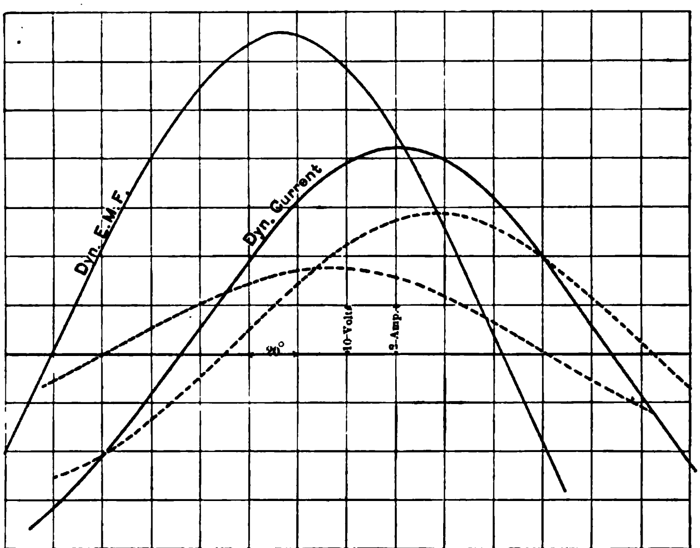


FIG. 3. Tesla Fan Motor. Period $\frac{1}{130}$.

are fastened to stiff brass wires, which serve as the axis of the coil. A vane in a beaker filled with glycerine damps the swinging and makes the instrument absolutely aperiodic. I have rarely used instruments which give more satisfactory results, the zero is invariable, readings may be taken with great ease and rapidity, while a reversal of the current gives equal readings on the two sides of the zero. To show the rapidity of the readings, six curves, representing different quantities in a step-up-and-down transmission were taken in a little over five minutes, and in this case two instruments were used for four curves—those at the sending and receiving ends of the plant,—

and therefore had to be switched from one side to the other at every reading. Twenty points were usually taken for each wave. The curves could of course be photographed instead of observed, but the latter is so much simpler and more satisfactory that—especially in a laboratory where there are plenty of observers—I much prefer it.

Contact Arrangement: This is shown in Fig. 2. As it comes outside of the belt, and as it was often necessary to remove the latter, the swinging arrangement shown was designed and constructed by the Messrs. Hutton. On the shaft was a hard rubber cylinder with the brass contact almost flush with its surface. The

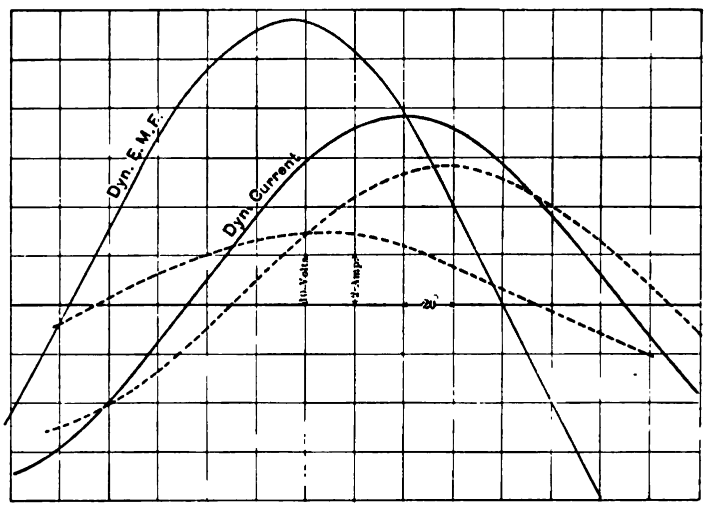


FIG. 4. Tesla Fan Motor—Held. Period $\frac{1}{130}$ second.

whole arrangement worked admirably. The results of our work will have to be another story. I will simply give a few to illustrate the method.

We have a small Tesla fan motor intended to work on an ordinary incandescent circuit. There are eight poles, the alternate ones having their windings in different circuits,—one set of poles having a few turns of coarse wire, the others having a greater number of fine wire turns. The curves in Fig. 3 show the condition of affairs when the motor was working; in Fig. 4 where the armature was held. In the second case the energy represented corresponds, of course, only to the losses. It seems to be the general impression by the way, that a rotating field motor starts up with the same torque as a corresponding continuous current machine. I have shown, however, that a two phase motor corresponds exactly to a converter,—or rather two converters,—in which the secondary has an outside resistance of $\frac{p^1}{p-p^1}$, where p^1 is the angular velocity of the armature and p that of the field. When p^1 is 0—that is when the motor is at rest,—it will be seen that the current is in the worst possible condition for starting and the torque for a given current is small. It is like starting a continuous current motor, with the brushes almost ninety degrees from the proper position.

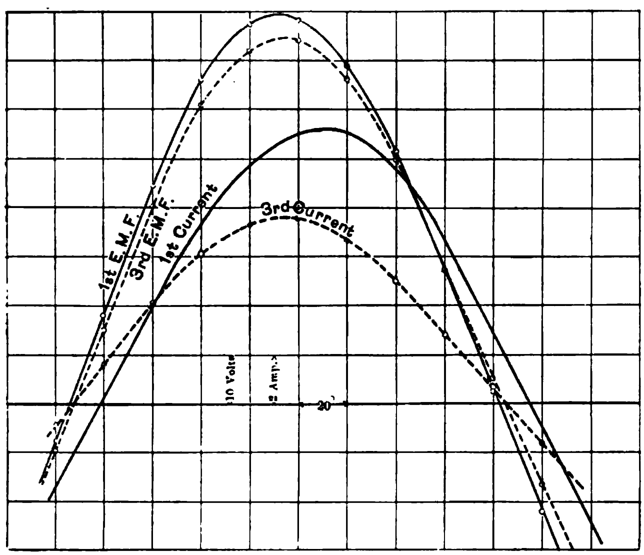


Fig. 5.

But most of our work has been with circuits in which both self-induction and capacity have been introduced. It is a well-known fact that circuits carrying alternating currents may be given the same period of vibration as the current, or to put it another way, circuits may be so arranged that with currents of a given period the sum of the energies stored up in the circuit and given out by it, is zero. With a condenser and self-induction properly adjusted, if energy from the current is being stored up in the condenser an equal quantity is being given to the current by virtue of the self-induction. That is, we can neutralize our self-induction by a capacity. I can hardly think of any fact more likely to play an important part in the future of alternating current work. For instance, if a circuit has in it a periodic current consisting of a number of sine curves of different periods—one-third, one-fifth, one-seventh, etc., the period of the fundamental wave; then if we put in inductive relation to this circuit another circuit whose period is—say—one-third that of the fundamental wave, this current will pick out the one-third period waves in the primary.

An ordinary sine curve E. M. F. may be made to give a periodic current wave with these higher harmonics in several ways—by having in the circuit a self-induction coil whose iron core is saturated when the current nears a maximum, or by using the same coil with a

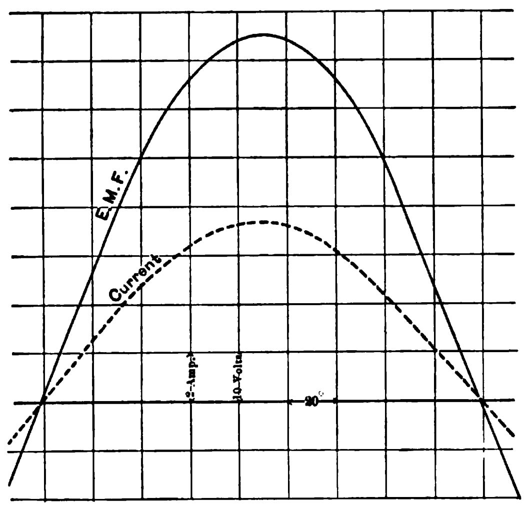


FIG. 6. Dynamo Direct on Lamps.

capacity which neutralizes one of the value of the varying self-induction; so we can produce these higher harmonics and we can pick them out. But it is a complex subject not to be treated here. In all such experiments however, there are several points which must be carefully attended to, or there will be very unsatisfactory results. If the iron core of the induction coil—provided such a core is used—is not properly laminated and annealed, or if there are considerable losses in the condenser the results will be disappointing. Take the case for example where there are eddy currents in the core and there is loss in the condenser. The first effect corresponds to a short-circuited secondary near the coil; the loss in the dielectric of the condenser means that energy is taken from the current, and this energy must be represented by the product of the current into the E. M. F., e corresponding to the transfer of energy, or it is $e. i.$ The value of e is a maximum when the displacement is greatest,—that is when the cur-

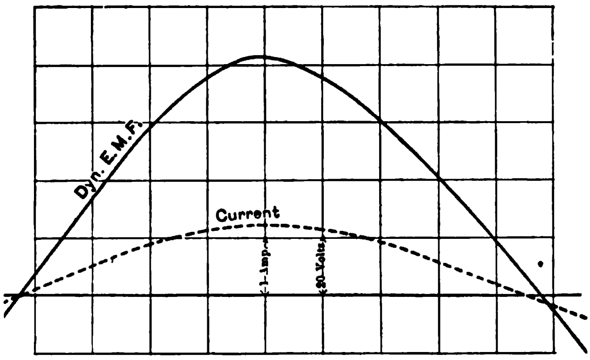


FIG. 7. Copper Condenser with Coils.
Cap. 1.85 M. F.'s. Wire Core.

rent is greatest, and for a given current and dielectric varies as $\frac{1}{c.}$ If we represent these effects by a revolving diagram as is ordinarily done, and suppose we have neutralized the self-induction by a capacity, we get something like the figure [Fig. 12]. The result is that the relation between R. I. and E. instead

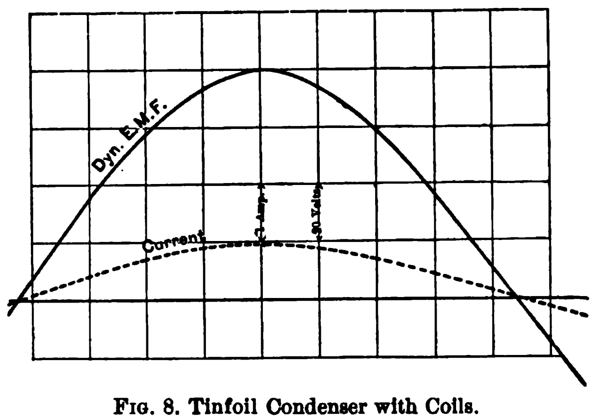


FIG. 8. Tinfoil Condenser with Coils.
Cap. 1.83 M. F.'s. Wire Core.

of being 1 to 1 as would be the case were there no disturbing causes, is 1 to 1+. That is, for a given E. M. F. the current is less than it should be, and a glance at the figure will show that it is thrown ahead of the E. M. F. No possible change in our self-induction and capacity can remedy this decrease in the current, although we may, of course, make the phase angle zero if we wish.

An excellent way to make an iron core, by the way, is to shellac

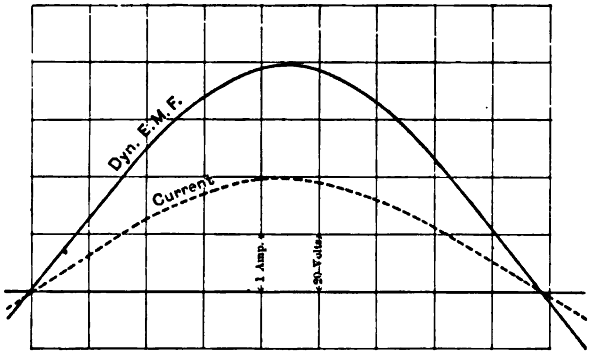


FIG. 9. Tinfoil in Parallel with Copper Condenser with Coils.
Cap. 2.675 M. F.'s. Wire Core.

fine, well annealed wires, spread them along a piece of thin paper, brush them over with shellac and then roll the mat so formed into a cylinder. The losses in a condenser are usually small. They are discussed in a paper of Messrs. Hutin and Leblanc, published

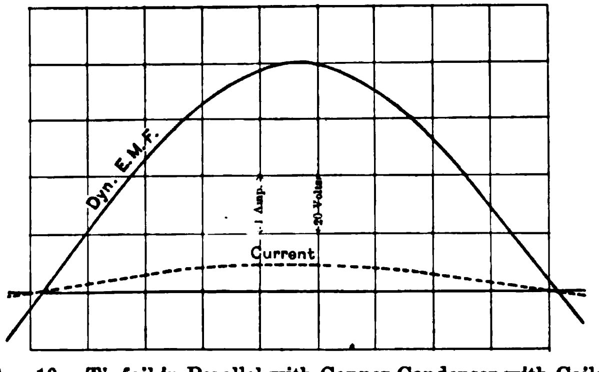


FIG. 10. Tinfoil in Parallel with Copper Condenser with Coils
Cap. 2.675 M. F.'s. Solid 1¾" Iron Core. Resistance of Circuit, 20.8 ω.

last spring in *La Lumiere Electrique.* We find however that if the condenser is made of very thin tinfoil and has a large area, then for heavy currents it may considerably decrease in capacity and offer a definite resistance to the current.

The curves given have been selected almost at random from a mass of data. We have not the time to discuss the results which are hardly within the scope of this paper. Figure 5 gives the curves at the two ends of a transmission plant where the voltage was raised from 50 to 1000 volts and reduced again. Fig. 6 gives the curves for the dynamo directly on the same lamps. It is seen that the transmission decreases the E. M. F. and current, and increases the lag of the dynamo current.

Figs. 7, 8, 9 and 10 give curves taken from the dynamo circuit when self-induction and capacities were inserted. In Fig.

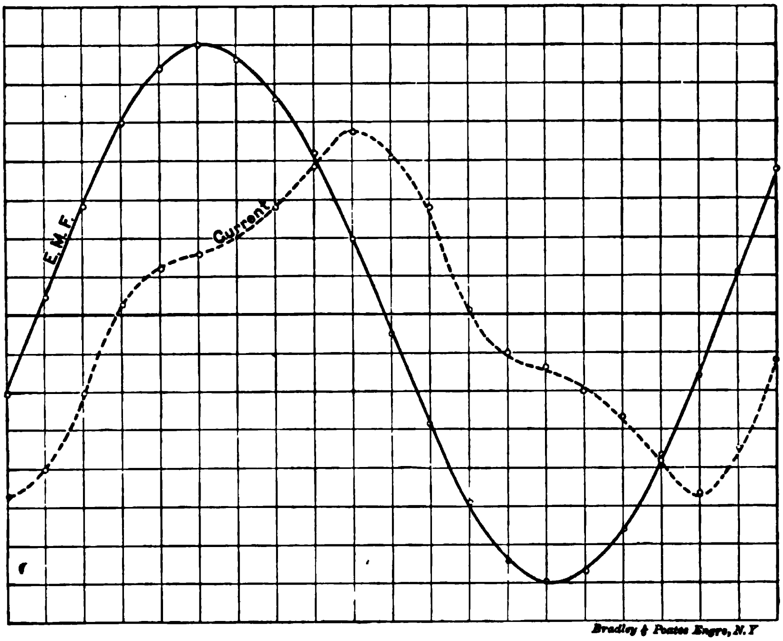


FIG. 11. Siemens Dynamo on Transformer; secondary open. Curves taken with experimental dynamometers.

7 the core of the induction coil was only fairly well laminated; and a condenser with copper sheets between paraffined paper was used. The maximum current is a little over 1.2 amperes, while it should have been about four amperes if there were no losses in the circuit. The second point of crossing is thrown out by a change of speed of the dynamo. Fig. 8 shows the result of substituting a tinfoil condenser of the same capacity in place of the copper one. In Fig. 9 both condensers were used and a considerable part of the wire core was withdrawn. In Fig. 10 with

the same two condensers, a solid iron bar was used as the core of the induction coil.

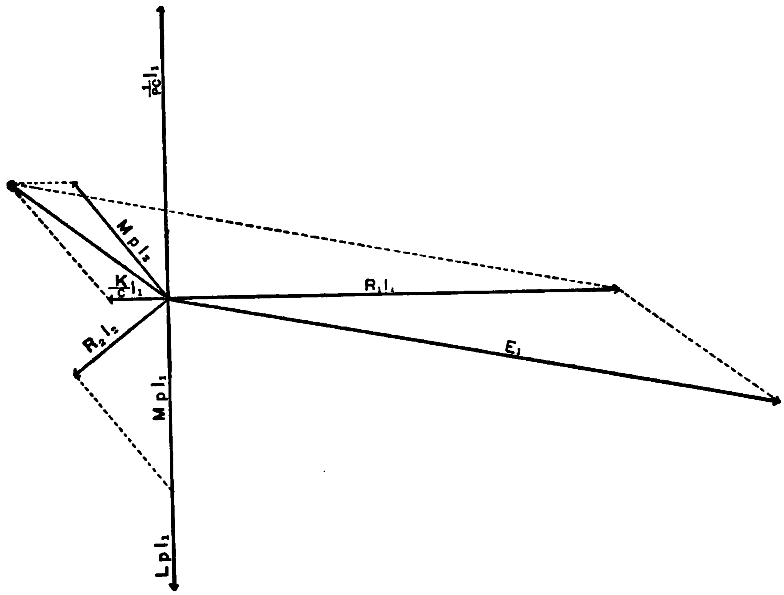


FIG. 12.

Fig. 11 gives the curves obtained in the circuit of a dynamo connected to a transformer whose secondary circuit was open.

DISCUSSION.

PROF. HENRY S. CARHART: Mr. Chairman, I wish to say a word, not at all in criticism of Dr. Duncan's paper, but rather to give some of my own experience in this matter. We have succeeded, by a very simple means, in getting these curves with only two observers, taking 20 points in five minutes. I have written off a few of the curves, but they are on a small scale. The apparatus is in general similar to that used in the older method, connected to the end of the shaft of the armature, with sliding contact. The instrument is well made and has worked perfectly from the start. The shunt is taken off from a single lamp of non-inductive resistance, 24 lamps across the primary. The current was 10,000 volts. I am not certain yet whether the lag between the current and the electromotive force comes out properly or not. In that case we use a galvanometer. In another instance the same apparatus is used, except that we use an electrometer. They came out better and faster, and are very satisfactory. The calibration was what I was about to speak of. An instrument made under precisely the same conditions with saturated paper, was put in place of the shunt around the lamp, and then run through the machine in exactly the same way, and through a commutating arrangement on the machine. We run this with precisely the same apparatus. Dr. Duncan's method very likely worked more rapidly, but this certainly answers very well for ordinary purposes.

Dr. Edward L. Nichols:—I should like to say, Mr. Chairman, that it seems to me that the paper, together with other work which we know of that is going on at the present time along these lines, goes to show what progress has been made in this kind of measurements within the last few years. We can all remember the time, when to get such curves at all was regarded as an achievement, a little later on it took an hour, then 45 minutes was boasted of as something wonderful. Now we have the statement that these simultaneous curves were obtained in five minutes. Professor Carhart tells us that he has taken them by the old method in five minutes. The world has seen great development in alternating current measurements. It seems to me that Dr. Duncan's paper is chiefly important therefore, not on the question of rapidity, but in the fact of getting absolutely simultaneous values for two curves, so that no change can take place between the taking of the electromotive force curve, andof the current curve. There is no lapse of time during which some change of condition might occur to vitiate the result.

Prof. Carhart: I forgot to say, Mr. Chairman, that our apparatus was provided with two disks, but we could just as well have put on four, and got three of four contacts at the same time, and measured three of four curves at the same time.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 6th, 1892, Vice-President Lockwood in the Chair.

RATIONAL AND EMPIRICAL FORMULÆ SHOWING THE RELATION BETWEEN THE MAGNETO-MOTIVE FORCE (H) AND THE RESULTING MAGNETIZATION (B).

BY CHARLES E. EMERY, PH. D.

PART I.

SEC. 1. It is proposed to present in Part I of this paper the results of investigations designed to ascertain the general principles underlying the observed relations of the electric exciting or magneto-motive force (H) to the resulting magnetization (B), with a view of developing a rational equation therefor. It is believed that rational functions based on physical facts have been found ample to account for the peculiar shape of the H-B curves of magnetization. The theory that magnetization is the circulation of an ether is examined by the law of the flow of fluids, with the gratifying result that a rational fluid function has been developed which corresponds very well with the observed curves of magnetization and which, moreover, shows decidedly a phenomenon equivalent to that of magnetic saturation. The observed results indicate a more intense action during the earlier stages of magnetization than is provided by the fluid function, but the discussion shows that the theory of molecular magnets appears quite sufficient to account for such intensified action. Following the discussion on this subject there are presented in "Part II," Sec. 23, empirical formulæ for practical use, corresponding satisfactorily with typical H-B curves derived from experiments, and in the "Conclusion," Sec. 36, a general formulæ is derived, embodying the fluid function first discussed and a linear function, which together satisfactorily represent, on a rational basis, the observed conditions throughout the entire range of observation, including Ewing's experiments with very high magnetizations.

SEC. 2. The human mind must found its impressions of unseen phenomena on analogy, so it is natural to suppose that all "action at a distance" is due to the motion of something extending through that distance. The rational discussion is based on a theory which has heretofore been proposed in substance, though generally with hesitation, shown by the fact that other plausible theories were advanced in the same connection. It will be considered that the magnetic field results from the circulation along definite lines of an ethereal atmosphere of such extreme tenuity that it moves readily through all bodies, fluid or solid, of which our senses are cognizant, though like other fluids capable of being moved and directed by other forces and of being concentrated in certain paths by particular materials.

SEC. 3. If this theory be true the etheric fluid should respond to the same laws as govern the flow of other fluids, air and water for instance, and we will first examine the formulæ relating to fluids tangible directly to our senses, and see if the flow of a fluid of such extreme tenuity that we cannot feel, see or hear it, but only judge of its presence and its circulation by the results produced, will show in such formulæ a substantial agreement with the observed results. Starting with the well-known formula derived from the law of falling bodies,

$$v = \sqrt{2\,g\,h} \qquad (1)$$

in which evidently v equals the velocity, g the acceleratrix of gravity, and h the head or vertical height of column, we may derive at once the formula for the flow of fluid in a pipe or constrained space as follows :

SEC. 4. If $a =$ the area of the channel or pipe considered, $D =$ the specific weight or weight of a cubic unit of the fluid considered, and $G_1 =$ the weight of fluid passing a given point in a unit of time, we have

$$G_1 = a\,v\,D \qquad (2)$$

By combination with Eq. 1 we have

$$G_1 = a\,D\,\sqrt{2\,g\,h} \qquad (3)$$

If p_0 equals the pressure per superficial unit, due to the head h, evidently

(4) $$p_0 = D\,h$$

(5) $h = \frac{p_0}{D}$, which, substituted in Eq. 3, gives

(6) $$G_1 = a\,\sqrt{2\,g\,D\,p_0}$$

which is the ordinary form of the equation showing the force required to overcome the inertia of the mass and give the same a velocity necessary to produce the flow G_1 in a circuit without resistance.

Sec. 5. There are various external conditions which also affect the flow, depending upon the apparatus and materials employed such as the particular shape of the nozzle through which the fluid is to flow and the "hydraulic mean depth" and the roughness of the surfaces of a pipe or channel. These differences are usually provided for by considering either that it requires a certain head h_1 or pressures p_1 to overcome such resistances, so the total pressure required will be $p_0 + p_1$. Generally in practice the force p_0 required to put the mass in motion is so small that it may be neglected in comparison with p_1 required to overcome resistances. It is found also that the flow does not vary directly as the pressure p_1, so a function of p_1, or a function of the velocity easily reduced to a function of p_1, is generally employed to develop a variable coefficient of p_1, which will provide for the varying external conditions. On this basis $p_1\,(fp_1)$ (read p_1 multiplied by function of p_1) is to be substituted for p_0 in Eq. 6.

Sec. 6. With an elastic fluid the density D practically varies with the total pressure, so if we let D_1 represent the weight of a cubic unit at unit pressure, the weight due to any other pressure p_2 will be $p_2 D_1$, which is to be substituted for D in Eq. 6. Thus we see that for an elastic fluid the flow depends upon two variables, viz.: the density and the pressure required to overcome the resistances. Many formulæ have been developed to show the observed relations, some of which are very imperfect, except when applied to the observations upon which they were based, while others fairly express the true relation. Many years ago Napier advanced the theory, based on experiments with the discharge of steam through orifices, that the flow increased rapidly with the difference of pressure at the two ends of the orifice until the difference of pressure somewhat exceeded one-half the total pressure, when the flow abruptly became constant for all increased differences of pressure. During the construction of the plant of the New York Steam Company the writer had a series of experiments carefully made on the subject, and a smooth curve was obtained with limiting values such as indicated by Napier. In other words, the flow increased much more rapidly than the difference in pressure at first, and slower afterward, as if approaching a limiting constant value.

SEC. 7. The writer has obtained a rational function expressing these relations in the following manner which has not been heretofore published. If p be the total pressure, it is evidently equal to $p_1 + p_2$ above, viz.: to the sum of the pressures required to overcome resistance and available to increase the density. In any given case p is constant and p_1 and p_2 form different proportions of p. If, therefore, we consider that the portion p_1 required to overcome resistances $= rp$ the remaining portion p_2 to which the density is proportioned will equal $(1-r)p$. The expression $p_1\,(fp_1)$ (Sec. 5) may be replaced by $r\,(fp)\,p$ in which the coefficient of p has two factors r and (fp). So also the density (Sec. 6) $p_2\ D_1 = D_1\,(1-r)\,p$. The product of the two expressions is then $D_1\,r\,(1-r)\,(fp)\,p^2$. All the considerations above expressed may be embodied in an equation, and the difficulties some have encountered overcome by considering that Eq. 6, relating to the flow of an incompressible fluid, indicates the general form of a *differential* equation of the flow of an elastic fluid which will show the momentary rate of flow of its elementary masses. Calling G the weight of elastic fluid passing a given point in a given time and substituting the same for G_1 and the expression above for $D\,p_0$ in Eq. 6, squaring the result temporarily and expressing it as a differential, we have for the differential equation of the square of the flow of an elastic fluid the following:

$$(7) \qquad d\,G_2 = 2\,a^2\,g\,D_1\,p^2\,(fp)\,(1-r)\,r\,d\,r$$

Integrating and taking the root we have

$$(8) \qquad G = \left(2\,a^2 g\,D_1\,\left(\frac{r^2}{2} - \frac{r^3}{3}\right)(fp)\ p^2_{max}\right)^{1/2}$$

$$\text{Making} \quad \left(\frac{2\,a^2\,g\,D_1}{6}\right)^{1/2} = A, \text{ we have}$$

$$(9) \qquad G = A\,(3\,r^2 - 2\,r^3)^{1/2}\,(fp)\,p_{max}$$

In applying this equation to etheric magnetic flow, it should be borne in mind that Ewing shows that the magnetization B is made up of two parts, one due to what we call the concentrating influence of the iron, which in connection with a somewhat different course of reasoning he calls I, and to which Eq. (9) can only be made to apply, and the other directly proportioned to H, due to what we describe herein as the flow of lines through the space occupied by the iron as though no iron were present. For etheric magnetic flow, then, the above equation takes the form

(10) $$I = A\,(3\,r^2 - 2\,r^3)^{\frac{1}{2}}\,(f\,H)\,H_s$$

in which H_s = the value of H when the iron is saturated. We have also

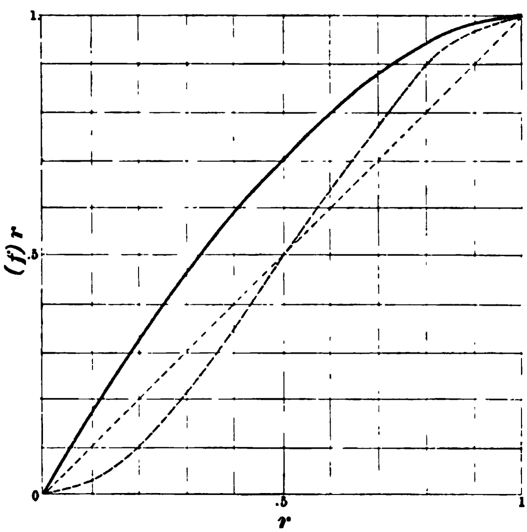


Fig. 1.

(10a) $$B = (H + I) = H + A\,(3\,r^2 - 2\,r^3)^{\frac{1}{2}}\,(f\,H)\,H_s$$

in which the function $(3\,r_2 - 2\,r_3)^{\frac{1}{2}}$ develops a factor of the variable coefficient of H_s, depending upon the law of the flow of fluids, and all influences on the value of I, due to external causes, are provided for by the other factor, $A\,(f\,H)$.

SEC. 8. In the expression $\sqrt{3\,r^2 - 2\,r^3}$, if $r = 0$, so that no part of the pressure is expended to produce motion, the whole equation reduces to 0 and there is no flow. If $r = 1$ the expression containing r reduces to unity. The ordinates of the fluid function are shown proportionally in Fig. 1. A direct linear function is shown by the diagonal. The modification due to $3 r^2 - 2 r^3$ is represented by the reversed curve in dotted lines crossing the diagonal at the center of the figure, and the complete function including the square root of the above is shown by the heavy line curve. The latter is in general similar to a curve showing the relation of the exciting force H to Ewing's intensity of magnetization I, and also resembles an H-B curve of magnetization, with a less intense initial action, which is yet to be provided for by substituting in Eq. (10a.) the value of $(f\, H)$. In Part II a number of H-B curves are shown, which may be examined for comparison.

SEC. 9. If we adopt the theory of etheric flow, we must conceive that the magnetization expressed at present as a definite number of magnetic lines is represented by the flow of a definite weight of etheric fluid. Recalling the signification of r and $1 - r$ in connection with Eq. (7), it will be seen that the fluid function simply shows that when r is small, but little of the exciting force is expended in forcing forward the etheric fluid and the larger portion of such force is utilized in increasing the density of the etheric fluid circulated, so that the weight circulated, and therefore utilized, is large compared to the exciting force expended to produce circulation, a higher percentage of the total exciting force is utilized and a higher efficiency of transmission obtained. When, however, the flow in a given area is increased, a larger proportion of the exciting force is required to produce the circulation and a smaller quantity available to increase the density, so the weight moved approaches a limiting or constant value which evidently will be reached when the volume is infinite and the density zero, a condition typified when $r = 1$ in Eq. (0) and Fig. 1, and by the magnetic condition that the permeability μ and induction I, due to the iron, each reach a maximum. *We therefore call especial attention to the fact that the simple laws relating to the flow of tangible fluids show a limiting condition analogous to that of magnetic saturation.* If as in Sec. 44, the value of $(f\, H)$ in Eq. (10) be derived by modifying the exponent of the fluid function, evidently at saturation, from Eq. (10.) $I_s = A H_s =$ also K Sec. 42. and from Eq. (10a), $B_s = (A+1)\, H_s$.

SEC. 10. The fluid function not only has an important bearing on the H-B curve of magnetization, as the shape of the curve would indicate, but may also, it is thought, be applied to correct on a rational basis the laws of the magnetic circuit. Recurring to formula 10 and to curves shown in Fig. 1, it is evident that, for a circuit of low resistance, very small values of r apply. When there are air gaps in the circuit increasing the resistance there should by analogy be a high pressure developed in the portion of the iron excited and a great fall of pressure at the gaps producing the principal resistance. This would require higher values of r, the same as if more etheric fluid were to be forced through a circuit of low resistance, but the actual flow or flux through the circuit containing the resistance would be less than in the other case, and this would of itself cause the resistance in the excited portion of the circuit to be less and permit a higher pressure there than if the same weight of etheric fluid (number of magnetic lines) were flowing at the time as would flow with the same exciting force in a circuit of low resistance. These considerations show that the laws of etheric flow in a magnetic circuit of low resistance need modification when applied to a circuit provided with air gaps. The fluid function above developed should aid in making the necessary corrections. The whole subject is so broad that this branch cannot at this time be further considered.

Sec. 11. It is apparent that the changes of the coefficient of H due to the fluid function alone are insufficient to account for the extreme values and abrupt changes in H-B curves of magnetization. We, however, find that not only do the laws relating to the flow of elastic fluids impose no condition antagonistic to the adoption of the theory of etheric flow, but on the other hand the elements of the fluid function vary in the right direction, and show a limiting value akin to magnetic saturation. They therefore aid in the development of the H-B curve, and in addition indicate means whereby one general law may be extended from the excitation of an iron ring of low magnetic resistance to magnetic circuits of the highest resistance.

Sec. 12. As mentioned above, the shape of nozzles, the hydraulic mean depth and the roughness of pipes and natural channels modify the flow of tangible fluids, as represented by $(f\,p)$ in Eq. (9), so in investigating etheric flow the conditions of the problem other than those imposed by the fluid function must be based on external conditions due to the environment represented by $(f\,H)$ in Eq. (10), and one of the elements of the H-B

curve of magnetization be derived not from the laws relating to the flow of fluids, but from the peculiarities of the material used for the concentration and transmission of the etheric current (magnetic lines of force), iron for instance, as modified by the

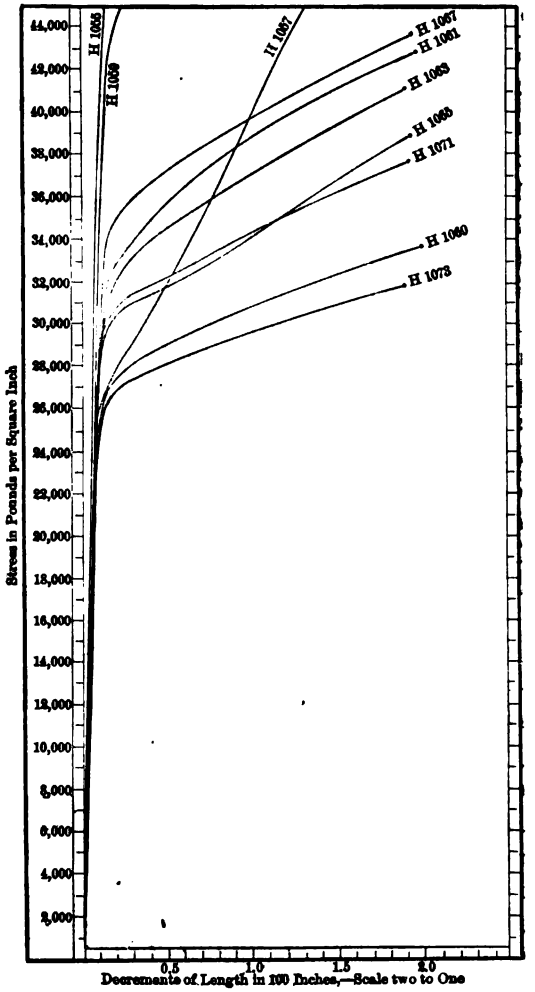


Fig. 2.

reactions between the flowing current and the molecules of the iron.

Sec. 13. At this point special attention is directed to Fig. 2, which is a reproduction of one of Kirkaldy's sheets, showing the decrements of length, under a gradually increasing thrusting stress, of ten Fagersta steel plates, each 100 inches long, part of which were annealed. The general similarity of appearance between the several curves and the typical *H-B* curve, Fig. 3, will be at once apparent. Curves showing the results arising from the mechanical compression of soft steel, rather than of iron, have been selected, simply from the fact that few compression curves are accessible in the publications. Curves showing increments of extension are more familiar and very much resemble those given, but the compression curves are better adapted for the present purpose, as will be seen hereafter. Corresponding curves for iron would show more initial slope and the sharp bend marking the elastic limit would occur at a lower strain. We wish simply to call attention to the general similarity, and this would evidently be even more marked were the horizontal scale of the strain diagram somewhat exaggerated. The magnetization rises sharply till saturation is approached, when its rise is quickly checked and the abrupt turn results. The strain curve shows the same quick rise and the same sharp turn at the elastic limit. The writer, after investigation, considers these similarities mere coincidences, but they are so remarkable that he has thought it better to present the curves for the consideration of others. They in a sense strengthen the theory of "molecular magnets," which the writer considers of value in a subsidiary sense only, Sec. 19, though it has been so well studied as to appear sufficient in itself to account for most of the phenomena. It seems necessary to present the arguments in favor of this theory somewhat in detail.

Sec. 14. According to the theory of Weber the molecules of iron become minute electro-magnets, which are by the operation of magnetization swung from accidental positions more and more nearly toward parallelism. This theory considers that the magnets are subject to a kind of constraint which tends to return them to their original positions. In Maxwell's amplification of the theory, the constraint is identified with molecular attraction, and this assumption agrees with the observed fact that if a moderate exciting force be applied and removed the magnets will swing back to their original positions, and the extent of the motion be sensibly proportioned to the force applied. Ewing claims that reaction among the elementary magnets themselves is sufficient to account for the phenomena, or, as understood by the writer, that on the withdrawal of the exciting force the original magnetic condition reasserts itself.[1] This theory would seem to be insufficient to account for the great magnetic efficiency of the softest iron which retains no trace of permanent magnetism. All of the modifications appear to have value, but the reactions due to molecular attraction, considered by Maxwell, are considered of the greatest importance.

SEC. 15. The strain diagram, Fig. 2, appears to confirm the theory of molecular magnets as modified by Maxwell, as it can be said that in one case we have a given material subjected to external mechanical forces, and in the other to the internal forces of magnetism; that the molecular attraction overcome in swinging the molecular magnets towards parallelism is represented by the strength of the material to resist crushing and tensible forces, and that the elastic reaction due thereto measures the intensity of the possible magnetization during the initial stages, shown by the curve of magnetization, Fig. 3, up to the abrupt turn. At or about that time, the molecular magnets have reached nearly the condition of parallelism, and are offering great resistance to further motion, and this effect is heightened by the fact that the several molecules are being attracted toward each other, actually shortening the mass and making further motion more difficult, so that after the approach to saturation, shown by the rapid bend in the curve, Fig. 3, the only additional magnetization which can be received by the molecules is that due to their still closer approximation to parallelism, and to the results must be added the increased effect due to the flow of lines in the space occupied by the magnet considered as if no iron were present.

SEC. 16. The conception is strengthened by what we know of the physical effects shown in magnetizing iron and of the results of external forces upon magnetized iron. Villari discovered, and Prof. J. J. Thomson has elaborated the fact, that weak magnetizing forces cause iron to elongate, and that as the magnetizing forces increase, the elongation is lost and an actual shortening takes place proportioned to the magnetization. The writer considers that the initial lengthening may be well explained by the fact that the molecules, lying in various directions, at first need room to arrange themselves in the same general direction, and that therefore the initial effort produces expansion, whereas

1 See Ewing on "Magnetic Induction." § § 163–171.

afterward, when such molecules are arranged approximately in the same direction, they can readily approach each other in response to the polar attraction between their adjacent ends. So also heating at first increases the intensity of the magnetization and afterwards decreases it, which we explain on the ground that it at first helps separate the molecules so as to facilitate their axial re-arrangement, and afterwards serves to separate the re-arranged molecules and prevent as close approximation as would be the case without the increased temperature. Again, elongation in general reduces, and compression increases magnetization with a given exciting force, which corresponds with the considerations above given. Bidwell's experiments show that nickel does not have the so-called "Villari reversal,"[1] which does not conflict with the above explanation, as we have simply to consider that its molecules are originally arranged in proper direction. On the contrary, cobalt is affected in the opposite way to iron, which may be explained by the fact that the molecules are so differently formed that they approach parallelism better by a movement in a different direction.

Sec. 17. The forces required to deflect the molecular magnets towards parallelism during the initial rise in the curve must on this theory be proportioned principally to the modulus of elasticity of the iron used. It may be that the angular change in direction of the molecules must also be considered, which will complicate the problem. The other features of the curve can evidently be explained by the extreme forces necessary to deflect still nearer to exact parallelism magnets tended to be held by definite elastic forces out of parallel, and to the energy that can be stored during these reactions must be added the flow through the space occupied by the magnets as if no iron were present. The action on the molecular magnets tends to a limit, and any curve plotted therefrom must therefore be an asymptote, and superimposed thereupon must be the linear values due to the direct action of the exciting force in moving lines through space independent of the special qualities of the iron in such space.

Sec. 18. By carefully reviewing the considerations expressed in Sections 15 to 17 inclusive, it will be observed that in presenting the Weber–Maxwell–Ewing theory of molecular magnets and the strain diagram, Fig. 2, in connection therewith, as a means of

1 Ewing on "Magnetic Induction." § 143.

finding a rational reason for the greater initial rise of the *H-B* curves of magnetization, than is shown by the fluid function, Eq. (10), such theory of molecular magnets offers an interesting and somewhat plausible explanation of the whole phenomena without necessarily involving the theory of etheric flow. The writer, however, contends that *etheric motion of some kind necessarily follows from the phenomena of magnetic action at a distance* (Sec. 2); that magnetic phenomena rather indicate a flow than a transfer of vibrations; that the fluid function plotted in a curve shows a general similarity to an *H-B* curve and a limiting condition analogous to magnetic saturation (Sec. 9); that such fluid function therefore confirms the theory of translatory rather than vibratory movements of the ether to explain magnetic phenomena, and that, therefore, such function is of the highest importance as evidence to connect magnetism with ethereal flow. On the contrary, the theory of molecular magnets does not aid in the explanation of action at a distance, but is still of value to intensify the effects shown by the fluid function.

SEC. 19. Recurring to the considerations expressed in Sections 15 to 17, we may allow that the elastic reactions due to molecular attraction measure the intensity of the possible magnetization during the initial stages shown on the diagram, Fig. 3, up to the abrupt turn, but it is not believed that the highest possible magnetizing force can equal, much less exceed, the high resistance to expansion or compression shown by the strain diagram, Fig. 2. Granting the theory of molecular magnets and the swinging of the same by magnetizing forces, such swinging, resisted by such great forces as are shown by the strain diagram, must be through very limited arcs. It is believed, therefore, that the molecular magnets simply act to intensify the magnetization through the range it is possible to swing the same, and that higher magnetizations to the point of saturation are in the main governed by the laws of the flow of fluids exemplified by the fluid function developed above. In the "Conclusion," at Sec. 44, it is shown that the intensification due to molecular magnets may be considered in Eqs. (10) and (10a) by simply changing the exponent of the fluid function and a very gratifying accordance with experimental results is there obtained on such basis.

SEC. 20. In closing this branch of the subject, it will be of interest to consider how other physical phenomena can be explained if it be finally settled that magnetism is due to the circulation of an ethereal atmosphere. In such case we must imagine that the ether pervades all space, and we may suppose it susceptible to vibrations and therefore capable of transmitting vibratory forms of force, such as light, without interference with the phenomena or magnetism due to the circulation of its ultimate particles. This atmosphere need not necessarily be the luminiferous ether, though there is no reason why it should not be so. The etheric fluid itself may pass freely through all substances, gaseous, liquid or solid, and yet its vibration known as light be damped and checked by some of such liquids and solids, but flow freely in others known as transparent. It will be more difficult to consider one mode of motion of the same ether as light and another as electricity, for both modes of motion should be damped by the same substances that dampen light, whereas we know that light is readily transmitted through glass and electricity is not, and that electricity is readily transmitted through copper and a similar class of substances known as conductors, which do not transmit light. If magnetism be the circulation and electricity a form of vibration of the same ether, there would be a more direct transformation of electric into magnetic force, whereas we know that no direct transfer takes place. A magnetic flow and an electric current may be moving at the same time in the same piece of metal, an iron magnet for instance, without one modifying the other in any way.

Sec. 21. Any explanation founded on the analogy of the polarization of light should be proved from some direct transformations of electricity into light without heat. Tesla appears to be doing this, but it is believed that his results can be explained on the basis that the passage of a high potential and high frequency alternating current through a low conducting medium actually puts the ether in vibration, thus producing light as above indicated. It is believed also that the apparent transmission of high tension discharges through the dielectric instead of the conductor will eventually be traced to magnetic phenomena, leaving us free to consider substantially as in the past that electrical phenomena are due to a form of motion of the molecules of solids which are susceptible to this kind of motion, like metals of the copper class, though the molecules of all substances, even of gases, and possibly of ether, are conductors in a limited sense or under peculiar circumstances.

SEC. 22. The subject has proved of great interest and has been considered of such importance that it is submitted to the profession in its present stage of progress in order that the minds of others may become occupied in the same direction and aid in the complete solution of the complex problem, using as much of the above as may survive the test of criticism and of further experiment.

PART II.

SEC. 23. We will now proceed to the second branch of the inquiry, viz.: the development of empirical formulæ to represent typical H-B curves of magnetization. Such curves, though empirical, will enable equations to be completed, involving varying values of H or B, and thereby permit the application of the mathematical laws of maxima and minima with all the important conditions of the problem included. Empirical formulæ serve also to correct errors in particular records by general comparison through the whole range of the observations and at the same time furnish a more ready and accurate means than arithmetical interpolations to obtain intermediate values really dependent upon complex functions.

SEC. 24. Many approximate formulæ have been suggested for the purpose, of which one of the forms proposed by Frolich, of an expression developed by Lamont and others, has been most generally used. Frolich's equation, in the form

$$B = \frac{H}{a + b\,H} \tag{11}$$

to which all the other forms may be reduced, will, with given constants a and b, approximately represent a considerable portion of some H-B curves of magnetization. In Fig. 3 the application of Frolich's formula is shown in dotted lines in connection with an H-B curve shown in full lines for a Norway iron ring, based on experiments of Rowland in 1873 and presented in a recent paper of Mr. Kennelly.[1] The Frolich function contains

1 "Magnetic Reluctance," by A. E. Kennelly, TRANSACTIONS, Nov., 1891, vol. viii., p. 492. If Eq. (11) in text be divided through by B, we have

$$\frac{H}{B} = \rho = a + b\,H \tag{12}$$

which is the linear equation of the reciprocal of the permeability, or of the "reluctance" ρ, given by Mr. Kennelly. This shows that the Frolich and Kennelly formulæ are identical, though stated in different terms. The constants developed by each are applicable in the formulæ of either, and, in the only two constants, so that it can only be passed through any two points of a curve, and is therefore frequently unsatisfactory except very near the points of application.

SEC. 25. The writer has found it of advantage in developing empirical formulæ to use well-known curves which bear a general

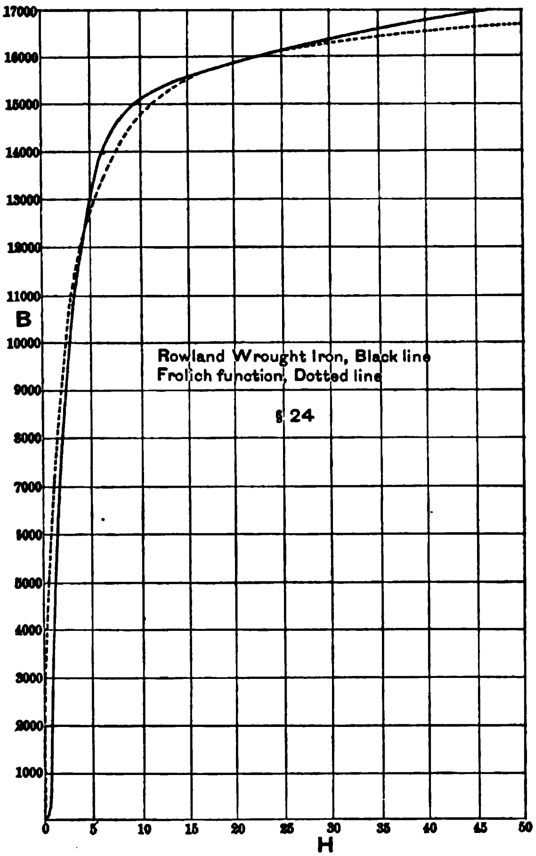


Fig. 3.

resemblance to the curves to be fitted. *H-B* curves of magnetization bear some resemblance to those given by ordinary logarithmetic formulæ, and also resemble a simple hyperbola, though

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application above, made the value of the reluctance for the second branch of the reluctance curve obtained from the above experiments by Mr. Kennelly is used as the denominator of the fraction in the Frolich formula, Eq. (11). Other applications are given by Frolich in his original papers, in *Electrotechnische Zeitschrift*, 1881, 1882, and by Mr. Kennelly in the paper referred to.

the two branches are rarely symmetrical. An equation well adapted for practical use is that of an hyperbola in the form

$$B = c + \frac{b + H}{a} \qquad (15)$$

There being three constants in this equation, the resulting curve can be passed through any three points of any experimental curve by deriving the values of the constants by simple substitution.[1] Some *H-B* curves of magnetization may be roughly shown by one application of this formula, but by making one application to include the limit from $B = 0$ to some definite point above the abrupt turn, with the third point on or just below the turn, the curve will generally be accurately shown between these limits, and another application, made to three points above the higher limit, will generally show very accurately that branch of the curve. Moreover, the two curves extended will generally coincide practically for a little distance either side of the junction, and it is possible to make the first differential coefficients of the two alike and thereby join the two curves at the same point and at the same angle and make the curve continuous, but this refinement will rarely be found necessary. No attempt is made in this connection to apply the formula to the sharp bend near the origin, marking the excitation necessary to cause the molecular magnets to turn toward approximate parallelism (Sec. 16), but the application can readily commence at excitations of 2 to 3 or 5 for soft iron and steel respectively, and this has a rational basis as shown in Section 41.

SEC. 26. The first application of this curve will be made to the experimental determinations of Mr. Steinmetz, given in one of the series of experiments made in connection with his researches on the law of hysteresis.[1] In these experiments three different samples of sheet iron were tested, one from a Westinghouse converter and the other two from iron of different thicknesses used in the Eickemeyer manufactory, and all showed a remarkable uniformity in result. The experimental values of *B* given in Table III, p. 15 of the paper of Mr. Steinmetz, are reproduced in

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1 It would be more rational to separate *H* and *I* in these formulæ somewhat as in Eq. (10a), but in this branch of the subject we are only seeking to fit formulæ to expermental curves, which can be done as well with the equation in its simpler form.

1 Steinmetz on the Law of Hysteresis. TRANSACTIONS, vol. ix, p. 1.

Table I.,

Showing, in different terms, the magnetomotive forces and resulting magnetizations of wrought-iron, in connection with experimental results of Steinmetz, Ewing and Hopkinson, and calculated values from empirical and general formulæ.

1	2	3	4	5	6	7	8	9	10	11
	$1.257 H_1$	$6.4514 H_1$	$3.109 H_1$		$6.4514 B$					
ELECTRIC EXCITING, OR MAGNETOMOTIVE FORCE.				MAGNETIZATION IN MAGNETIC LINES.				Exciting force.	MAGNETIZATION.	
Per square centimetre.		Per square inch.		Per sq. centimetre.	Per sq. inch.	Per square centimetre.		Lines per sq. centimetre.		
				Steinmetz.				General Formula (29) and (30)		Thomson (see Table 2.
Amp. turns. H_1	Mag. lines. H	Amp. turns. H_2	Mag. lines. H_2	B	B_2	B Form'la (16a)	B Form'la (16b)	H	B	B
1	1.26	6.45	8.11							
2	2.51	12.90	16.22	1700	10967	1700				
3	3.77	19.35	24.33	4200	27096	....				
4	5.03	25.81	32.44	7400	47740	7760	....	5	10086	10000
5	6.29	32.26	40.55	9200	59353					
6	7.54	38.71	48.65	10400	67095	10400				
7	8.80	45.16	56.76	11160	71998					
8	10.06	51.61	64.87	11850	76449					
9	11.31	58.06	72.98	12470	80449	....	....	12	12360	13000
10	12.570	64.51	81.09	13070	84320	12797				
12	15.08	77.42	97.31	13750	88707					
14	17.60	90.32	113.5	14260	91997	14215				
16	20.11	103.2	129.7	14600	94190					
18	22.63	116.1	146.0	14900	96126	14941	14944			
20	25.14	129.0	162.2	15200	98061	15202	15200			
25	31.43	161.3	202.7	15700	101287	15682	15785	28 5	14494	15000
30	37.710	193.5	243.3	16200	104513					
35	44.00	225.8	283.8	16680	107609					
40	50.28	258.1	324.4	17050	109996	....	17184			
45	56.57	290.3	364.9	17500	112900					
50	62 85	322.6	405.5	17900	115480	....	17901	52	16036	16000
55	69.14	354.8	446.0	18300	118060					
60	75.42	387.1	486.5	18650	120319					
65	81.71	419.3	527.1	19030	122770					
70	87.99	451.6	567.6	19380	125028	....	18996			
75	94.28	483.9	608.2	19730	127286					
80	100.6	516.1	648.7	20080	129544					
85	106.9	548.4	689.3	20400	131609	....	....	105	17945	17000
90	113.1	580.6	729.8	20750	133867	....	19796	200	19760	18000
	502.	....	....	....	.....	....	....	502	21800	
	1002.	....	....	....	....	....	... ...	1002	22300	
Ewing.										
	1490	....	......	22650	....	....	....	1490	22790	
2865	3600	18483	23232	24650	159027	....	24649	3600	24900	
	8600	....	....	30270	....	....	......	8600	29900	
	19450	......	... .	40820	....	....	....	19450	40750	

column 5 of Table 1 of this paper, and the exciting forces given in ampere turns per square centimeter in the paper of Mr. Steinmetz are here reproduced in column 1. The exciting forces in terms stated, herein designated (H_1) are so regularly distributed that the opportunity has been embraced to add for the purposes of comparison the corresponding number of magnetic lines per square centimeter (H); also the corresponding number of ampere turns per square inch (H_3) and the corresponding number of magnetic lines per square inch (H_2). There are also added in connection with the magnetizations in magnetic lines per square centimeter the corresponding magnetizations in magnetic lines per square inch (B_2).

Sec. 27. The equations in the form of Eq. (15) showing the magnetizations B (mag. lines per sq. cm.) in terms of the exciting forces H_1 (amp. turns per sq. cm.) are as follows:

For $H_1 = 2$ to 20 (Steinmetz)

(16a) $$B = 17730 - \frac{54021}{H_1 + 1.37}$$

For $H_1 = 20$ to 2865 (Steinmetz)

(16b) $$B = 24908 - \frac{755962}{H_1 + 57.87}$$

The corresponding equations showing the magnetizations B_2 (mag. lines per sq. inch) in terms of the exciting forces H_3 (amp. turns per sq. inch) are as follows:

For $H_3 = 13$ to 129 (Steinmetz)

(16c) $$B_2 = 114383 - \frac{2248380}{H_3 + 8.838}$$

For $H_3 = 129$ to 18500 (Steinmetz and Ewing)

(16d) $$B_2 = 160692 - \frac{31463500}{H_3 + 373.34}$$

Sec. 28. Several values calculated by formulæ (16a) and (16b) are given in columns 7 and 8, Table I. The largest variation for formulæ (16a) appears for $H_1 = 4$. The Steinmetz results at this point are phenomenally low, as will be seen by comparison with the corresponding value for Hopkinson's experiments in column 11. It has been thought desirable to present these careful experiments by Mr. Steinmetz with the Eickemeyer apparatus for comparison with other experiments, but it will be observed by comparing Tables 1 and 2 that for all values of B, greater than for $H_1 = 10$, the Steinmetz results are higher than those customarily given, so much so in fact as to suggest hesitancy in using the samé until the methods of observation are thoroughly discussed. It has been thought that the three specimens of sheet iron tested by Mr. Steinmetz would on analysis prove to be steel, but the results are even higher than those obtained for steel in the Cornell experiments hereinafter referred to, as shown in Fig. 4.

SEC. 29. As a matter of interest the upper limit used in determining equation (16*b*) was based on Ewing's experiments[1] with exceedingly high magnetizations, the value selected, as seen at bottom of Table I, being for $H_1 = 2865$, $B = 24650$. This fact makes the results from Eq. (16b) fall below the higher of the observed Steinmetz results. There would have been no difficulty in confining the formula to the range of observation, when it would have fitted more accurately throughout its whole length as shown in subsequent applications. The interest attached to a formula reaching so nearly to the extreme limits of observation has been thought to warrant this application. It will be observed however that the equation only fits the one value from Ewing selected. The others can only be reached through a more general formula like Eq. (26) to be discussed hereafter. (See column 10).

SEC. 30. The second application of formula (15) has been made to the tabulated results given at page 143 of the 4th edition of Prof. S. P. Thompson's work on "Dynamo Electric Machinery." This table, as is known, was obtained by averaging the ascending and descending values of B obtained during experiments by Hopkinson on wrought-iron. The empirical formula showing approximately the tabulated magnetizations B (mag. lines per sq. cm.) in terms of the exciting forces H (mag. lines per sq. cm.) are as follows:

For $H = 1.66$ to 52 (wrought-iron)

(17a) $$B = 16819 - \frac{55656}{H + 3.049}$$

For $H = 52$ to 666 (wrought-iron)

(17b) $$B = 20816 - \frac{848915}{H + 117.5}$$

1 Ewing on "Magnetic Induction." Ed. 1892, Table XII, p. 144.

TABLE II.,

Showing magnetomotive forces and resulting magnetizations of wrought-iron, in different terms, in connection with average results of experiments by Hopkinson, tabulated by Thompson, and calculated values from empirical formulæ; showing also Cornell experimental results with mitis metal and calculated values from empirical formulæ connecting the initial results for mitis metal with the Hopkinson results for wrought-iron.

1	2	3	4	5	6	7	8	9
ELECTRIC EXCITING OR MAGNETOMOTIVE FORCE.			MAGNETIZATION IN MAGNETIC LINES.					
Mag. lines.	Ampere turns.		Per sq. cm.	Per sq. inch.	Per sq. cm.	Per sq. cm.	Per sq. cm.	Per sq. cm.
Per sq. cm.	Per sq. cm.	Per sq inch.	THOMPSON.		FORMULA (17a)	FORMULA (17b)	CORNELL mitis No. 22.	FORMULA (18a) Compromise.
H	H_1	H_3	B	B_2	B	B	B	B
1.66	1.32	8.52	5000	32257	5000			
4.0	3.18	20.53	9000	58063	8924		6250	6617
5.0	3.98	25.66	10000	64514	9904		7750	7729
6.5	5.17	33.36	11000	70965	10991		9100	9038
8.5	6.76	43.62	12000	77417	12000		10450	10335
12.0	9.55	61.58	13000	83868	13121		12000	11875
17.0	13.5	87.24	14000	90320	14043		13350	13230
28.5	22.7	146.3	15000	96771	15055	15001	15000	14817
52.0	41.4	266.9	16000	103222	15808	15808	16300	16072
70.0	55.7	359.2				16289	16850	16502
105.0	83.5	538.9	17000	109674		17001		
200.0	159.1	1026.	18000	116125		18143		
350.0	278.4	1796.	19000	122577		19000		
666.0	529.8	3418.	20000	129028		19733		

For exciting forces H_3 stated in ampere turns per square inch and magnetizations B_2 in magnetic lines per square inch, these equations take the form

For $H_3 = 8.5$ to 267 (wrought-iron)

$$(17c) \qquad B_2 = 108506 - \frac{1842826}{H_3 + 15.649}$$

For $H_3 = 267$ to 3420 (wrought-iron)

$$(17d) \qquad B_2 = 134292 - \frac{28108425}{H_3 + 603.06}$$

SEC. 31. On account of the tables, etc., only the preliminary paragraph of the second part of this paper was read at the General Meeting, so this part of the paper has been revised to include the consideration of the experiments presented at such meeting by Dr. Nichols recorded in the paper of Messrs. Thompson, Knight and Bacon on "The Magnetic Permeability of Special Irons for Electrical Purposes." As these experiments were part of the regular course of study in the Department of Electricity at Cor-University, it is due to that institution and Dr. Nichols, and prevents confusion, without disparagement of the excellent work of still another Thompson and his associates, to refer to such experi-

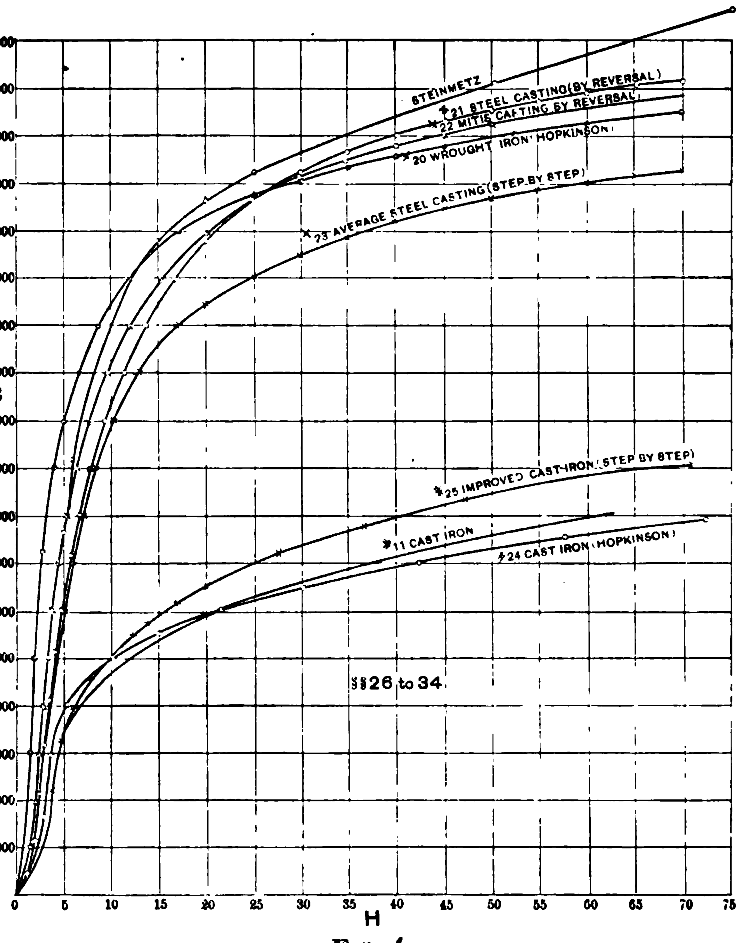

Fig. 4.

ments as the "Cornell" experiments, designating the curves by the numbers written thereon in the original paper. See Fig. 4.

Sec. 32. An examination of the Cornell experiments shows clearly what we had previously gathered verbally from Mr. Steinmetz, and what has probably been known to large manufacturers for some time, that some samples of soft steel, either in the form of castings or plates, though showing less magnetization for low exciting forces than iron, really attain a higher magnetization than iron as the exciting forces are increased. Though the Cornell paper shows the latter fact in regard to many specimens, it is not true of all, so it is thought that in practice without tests, higher values than those of S. P. Thompson for wrought-iron should not be considered. The initial magnetizations shown by wrought-iron are, however, too high for steel and mitis metal, so an empirical equation has been developed in the form of Eq. (15) to include both limitations. The initial values have been made to imitate the Cornell results for specimen No. 22 of mitis metal, the results from which are a fair average of those from iron and steel as may be seen by comparing column 8, Table 2. The higher values by equation have been caused to follow closely the Thompson–Hopkinson values, column 4, Table 2. This compromise curve can, between the limits of the Cornell experiments, be expressed by one equation as follows:

For $H = 3$ to 70 (Compromise iron and steel)

(18a) $$B = 17868 - \frac{102576}{H + 5.1165}$$

For $H_s = 14$ to 350 (Compromise iron and steel)

(18c) $$B_2 = 115274 - \frac{3396394}{H_s + 26.26}$$

Several values from Eq. (18a) are given in column 9, Table 2.[1]

SEC. 33. The Cornell curve No. 23 showing magnetizations for average steel castings can, by slightly reducing the lower values, also be expressed by one equation, as follows:

For $H = 5$ to 70 (Av. steel casting)

(19a) $$B = 17035 - \frac{124740}{H + 6.304}$$

For $H_s = 25$ to 360 (Av. steel casting)

(19c) $$B_2 = 109900 - \frac{4130266}{H_s + 32.3546}$$

1 Since writing the above it has been found that the Frolich function, Eq. (11), which, as has been explained will not fit closely some forms of H-B curves, can be adapted to show satisfactorily a compromise steel and iron curve throughout a considerable range. The tendency of the function to decrease the higher values, can be overcome by making another application of the formula through a different range. The advantage is that, when a table of reciprocals is available, the arithmetical solutions are even more simple than for the equations

SEC. 34. The curve, No. 24, Fig. 4, for cast-iron, based on experiments by Hopkinson, given by Thompson at page 302, 3d ed. of his book previously referred to, shows results approximately agreeing with those from ordinary American cast-iron, though an improved quality gives higher results, as shown in Cornell No. 25, Fig. 4. The Thompson–Hopkinson curve may be formulated as follows:

For $H = 5$ to 80

(20a) $$B = 9572 - \frac{164201}{H + 24.469}$$

For $H = 80$ to 127

(20b) $$B = 6300 \times 21.3\ H$$

a simple rectilinear function which will answer, for the limits stated and the rarely used higher results may be obtained from a table.

For $H_3 = 25$ to 400

(20c) $$B_2 = 61753 - \frac{5436859}{H_3 + 125.58}$$

For $H_3 = 400$ to 615

(20d) $$B_2 = 40644 \times 26.774\ H_3$$

The Cornell experiments show for some specimens of cast-iron higher results than those given by Thompson, but for some of the results a falling off during low magnetizations similar to that for steel is to be observed. When high magnetizations are to be secured in any case, a safer number of field turns will be secured by using a curve of what may be called the "delayed action" or steel form. We accordingly give a single

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above given. For this purpose we preferably apply Eq. (11) by dividing through by H, so as to show the permeability, μ, and in this shape the following formulæ will be found very convenient:

For $H = 6$ to 105,

(18f) $$\mu = \frac{10^7}{554.2\ H + 3624};$$

For $H = 105$ to 184,

(18g) $$\mu = \frac{10^6}{5.182\ H + 80};$$

For $H_3 = 30$ to 540,

(18h) $$\mu = \frac{10^7}{108\ H_3 + 3624};$$

For $H_3 = 540$ to 943,

(18i) $$\mu = \frac{10^6}{H_3 + 80}.$$

Compromise Iron and Steel.

equation for a curve closely resembling Cornell No. 11, which gives lower initial values for cast iron than those of Thompson–Hopkinson, but slightly increases the higher values. Such equation is

For $H = 3$ to 70 (Compromise cast-iron)

(21a) $$B = 9980 - \frac{168120}{H + 19.476}$$

For $H_3 = 14$ to 360 (Compromise cast-iron)

(21c) $$B_2 = 64385 - \frac{5566621}{H_3 + 99.9586}$$

SEC. 35. It is believed that the several examples above given can be advantageously employed in practice, and that the same illustrate the applicability of the system so that others can construct curves specially adapted to the particular material used. In countries where English units are employed the H_3-B_2 formulæ will be found a great convenience, as from them the magnetization in magnetic lines per square inch can be obtained directly from the number of ampere turns per square inch without first ascertaining the several results in lines per square centimeter, and the results can readily be compared with those on another basis by reference to Table 1. The numbers of each H-B equation referring to square centimeters are marked sub-*a* and sub-*b* for the earlier and later portions of the curve respectively, and the same numbers with sub-*c* and sub-*d* added give the corresponding H_3-B_2 results for square inches. For some pur poses it may be convenient to read magnetizations approximately from a curve on a large scale or from a table. but there are many cases when this will not answer, and it will be found that a particular value can be ascertained by making the full calculations from the formula about as quickly as by interpolation and with much greater accuracy and satisfaction. Independent of this the formulæ are of great value for use under the conditions stated in Section 23. When B_2 equations of magnetizations per square inch are used, other formulæ in which the values are substituted may require modifications, but the same are of a simple and evident nature.

CONCLUSION.

SEC. 36. The previous discussion in Parts I and II of the theoretical and practical phrases of the general question now form a sufficient foundation for the development of a general equation.

It will be observed that in the hyperbolic formulæ, Eq. (15), the first term c of the second member really represents, so far as this form of equation can, without separating I as in Section 7 and Section 40, the number of lines which will saturate a given material through the range to which the formula is applicable. For instance, the apparent saturation limit for Eq. (17a) is 16819, but we also observe that the apparent saturation limit for Eq. (17b) is 20816, or considerably higher than in the other equation applying to the initial portion of the same curve. These formulæ appear, therefore, to sustain a view which has been expressed by others that the saturation limit rises as the exciting force is increased. This apparent confirmation is, however, due to the inapplicability of the particular formulæ to represent the conditions for widely different values, though it is quite sufficient to merely show between limits the relations of H and B. It should be noted that the upper branch of the curve being an asympote will continually approach the limiting value c in Eq. (15), but never reach it.

Sec. 37. Ewing states distinctly (p. 149), that saturation had been definitely reached within the limits of his experiments, though, as stated in different language, additional lines were added above that limit by the action of the solenoid as if no iron were present. It may readily be shown that his experiments sustain these views. If we subtract the values of H, accredited to Ewing in Tables 1 and 3, from the corresponding values of B, we have, as shown in the third column of Table 3, headed $B - H$, a practically constant quantity, which may be called absolutely so in view of the difficulty in making close experimental readings under such extraordinary conditions. The aver-

Table 3, Based on Experiments of Ewing.[1]

H	B	$B - H$
1490	22650	21160
3600	24650	21050
0070	27130	21060
8600	30270	21670
18310	38960	20650
19450	40820	21370
19880	41140	21260
		7) 148220
		$K =$ 21174

1 See foot note. § 29.

age of the several values of $B - H$ is 21174, and this must certainly mean the maximum or limiting value of I, Section 7, or the number of lines representing the saturation of the particular material experimented upon.

Sec. 38. Table 3 also shows that at these high limits the magnetization increases directly with the exciting force and is

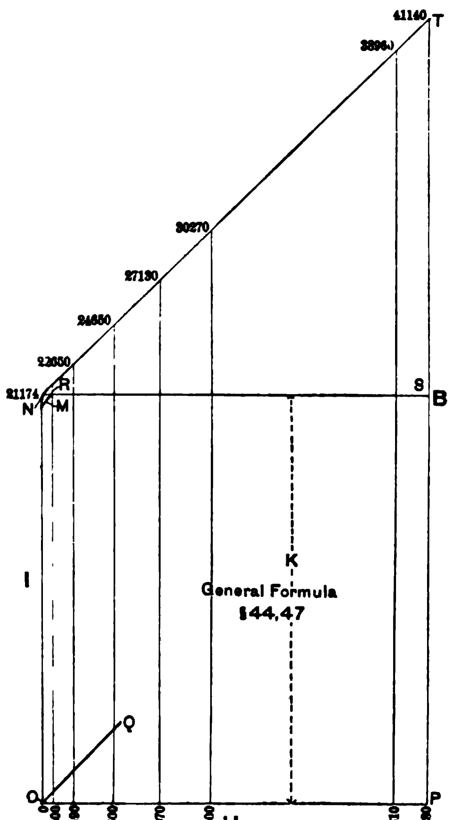

Fig. 5.

numerically equal to the saturation value of I, plus the exciting force H, and indicates that this law extends from these high values back to the origin where the exciting force and magnetizations are zero. If in Fig. 5 we let the ordinates of the triangle $R\ T\ S$ represent the lines of magnetization due to the solenoid, or substantially in the language used in Section 17, to the number of lines circulated through the space occupied by the iron as if no iron were present, the base and altitude of this triangle will each equal H, and on the principle above stated, this triangle must be superimposed upon a rectangle of which the base $= H$ and the altitude equals the saturation limit of the iron or I maximum which we will call K. The figure has purposely been drawn to scale to include the highest values given by Ewing (See Table 3), viz.: for $H = 19880$, $B = 41140$.

SEC. 39. Further investigations appear to show that the iron which produces a concentration, $K = 21174$ lines per square centimeter reaches saturation with an exciting force H_s between 500 and 2000 lines, whereas less than 100 lines are generally used, so the only part of the trapezoidal figure 5 which we refer to in prac-

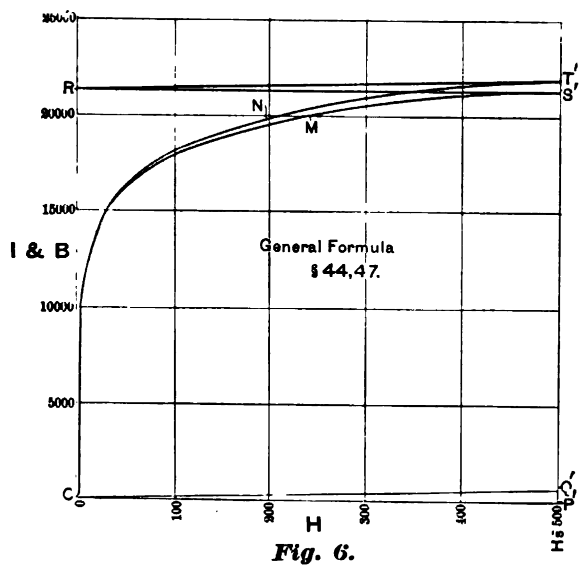

Fig. 6.

tice is about $\frac{1}{200}$ of its length, or about $\frac{1}{5}$ of the portion included between the ordinates at the origin and the parallel line close thereto marked 500. In order to ascertain how the ordinary H-B curve of magnetization applies within this limit, it is necessary to make another view, Fig. 6. extending from $H = 0$ to 500, the range included between the first two ordinates in Fig. 5, but with the horizontal scale magnified. In this view R T_1 S_1 represents the initial portions of the triangle R S T in Fig. 5, and O R S_1 P_1 represents similarly a portion of the rectangle below the same. M represents a modified curve of magnetization in which the ordinates of an ordinary *H-B* curve are shortened by the corresponding values of *H* when measured from the base $O\ P_1$, and *N* represents the same curve of reduced height when the ordinates are measured from an inclined line $O\ Q_1$ parallel to $R\ T_1$.[1] The curve gore between *M* and *N* has the same area as the portion of the triangle from the ordinate at the origin to the point of tangency of the curve, so the upper curve *N* represents the entire *H-B* curve of magnetization if its ordinates be measured from the base $O\ P_1$.

SEC. 40. We may now formulate on a rational basis the values of *B* for the whole length of the curve or diagram above developed. There are three distinct influences acting to produce this curve, 1st, the magnetic lines proportioned to *H*, shown by the triangle *R T S*, which affect the result throughout the entire range; 2nd, the concentrating influence *I* of the iron, the maximum value of which adds the additional magnetic lines *K* shown by the altitude *O R* of the rectangle, and 3d, the influence which causes the initial delayed action of the iron, shown by the reversed curve at the origin, *O*, Fig. 6. (See also Fig. 4.)

SEC. 41. The 1st influence above stated may be simply expressed by adding *H*, variable, as a term in the equation. The 3d influence may be measured by the number of lines necessary to expand the core, disengage the molecular magnets from their accidental positions and arrange them substantially parallel, as explained in Section 16, and as may be represented by starting the curve a definite distance from the origin. Of course a function could be employed to develop a curve joining the origin with the main curve, but it is unnecessary in ordinary practical work. If we represent by *k*, the number of lines required for the purpose above explained, we have but to use in the equation developed, $H - k$ instead of *H*, thus practically causing the curve to intersect the axis of abscissæ at a distance, *k*, from the origin.

SEC. 42. The second influence, *I*, due to the action of the iron in initially building up the magnetization, is, as has been previously discussed, Sec. 7, a function of *H* or $(f\ H)$ acting only from $H - k$ to the point of saturation. If we let H_s equal the number of lines of exciting force required to produce saturation and *K* the magnetization at saturation, due to the iron alone, we may write

1 This is the *I-B* curve of Ewing.

From $H = 0$ until $H = H_s$ and $(f\,H) = K$

(22) $$B = (H - k) + (f\,H)$$

When H is greater than H_s

(23) $$B = (H - k) + K$$

Sec. 43. We may base the function of H, $(f\,H)$ in Eq. (22) on the fluid function, viz.: $(3\,r_2 - 2\,r_3)^{1/2}$ developed in Section 7. In this function it will be recollected that r is a ratio varying only from 0 to unity. The value of r in this case is evidently the actual number of lines available for excitation, viz.: $H - k$ divided by the exciting force at saturation, viz: H_s, or

(24) $$r = \frac{H - k}{H_s}$$

Sec. 44. In the form given above the fluid function is, as stated in Section 11, of insufficient intensity. If we consider, as is probable, that the molecular magnets act to change the intensity in accordance with the same laws as the fluid function acts, we can change the intensity shown by the fluid function by simply changing its exponent. As r is fractional, the intensity will be increased by decreasing the exponent. Multiplying such exponent by $\frac{1}{m}$ in which m is, in a sense, the coefficient of intensification, and putting n equal to the product of $\frac{1}{m}$ by $\frac{1}{2}$, the exponent of the fluid function, we have

(25) $$n = \frac{1}{2\,m}$$

Substituting such fluid function with n as the exponent in place of $(f\,H)$ in Eq. (22), we have

For $H = 0$ to $H = H_s$ and $(f\,H) = K$

(26) $$B = (H - k) + K\left(3\left(\frac{H-k}{H_s}\right)^2 - 2\left(\frac{H-k}{H_s}\right)^3\right)^n$$

For H greater than H_s, Eq. (23), applies as before.

That is, above the point of saturation the iron ceases to act to concentrate magnetic lines, so the fluid function must be caused to disappear as r reaches its limiting value, unity.

Sec. 45. Before substituting actual values in the above equation we will examine the remarkable properties of the simple equation underlying the fluid function, viz.:

(27) $$y = a\,r^n$$

when r is a ratio less than or not greater than unity and the exponent n is fractional or not greater than unity. If in Eq. (27) $n = 1$ the equation is that of a straight line and the different values of y, as r is varied from 0 to unity, will plot in a diagonal. (See Fig. 1) If $n = 0$ the ordinates for all values of r will equal unity and the same will all plot in the upper horizontal line of Fig. 1. For the lowest conceivable fractional value of n the values of the ordinates in the equation will plot in a right angle. This curious function therefore developes two sides of a triangle as one of its limiting values and the diagonal of the same for its other limiting value, and for values of n, intermediate between 0 and 1, the whole area of the triangle will be filled with similar curves gradually changing in shape from a right angle to the hypotenuse of a right angled triangle. If instead of r a function of r be used, for instance the fluid function shown by the reversed dotted curve in Fig. 1. the limiting values of $(f)\ r$ will be the same, viz.: the right angle and the diagonal, but for decreasing values of n the triangle will be filled with curves modified in shape by that of the reversed curve. We can then intensify the ordinates of the fluid function embodied in Eq. (26). (See Section 43) as described in Section 44, by decreasing its exponent by a multipler $\frac{1}{m}$, so as to develop a curve either departing little from a diagonal as in Fig. 1, or so as to approximate a right angle, or, at will, to take any intermediate position.

Sec. 46. It is evident, in accordance with the principles above explained in relation to Eq. (27). Section 45, that the values of k, K, H_s and n Eq. (26) can be so modified as to embrace the same conditions and trace a curve practically identical with any regular H-B curve of magnetization. The equation is, however, not a simple one to operate, so no attempt has been made to use fractional exponents extended to several decimal places as would be required to fit a particular curve. In a particular application now to be presented, the constant values employed were as follows:

$k = 2.3$, $H_s = 500$, $K = 21300$ and $m = 6.25$ so from Eq. (25)

$$(28) \qquad n = \frac{1}{2m} = \frac{1}{12.5} = 0.08$$

On this basis we have by substitution in Eq. (26)

For $H = 0$ to 502

(29) $B=(H-2.3)+21300\left[3\left(\frac{H-2.3}{500}\right)^2-2\left(\frac{H-2.3}{500}\right)^3\right]^{0.08}$

For H greater than 502 from Eq. (23) we have

(30) $B = (H-2.3) + 21300 = H + 21298$

SEC. 47. A curve derived from the general equation, in the form above is shown at N in Fig. 6, and several values are given in column 10 of Table 1 for comparison with the results obtained by Steinmetz, shown in column 5, and those of Hopkinson by Thompson, shown in column 11. The initial rise shown by this particular form of the general equation is more like that of Thompson than of Steinmetz; the curve then rises less rapidly, and coincides with Thompson for $B = 16000$, after which the general equation values run intermediate between those of Thompson and Steinmetz, and finally correspond with the experimental results of Ewing, shown at the bottom of the table, with a surprising degree of accuracy, considering the difficulties of the problem.

SEC. 48. It thus appears that by the combination of the fluid function with a rectilinear one, a general expression is produced on a rational basis applicable both for moderate magnetizations and the exceedingly high ones given by Ewing. It has been shown in Part I, Section 11, that "the laws relating to the flow of elastic fluids impose no condition antagonistic to the adoption of the theory of etheric flow, but on the other hand the elements of the fluid function vary in the right direction and show a limiting value akin to magnetic saturation." So also, as per Section 18, the fluid function "confirms the theory of translatory rather than vibratory movements of the ether to explain magnetic phenomena." In this conclusion we have shown the adaptability of the fluid function to represent actual experimental results accurately, which furnishes still further evidence to prove the identity of magnetism with an etheric flow, which can be intensified by molecular magnets, thus utilizing in part the theoretical work that has has been done in that direction, as outlined in Sections 13 to 17, and providing at the same time for action at a distance, Section 2 and Section 18, through a medium extending through such distance.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 6th, 1892. Vice-President Lockwood in the Chair.

A DYNAMO INDICATOR, OR INSTANTANEOUS CURVE-WRITING VOLTMETER.

BY GEORGE S. MOLER.

In connection with the work in dynamo and motor testing in the physical laboratory of Cornell University, it was found desirable that some method should be devised which would enable the student experimenting, to very quickly explore the field of a machine, so that he could study some of the changes which might take place even in a few seconds. The double brush method of Dr. S. P. Thompson, and the single brush method of Mr. W. M. Mordey, are in use and give excellent results, but either of these methods requires a few minutes at the very shortest to obtain the data for a single curve.

To attempt to meet this want the writer devised the instrument which is the subject of this paper. It is intended to be used in tracing those curves which show the changes in potential of the two ends of a single coil of the armature, and also those showing the changes between one brush and one of the commutator bars, as the armature revolves. The instrument consists in the main of a very rapidly vibrating needle of a voltmeter, and a smoked cylinder against which the pointer is made to press at the required moment. The curve is traced during a single revolution of the armature, and is then easily transferred to paper, and is thus placed in a permanent form to be studied at leisure. The voltmeter, which is inclosed in the body of the instrument, is of the permanent magnet form. The needle is of soft iron, and is very short, and held at zero by being placed between the poles of a powerful steel magnet. The pointer is made of aluminium and is quite short. It is shaped so as to be as light as possible, and so that the air cannot offer much resistance to its motion. The cylinder is of metal and very smoothly finished, so that it will offer little resistance to the movement of the pointer. It is mounted upon a short shaft and is arranged so that it can be slid to several different positions; a spring dropping into notches holds it at each place. The stationary pivot at *A*. Fig. 1, is made with a spring so that the cylinder can be quickly removed for smoking or for transferring the curves. This short shaft is connected with the driving shaft of the instrument by projecting pins at *B*, so that it will always maintain the same relative position with the pin at *C*. The pin *C* is attached to a sliding sleeve which is pushed toward the point of the shaft by a spring. A hole or a pin in the end of the armature shaft is to engage with the pin *C*, so that

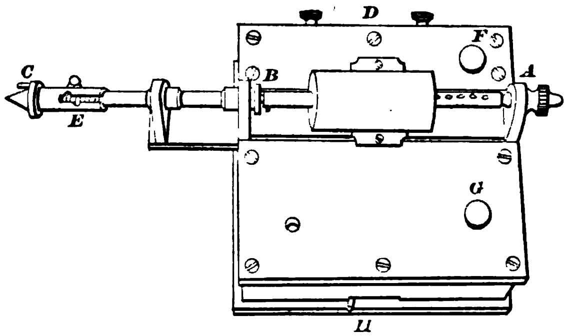

Fig. 1.

the cylinder will always have the same relative position with the armature. To operate the instrument, two insulated wire hoops or bands are to be wound around some convenient part of the shaft or commutator, and one is to be connected to one commutator bar and the other to one of the adjacent ones. Small brushes are to be made to press upon these bands, and they are to be connected to the binding screws at *D*. The cylinder is then lightly smoked by removing it and revolving it over a candle or gas flame; then it is placed in position. The sleeve carrying the pin *C* is pulled back and latched in the notch *E*. Then the point is pressed into the centre hole in the end of the armature shaft; this will put the drum in motion; then by letting the projecting knob strike the finger the sleeve will be unlatched, and will spring forward and engage with the pin in the end of the armature shaft. Then pressing the button *F* closes the circuit, and pressing *G* brings the pointer against the drum. *H* is a reversing switch. The base line of the curve is drawn by pressing *G* only. Another form of curve will be obtained if one of the terminals of the indicator is attached to one of the permanent brushes of the dynamo, and the other to one of the brushes pressing upon the band connecting with one of the commutator strips. Also a temporary exploring coil may be wound upon the armature, and its terminals may be connected to the indicator.

The voltmeter of the indicator is necessarily one of low potential, so that the changes in a single coil will produce a suitable deflection. For greater changes of potential a resistance must be used in series with it. The curves are transferred from the smoked cylinder by dampening a sheet or paper and then roll-

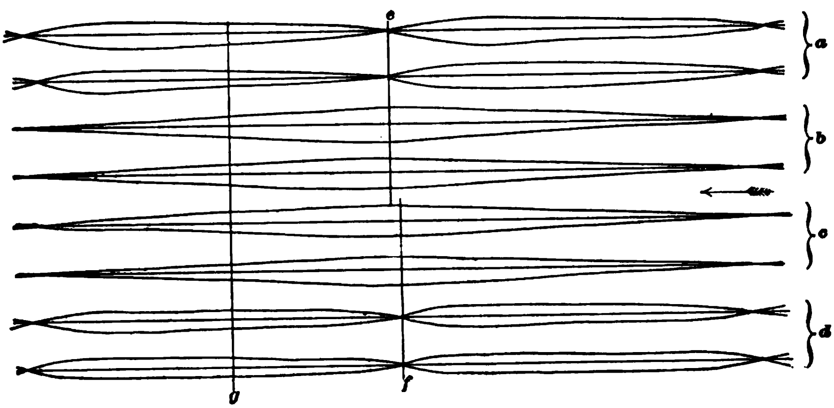

Fig. 2.

ing the cylinder over it. Three distinct copies have in this way been made from one set of curves. One of these instruments has been built and has been tested in various ways and is found to give very satisfactory results. The rate of vibration of the needle was determined while the pointer was in contact with the revolving drum and was obtained as follows :—A current was applied so as to produce a deflection, then while the drum was revolving brought in contact with it and the circuit was then broken, making a wavy line extending part way around the drum before it died out. The average rate of oscillation as determined from over 40 measurements was 103 per second, and the damping effect was so great that in .04 of a second the needle was brought to rest. It was also observed that the deflection was not changed by bringing the pointer in contact with the revolving drum.

One of the desirable features of the indicator is the rapidity with which the curves can be made. The cylinder-full of curves, eighteen in all, with their base lines, was made in 73 seconds, so it is seen we can explore the field many times while a dynamo is charging up just after being started, or while any great change in load is being made.

In Fig. 2 are shown some of the curves produced by exploring the field of a 20-ampere shunt-wound dynamo of the consequent pole type. The dynamo was driven at a speed of 1075 revolutions per minute, and had an automatic regulator, which held it at 115 volts, with slight variations. The curves *a* and *b* were made while 20 amperes were flowing in the main line, and *c* and *d* while the outside circuit was broken. The curves *a* and *d* show the changes in potential of the two ends of a single coil. The line *g* shows the position of the centre of the pole piece, and the

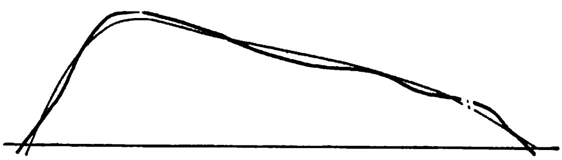

Fig. 3

arrow the forward direction of the curves. The double curves upon each base line, were made by reversing the terminals by means of the switch *II.* The line *e* is the position of the neutral point when 20 amperes were flowing, and *f* its position when the line is open. The difference in shape of the curves shown at *a* and those at *d* is very marked. The curves *b* and *c* were made by connecting one terminal to one of the dynamo brushes, and the other to one of the brushes connected to one end of a coil. These also show the change of the neutral point, and a change in shape for open and closed circuit.

The instrument is calibrated by comparison with a standard voltmeter. For each reading on the voltmeter a line is drawn around the drum. When the pointer is not in contact with the drum some of the effects of inertia can be noticed, but when contact is made they seem to almost disappear, and corrections may be applied to compensate for the lag on that account.

To test the reliability of the instrument one of the 20-ampere curves for half a revolution and similar to *a* Fig. 2, was taken at random, and compared with data obtained by two students. The heavy line, Fig. 3, gives the result which they obtained, working for at least an hour by the usual method. The fluctuations indicate the extent to which irregularities of speed and voltage interfered with the result. The light line shows the same curve as obtained by means of the "indicator."

Physical Laboratory of Cornell University,
May, 1892.

Discussion.

Prof Crocker:—Mr. Chairman, one point that strikes me in connection with this matter is the fact that the ordinates are so small that the character of the curve is not clearly shown. In other words, the curve is too nearly a straight line to clearly show any particular character. For example, referring to diagrams, Figure 2, they look too much alike. But I suppose a more critical examination, and a little more careful measurement would disclose the true character of the curve, and of course the true character of the action of the dynamo. If this simple apparatus, with all its convenience and rapidity of action, can give a curve which truly represents the curve of the dynamo in a way that is available, it certainly is a very useful instrument. It of course pretends to be an apparatus similar to the ordinary steam engine indicator, and would therefore be very useful to the electrical engineer, and would take the same place in electrical engineering that the steam engine indicator does in steam engineering. There is no doubt that such an instrument is needed—in fact almost required—in electrical engineering, and we would all like to see it perfected. I would like to ask Dr. Nichols if greater amplitude of vibration or height of ordinate could be obtained without introducing errors due to inertia.

Dr. Nichols:—Prof. Crocker's point is very well taken, and illustrates what may be considered the chief fault of the instrument in its present form. It should be said, however, that while these curves are of such small ordinates that they cannot be readily studied directly, they will bear magnifying. The line is a very fine one, and by measuring the ordinates and multiplying them by some convenient factor, a curve can be obtained which can be subjected to close inspection. This is an inconvenience, but I do not think that it vitiates the instrument where the measurements are of enough importance to admit of this method being used. You expend the time after your test has been made in working it up properly, and you get your measurement in a time so short as to be sure that the results are accurate. I have thought a good deal about the question of increasing the amplitude. I do not know whether it would be practical to multiply it many times or not. I think that without great change in the construction of the instrument the maximum is about reached. Still very likely a further development along these lines might lead to an instrument which would be rapid enough for the purpose, and which would give an ordinate that could be readily studied by the eye.

PROF. ROBERTS:—It seems to me, Mr. Chairman, that the curves might be enlarged, and at the same time the ordinates increased more than the abscissæ by photographing the curves at an angle.

DR. EMERY:—Mr. Chairman, I would suggest also that the diagram can be photographed through a cylindrical lens, as in that way the ordinates can be lengthened without changing the abscissæ. I will say that a similar experience has been gone through with in connection with the steam engine indicator. It is no trouble to enlarge a diagram if the small original is perfect in itself. Generally it will answer to have the measurements made through powerful magnifying glasses, or by a short-sighted person without glasses, and the method of photographing through a cylindrical lens need only be resorted to when it is desired to enlarge the diagram in one direction for the purpose of publication.

The meeting adjourned until 8 o'clock P. M., at the rooms of the Chicago Electric Club.

Inaugural address of the President at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 6th, 1892.

COMING DEVELOPMENT OF ELECTRIC RAILWAYS.

BY FRANK J. SPRAGUE.

It is a trite but mistaken saying that electricity is in its infancy. It dropped its swaddling clothes when Morse sent the first telegraphic message. It put aside dresses and pinafores when the dynamo machine and arc light were invented. The incandescent lamp, the telephone, the art of welding, the transformer, are incidents of buoyant youth. The modern electric motor and electric railway mark a vigorous manhood. The truly marvelous development of electric applications of every kind, the accomplishment of many things which in ignorance of the very art, or lack of knowledge of what are now well known facts, and more particularly the great commercial development of the transmission of power, whether for stationary purposes or for electric railways, has lead to many a foolish prediction and idle boast.

This is no age of inspiration, nor time for hopes never to attain fruition. It is above all things a practical age, perhaps too practical, but nevertheless one in which commercial enterprises to be successful must promise either a new field of development or economies in older fields. As the orthodox few have been waiting in sublime faith for many centuries, and will wait for many more, for the fulfillment of ancient prophecies, so too will impracticable electric enthusiasts vainly wait for the millenium when investments are boundless, performances limitless, and efficiencies unity.

It would perhaps have been proper in making my inaugural address to so representative a body as that of the electrical engineers, that I should touch upon the special discoveries and experiments which have recently attracted attention, but there have been so many enthusiastic and brilliant workers that neither the time at my disposal nor the knowledge I possess would permit me to do justice to their work ; hence it seems better to take up a subject with which I have been more particularly identified, which to-day commands so much attention, and concerning which there are such conflicting opinions. While finding encouragement in the achievements of our profession, I think the time opportune for a word of caution.

Electric street railways are no longer experimental, nor is their success problematical. Their history for five years is that of an almost unequalled development. Almost within a decade has occurred the first working of a practical electrical railway. In a third of that period there have been put in operation or under contract more than 450 roads, equipped with nearly 6,000 cars and over 10,000 motors, and with over 3,000 miles of track. There is made a daily mileage of not less than 700,000 miles, and over a billion of passengers are carried annually. At least $75,000,000 have been invested in this industry alone; 30,000 horses in a single year have been relieved from the slavery of street car propulsion; stables are disappearing and streets becoming cleaner; luxurious cars are running on smooth, well-built and rigid roadbeds. Dividends have been increased, expenses reduced, investments enlarged, the unproductive has become productive, the impossible possible. Land values have been increased, habitable limits extended, homes created and time saved.

We no longer hear seriously of the dangers of the trolley wire, the failure of service. The time has come when legitimate investment is amply warranted. Electric street railway construction has become a matter of engineering, not experiment. Not only have the smaller towns adopted what is the only available means of current supply, but the larger cities are following their example. St. Louis and Baltimore, Minneapolis and St. Paul, Buffalo and Rochester, Boston and Brooklyn have fallen into line, and latterly even Philadelphia seeks an improved street service, and in New York public interest is being aroused. In the latter city it is, of course, impossible to tell how successful will be the attempt to introduce electric propulsion. There is a strong and in many respects a legitimate objection to overhead wires. Many unsightly poles and badly strung wires have disappeared, and their place taken by an underground service. The general feeling of opposition to poles and wires ought not, however, to act as a barrier to such reasonable and proper introduction of an overhead system of supply as the conditions now existing in that city very properly warrant. I have frequently pointed out the fact that the greatest good can come to the greatest number, especially in the overburdened condition of transit which there exists, if certain of the lines were electrically equipped; wherever, in fact, there would be no street obstruction.

In broad streets, where the tracks occupy only a small portion of the street and are near together, a line of poles of ornate design with arms projecting on either side, can follow the centre of the street, the same poles being used for lighting. Such a street, it seems to me, is Eighth avenue. Then, too, where there is a middle division or park, such as exists in many boulevards, and which is now used for telegraph poles, there is opportunity for an electric construction which would be entirely unobjectionable. On streets occupied with elevated structures, those structures themselves would be used for a practically rigid overhead system.

Among the numerous places in New York where an overhead system could be put in perfect operation, are Central Park west, the Boulevard from Fifty-ninth street up, a part of First and Second avenue lines, the Third, Sixth and Ninth avenue lines, and all the suburban extensions from the annexed district. I am not sufficiently familiar with the streets of Chicago, which is the last remaining city which must consider electric street railways, to suggest a plan. In these large cities, however, one condition should be insisted upon, and if this condition is met in the proper spirit, then much of the objection which has been raised against an overhead system must necessarily disappear.

The construction must be of the very best. The only overhead line allowed should be a contact wire with sufficient strength; main conductors and the feeders should be put underground in proper conduits. There would then be overhead only a wire necessary for the smallest duty and of the requisite strength. In many streets of course the cable will hold its own until an electric conduit or surface contact system shall be proven satisfactory. Impressed by the great development of this great industry and brought face to face with the changes it has wrought, the query is continually made—will the electric motor replace the steam locomotive? It is similar to the older question—will the telephone replace the telegraph? Will the electric light annihilate the gas system—and in all soberness a like answer can be made: — It will not, but it will, as the electric light and as the telephone has done, create a field of its own, and will replace a portion of the service now done by steam. It seems to me that the growth of electric railways will proceed something in this order:—First, the street systems in the various towns, then connecting lines between adjacent towns following the line of highways, then longer connecting lines, either on the track of existing steam lines, or growing bolder, on exclusive rights of way on the same order. Then will come suburban traffic on a larger scale, and freight transfer systems, and finally the more ambitious project of trunk line service under limiting conditions, such as I will specify. It has been very properly said that a man will make the first long ride on electric railways by transferring from one town system to another through connecting links, rather than on individual roads.

This is precisely the process by which great steam systems have been built up, although, of course, starting on a larger scale, and it is but natural that this shall be one step in the development of electric railways. But evidently this natural process of evolution does not offer scope enough for the more enthusiastic, and we are now and again treated to an ideal electric road to be built on plans boldly defying both geography and the abodes of civilization. An air line route according to rules of surveying allowed only in Russia and on the desert of Sahara; abolition of the grades and street crossings; rigid and continuous rails; loaded cars of light weight, each operated by its own motor and making few or no stops; unlimited potentials and undiscovered resistance to insulation; new physiological and engineering laws; indestructible machinery; unheard of powers of braking and new methods of train operation and signaling; around all a clear atmosphere, above all a perpetually smiling heaven, and behind all an unlimited bank account and the unlimited confidence of the investor. These are some of the characteristics of such a road, but perhaps it is only fair to ask, given some of these conditions, what would be the capacity of steam traction?

No one will question the capacity of a motor to do the necessary work required, or to make a speed superior to that of the steam locomotive, provided sufficient energy be delivered to its terminals, but we must deal with existing or probable methods of supply. It is true that the speed at which a train is propelled by steam has only increased about 50 per cent. in sixty years, for in 1832 the "Matthew Baldwin" often made a speed of a mile a minute; but we must not confound speed with power, for while the maximum speed has not been so materially increased, the endurance, the perfection of the mechanism and the economy of performance have made great strides, and the increased speed, which is by no means the maximum possible of a locomotive *per se*, has been attained at much higher powers, and the schedule time has been shortened principally by cutting down grades, straightening curves, filling up ravines, abolishing trestle works, replacing wooden bridges by permanent ones of iron or stone, by the use of heavier and stiffer rails, better switches, improved methods of automatic signaling, the interlocking switch and signal system, and the abolition of grade crossings; in short, by improvements in details and management which permit of higher speeds on more extended sections of road because of greater safety, lower traction coefficients and a greater degree of confidence possessed by the engineer.

All these things are necessary for high speed electric railways, and any general improvement that will be of benefit to the latter must necessarily be of service to the former. Now, any predictions which are made concerning the future of electric propulsion, either in ignorance or disregard of the possibilities of steam duty, and the limitations necessarily existing in all systems of transportation, deserve and will receive little consideration. Hence let us note a few of recent locomotive performances.

Almost every one is familiar with the remarkable run recently made by a Schenectady locomotive hauling a special train on the New York Central Railroad, when the distance of 439½ miles from New York to Buffalo, was made at an average speed of nearly 60 miles per hour, and which was the precursor of the Empire State express, which makes the regular run at an average speed of over 52 miles per hour.

More recently we have accounts of an interesting record made by a well-known writer on two runs between New York and Albany, on which a large number of indicator cards were taken. The weight of the train was about 270 tons. The steam pressure varied from 160 to 170 pounds. From an inspection of about a dozen cards, the indicated horse power varied from 551 horse power at 44 miles to 1,120 horse power at 78.9 miles. At 60 miles per hour, the train resistance is stated to have been 15 pounds per ton, and at 70 miles, 17.10 pounds per ton. About seven pounds of water were evaporated per pound of coal. A remarkable statement concerning this performance was made by Mr. Sinclair, which, while almost incredible, will, if borne out by an analysis of facts, prove to be something of a surprise to those who make their prophecies of the electric economies by comparative statements. In the description of these tests it is stated that the whole trip shows an indicated horse power per hour for an average expenditure of only about 3⅛ pounds of coal per hour. This is far better than many stationary engines.

On the Central Railroad of New Jersey, one schedule rate is 86½ miles in 89 minutes, which is made where there are a number of necessary slackenings. On May 13th, the time was taken of the speed of a Baldwin compound locomotive for a considerable period of time on one of the regular runs. Ten continuous miles were made in 452½ seconds and five were made in 222 seconds. The fastest time taken was 44 seconds, and the slowest noted was 47. On February 26th a similar compound passenger locomotive running on the same road broke all steam records by running a mile in 39½ seconds, or at the rate of nearly 92 miles per hour. At this speed the indicator cards showed 930 H. P., and the drivers, which are 78 inches in diameter, were making 395 revolutions per minute. In the very near future, I expect to have the pleasure of riding on a locomotive when going at these high speeds, and I presume my respect for steam locomotion will not be diminished thereby, nor, on the other hand, will my confidence in the possibilities of electric propulsion under the proper conditions. Experimental runs have been made with an electric locomotive at the rate of one mile in 30 seconds, that is, 120 miles an hour, and I confidently expect some day to go at that rate. But it will be under special conditions and not on the regular trunk lines of this country, and it is the height of folly to suggest that these steam trunk lines are to be abolished. In making these very high speed runs, there is not much attempt at maximum economy of coal consumption, the necessity being to generate steam as fast as required by the cylinder, but on taking an average of five trips, I find that there was evaporated 7.19 pounds of water per pound of coal used, and 9.41 pounds of water evaporated per pound of coal consumed. The total weight of train varied from 213 to 241 tons. The personal equations of engineer and fireman necessarily enter seriously into steam operations, and this, compounded of course with the peculiarties of each engine, and the conditions of service, is shown in railroad reports. In this connection, I recently inspected a number of engine sheets. On one, which gave the duty of 25 engines, the average total cost per engine mile was 10.85 cents, of which 2.66 was for fuel. The total cost varied from 6.8 to 19.24 cents, and the fuel (wood) from 1.96 to 4.77 cents. On another sheet, giving the performance of 22 engines, the total cost per engine mile was 14.70 cents, of which the fuel cost 4.61. The total cost varied from 8.82 to 27.98 cents, and the fuel cost from 2.04 to 7.48. In still another, that of the performance of 18 engines, the total cost per engine mile was 14.73 cents, of which the fuel (coal) cost 6.62 cents. The total cost varied from 10.04 to 22.52 cents, and the fuel cost from 3 82 to 13.84 cents.

In discussing the electric system there is often a confusion of statements with reference to economy. Despite the undoubted fact that the electric motor can probably be run at variable high speeds with less variation of economy than can the steam locomotive, we must not forget that in the latter we are considering the economy of the unit as a whole, not merely of the steam cylinders but also of the boiler and the furnace. In electric propulsion a similar comparison of economies must take into account the variable duty of the central station and the losses on the line as well as those in the motor, and where single units are used, the variation in economy of the whole system would be much greater than in the steam locomotive. There will be only a reasonable fixed efficiency of the central station and the line, when the number of units is large enough to make the load on the central stations nearly constant.

Let us now consider another class of duty. Some time ago I made a very careful analysis of the work done on the elevated roads in New York City with a view of determining the coal consumption, and the duty performed by the locomotives. At the time this investigation was made, now nearly seven years ago, there were in use on the Third avenue division 63 trains at one time, running at very close intervals. The weight of the trains was from 80 to 90 tons; the speed was often as high as 20 to 25 miles an hour; stops were made every third of a mile; in short, the duty demanded of the engines was exceedingly severe. The maximum indicated H. P. of the locomotive was found to average about 163 H. P., although on occasions these locomotives have been worked up 185 H. P. Work was divided approximately as follows:

Acceleration in starting 59 per cent., lifting 24.3 per cent., and traction 16.7 per cent. The average H. P. exerted was 70.3 H. P., considerably less than one-half of the maximum. The work on the line was so distributed that there was an almost constant total duty of about 4,500 H. P. The locomotives were on duty 20 hours, but used steam only six hours, and including all losses when standing still and the amount of steam used in braking there was a H. P. development for about 6.2 pounds of coal. I believe that these figures are entirely reliable, and they show a remarkable performance when we consider the class of duty.

An analysis of the coal expenditures showed that, with an efficiency of 60 per cent. and without any of the energy of the train being returned to the line, the relative coal expenditures between steam and electricity would be about in a ratio of 2 to 1, but if the energy of the train was returned to the line to the extent which I believe is possible, then the relative expenditure of fuel would be in the proportion of 7 to 2. Since the coal charge on the four divisions was at that time about $550,000, it can easily be seen that, independent of any question of saving in the care of the structure, and any deduction of depreciation of the motor equipment, the fuel saving would be sufficient to pay a good interest on the cost of electric equipment and a large interest on the cost of electric equipment minus the value of the present engines. I have no reason to doubt the soundness of the conclusions I then made.

You will have here in Chicago, however, a somewhat more advanced condition of affairs. A compound type of locomotive has been adopted for the elevated road service, and I believe it will show an increased economy over that of the operation of the New York roads. Consequently, in discussing the question of economy, it is necessary to get full information concerning the duty which will be done here. In discussing high speed possibilities and limitations, the testimony of Dr. Dudley as given in a discussion of a paper before this Institute, Feb. 24th, 1891, is interesting.[1] There are, generally speaking, three distinct elements constituting the resistance of train movement on a level, and they have a most important bearing when we consider the

1. TRANSACTIONS, Vol. viii, pp. 82 and 86.

operation of long or short trains, and at high speeds. One of these elements is the rolling friction of the train in its bearings; with good rolling stock this is about eight pounds per ton. For all reasonable speeds it is probably fairly constant, provided the lubrication is good. Another element is that of air resistance which varies with the shape of the forward end of the train, the condition of the air, the direction of the wind, and the velocity of movement. The third I may call the train lifting or rail bending effort, which depends upon the weight and swiftness of the rails and solidity of the road-bed.

Dr. Dudley stated that on the New York Central system he found the trains of about 250 tons when running at a speed of a mile a minute, have a resistance of from 10 to 12 pounds per ton, but that on short trains of two or three cars the resistance sometimes ran as high as 35 or 40 pounds per ton. This is probably due not to any change in the friction of the bearings, but to the fact that the air resistance enters as a much higher exponent of the total. It at once emphasizes the fact that the operation of short trains at high speeds must, no matter how good the track or how favorable all other circumstances, be with a train resistance higher than required by long and well vestibuled trains. Such a shape can be given to the front of an electric locomotive as will make the air resistance not over one-half that presented by a plain surface of equal cross-section and perpendicular to the line of motion, but even this fact does not alter the other, that the resistance per ton must be higher for small trains than for large ones.

Dr. Dudley further stated, in speaking of the influence of stiff rails, that the difference in power required on the "Chicago Limited" when running on an 80 and a 65 pound rail was from 75 to 100 H. P. per mile, that is, somewhere between 10 and 12 per cent. of the power actually developed, and he estimates that with a 105 pound rail, which is nearly twice as stiff as the 80 pound rail, there would probably be saved another hundred H. P. per mile, making a total saving of a quarter by less than doubling the weight of the rail. In his opinion it is perfectly safe to run a steam engine 120 miles an hour on this heavy rail. Such rail improvements increase speed possibilities with present engines, but we have not related the limit of steam duty. Almost all the locomotive work of the United States has been done up to the present with simple engines. Their weight and capacity has been increased, their steam pressure raised until the standard is now about 140 pounds. Within recent years, however, the compound locomotive has come into use, and there is a comparatively large number of them in daily service. The steam pressure has gone up to 180 pounds as a standard, working sometimes as high as 200 pounds, but these are by no means the limits of steam pressure.

On the Paris, Lyons and Mediterranean railway the standard for steam pressure for compound locomotives is 250 pounds. The compound locomotive has still its battle to fight, but I think it would be a rash man who will say that the days of still higher steam pressure are not to come, and that the triple expansion locomotive will never exist. Speed, capacity and coal economy are, however, not the only questions to be considered in railroad operation, and in discussing the general subject, it will be found that the signaling and braking questions at high speeds are serious ones. Undoubtedly an electric train with distributed motors, making the weight of the train available for traction, could by using the motors as dynamos to return the energy of the train to the line from the highest to mean speeds, and then on a local circuit, be more quickly and effectually slowed down and stopped than where shoe brakes are used, and both methods of course would be available. But if using a motor ahead of a train then there will be comparatively little difference in the stopping power. When riding at 60 or 70 miles an hour, it is a very quick stop to bring a train at rest in less that 2,000 feet. This is often as far as any signal can be made out, especially when the weather is at all thick. Hence we may expect to find on electric railroads, if high speeds are to be attained, and quite possibly also on steam railroads, an extension of automatic signaling so that trains indicate on more than two sets of signals. At present the practice is to divide the line into sections, and when a train passes a certain point it sets danger and cautionary signals, dropping the danger signal on the section just preceding, and the cautionary signal on the one behind.

Turning now to the greater powers, we must not confuse the terms "large powered" and "trunk line" work.

These are two statements which I think will need no corroboration. If we had a continuous train movement completely occupying a track system, there can be no question but that its operation from a central source by electricity would be more economical than if operated by steam locomotives. So, too, if a large number of units in reasonable proximity are moved, and the stopping and starting so regulated that the total demand upon the central stations is fairly continuous and equal, then there is no question as to economy of electric propulsion as compared with steam. On the other hand. the operation of a single or very few units over a long distance would be so uneconomical and afford so small a return on the investment required, as to make it prohibitory. Between these two, lies the condition of operation where steam and electricity meet on planes of equality; as the number of trains decreases, steam operation is the more economical; as the number increases, electricity must be preferred.

In discussing the use of electricity instead of steam, a well-known steam engineer recently stated that in his judgment it must be conceded that electromotive force for the propulsion of cars will not be economical except for suburban traffic, and upon certain sections of important trunk lines, like the New York Central between New York and Albany, the Pennsylvania system between New York and Philadelphia, and other lines of like character where it is necessary to dispatch a large number of comparatively light trains every day, and at short intervals. The principal field for a power of this kind would be in suburban service long enough to make the ordinary street electric cars unpopular because of the time required, and in such cases as these mentioned above; also for moving freight trains in cities; that is, for the performance of transfer service. This is precisely in line with the argument which I have advanced from time to time, and which I illustrated in a paper before the National Electric Light Association at its convention in Kansas City, where I outlined the possible service between New York and Philadelphia, which I believed to be practicable, and to which I will again refer.

I must repeat that it narrows itself down to the one question as to the number of trains operated between the two terminal points. Make that number of trains sufficiently large, and the electric motor is the best means of propulsion, whether for high or low speed, whether for large or for small cars. Decrease this number, and we must rely on steam propulsion, or, to put it in another way, the answer to the query, "Will electricity take the place of steam for railroad purposes," is:—Only in part, and then only when the number of units operated between the terminal points is so large that the fuel economy would pay a reasonable interest and depreciation of the necessary cost of the central station and the system of conductors.

Of course I do not in this general reply consider those special cases where advantages are to be gained for which there is a return for capital in another direction. Such a case is that of the Baltimore tunnel, where the investment and cost of operation will be greater than that for steam propulsion; in fact, there will practically be no economy in power, because the steam locomotives are not done away with, but simply unused for a period of a little over a mile. There is in this specific case, however, the incidental advantage of doing away with the necessity of a ventilating plant, and yet getting rid of the annoyances incidental to tunnel service.

Trunk line transportation being a great problem, we should not attempt the simultaneous solutions of all the questions involved, but instead, determine what those questions are, consider their sequence and the probability of success, and solve them in their order.

Every system has its limitation. The electric is not exempt from this law, and hence it will set forth what are well-known limiting laws concerning the transmissions of energy. They have been stated time and again, but somehow or another, people often lose sight of them in discussing the questions of investments in large electric railways, so that I think it would be well perhaps to restate and emphasize it.

The weight of copper necessary to transmit a given amount of power with a fixed loss will vary inversely as the square of the electromotive force used.

The distance to which it can be transmitted with a given weight of conductor will vary directly as the pressure.

The distance to which it can be transmitted over a conductor with a given cross-section will vary directly as the pressure.

The weight of copper necessary where the supply station is in the centre of a system is only one-quarter that required if the station is at one end.

The weight of copper will vary inversely as the square of the number of supplying stations properly placed.

The electromotive force required will vary inversely as the number of stations.

Lack of knowledge of these simplex and unalterable laws has led to much misconception of electrical possibilities, and these have not been confined to electrical engineers.

In many of the suggestions which have been made even by practical steam engineers, there has been an unnecessary confusion of the practicable and impracticable, and the specific object which should have been borne in mind has been lost sight of.

Committees have drawn impossible specifications for trunk line service, and demanded of electric motors a capacity and performance superior to that of the best compound steam locomotives. I unhesitatingly pronounce any attempt to build some such machines for the present, certainly unnecessary and impracticable.

The service thus suggested, if at all needed, will for many years be the better performed by the steam locomotive than the electric.

Leaving out of present consideration trunk line work, there are three problems requiring solution in the application of electricity to propulsion on a large scale under conditions existing, for example, in Chicago or in any other place where there is a movement of a large number of trains on more or less complicated tracks, as will be found at almost all terminal railway stations. They are:

First:—The development of an electric locomotive of ample power which shall be as readily controlled as the steam locomotive, and shall be reliable in operation, and shall show a high economy. Of course such a machine must have all the adjuncts which are necessary for train movement.

Second:—A system of conductors and method of supporting the same which can be relied upon for ample supply of current and absolute certainty of continuous contact at all speeds on curves, switches, cross-overs and the multitudinous combination which exists on yard tracks.

Third:—A system of automatic block signaling, which while effective for steam traffic will not be thrown out of operation by the use of tracks as conductors of electricity for a general supply. This is a more serious question than is at first considered, for this use will materially interfere with if not absolutely destroy the utility of what is known as the rail circuit system.

This third problem is one which must necessarily follow the development of the other two, as the automatic signaling systems now existing have followed the development of steam practice.

While I am not by any means thoroughly familiar with the various methods of automatic signaling, I believe I am justified in saying that there is none at present existing, which will meet all the requirements of railway practice, and which can be operated on tracks used by both steam and electric locomotives, where the rail is used as a part of the supply circuit. Some of the best known systems of signaling would be rendered entirely inoperative.

As difficult as it may seem to devise such a system, I believe that it certainly can be developed, but only properly so on a section of track which is more or less experimental on which at the time of operation automatic signaling is unnecessary, but which is actually operated by both classes of service. Such an experimental section would be a combination of single and double tracks with all the varieties of curves, crossings, switches and ladders, such as would be found in any large yard.

It will probably be found necessary to erect a variety of conductors. From the most careful consideration which I have been able to give to the subject, I believe there is one way, and only one way, in which the current can properly be supplied in any complicated system, and that is from the overhead conductor, practically rigid in character, following very nearly the centre line of all tracks and switches with no movable overhead parts, and with return through the rail. The locomotive would then practically be moving between the two electric planes, the lower being the guiding one. I know there has been a great deal of talk about other possible systems of supply. We have heard much of the charged rail using low potential currents supplied at frequent intervals by motor generators driven from a central station. Since we have discovered no conductors devoid of resistance, and the art of welding is not particularly applicable for railway service where moving contacts are a necessity, little credence need be given to any scheme of this character.

We hear again of the central rail supported on posts in wells between the tracks. A centre rail may be acceptable on a system like that of the elevated roads, but in ordinary railroad work any ditch intended to drain a track so as to keep insulators dry and keep snow away from them would probably so open the track that any moisture and frost would cause upheavals of serious character, and the cost of maintaining the track would be prohibitory. The use of snow machinery for keeping the track clear would be impossible, and anything underneath the cars is in the most exposed place for sustaining damage by defective rolling stock, and continually liable to all sorts of mechanical injuries and accidents with all the evil results of interruption of current, short-circuiting and stoppage of traffic.

Another system which has been proposed is that of conductors supported on posts alongside of the track and elevated but three or four feet above it. While not open to so serious objections in the matter of insulation as a centre rail system, its use is manifestly not to be thought of where there are crossings or switches. Even on a straight clear track in a hard climate there would be most serious trouble in the matter of clearing the tracks from snow, and at the grade crossings in this country gaps in the conductors would be too great for the contacts on a single locomotive to stand.

Some time ago I was requested on the behalf of a well-known financial man, whose enthusiasm as to the possibility of electric traction is well known, but who is withal a most practical railroad man, to inspect various railroad terminal tracks in this city with a view of, first, the substitution of the switching work now done by a part or all of the 1,800 or more switch engines by electric motors, and eventually the operation of suburban service.

Considering the railroads merely as they exist on a number of systems in Chicago, in the space of about two square miles, or more exactly, one and a half miles in length by three-quarters of a mile in breadth, it is no exaggeration to say that there is or will be not less than 75 miles of track, and switches and crossings, with their various combinations, almost innumerable.

I went over and over some of these tracks with the one thought in my mind—How can the current be delivered to the locomotives and how can the automatic signaling be done? And I was forced to the one conclusion to which it seems every man who makes the investigation must come, and that is that the overhead system of supply is the only one, but that it must be as substantial and thorough in character as that of any other part of the system, and that in view of the cost, such a system is only permissible where the number of units operated is large and continuous. These conclusions are not new, but they have been emphasized by the particular problem which is here represented.

Intimately connected with the question of conductors, and one of the most serious ones which has to be met by the electrician is of potential. The personal danger limit of continuous or ordinary period alternate currents is pretty well determined, and it seems generally admitted by constructors that the danger limit for the continuous current machine, with its commutator, is about the same as the personal danger limit.

Hence we meet with two dilemmas. If using continuous current motors, we are limited to a difference of potential per machine of 1,000 to 1,200 volts, and we can, so far as safety of the machines is concerned, probably go above this limit only by putting the motors in series, precisely as has been proposed for long distance stationary transmissions. If this is not done, then we have the introduction between the transmitting dynamo and the receiving motor of a motor generator system, another pet theory which is often suggested but which I unhesitatingly pronounce as so uneconomical as to be impracticable. If using an alternate current system, then converters must be used, either distributed along the line and supplying the working circuit or placed upon the locomotive to safeguard the motors. While the use of a converter under these conditions is not as objectionable as the use of a motor generator, it cannot commend itself as a very practical scheme, and certainly in view of the fact that no single phase, single alternate motor promises, up to the present, serious success. For the present, and, I think, for a long time to come, we must confine ourselves to the consideration of railroad problems, where continuous currents are used, and where the traffic between two points is sufficiently large to justify the investment in central stations and conductors which would be required for the operation of such a system. There are two methods of propelling trains electrically, one by following steam practice, that is by building a motor and hooking it to the head of a train, the weight of the motor being such as is required for the necessary power and traction when grades or slippery tracks are encountered. From all that has been developed up to the present, to get the control that is necessary and to build the machines safely, the electric locomotive will weigh nearly as much per horse power as the steam locomotive. This weight can be better distributed, but I do not think, if steam practice is followed on trunk line service, that there could be any very material reduction of weight of train.

The other plan is to have each car propelled by one or more motors. This would be the ideal system as far as propulsion goes, provided the electric motor was unlike all other mechanical apparatus, and that it never failed, and if a number of machines could be as well taken care of, cost no more and show as little depreciation as fewer machines of larger capacity operated as a unit. Should we ever arrive as we hope, to possession of a single circuit alternate current motor, then in view of the simplicity of its control, we may fairly hope for the distributed motor system. But here also the capacity and likewise the weight of the motor being determined by the total duty done, the weight of train limit would not be decreased, but rather increased. If, on the other hand, single units are used, the query naturally arises, what form would the electrical locomotive of the future take? I do not think this is by any means settled; undoubtedly gearless machines will be used, but whether they will be mounted directly upon the axle, or whether they will movably inclose the axle and be flexibly connected to it while their weight is carried on springs on the truck, or whether the motor will be carried on the truck frame and connected to the drivers by the ordinary coupling rods, are questions which will be determined eventually by the depreciation per car mile upon the motors, trucks and road-bed as well as by the speed to be attained. Whatever the method of mounting the motor is adopted, for reasonable weights and powers, a two axle truck will be used, but where large powers and weights are necessary, two such trucks will be coupled together so as to keep the weight upon each wheel within limits, and this will carry a cab containing the regulating and collecting devices, and so shaped as to offer the least resistance to air pressure and high speeds. I have never advocated the use of a connecting rod in transmitting the motion from an armature to a driving axle, but I think it fair to say in this respect that the so-called hammering effect on the rails, said to take place in the ordinary locomotive driver where the weights are counter-balanced, exists more in imagination than in fact, and that the chief trouble in the use of the connecting rod is the change of direction of its movement. Among the roads that are ripe for the electrical engineer, and on which in the near future I hope he will demonstrate he has a most legitimate claim, are the New York elevated and the Chicago elevated, the handling of the trains on the New York Central and Harlem roads below the Harlem river, the long talked of rapid transit road of New York, the Metropolitan underground road of London, the proposed tunnel roads in London, Paris and Berlin, and coming more immediately home, suburban service such as that of the Illinois Central railroad, a most ideal track for the electrical engineer, and last, and as it will prove one of the most important, the operation of the terminal and warehouse systems for the interchange of freight on the lines entering a city situated as is Chicago. Taking this last, we have here a definite problem, now performed in a more or less satisfactory way by steam service. It is a problem large enough of itself. It has little connection with electric trunk line service, and the present impracticability of the latter has little bearing upon the thorough practicability of the former. Eighteen hundred or more switch engines, many of them on duty twenty-four hours a day, a large portion of the time standing idle, puff their foulness into your overburdened atmosphere, because from 80 to 90 per cent. of all the freight that comes into the depots of this city ought never to come inside its limits, and would not, were there a practical way provided to transfer it from one railroad to another outside the city limits. It has been suggested, and it seems to me a most feasible plan, that there shall be established a vast system for interchanging freight on the various railroads by a great 6-track crossing belt road which shall form a common zone of transfer either by itself or in combination with freight warehouses or storage yards. Undoubtedly there are many difficulties in the way, but from an electrical standpoint there is absolutely no question but that such a system of belt line is practicable.

With such unsolved problems, such abundant fields, I deem it unnecessary now to attempt to build electric locomotives to pull trains of great weight 100 miles an hour, or to develop a system of conductors for trunk line service which is not possible for yard duty, or to consider a central station or track equipment for a duty never required. This problem is in a measure an experimental one, which being carried to a certain measure of success will clearly point the way for a future development and outline its limits. I may be pardoned perhaps if I take radical views in some matters of railroad practice. I have fortunately or otherwise been thrown into direct touch with all the larger work which is to be done in this country during the coming year, and it gives me pleasure to announce, what many of you know from the current news of the day, that there will probably be in operation in the United States within 12 months, not less than five locomotives varying from seven to twelve hundred H. P. and from 45 to 80 tons in weight. The character of the work done will vary. In that work which I am most concerned from a personal standpoint, a 700 H. P. electric locomotive will be built for experimental work, and to attempt to solve as far as may be the various problems which are involved in railroad practice in Chicago. If my judgment is followed there will be an experimental section of track in the form of a loop about 13 miles long with 18 miles of rail, and with every variety of single and double track construction, and simple and compound crossings and switches.

On this I hope to see erected such varieties of overhead construction as may be found best to meet the various kinds of service, and where the railroad problems on tracks jointly operated by steam and electricity can be developed in the most satisfactory manner.

On this track there will be not only this locomotive, but also one of equal rated capacity supplied by one of the larger manufacturing companies.

The duty demanded of these machines will be severe. They will be required to haul a train of not less than 450 tons, at 30 miles an hour, up a grade of 26 feet to a mile.

They will probably be required to develop their full rate of capacity at all speeds between 30 and 60 miles per hour, and if there is sufficient track room they will be driven at a speed of at least 75 and perhaps 100 miles per hour for short distances. The potentials used will be nearly double that at present obtaining in street railway practice.

A still larger problem, so far as power goes, although not in the variety of conditions which will have to be met, will be that recently taken for the operation of the belt line tunnel now being constructed in Baltimore to avoid the necessity of boat transfer at Locust Point. The duty of the motor will be to propel the train with engines coupled on, but not in operation, through a tunnel about 6,000 feet long.

The conditions require the motors, which will weigh about 80 tons and have a capacity of about 1,200, to propel a 1,200 ton freight train up a grade of 42 feet to the mile at a speed of 15 miles. Passenger trains of 450 tons weight must be regularly started from rest twice in the tunnel on this grade, and in an emergency the freight train must be started. The draw bar pull under regular duty, and when not starting, may be as high as 35,000 pounds.

Perhaps the traffic from New York to Philadelphia affords as good an example as any of what may be done on regular passenger service, provided the track is clear enough.

For this I some three years ago, and again in the *Forum* of September, 1891, outlined an electric express service, with a method of supply through a rod carried above the car and a return circuit through the rails and earth.

The current was to be supplied from one or more central stations, equipped with high-class triple expansion engines, driving multipolar dynamos directly coupled. What the electrical engineer, and the railroad man as well, need to know is whether the electromotive force required on the line, and the number of stations necessary would be prohibitory.

No attempt was made at an excess of speed, but I confined myself to the average speed of a mile a minute for a distance of 90 miles, and considered a through service only. I assume a total weight of copper of only about two-thirds that which exists on the long distance telephone line between New York and Boston. The trains were to be two car units, leaving every 10 minutes.

I found with these conditions the stations and potentials would be about as shown in the following table:

Station.	Miles apart.	Potential. 2 wire.	3 wire.
1	—	3,600	1,800
2	45	1,800	900
3	30	1,200	600
4	22½	900	450

If the three wire system is used, that is, the rails as a compensating conductor between two trolley rods, then, with only two stations forty-two miles spart, it is seen that the potential is less than 1,000 volts, and this we undoubtedly we can handle.

I am not prepared to say that we may not use even a higher pressure, because I believe whatever is demanded in the interests of economy, all things being considered, will be used, but if we can reduce the potential to perfectly safe and reasonable limits by multiplying the number of stations, then those stations should be increased so long as the increase does not seriously affect the general expense of working. On a service of this character, where I have made the conditions distributed work, and the despatching of units at brief intervals, which conditions, I repeat, are absolutely necessary if we are to consider long distance transportation by electricity, such increase of stations as is advisable will not increase the cost of central station operation.

Such is the work before you, a work well meriting your best efforts, yet it is well to temper your enthusiasm with prudence.

Limit your attempts to the solution of those problems which will prove of practical benefit.

Do not chase rainbows. They are beautiful and poetic, but they have small place in the world's economies.

Remember that neither sentiment nor ignorance are winning cards, but lessened costs of operation for equivalent duty and increased returns on invested capital.

All this is said in no spirit of discouragement, for I yield to no man in my confidence in the future of electric traction. No new field is so rich, none more pregnant with great possibilities, but the growth of the work will be more expeditious and healthy if we separate the visionary from the real, the impracticable from the practicable.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, Vice-President Lockwood in the Chair.

THE MAGNETIC PERMEABILITY OF SPECIAL IRONS FOR ELECTRICAL PURPOSES.

BY MILTON E. THOMPSON, PERCY H. KNIGHT AND GEO. W. BACON.

During the last year or two there has been a marked change and improvement in the qualities of iron used in the construction of electrical machinery. It is now generally well understood that not only are the efficiencies of transformers, dynamos and motors increased by improving the quality of iron used, especially where this iron is subject to changes of magnetism and consequent loss by hysteresis, but also that the capacity of any given machine will be greatly increased by improving the quality of the iron. Thus, in the majority of dynamos, the capacity of the machine is limited largely by the heating of the armature, and the greater part of the heat developed in an armature is usually produced in the core. If the heat developed in the core can be reduced by improving the quality of iron used, enough extra current may be taken from the armature to balance this saving in the core. Again, in a dynamo or motor, the principal part of the weight of the machine is due to the field magnets. If the permeability of these field magnets can be doubled by improving the quality of the iron used for their construction, the weight of these magnets may be reduced in the same proportion. In many classes of dynamo machinery, as, for instance, railway motors and marine dynamos, this saving in weight and consequent increase in the capacity of a machine of given weight is of great importance. It has long been known that the magnetic value of wrought-iron is several times as great as that of cast-iron; but the readiness with which cast-iron may be molded to the desired shape for field magnets has kept it in favor for this purpose, in spite of its low permeability. A demand has arisen for a quality of iron which shall have high permeability, and still possess the quality of being easily cast into the proper shapes for field magnets for dynamo machinery.

Many attempts have been made to improve the quality of cast-iron, but for the most part with little or no success; and cast-iron stands to-day as a metal having nearly the same magnetic value for any and all qualities, though some slight improvements have been effected by some makers, as will be seen later. Attempts have also been made to produce castings from wrought-iron, and lately with fairly good success. This is accomplished in general by melting down scrap wrought-iron in crucibles, rendering it fluid by the addition of a small quantity of aluminium and pouring as with ordinary cast-iron. A great many extra precautions have to be taken to insure sound castings, and as a rule the castings made from this " mitis metal," as it is usually called, are rough and somewhat difficult to work on account of their roughness. These castings haves hown themselves to be of very much higher permeability than cast-iron, and have rapidly come into favor, especially in the construction of railway motors. Makers of steel castings have also been experimenting, with a view to producing a metal suitable for field magnets of dynamo machinery. Some of them have been very successful in this undertaking, and steel castings for field magnets are to-day an undoubted success. Manufacturers of sheet iron have also been trying to keep up with their fellow workmen in this line, and not a little experimenting has been done, with a view to the production of better qualities of sheet iron.

The writers having recently made, in the laboratory of Cornell University, quite a number of tests of samples of various special irons from different manufacturers throughout the country, it was believed that some of the results obtained would prove of interest to the general electrical fraternity. The method used for these tests was a modification of that used by Rowland, the samples being prepared in the form of rings, and wound with two sets of windings, a primary and a secondary. The magnetizing current was passed through the primary circuit and measured by means of a Weston ammeter. A ballistic galvanometer placed in the secondary circuit measured by its throw the magnetic induction due to any given change in the magnetizing current.

Two different plans were tried in taking the curves and found to give slightly different results. The first was the reversal method, in which the current was commenced at its maximum value and its direction reversed several times by means of a reversing switch, in order to bring the magnetism up to its full value, the secondary circuit being open during this operation.

The secondary was then closed through the galvanometer, the current reversed, and the induction measured by the throw. The current was then slightly reduced, reversed several times as before and the reduction again measured on reversing the current. In this way the magnetizing current was gradually reduced to zero, and from the data thus obtained curves were plotted with magnetic lines per square centimeter for ordinates and magnetizing force for abscissæ. In the other method, which was used for taking most of the curves and which gives the results nearly like those obtained by Hopkinson and which are generally accepted as standards for wrought and cast-iron, the sample was first completely demagnetized. In some cases this was done by simply reversing the current through the primary and at the same time gradually reducing it to zero. By this method, however, no samples except those composed of wrought-iron sheets were successfully demagnetized, which might suggest that the Foucault currents set up by the reversal of the magnetizing current tended to keep up the magnetization. An alternating current of both high and low periodicity was also tried without success, and it was only by finally heating the samples to a cherry red heat and allowing them to cool in air, so as not to change materially their softness, that total demagnetization was obtained. The sample being demagnetized, a small current was passed through the primary and the induced magnetism measured by the throw of the galvanometer. The current was then slightly increased and the deflection of the galvanometer again noted. And so on up to the maximum magnetizing force, the current being gradually increased step by step. The current was then reduced step by step to zero, reversed and increased step by step to a maximum equal to that of the other direction. This descending and reversal curve was taken simply to serve as a check upon the demagnetization and upon the accuracy of the observations of the ascending curve, and only the latter was plotted. Curves obtained from the same sample by the reversal method and by the step by step method were found to differ from each other by eight or ten per cent. at maximum values, the curves by the reversal process reaching the higher values. The magnetization of field magnets of dynamo machinery would probably reach higher values than that given by either of these methods of testing, for the iron, being subject to vibrations from the rotating parts of the machine, and being at the same time under a continuous magnetizing force, would no doubt reach as high magnetic values as could be obtained by any method of testing.

The results obtained are embodied in the accompanying

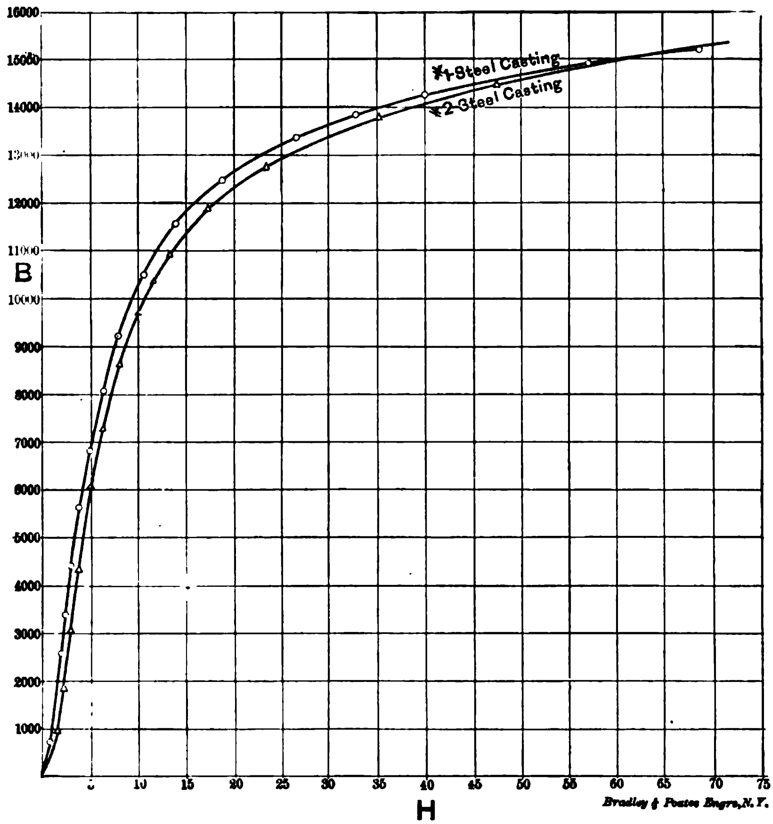

Fig. 1.

curves, which present the results of tests on samples of iron from a dozen different companies, in many cases a large number of samples of the same kind of metal having been tested. Referring to these curves:—Fig. 1 presents curves of two samples of steel castings from two different companies. The curves show both samples to be of very good quality, sample No. 1 being slightly the better of the two. Fig. 2 shows two more curves of steel castings, No. 3 being an average curve of about a dozen different samples of steel castings furnished by one maker, and No. 4 being an average curve of several samples of steel castings furnished by another company.

The different samples represented in curve No. 3 did not

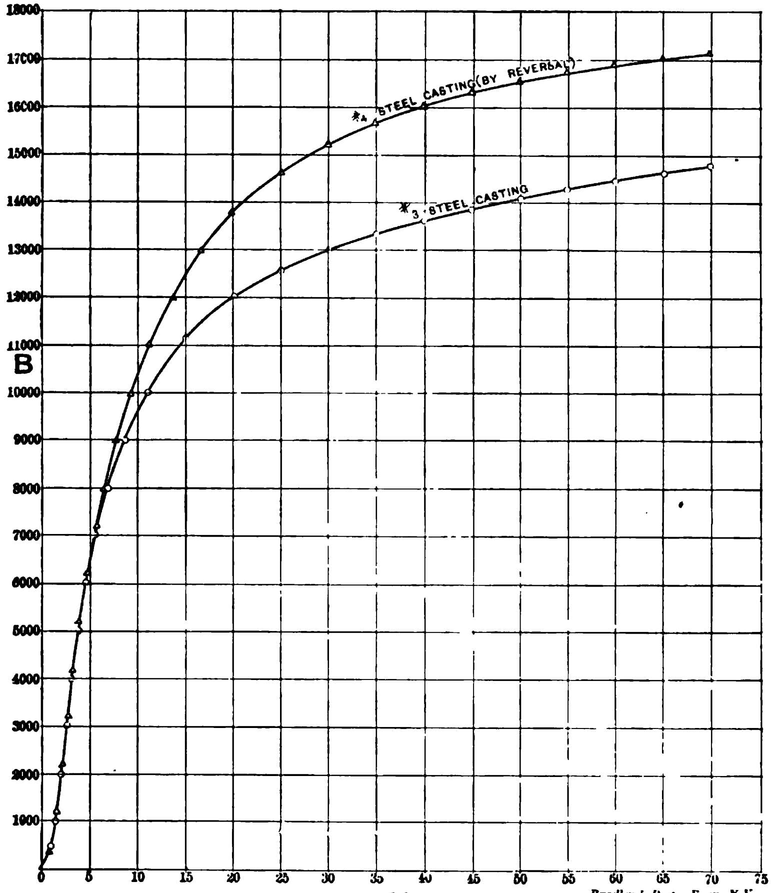

Fig. 2.

differ very materially from one another, and there was but a very slight difference in the samples represented by curve No. 4. Curves Nos. 1, 2 and 3 were taken by the step-by-step method, while curve No. 4 was taken by the reversal method, which will account for the high value of this curve, in a measure, though it is very probable that the quality of the steel represented by No. 4 was somewhat better than that of the other samples. The curves on Fig. 3 were all taken by the rever-al method. Curve No. 5 is the average of two different samples of wrought-iron castings from the same maker, the two samples prepared at different times and from different pourings showing almost identical qualities. The magnetic value of mitis metal, as shown by curve No. 5, differs very little from that of

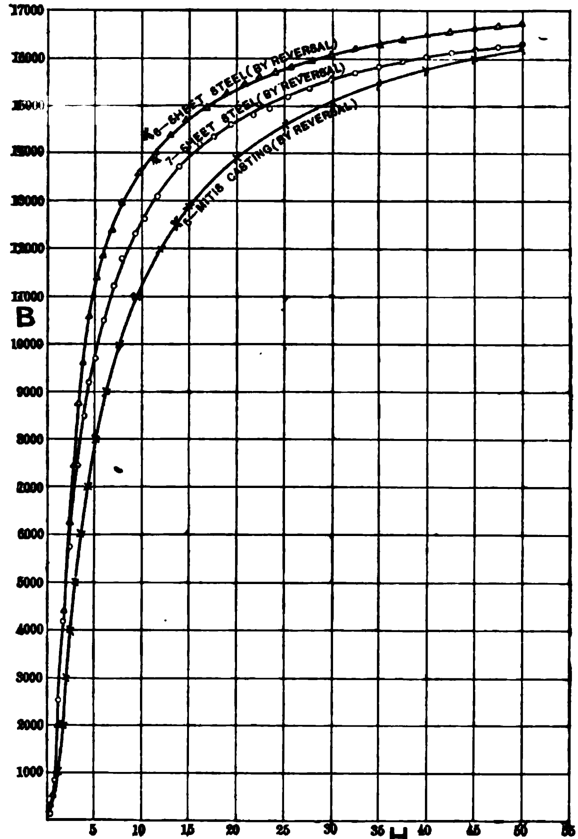

Fig. 3.

steel of good quality, as shown by curve No. 4. Curves Nos. 6 and 7 are from two samples of sheet steel of somewhat peculiar manufacture, inasmuch as they are said to contain no manganese, that element being perhaps the most objectionable impurity in mild steel, so far as its magnetic properties are concerned.

The two samples from which the curves were taken were made as an experiment, and by slightly different processes. They show excellent magnetic values, especially No. 6, and seem to indicate that sheet steel may some day come into extensive use for armature cores, etc. Curves No. 8, No. 9 and No. 10 of Fig. 4 are from three different samples of sheet iron used for armature cores and transformers by three well known electrical companies. Neither of these is up to the values given by Hopkinson for good wrought-iron, but the difference in the method of taking the curves may

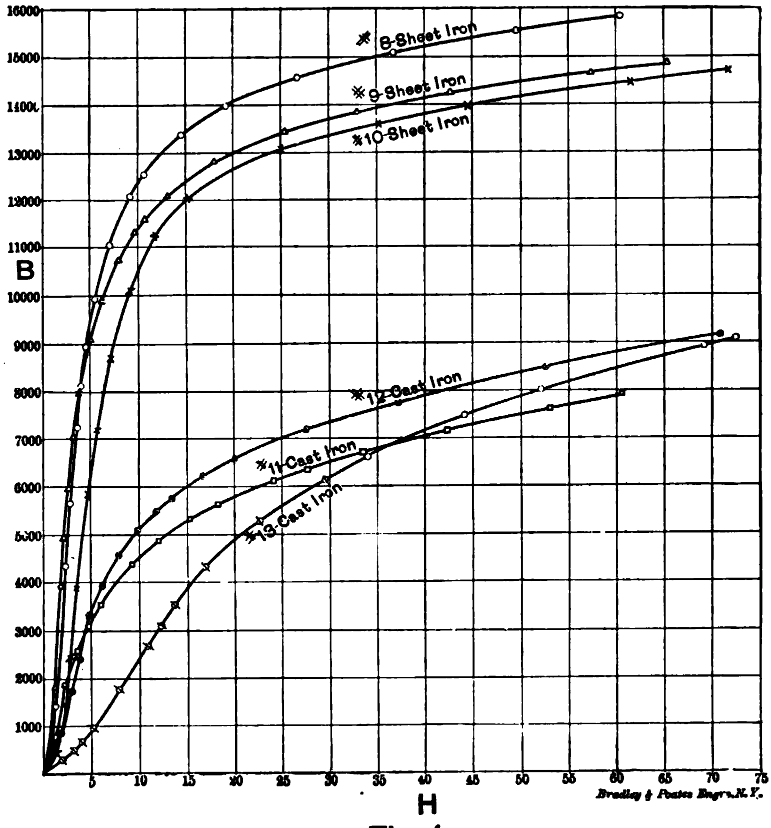

Fig. 4.

account in a measure for their being lower. These curves were taken by the step-by-step method. Curves No. 11, No. 12 and No. 13 of Fig. 4 are from three different samples of cast-iron, used by three electrical companies for field magnets of dynamo machinery. Sample No. 11 is an ordinary quality of cast-iron and differs from the values given by Hopkinson for cast-iron by only an inappreciable quantity. No. 13 is rather peculiar, in that for high values of magnetizing force it is slightly better than ordinary cast-iron, while for low values it is much poorer. Its magnetic properties are more like those of hard steel than of cast-iron. No. 12 shows a metal whose magnetic value is from 10 to 15 per cent. higher than ordinary cast-iron, the curve still keeping its same general shape. This sample would seem to indicate that there is such a thing as improvement in the magnetic

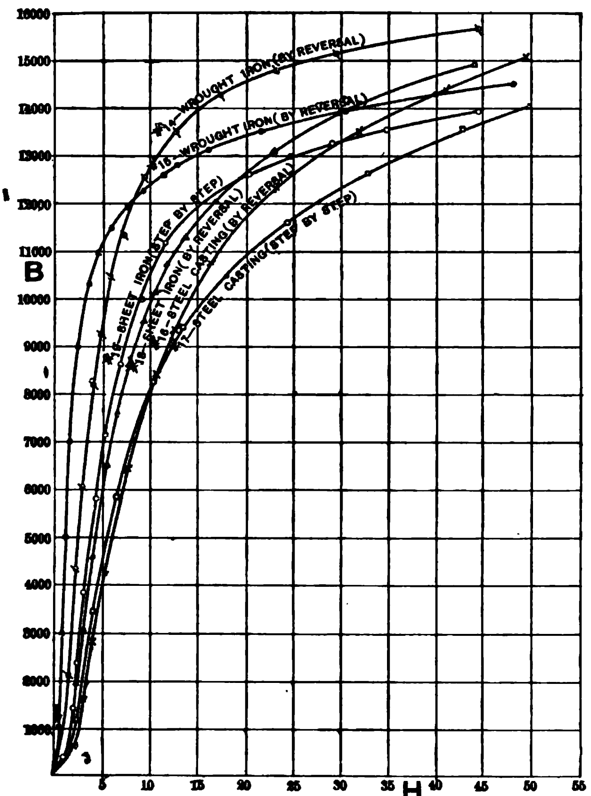

Fig. 5.

qualities of cast-iron. Curves No. 14 and No. 15 represent two different samples of wrought-iron, used by two electric companies for field magnets. These curves were taken by the reversal method, and indicate for the metals a value considerably below that of the best wrought-iron.

Curves No. 16 and No. 17 are both from the same steel casting, and show the difference between the step-by-step method and the reversal method. Curve No. 16 is by reversal, and No.

17 step by step. Curves No. 18 and No. 19 are both from one sample of sheet iron, No. 18 being taken by the reversal method, and No. 19 by the step-by-step. A similar difference in the two methods is indicated by these two curves. Fig. 6 is an attempt at a comparison of some of the more interesting of the curves

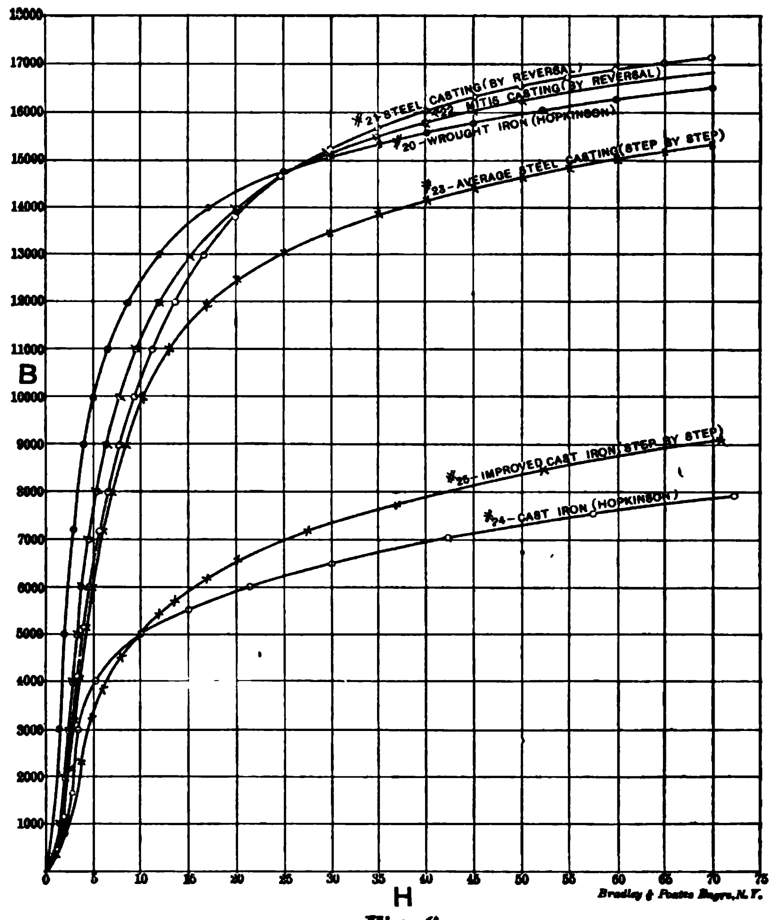

Fig. 6.

mentioned above. Curve No. 20 is Hopkinson's curve for wrought-iron. Curve No. 23 is an average curve for steel castings as made by four different companies. Curve No. 21 is a good quality of steel casting by the reversal method, and No. 22 is an average of mitis metal, by the same method. Curve No. 24 is Hopkinson's curve for cast-iron, and No. 25 is an extra quality of cast-iron, which would seem to show that there is still a chance for the standard of cast-iron to be raised. A comparison of curves No. 20 and No. 23 shows that the magnetic value of the average steel casting is only about eight per cent. below that of the best wrought-iron, and from curve No. 21 we might infer that it would be perfectly safe to use for the best steel castings the magnetic values given by Hopkinson for wrought-iron. Comparing curves No. 21 and No. 22, we see that there is practically very little difference in the magnetic values of steel castings of the best quality and mitis castings, and there seems to be no reason for believing that the former cannot be made of quite as good quality as the latter.

Comparing both of these metals with curve No. 24, their magnetic values are so far superior to that of cast-iron that it seems quite certain that only the cost of production can stand in the way of their rapid and almost universal introduction for field magnets of dynamos and motors. When we consider that the cost of steel rails is but little different from that of cast-iron, it seems reasonable to suppose that when the art of making steel castings comes to be better known and more fully understood, and better facilities are provided for their manufacture, such castings can be produced at a cost but little in excess of that of cast-iron. Considering then the great superiority of cast-steel over cast-iron for electrical purposes, it seems safe to predict that the day is not far distant when steel castings will almost entirely replace cast-iron in the construction of dynamo machinery, and the improvement in such machinery resulting from this change will be perhaps one of the greatest steps that has ever marked the progress of the electrical industry.

Discussion.

The Chairman [Vice-Prs't Hering] :—I am sure that we all feel very much indebted to Dr Nichols for reading, or I should say, for explaining and at the same time discussing this paper in the very interesting way in which ne did. The paper is open for discussion. There are doubtless here many who have worked in this field, and we would be very glad to hear from them.

Professor Carhart :—I am very much interested in the paper and in the results. Particularly because I made some similar experiments two years ago, and secondly because some of my students are now carrying on experiments similar to these. Nearly two years ago I tried the relative permeability of sheet-iron of several varieties; sheet-iron and mitis steel, and the results entirely confirmed those given in the paper. I found that certain varieties of mitis steel have higher permeability than sheet-iron. I find quite a decided difference in that direction. I should like to ask Dr. Nichols about the hysteresis curves of the steel as compared with the sheet-iron.

Dr. Nichols:—I will say that the hysteresis curves have been obtained in some of these specimens, but that work is still going on I should like to say also, in addition, as a contribution to the

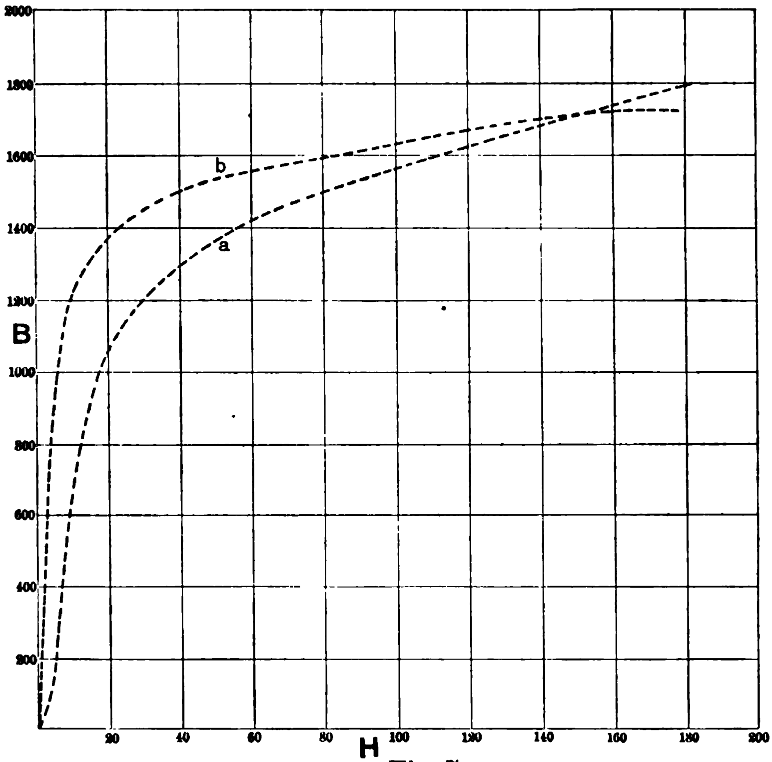

Fig. 7.

discussion, that a third set of measurements, carried on by another observer in our laboratory, was entirely confined to the question of open hearth steel as we get it in the form of boiler plates and armor plates made for the government, the test rings being cut directly from such plates. It was found that these open hearth steels, as manufactured for boilers, and for the armor for vessels, show precisely the same qualities as the average of the steels, treated of in the paper under discussion. The magnetization curves of two such open hearth steels, tested by the obsever of whom I speak (Mr. F. W. Throop) are given in the following diagram. Curve *a* was obtained from a ring cut from a government armor plate, *b* from a similar ring of fire-box steel.

DR. EMERY:—Mr. President, my statement yesterday that the permeability of steel at high magnetizations was greater than that of wrought-iron, was based upon statements of Mr. Steinmetz, who has done a great deal of good work in this direction, and upon tests of experimental motors with steel lamina in the armature, which gave very excellent results. I will ask Dr. Nichols to state for the record whether the curves based on Hopkinson's experiments are the actual experimental curves or those presented by Thompson, which show the averages of the ascending and descending values.

PROFESSOR NICHOLS:—I am not sure that I can answer that in the way it is put for the purpose of a record in this matter, for I am not quite positive of it. I think it is the ascending curve of wrought-iron. The intention, of course, was to get a Hopkinson curve which was in every respect comparable to those just described.

PROFESSOR JACKSON:—Mr. President, I did not hear this paper, but I do not see anything on the sheet of curves regarding the chemical analysis. I have done some work of this kind, and have found that the amount of carbon in steel castings and also in rolled steel has a great deal to do with the permeability, and also a great deal to do with the form of the curve of magnetization. By controlling the amount of carbon, and also by controlling the amount of manganese (these being the common impurities which have the greatest effect on permeability, we are enabled to vary the form of the curve of magnetization considerably. If Dr. Nichols has an opportunity to carry out a consecutive series of experiments, determining the amount of carbon and manganese in mild steel, of which he makes permeability tests, he will get some very useful results, far more useful indeed than the permeability tests can possibly be without the chemical comparisons.

The variation of the magnetic properties of iron and steel by aluminium alloys seems to be due simply to the effect of aluminium as a flux. As a flux it changes the proportion of carbon; and hence may be used to advantage, though its presence is a disadvantage where its fluxing properties are not required. The purer the iron is, the better the magnetic result seems to be, *i. e.*, the higher the curve of magnetization will run before it makes a bend. By the introduction of aluminium we reduce the magnetization at the point of saturation (just exactly as would be the case by the addition of carbon or manganese); but aluminium controls the carbon to a certain extent in mild steel, and it has a marked effect in some cast-iron. In cast-iron the control of silicon seems to be of about equal importance with the control of aluminium and manganese.

MR. BRADLEY:—Professor Jackson, have you analyzed cast-iron?

PROFESSOR JACKSON:—I started in on cast-iron, but did not get very far, so that I cannot give any thoroughly good results. A number of test pieces of different kinds of cast-iron were made. One piece was made of very hard cast-iron, an iron that chilled badly, and which it was almost impossible to work either on a lathe or with a file. and its magnetic properties were very poor. By properly alloying with aluminium when the iron was cast, we succeeded in making the carbon come out in the form of graphitic carbon instead of combined carbon, giving a good soft iron with quite fair magnetic properties. It seems impossible however to produce quite as good magnetic properties with aluminium present as first-class *graphitic* iron shows without the aluminium.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892. Vice-President Hering in the Chair.

NOTES ON WIPING CONTACT METHODS FOR CURRENT AND POTENTIAL MEASUREMENTS.

BY PROF. BENJ. F. THOMAS.

In the discussion on Mr. Milton E. Thompson's paper on "A Study of an Open Coil Arc Dynamo," read before the Institute on the 21st of May, 1891, Dr. Geyer referred to some work done at Stevens Institute by the writer, in which work the wiping contact method seems to have been used for the first time. The following brief account of the work is presented at the request of several members of the Institute.

In the latter part of July, 1880, President Morton requested the writer to determine the power required to maintain the arc of a Brush arc light, supplied with current by a Brush dynamo machine.

Ammeters and voltmeters were then unknown, and among the electrical instruments in the Stevens laboratory the most convenient for the purpose seemed to be a tangent galvanometer for the current measurement, and a condenser and Thomson galvanometer for potential. The condenser was a one-third microfard standard, and the galvanometer 7,000 ohm, four-coil astatic, both made by Elliott Bros. As every one now knows would be the case, trouble was encountered the moment the potential readings began. The condenser being first connected to the two carbons, and then discharged through the galvanometer, the successive throws of the needle were found to vary widely, and what seemed at the time most curious, *the throws were sometimes to right, and sometimes to left.* A little reflection showed that while varying throws in one direction might be due to varying resistance of the arc, throws in opposite direction could only be produced by an actual reversal of the potentials of the two carbons. This, of course, led to the conclusion that the potential difference at the terminals of the dynamo must vary with the angular position of the armature as it revolved. Wishing to know the character and magnitude of the variation, the writer devised what is now known as the wiping contact method, the natural and only expedient for the purpose.

The condenser was joined, through the usual discharge key, to

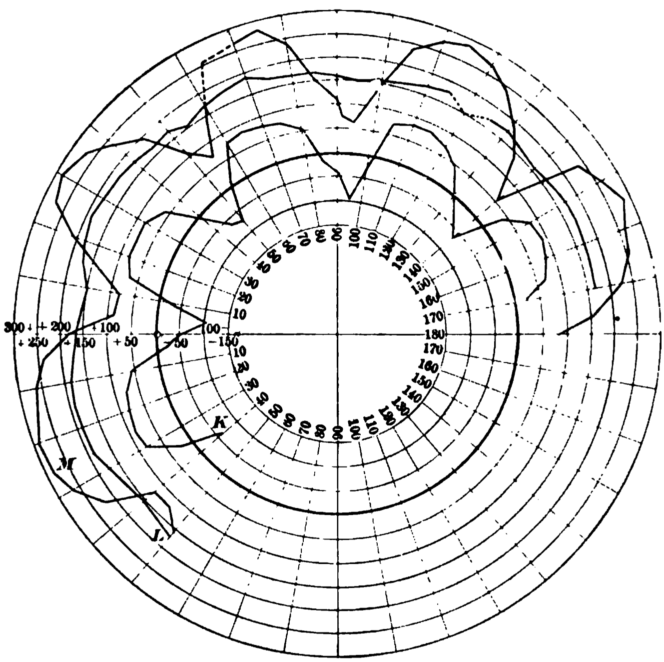

Fig. 1.

the terminals (or other points) of the dynamo, by two insulated wires. At the dynamo one of these wires was cut, and the cut ends attached to a pair of well insulated flat springs of metal, mounted on the outer end of a radial arm, the latter fastened to a horizontal rod, coaxial with the armature. A well insulated piece of metal was fastened radially on the face of a disk attached to the armature shaft, and the two brushes set so that they were lightly touched by the radial strip at each revolution of the armature. A pointer attached to the horizontal shaft carrying the radial arm and contact springs, moved over a divided circle on the support of the arm, so that angular positions could be read. The contact device thus acted as an open circuit key, the closing of which, and the consequent charging of the condenser, could only take place when the armature was in a definite position. The process of obtaining the curve of potentials through a revolution

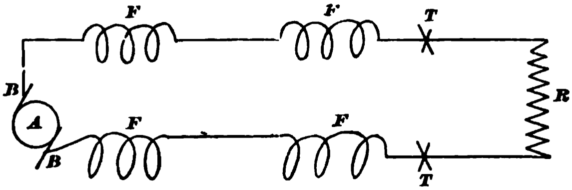

Fig. 2.

of the armature is now so familiar that further description is unnecessary.

In carrying out the examination of the machine, a non-inductive resistance of german silver wire was prepared to avoid complications from the action of the arc lamp. When this was used as a load for the machine, the throws of the galvanometer changed at once from the erratic behavior observed at first, to the beautifully regular and uniform character now so familiar to all who have used the method under proper conditions.

Fig. 1 is a copy, to scale $\frac{2}{10}$, of the original curves of measurements made August 4. The inner circle gives the angular readings of the circle over which the pointer moved. Deflections of the galvanometer, on discharging the condenser through it, are plotted radially, at the angles at which they were obtained, the

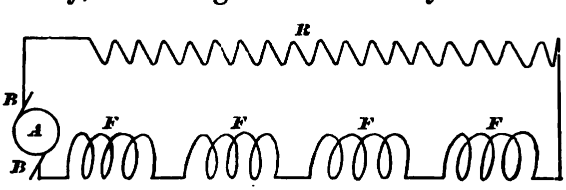

Fig. 3.

heavy circle being taken as zero. The scale is .2 volt per division. Curves *K* and *L* were obtained with the machine connected as in Fig. 2, in which *A* is the armature, *B B* the brushes, *F F* the four field coils, *T T* the terminals of the dynamo, and *R* the non-inductive resistance. The curve *K* gives the deflections obtained when the condenser leads and wiper were joined at *T T*. It will be observed that the curve is symmetrical, giving eight maxima and eight minima per revolution. The minima are below zero, and explain the reversed deflections observed in the first work on the arc. The resistance *R* being non-inductive, *K* is also the curve of current strength, to a different scale, and shows that the machine was an alternating current machine, although the excess of positive area over negative shows an average positive current. Curve *L* was taken with the machine in the same condition as before, but with the condenser leads attached to the brushes at *B B*. It gives the varying potential of the armature, as modified by the inductive reaction of the field, and shows the same symmetry, with less distortion. For curve *M* the field coils were all thrown on one side of the armature and condenser leads attached to *B B*, as in Fig. 3.

To ascertain the effect of an inductive external resistance on the terminal potentials of the machine normally connected, the connections used in obtaining curve *K* were repeated, the only change made being to insert the six coils of the large Stevens electromagnet with the non-inductive resistance *R*, adjusting *R* to get the same current strength used in getting curve *K*. The resulting curve showed the same characteristics as *K*, but much magnified, deflections ranging from — 300 to + 550. Many other curves were taken, with the machine self-excited and separately excited, on various loads and on open circuit, but the results, though interesting, are not of sufficient importance now to occupy your time. The most interesting curves and results were presented as a joint paper by Prof. Morton and the writer, and read by Prof. Morton before the American Association for the Advancement of Science, at its Boston meeting, August 25–30, 1880. Immediately after that meeting the writer entered on his duties at the University of Missouri, and had no opportunity to resume the use of the method until his removal to Ohio in 1885. It was used in that year by his students in an examination of the Thomson-Houston arc dynamo, substituting a Thomson portable electrometer, with Leyden jars to increase its capacity, for the condenser and galvanometer. Since then the method has been used in this laboratory on various apparatus, and in various ways, but it is needless to recount the details.

Our experience with the method leads us to prefer the Thomson portable electrometer and Leyden jars, to all other instruments for high potential curves. The electrometer is dead beat, is a zero instrument, and is easily and quickly set. As usually made, its constant is from two to three volts per division, and one can easily set to within that amount. The error resulting from an improper reading, say one division wrong, would be of course serious in reading low potentials, but these readings only occur on nearly straight parts of high potential curves, and might be entirely omitted without serious error.

Next to the portable electrometer, we prefer the Thomson electrostatic voltmeters. For low potential curves nothing has yet proven superior to the potentiometer method as used here, and described by the writer at the American Association meeting at Washington last August. The potential difference to be measured

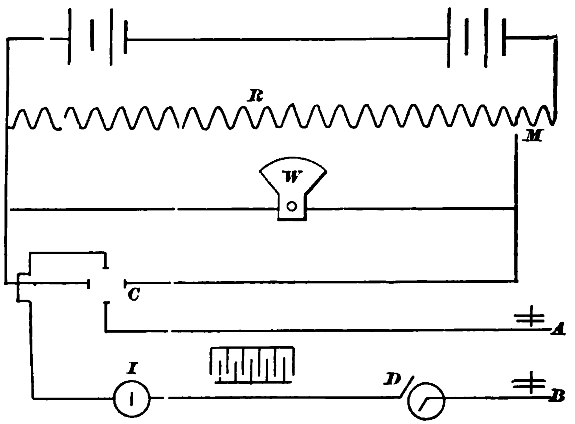

Fig. 4.

is balanced against that produced by a battery in a resistance as in Fig. 4.

In the figure, *R* is a resistance of some convenient form, with which contact may be made with a movable terminal *M*, or which may be varied between or beyond the terminals of the Weston voltmeter *W*. From these terminal wires leads through a commutator *C*, a sensitive galvanometer or telephone *I*, and the wiper *D* to any points *A B*, whose potential curve is desired. The whole being in operation, and *C* properly placed, *M* or *R* (or both) is adjusted until *I* shows no current, when the potential difference existing at *A B* is read off directly in volts on the voltmeter *W*. The use of the telephone is due to R. D. Mershon, a graduate of the university, who described the method in the *Electrical World* of August 29, 1891.

Fig. 5 is a part of the potential curve recently taken from a Brush open coil motor, run as a dynamo on an inductive load. One-fourth of the complete curve is shown, and the parts not given are quite symmetrical with this. No "smoothing" is applied, but the observed points are joined by straight lines. The sharp angular form shown is due to the fact that readings were taken at intervals of five degrees, except between 25 degrees and 35 degrees, where readings were taken at each degree, to determine the character of the sharp variation between 30 degrees and 35 degrees. The change of 130 volts which occurs between 32 degrees and 33 degrees is unique and noteworthy, yet it is perfectly definite and characteristic, and has been repeatedly ob-

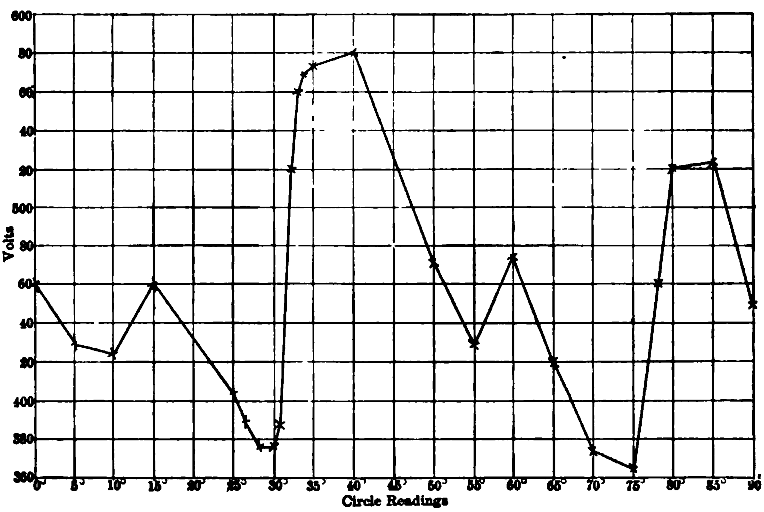

Fig. 5.

served under like conditions. The use of ammeters and voltmeters or galvanometers in power measurements on such machines must, as pointed out in the paper of 1880, lead to incorrect results.

In Mr. Thompson's paper referred to above, reference is made to Joubert's use of the method in 1881, and in the recent edition of Thompson's Dynamo-Electric Machinery, it is described as Joubert's method. In view of the work here described, and its presentation before the American Association in 1880, it seems proper to claim the method, which in the hands of Dr. Duncan, Professor Ryan and others, has led to such valuable results, as an American method.

Discussion.

Dr. Nichols:—Mr. President, this is a subject in which I feel very much interest. It seems to me that we owe Prof. Thomas an expression of thanks for taking the trouble to revive the ancient history of this particular method which has grown to be of such importance. At the time when these measurements were made, they were so little appreciated as to have attracted no attention. The paper, as we know, was presented at the American Association for the Advancement of Science, and was regarded as a curious thing; and a dynamo itself at that time was regarded as hardly worthy of study in this country. So far as I know the history of this matter, the next place where this method crops out was in 1884, in Philadelphia, where it began to be seriously considered, and where it was put into practice, or at least considered one of the ways in which dynamos were to be studied. And certainly from that time on, in various laboratories, it was the method for practice work on dynamos, year after year. Prof. Jackson himself, who is with us to-day from Madison, doubtless can remember a great number of curves which he took by this same method in the laboratories of Cornell University in those days. The application of it to alternating current curves should doubtless be credited to Joubert. The graphic data accompanying the paper. I think is extremely interesting in its bearing upon the history of this important method, and is well worthy of a place upon our records.

[A vote of thanks was tendered to Professor Thomas for his efforts in collecting these facts for the benefit of the Institute, and upon its invitation.]

Mr. Chas. F. Scott:—Mr. Chairman, I may make a statement with regard to the use of the telephone method referred to by Prof. Thomas. Mr. Mershon, to whom that method is due, is now with the Westinghouse Electric Company, and has used the method in the laboratory work of the company in taking curves of electromotive force and current from alternating machines. The telephone is an extremely delicate instrument, and as we all know, is very liable to give undue prominence to sounds that are not wanted. In using the telephone we found that various sounds from the dynamo engine room could be distinctly heard, but the click of the contact is peculiar and can easily be detected and the sliding resistance can easily be adjusted so as to eliminate the sound of the contact, showing that the proper adjustment is made although other sounds may still be heard. Repeated settings can be made with very great accuracy. On one occasion a gentleman who was not accustomed to making electrical readings was invited to make a number of settings. I took the readings on a Weston voltmeter, and they ran something like this: 76.9, 76.8, 76.9, 76.9, and so on, showing that the method is susceptible of very great accuracy. It is a practical method, and can be readily and rapidly applied.

Professor Jackson:—Mr. President, I think in the fall of

1885 I first learned of a similar method when I went to the laboratory at Cornell University. We then had several machines arranged for very careful examination in this manner: One was the old Ball dynamo, and I remember going through that machine with a great deal of pleasure a number of times. I have no doubt from the results that have come from Cornell since those days, that they have used and explained the methods many times. The method is undoubtedly one of the most satisfactory that can be used for studying the action of a dynamo.

The portable instrument that Dr. Nichols spoke of yesterday for taking somewhat similar curves, I am very much interested in, and trust that the subject will be more fully developed in the laboratory at Cornell. Such a portable instrument must be the natural outcome of the careful study that is now being made of the magnetic fields of dynamos, and if it can be put into commercial shape it will be practically invaluable to dynamo manufacturers.

Professor Carhart:—Mr. President, it would be well to have a little corroborative testimony of what Professor Thomas has stated. It does not go back to 1880, but I remember very distinctly in 1884, in Philadelphia, Professor Thomas and I were examining different machines, and the reference to this Ball machine revives it very strongly. We came in the vicinity of that, and I recollect Professor Thomas expressed a very ardent desire to explore the region around the armature of that machine, and that accounts for his interest in the subject, because he had already been practicing this method.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, Vice-President Hering in the Chair.

A LIFE AND EFFICIENCY TEST OF INCANDESCENT LAMPS.

BY PROFESSOR B. F. THOMAS AND MESSRS. P. MARTIN AND R. H. HASSLER.

Much has been written and said concerning the efficiency of the incandescent lamp, and of the relation between its efficiency and the length of life to be expected from it. High efficiency lamps have their advocates and low efficiency lamps have theirs. It is pretty well understood by those whose work has put them in a position to appreciate the facts, that the question as to the choice of the lamps which will have the best influence on the profit and loss account of the consumer, depends on other things than first cost, efficiency and life. It is understood by such persons that the cost of producing the current supplying the lamps, and the steadiness of voltage maintained on the lines are important factors in the choice; the high efficiency, short life lamp being best under conditions of steady voltage and expensive current, and the low efficiency, long life lamp where current is cheap or regulation poor.

The general public, however, does not understand the question so clearly, and unfortunately that part of the literature of the subject which is found in the advertising columns of the electrical press, does not tend to relieve the embarrassing ignorance of the buyer. Statements of the marvelously long life of certain lamps are followed in a week by ludicrous accounts of searches for them with a lantern, and of the imminent peril of the country, arising from the exhaustion of our coal supply by the running of such lamps. Again we are startled by statements of the wonderful results attained by lamps of some certain make, as indicated by the number of such lamps which can be maintained at full brilliancy by the expenditure of a horse power. But immediately it is said that the insane asylums of the country are full of station managers and stockholders, whose cases have become hopeless through contemplation of the number of such lamps bought during the year. There is as great divergence between the published claims of lamp makers, and the statements of the experience of station managers. Makers generally say that they will guarantee 600 hours life for their lamps, and from 10 to 14 or more lamps per horse power, but some station managers insist that they do not get an average of 400 hours life.

Lamp makers have, from necessity, made a study of their own lamps, and of those of other makers also, as to efficiency and life, and they know, better than any one else, the character of the incandescent lamp of to day. But naturally they, if they say anything on the subject, tell about the good points of their own goods, and the bad points of others, and, as naturally, the buying public say that all their statements are questionable. Much good work has been, and is being done in college laboratories on lamp efficiencies, and the results are published and accepted, but on the equally important question of life the laboratories are silent. The tests of the Franklin Institute stand as a model piece of work, but that work is now eight years old. Farther, the lamps tested at that time were furnished by the makers themselves for the purpose of test. Believing that the public would be interested in the results of a test of commercial lamps, as to both efficiency and life, the writers have carried out such a test and give the results in this paper. The test was made at the Electrical Laboratory of the Ohio State University, Columbus, O., and all expenses incurred were paid by the trustees.

Considering it of prime importance for our object that the lamps tested should be of the same character as those usually sold to consumers, we bought some lamps of regular dealers, as in the usual course of business, and obtained others from lots supplied for central station use. Lamps of the following makes were obtained, no attempt being made to get lamps of any given efficiency of any make: A. B. C., Beacon, Columbia, Economic, Packard, Pennsylvania, Standard, Thomson-Houston, Edison, Perkins, Sawyer-Man, and Steuben. In ordering (through persons purchasing for us in Chicago and New York) we called for ten 110-volt lamps of 16 C. P. in each case, but on receiving the lamps we found three lamps out of 10 of one make labeled 111 volts. The three were excluded and seven put in, but another lot of 10 of the same make, correctly labeled, was obtained. Ten of another make were received with the original marking, 111 volts in ink, changed by pencil to 110 volts. They were also excluded, and a new lot of 10 of that make, correctly labeled, obtained. Ten Sunbeam lamps were divided into two lots of five each, evidently supplied as a sample lot, and were excluded. We could not get others of that make in time to enter the test. There were, therefore, in all 127 lamps, labeled 110 volts and 16 c. p., of 12 well known makes, 17 lamps in two separate lots of one make, and 10 each of 11 different makes.

For convenience in making the photometric measurements, the lamps were mounted vertically in horizontal rows of 20 on a light vertical rack, six feet high and 20 feet long. The rack was made in the form of ordinary shelving, having five vertical pieces of pine, four inches wide and one inch thick, and four horizontal strips of the same width, the four inch face being horizontal. The whole was rigidly braced diagonally, suspended by strong cords passing over pulleys in the ceiling and counterpoised by weights. This arrangement enabled us to bring each row of lamps to the level of the photometer described below, by raising or lowering the rack, and definiteness of position was secured by spiking to the brick wall of the photometer room two 2 by 4 inch vertical guides, against which the rack was pressed, and fastened each time by stout inclined pins, passed through the diagonal braces into holes bored in the guides.

A system of positive mains was arranged by fastening a No. 2 wire along the face of each horizontal strip in the rack, and joining them at the middle of the rack by a vertical No. 0 wire. A set of negative mains similarly made was placed on the opposite side of the rack. Flexible okonite cable of equivalent section joined the No. 0 vertical wires to the ends of the dynamo mains, fastened to the wall, which point is called the centre of distribution. Porcelain keyless wall sockets were screwed in place on the horizontal rack strips, and joined to the mains on each side by No. 16 wire. All connections were well soldered.

A Thomson centiampere balance provided also with a resistance for obtaining standard potential readings was used as a standard for current and potential. Its constants had been repeatedly checked by a voltmeter, and by Clark cells, and found correct and constant to within one part in one thousand. Two Weston milliampere meters and two Weston voltmeters were used in the current and potential readings on the lamps. The ammeters were graduated to 10 milliamperes, readable to one milliampere, and the voltmeters in volts, readable to tenths. The Weston instruments were compared with the Thomson balance at intervals, and found correct, or affected by a small, constant error, which was applied as a correction.

Current was supplied to the lamps by a 200-light Thomson-Houston dynamo, of the spherical armature type, which proved to be an excellent machine for the purpose. Owing to the variable speed of the engine, due to varying load and steam pressure, a special automatic regulator was devised and applied to the dynamo, to keep the potential at the centre of distribution constant. This was effected by causing a small motor to slide a contact piece along two vertical german silver wires joined to an extension of the field coil of the dynamo, a current being sent through the motor in one direction or the other as needed, by relay points, the relays being controlled by an indicator attached to wires leading to the centre of distribution. As used, the combination proved very satisfactory, keeping the potential difference at the centre at 110 volts, within a limit of $\frac{1}{4}$ of a volt either way. It could readily have been set to a smaller margin, but that was not considered necessary.

For the candle power measurements a two candle power Methven screen was used, the gas being passed through a Methven carbureter containing pentane. Its constant was checked by standard candles. Three 32-candle power Edison lamps were used as working standards. Each was checked at intervals by comparison with the Methven screen on a 100-inch photometer bar, a slide wire resistance enabling us to adjust the current through the lamp to a definite strength, which was always the same for a given lamp. The currents used were such as to develop about 18 candle power in the standard lamp. Instead of the usual Bunsen or Leeson disk, we used a Lummer-Brodhun prism, made by Schmidt and Haensch. It gave us much better satisfaction than the best Leeson disks we have been able to obtain.

In front of the test rack and parallel with it was placed a bench with a guiding rail, along which a Weber portable photometer was arranged to slide, so as to be placed successively in front of each lamp in a row on the test rack. Instead of the little benzine standard lamp which was removed, a 16-candle incandescent called the reference lamp was placed at a distance of about 800 centimeters from the end of the tube to which the bezine standard is attached. In taking the candle power of the lamps under test, the photometer was first placed in front of one of the working standards. By means of a conveniently arranged slide wire resistance, the current through the standard lamp was accurately adjusted to the strength used with it, when its candle power was measured on the standard photometer against the Methven screen. Care was taken that the adjustment of current was right when the measured potential at the terminals of the reference lamp was just 110 volts. Readings of the standard lamp against the reference lamp being taken the photometer was then moved in frout of each lamp under test, and readings taken of each against the reference lamp. The candle power of each lamp was then found by comparing these readings with those obtained opposite the standard lamp. The reference lamp being of the same character as those under test, and connected to the same mains, the slight changes in potential allowed by the regulator affected alike the candle power of the reference lamp and the test lamp being read, allowing us to take readings more rapidly than we could have done had it been necessary to adjust and hold the potential at 110 volts.

Before the duration test began, the mean horizontal candle power of each lamp was determined in the usual way, and the ratio of this mean to the candle power found when the plane of the ends of the filament was perpendicular to the photometer bar was found, and used as the distribution factor. The lamps were placed on the rack in the same position with respect to the Weber photometer, at a distance of about one meter from its plate, the exact distance of each lamp being measured and used in the calculations on it. All results are expressed in terms of mean horizontal candle power. The unavoidable delays encountered in starting the test made it impossible to determine the spherical distribution without cutting short the time of run which we had set as desirable, viz., 1,200 hours. The duration test was begun on March 17, and it was necessary to run night and day, Sundays excepted, until the night of May 14, to complete the 1,200 hours. The run began with 77 lamps on the rack. The remaining 50 lamps were received later, and placed on the rack with the others 187 hours after the start.

As the methods used involve nothing particularly new, and have been fully described in print many times, we have consid ered it unnecessary to do more than state the general outlines, as above.

The object we had in view in undertaking the test was, to determine the character of the incandescent lamp as a commercial product, not as a scientific instrument. The number of lamps of each make taken was, of course, too small to base a fair judgment on as to the absolute or relative merit of the lamps generally sold by the makers. For that purpose some hundreds of lamps of each make, taken from different lots, would have to be tested, which it was of course impossible for us to do. For this reason we have considered it unfair to the several makers concerned, to give their names in connection with the results on their lamps, but have instead designated each make by a letter, and each lamp by a number. We believe, however, that the average of the results of all makes may be taken to represent fairly well the character of the average commercial lamp.

The results of the test are given in the following tables, the values given being in each case the average for a given make of lamp. Table I. gives in the second column the average value of the distribution factors found for the 10 lamps of make " A," and the average value of the mean horizontal candle powers for those lamps at intervals after the beginning of the duration test, expressed in hours by numbers in the first column. The third column gives corresponding values for the lamps of make " B," and so on. Table I. includes the lamps started March 17. Table II. contains similar data for the lamps started 187 hours later.

TABLE I.

Lamp.	A	B	C	D	E	F	G	K
Distribution factor	1.05	1.07	1.01	1.11	.989	1.01	1.01	1.02
Hours from start,	C. P.	C. P.	C. P.	C. P.	C. P.	C. P.	C. P.	C. P.
0	16.0	13.1	14.1	16.1	15.9	14.2	17 1	17.0
93	15.0	12.4	14 8	16.1	13.7	12.1	15.9	16.1
233	13.65	12.4	14.9	16.0	13.1	12.9	16.4	16.5
324	12.2	11.0	14.8	13.9	10.9	10.8	14.5	13.9
392	11.7	10.5	14.0	13.2	10.5	10.4	13.6	13.4
441	11.3	10.2	14.2	12.7	10.1	10.2	13.3	13 1
537	10.9	9.9	13.6	12.3	9.9	10.0	13.0	13.0
637	10.7	10.1	13.0	11.9	9 5	10.1	12 4	12.4
785	9 4	9.2	12.6	10.5	9.1	9.1	11.4	10.9
833	9.1	8.6	All out	10.1	8.5	8.5	10.9	10.3
883	8.6	8.2	....	9.3	7.7	8.0	10.4	9.8
972	8.6	8.3	....	9.2	7.6	8.0	10.4	10.0
1,105	8.6	8.2	....	9.2	7.4	8.0	10.3	9.5
1,190	8.2	8.0	....	9.0	7.5	8.0	10.4	9.6

Table II.

Lamp.	L.	M.	N.	O.	P.
Distribution factor.	1.10	1.00	.911	1.00	1.02
Hours from start.	C. P.	C. P.	C. P.	C. P.	C. P.
0	13.2	12.5	14.1	17.0	14.6
71	12.6	12.5	13.5	....	....
137	10.7	12 6	11.7	16.4	15.9
205	10.1	11.9	11.0	14.8	13.6
254	9.7	11.6	10.4	14.0	13.0
319	9.3	11.8	10.1	13.3	12.3
450	8.9	11.5	9.4	11.6	11.6
598	7.8	10.6	9.3	10.8	9.7
646	7.6	9.6	8.2	9.6	9.2
696	7.1	9.3	7.9	9.0	8.4
785	7.1	9.4	7.8	9.0	8.7
837	6.8	8.7	7.5	8.3	8.5
1003	7.1	8.8	7.4	8.0	8.4

Table III. gives the average current strength found for each make of lamp, at times given in the first column:

Table III.

Lamp.	Mean current strength in amperes.												
	A	B	C	D	E	F	G	K	L	M	N	O	P
Hours.													
0	.567	.532	.693	.639	.589	.532	.662	.613	.458	.547	.568	.609	.536
100	....	....	..	....	....	..	....	....	.444	.532	.557	.665	.534
107	.575	.545	.760	.668	.581	.519	.68[illegible]	.629	....	....	....	..	..
275	.567	.540	.778	.655	.566	.516	.681	....	..	....	....	....	....
380	....	....	....	....	....	....	....	....	.425	.513	.528	.615	.511
555	.548	540	.770	.633	.541	.504	.662	....	...	....	....	....	...
615		..	....	....	....	....	...	....	.418	.505	.519	.595	.495
790	.540	.535	.770	.619	.5[illegible]0	.498	.654	.581	...	....	....	....	
930	..	....	....	....	....	....	....	...	.417	.500	.508	.585	.476
1,105	.535	.529	.000	.611	.517	.495	.649	.577	....	....	....	....	....

Table IV. gives the mean percentage of original candle-power for each make at times given in the first column:

Table IV.

Lamp.	A	B	C	D	E	F	G	K	L	M	N	O	P	Average.
Hours.	%	%	%	%	%	%	%	%	%	%	%	%	%	%
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100
100	93	94	106	101	92	9[illegible]	95	93	87	100	87	95	107	95.6
200	86	89	109	99	84	86	90	87	78	98	79	87	97	90
300	79	83	106	93	77	81	86	83	72	94	72	80	86	84
400	74	80	102	82	72	77	81	78	67	90	67	72	78	78.4
500	69	73	98	75	66	70	77	74	63	86	63	66	71	73
600	64	70	94.	70	61	66	73	70	59	80	60	60	65	68.6
700	61	67	91	66	57	62	70	67	55	75	56	55	60	64.7
800	58	64	90	63	53	59	66	63	54	73	55	51	58	62
900	55	63	All out	60	51	57	63	59	53	70	53	49	56	57.4
1,000	54	62	....	58	49	56	62	58	54	70	52	47	57	56.6
1,100	52	61	....	57	47	56	61	57	....	...	....	....	....	55.8
1,200	51	61	....	56	47	56	61	57	....	...	...	....	...	55.4

Table V. gives the average watts per mean horizontal candle power for each make, at times given in the first column:

TABLE V.

	Watts per mean horizontal candle power.													
	A	B	C	D	E	F	G	K	L	M	N	O	P	Av.
Hours.														
0	3.0	4.4	5.4	4.3	4.1	4.1	4.2	3.9	3.8	4.8	4.4	3.9	4.0	4.2
100	4 3	4.8	5.6	4.5	4.4	4.3	4.6	4.3	4.2	4.7	4 9	4.5	3.8	4.5
200	4.6	5.1	5.6	4.5	4.7	4.6	4.9	4.6	4.6	4.7	5.3	4.9	4.1	4.8
300	4.9	5.4	5.7	4.8	5.0	4.9	5.0	4.8	4.9	4.8	5.7	5.2	4.5	5.0
400	5.2	5.6	5.9	5.3	5.4	5.1	5.3	5.0	5 2	4.9	6.1	5.4	4.9	5.3
500	5.5	6.1	6 2	5.8	5.7	5.5	5.5	5.2	5.5	5.1	6.3	5.8	5.2	5.6
600	5.8	6.4	5.4	6.1	6.1	5.8	5.7	5.4	5.8	5 5	6.7	6.3	5.[illegible]	5.9
700	6.1	6.7	6.6	6 4	6.5	6.1	6.0	5.6	6.1	5.8	7.0	6.0	6.1	6.3
800	6.4	6.9	6.7	6.7	7.0	6.4	6.3	5.9	6.3	5.9	7 2	7.4	6.2	6.6
900	6.7	7 1	....	7.0	7.2	6.6	6.6	6.2	6.4	0.1	7.4	7.7	6.3	6.8
1,000	6.8	7.1	....	7.2	7.4	6.8	6.7	6.4	6.2	6.1	7.5	7.[illegible]	6.2	6.8
1,100	7.0	7.2	....	7 3	7.6	6.7	6.8	0 5	....	..	....	...	....	7.0
1,200	7.1	7.2		7.4	7.6	6.7	6.7	6.5	....		....	....		7.0

From the data given in the tables plates I. to XIII. are constructed. Each plate refers to a single make of lamp. Plate I. gives curves relating to the average lamp of make *A*. In it curve *a* gives percentage of initial candle power, *b* gives watts per candle power, *c* gives candle power, *d* gives current strength, and *e* gives number of lamps burning. The time scale is common to all curves. The curves are lettered alike, are drawn to the same scale, and have the same starting points in each of the plates.

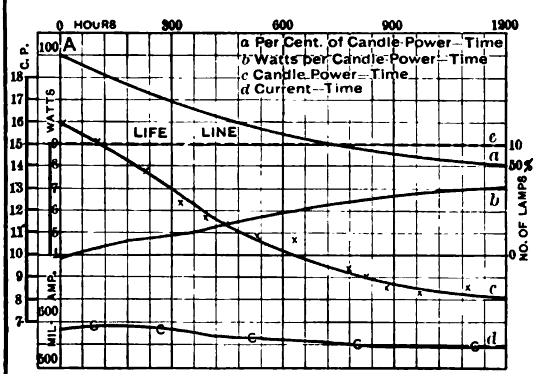

Plate I

The make of lamp referred to is indicated by the letter in the upper left hand corner of each plate. Curves *c*, *d* and *e* are plotted from observed values, but curves *a* and *b* are obtained from points 100 hours apart on *c* and *d*, combined, with the voltage 110 for *b*.

Want of time, due to the pressure of other duties, prevented

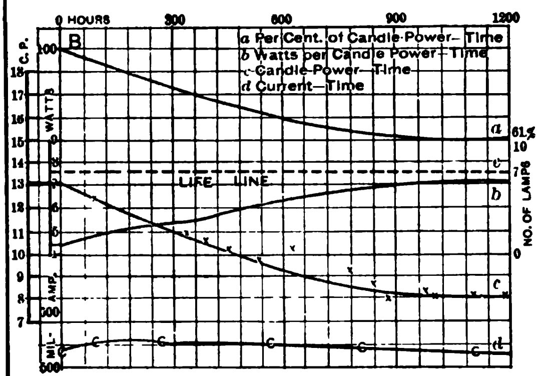

Plate II

our taking readings as often as we would like to have done, and prevented also the examination of a number of points of interest which developed as the test progressed. For the same reason we

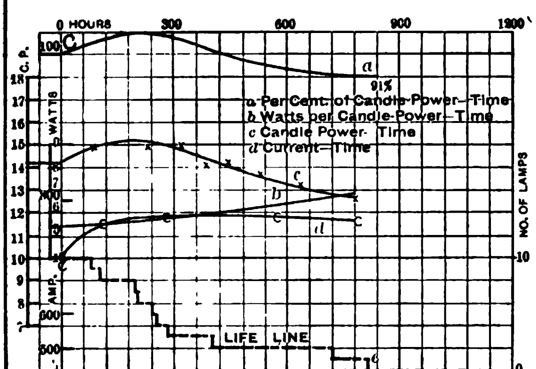

Plate III

are unable to include the data and curves for the individual lamps.

Thirty-one lamps in all were broken, distributed as follows: All of the C's (10), 2 D's, 8 E's, 2 K's, 4 L's, 1 M and 2 N's. All the lamps of A, B, F, G and O makes survived, the O's for 1,013 hours, the others for 1,200. The average life of the C's was 386 hours.

Plate XIV. gives two sets of curves. One set gives the curve of general average of percentage of initial candle power with respect to time, derived from the averages of the several makes, and beside it, the curve of the make which showed highest percentage throughout, marked min. drop. make M, and also the curve showing lowest percentage, marked max. drop, make L. The other set shows the general average of watts per candle power, and also the curves of the two makes showing the maximum (make N) and minimum (make M).

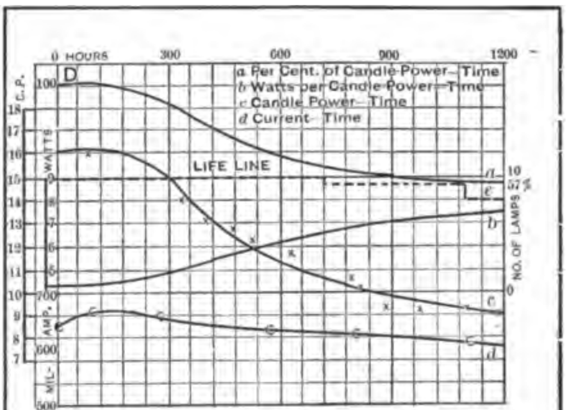

Plate IV

Examining the results first for candle power, we find the value 14.5 as the average of all the lamps tested at the time the current was first turned on them. Of the 13 separate lots, six only show an initial candle power of 16 candles (neglecting tenths), though one make which started at below 15 rises above 16 within the first 100 hours. The lowest initial candle power is found for make M. Makes G, K and O start at 17 candle, the highest figure reached at the start.

Looking at the curve which gives the average percentage of initial candle power, Plate XIV., we find that the lamps on the average grow dim at a steady rate, falling off to 90 per cent. in about 200 hours, to 68 per cent. in 600 hours, and end at 1,200 hours with a little less than 55 per cent. Deferring the consideration of the C lamps, the M lamps sustain their power best, losing only about six per cent. in the first 300 hours, and ending a little under 70 per cent. of their initial candle power. The L

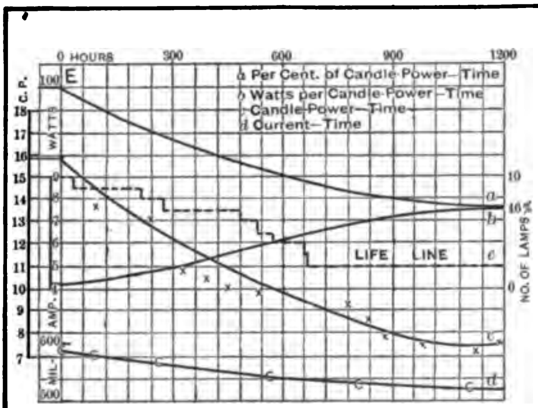

Plate V

lamps drop rapidly on the start, losing 30 per cent. in the first 300 hours and ending at 54 per cent. The E's and the O's drop to 47 per cent. at the close, but sustain themselves better than the L's in the earlier part of the run.

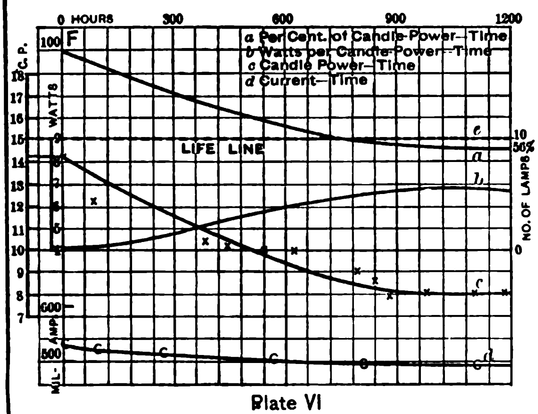

Plate VI

With respect to efficiency, using the term in its ordinary signification, as measured by watts per candle power (though in this sense the reciprocal is the proper measure), Plate XIV. shows an average initial value of 4.2, rising to 5.0 at 300 hours, 5.9 at 600 hours, 6.8 at 900 hours, and 7.0 at the end. The M lamps again have the best place, starting high but ending low, at six watts per candle power.

But what shall we say of the results as bearing on the question of the life of the lamp? The answer depends on what we shall define the life of a lamp to be.

Is a lamp alive as long as current will go through it? Some advertisers think so, and they seem to have support in their opinion, for some of their patrons have sent them, with complimentary remarks, lamps through which current is said to have passed for 6,000 hours or more. Adopting this view, our test

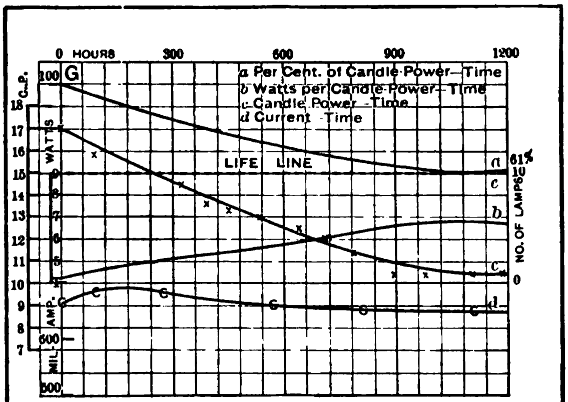

Plate VII

shows 96 out of 127 lamps decidedly alive at the end of an average of 1,120 hours, and the leveling of the average curves of Plate XIV. promises a considerable extension of their existence; 31 only have proven their mortality, and several of them lived to a good old age. The C's, poor things, all died young.

If we set the time of decease at the time when the lamp gives 50 per cent. of its initial candle power, as some claim, the lamps tested have passed 1,000 hours on the average, and certain makes have passed 1,200. If life be defined still with reference to percentage of initial candle power, but the limit be placed at 75 per cent., some individuals are still alive, but on the average, all died at 450 hours; 80 per cent. as limit cuts them off at 330 hours, and 90 per cent. at 180.

But there is yet another way of defining the life of a lamp. The one who ultimately pays for the lamp is the one whose premises are lighted by it, and the thing he is supposed to pay for is

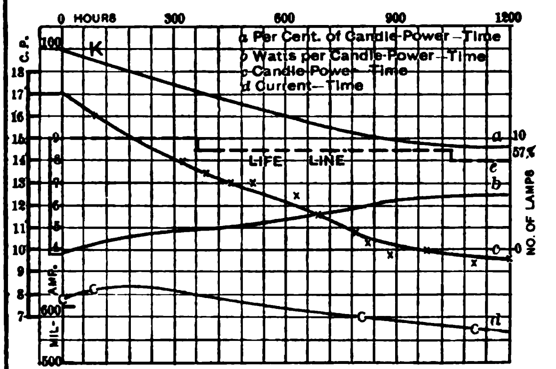

Plate VIII

light. For him, the lamp is dead when it ceases to give a certain candle power, without reference to what its candle power was when it was new. His premises, let us suppose, are properly lighted by a certain number of new lamps which actually give

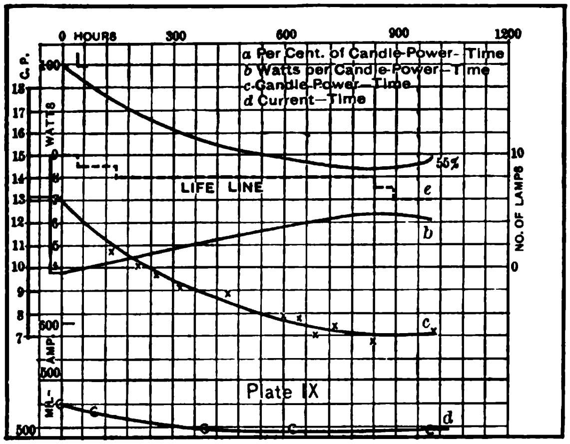

Plate IX

16 C. P. But when their light drops to 14 ($12\frac{1}{2}$ per cent.), he is no longer satisfied (and he ought not to be). For him the average lamp lasts about 240 hours. But if he is at liberty

to choose the make of the lamp, without reference to its efficiency, he will probably call for lamps of the G make, and get 400 hours service from them. If, however, he can induce the maker of the M lamp to make a lamp giving 16 c. p. when new, and having the same characteristics as those we tested, he will choose M's, and get 500 hours life. And that is the best that can be done for him, so far as this test shows. He would not have B's, L's or M's, as at present made at all, because they do not give 14 c. p. when new, and if the station manager put in F's or N's he would order them out in less than a week. The state of things revealed by this test, as to the actual candle power of new lamps, is certainly not what it ought to be.

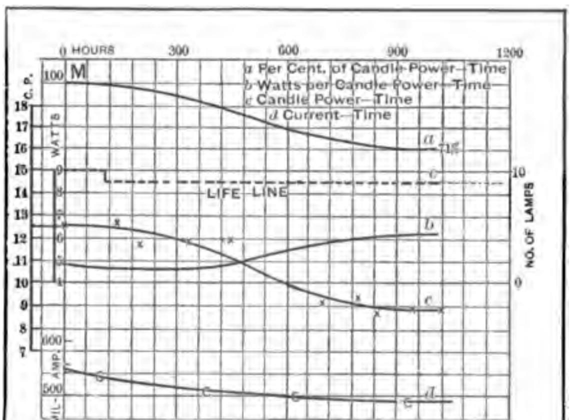

Plate X

At the conclusion of the life test we dismounted all the lamps and placed them on a large table covered with clean drawing paper and uniformly lighted. The several lots were carefully examined with reference to blackening, the lot which was blackened the most being graded 100, and the other lots graded as closely as we could judge by comparison with the blackest lot and with one another. The grades are as follows: 10, 12½, 25, 28, 30, 32, 35, 42, 45, 50, 75 and 100 per cent. of the blackening of the blackest lot. When the sorting and grading was satisfactorily completed, and the letters on the lamp bases examined, it was remarked that *the two lots which were least blackened were of the makes which are advertised as exhausted* *by mechanical pumps.* That they should both be so much alike in blackening, and both only one-half as much blackened as the least blackened of the mercurially exhausted lamps, is, to say the

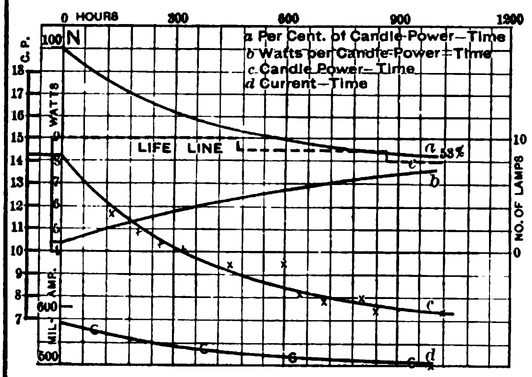

Plate XI

least, worthy of notice. It is, of course, not established that the observed freedom from blackening is due to the absence of mercury vapor in the lamps, as the makers claim, but if investigation

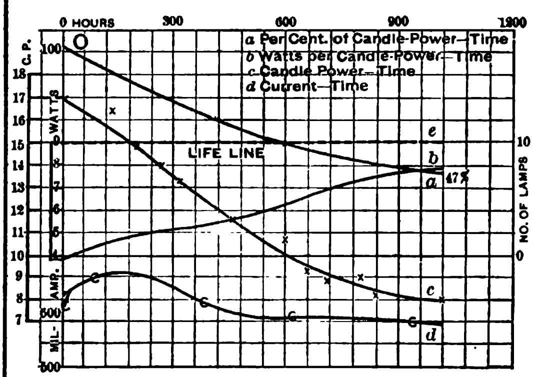

Plate XII

should establish the claim the mercury pump will probably become once more a laboratory instrument. [The lot of lamps graded 10 per cent., and the lot graded 100 per cent., were mounted together on cardboard and exhibited.] As the giving of the letters designating the several lots of lamps, with the percentages of blackening, would, after the above statements, serve to identify the makers in the preceding tables and curves, the letters are omitted.

With regard to the performance of individual lamps of each lot, we found in some makes greater uniformity than in others, indicating either greater uniformity in manufacture or greater care in sorting the finished lamps on the part of some makers. The A lamps were among the best in this respect, and the C's and F's among the poorest. [Curves showing the individual performances of the lamps of the three lots named were here shown and discussed.]

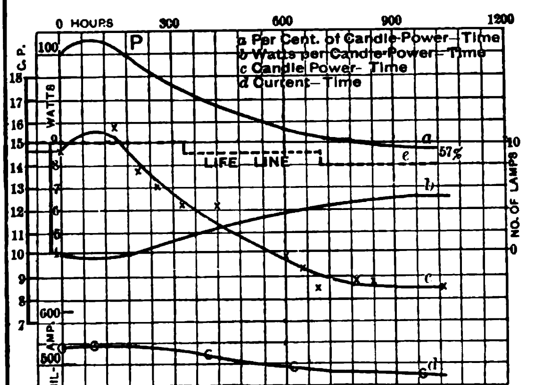

Plate XIII

So far as the lamps tested may be considered to fairly represent it, we draw from the test the following conclusions concerning the average 16 c. p., 110 volt, incandescent lamp:

First. The mean horizontal candle power of the lamp as defined, is only 14.5 when new instead of 16 as labeled.

Second. The candle power of the lamp diminishes at a fairly uniform rate as it is burned, the rate of decrease being roughly 10 per cent. of the initial candle power for each 200 hours burned.

Third. The lamp makers' claim, that the lamp will burn for 600 hours before breaking, is more than established, 96 out of 127 lamps being unbroken at the end of over 1,100 hours.

Fourth. Defining the life of a lamp to be the number of hours it will burn before it will fall from 16 C. P. to 14, we find the life of lamps in all respects like those tested, but so made as to give an initial candle power of 16, is 240 hours.

Fifth. The initial efficiency of the lamp is 4.2 watts per candle power. At 600 hours it is 5.9 watts and 1,200 hours 7 watts. The average efficiency during the first 600 hours is 5.04 watts.

Sixth. There is considerable difference in the rating of lamps by different makers, who nominally furnish the same article, the average initial candle powers of the several lots ranging from 12.5 to 17.0. There is also considerable difference in the unformity of the product of different makers.

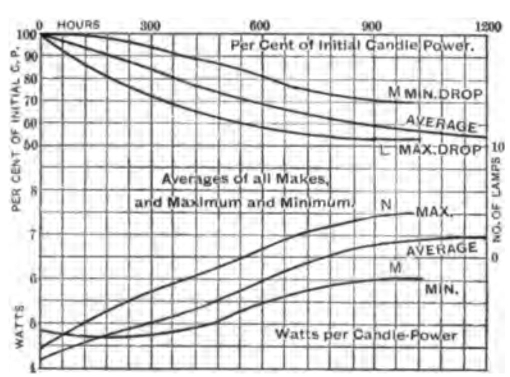

Plate XIV

The above conclusions properly complete this paper, so far as the purpose for which the test was undertaken is concerned. Some interesting points in the relative performances of different lamps may perhaps be alluded to in addition, since they cannot affect the makers.

Referring to Table V., lamps A, K, L and O have the same initial efficiency (3.9 watts per candle power), and for the first 700 hours A and L keep together, rising to 6.1 watts. K does better, rising only to 5.6 watts per candle power, while O rises to 6.9 watts. Referring to Table IV., there is greater difference among the makes named, the K's at 700 hours giving 67 per cent. of their initial candle power, while the A's give 61 per cent. and the L's and O's only 55 per cent. Of the four makes therefore the K's are best, since they maintain their candle power better and have the highest average efficiency. The differences, however, are so small as to make noteworthy the similarity between lamps of the same class, coming from different factories, as in this case. Comparing the F's with the G's in the same table, the F's have a slight advantage in efficiency on the start, but they come together in 500 hours. The G's, however, have such an advantage in the way they hold up in brilliancy as to balance the slight difference in efficiency and make them the better lamp.

The most interesting result, however, arises from a comparison of the lamps L and M. The L's have the highest initial efficiency (3.8), and the M's the lowest (4.8), excluding, of course, the C's, which can not be classed with good lamps. but after 250 hours burning the efficiencies are the same (4.75). At the start the L's are furnishing light at the least cost, but after 250 hours the M's have the advantage in this respect. If we suppose both makes to be used for 700 hours, the average efficiency is the same for both. But at this time the M's are giving 75 per cent. of their initial candle power, while the L's are giving only 55 per cent. For the consumer the M lamp is the better of the two, since the lighting of premises will be more uniform throughout the 700 hours of use supposed, and the cost of current for a given aggregate of candle power hours is no greater than with the L's. If the time of use of the lamps be, say, 400 hours, the choice is not so evident, and will depend on whether the slight difference in cost (watt hours) is of greater or less importance than constancy of candle power of the lamps.

A rough graphic comparison between the several makes of lamps may be made by considering the areas between the curves *c* and *a* of the several plates. The curve *a* is evidently parallel (raised three divisions) to the curve *c*, which would have been found if the initial candle power of each lamp had been 16 as labeled, other things being unchanged. The more nearly horizontal *a* and *b* are, and the lower *b* is, the better the lamp. As drawn, the curves can only give qualitative results by such comparison, but if the scale to which the *b* curves are drawn were properly chosen, the area comparison might give more accurate conclusions as to the relative merit of the several makes. It is clear that the form of the area between the *a* and *b* curves in Plate X. is nearer the ideal than any other, and that Plate XI. is poor. We are inclined to the belief that facts such as those alluded to in the comparison of the lamps L and M may lead to a modification of the views commonly expressed as to high and low efficiency lamps.

Discussion.[1]

The Chairman [Vice-President Hering.] We can be congratulated on having such a paper as this one, at our meetings. It is papers of this kind that are read with great interest by electrical engineers all over the country and bring the Institute such a good reputation. Any one who has ever attempted tests of this sort will know how very tedious it is to carry on such a long set of observations. There are a number of gentlemen in the room who have worked in this same field from whom we would be very glad to hear.

Professor Roberts:—With reference to the comparative testing of lamps—there are three methods:

1st. Running lamps at the voltage marked and measuring the c. p. and current during life, and plotting the curves in the manner Prof. Thomas has done. 2d. Running all lamps at the voltage at which they originally gave the c. p. marked, and in other respects proceeding as in the first case. 3d. Operating all lamps at the same efficiency. It is impossible to make comparisons when the test follows the first plan. Although the paper is of interest and valuable, it does not, to any extent, give comparative facts. The same objections hold good, for the most part, to the second plan. The proper method is to obtain lamps of the same efficiency; and if to be of the greatest value, as near as may be of the efficiency desired to use; and start them on the same basis. All large manufacturers of lamps make any efficiency desired; we have orders for 16 c. p. lamps between the limits of 50 watts and 75 watts—our standard being 55 watts.

Prof. Thomas states lamps purchased in the open market vary in c. p. I desire to mention the lack of knowledge of what is wanted on the part of the customer. In all probability the lamp will not be used within 4 per cent. of the voltage ordered for the greater portion, probably all of its life, and such a departure in the matter of voltage will make more difference in c. p. than is likely to exist in lamps sent out by the better manufacturers, although not by all. Probably 50 volt lamps are going to burn at 54 volts and 110's at 114 to 116 volts.

With reference to the life of the lamp and to blackening. It is true of some stations that when the lamp becomes blackened it is considered dead and removed, but in many stations the following method is pursued:—The manager receives a complaint that some good customer has not light enough, and he instructs his superintendent to "raise the voltage a little." The next day he visits the customer and all are happy. When the end of the month comes and the "lamp renewals" report is shown him he

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1 This paper, as originally presented, was discussed at length by Mr. J. W. Howell, and has since been revised by the author. In view of the changes made therein, Mr. Howell's remarks, as well as those of the author in reply have been withdrawn.—Editor.

immediately complains to the lamp manufacturer. I recently had occasion to inspect a large isolated plant. The office had the lowest voltage (the distribution was very bad, owing to additions of lights since original installation and without increase of wires), the consequence was that the lamps had lasted for thousands of hours, but were very black and were giving about four C. P. In the warerooms, where plows and other bulky articles are stored, the lamps gave about 25 C. P., and had a short life. I advised the renewing of all lamps in the office the first of each month (statement time) and taking the old lamps for the warehouse.

The paper does not touch upon the fact, that the source of most of the complaints about lamps is the lack of appreciation of the effect of variation of voltage on life. I have been a manager and superintendent of electric light stations as well as a manufacturer of lamps and, therefore, have had experience on both sides. There are many places which we have investigated where practically, the above effect was not appreciated in the least. Many do not know what voltage they actually have at the lamp even at one time, and "suppose all the lamps are at the same voltage at all times as they take care it should be so *at the station*." As it is impossible to have actually constant voltage, and as one can not tell a customer that he does not know what he is talking about, it is only by saying, "of course, as you know," and "you know that," etc., that, in the course of time, he does know it. There is no "manufacturers standpoint." There is no reputable manufacturer but desires his customer to know all possible about the goods sold. The more the customer knows the better for the manufacturer. It is by personal missionary work and by the publication of such papers as the one we have just heard that the conditions necessary for the most satisfactory use of the lamp can be made known to the average purchaser of incandescent lamps.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, Vice-President Hering in the Chair.

SOME POINTS FOR THE ELECTRICAL ENGINEER.

BY HORATIO A. FOSTER.

Although it is the province of this Institute to consider largely the more theoretical side of electrical engineering, and rightly so, it is perhaps well that it should occasionally have brought to its attention that outside practical part, only for which theory would have no backing and therefore could not reach its proper development.

It has been the fortune of the writer during the last ten months to visit and inspect, both technically and financially, considerably more than a hundred central lighting stations.

Taken as a whole, it really seems as if much of the ordinary commercial common sense and the usual keen judgment of self-interest had been on a vacation when these plants were erected. In many cases this traces back—first, to the wiles of that slickest of all individuals, the agent, who is always willing to assure the buyers that his system of lighting will virtually run itself, and then to the fact that people were formerly so doubtful of the prospective profits that on going into the business they invested the smallest amount that would start the work. The consequence was, bad construction, bad machinery, bad lines, and, of course, an entirely unreliable service. Oftentimes the man put in charge was a novice, and that worst of all novices for the business, the local amateur electrician; and is it any wonder that the business was a failure for the first few years?

In some localities this condition still obtains, nothing having been done but to patch up the bad work of the past.

In a few cases the administration has been changed by putting at the head some substantial and tried business man, very much to the benefit of the concern. While, in many instances, even the large city plants suffer from the above causes, they also suffer from other conditions inherent in the size of their field.

The pioneers were so timid about the outcome, that the city station was invariably very much too small, and inside of two years had become so patched up and crowded, that rebuilding became necessary, and this in many cases was repeated two or three times.

There is probably no business extant which has been built over so many times and that has had the same quality and quantity of brains applied to it that is in such chaos as to the proper design of building and arrangement of machinery. In cotton or any other weaving industry, machine shops, foundries and similar establishments, it has long been determined which is the best form of building to erect, and those put up in the last ten years or so of a similar industry are planned in the same lines, differing only in size to suit the special case. Now, this not only fails to be the case in electric lighting, but outside of the two prominent systems of connecting the dynamo to its power—that is by direct belting to fast running engines, or by counter-shaft to larger slow running engines, there are scarcely a half-dozen stations in the state built on the same or similar lines.

So much diversity of opinion is shown in designing these stations, and oftentimes by those whose opinion should have no weight, but unfortunately does, that it has the effect to convince some of the investing public that the electrical engineer does not know his business and they might as well go it alone.

If some action could be taken by this Institute through a committee which should examine into proper station design and report on some few general plans and suggestions as to lines to be followed, it might go far toward establishing a better backing for our members who are in that branch. As it is I think it will be acknowledged, that far more electrical engineering skill is applied to the larger isolated plants; and that the central stations are enlarged or rebuilt under the management of the local superintendent or board of directors, who frequently lack technical hnowledge or even familiarity with recent improvements elsewhere. Quite often this is owing to the fact that the only experience they have had with an electrician has been the generally young inexperienced expert who was sent out to install the first plant, and they think they can make better use of their money by controlling it themselves.

The method of distribution should also have consideration, especially in reference to the amount and style of underground work which certain sizes of city will be able to stand.

This may seem a large question, but you can be assured it is one of the most vital to the future welfare of the industry. It may be said that it is not well to interfere in private business. and that electrical engineers can be trusted to remedy the evil. I assure you the electrical engineer individually "is not in it," to use a vulgar phrase, and sad to say, has never been in it to any extent. Quite often officials of the electric lighting companies take a jaunt through the country visiting different stations for models for a new one for themselves. This often results in a worse muddle than ever, as they seldom find two stations at all similar, and they return resolved to use their own judgment.

This leaves the real electrical engineer out in the cold, at a point where if known he could by consultation do much good but many of these company officials never heard of the American Institute of Electrical Engineers and need to have it brought to their notice in some way.

Some may think that in time the electrical engineer will be called in and consulted, as are engineers of other works, but at the present rate I am afraid many will be angels or worse before the majority of electrical central station companies come to that point.

Perhaps if instances be mentioned under the following heads a better understanding can be arrived at, viz.: Location; foundations; construction of station; motive power; arrangement of machinery, and location and construction of lines.

LOCATION.

The location of plants is not now so generally bad as in the past, although we occasionally find a station in a location for which no excuse is apparent, as, for instance, one located in the basement of a carpenter shop at a long distance from fuel supplies, and only plenty of condensing water to recommend it; insurance rate, three per cent. or more. Another located nine miles away from a village of two thousand people to take advantage of water power never surely available all the year, and since destroyed entirely for the greater part of the year. Another placed so low down in reference to its water power as to be flooded in freshets. Another located more than a mile from fuel supplies, and the center of distribution at the top of a long, steep hill, with not even free water to recommend it. Another so located in relation to a very intermittent water power as to be unable to take advantage of the water for condensing purposes and now running the poorest kind of a slide-valve engine. Another located in a rickety, old, uncared-for part of a gas-house, where coke is scarce, and apparently plenty of water power available within a half mile.

Another located a long distance from center of distribution and coal supplies, to take advantage of cheap land and cheap fuel, the last of which has since proved very unreliable, when seemingly land could have been had much more central, with a much surer supply of cheap fuel, and to cap all, the value of that land has since increased enough to have paid the entire cost of the station at any moment it be desirable to sell.

One advantage of some of the older centrally located stations has since been learned in the increase in value of such real estate. One such station visited will enlarge and rebuild soon, and will sell its present real estate for enough advance to go far toward paying for the new station, and there are others which can, I think, tell the same story. In fact, in the present problematical growth of the future, a well-selected piece of ground may prove a very valuable part of the investment.

Foundations.

Foundations are now much better than in the past, and some of those now placed under dynamos would sustain almost anything that could be put on them. Poor foundations are occasionally seen though, as for instance those under a large bank of boilers in a station which was erected and started in six weeks. The boilers have since lurched forward until the fronts are some two or three inches out of plumb. In fact too little attention seems to have been paid to boiler foundations as a general thing.

Engines have fared better and when the ground has been good the foundations are to be little criticised.

One station has very large Corliss engines and owing to water soaked ground and limited time in which to build the brick foundations, they were placed wholly above the floor level of the dynamo room, and belts run both ways from the fly-wheels to shafting on either side of the room.

Very few bad dynamo foundations are now met, but many unbalanced armatures are found which no amount of foundation would hold steady.

STATION CONSTRUCTION.

In station construction there has been no settled design, therefore the promoters have generally built as they saw fit, occasionally following suggestions of the agent. Of course many plants are located in buildings already up, in which case the machinery had to be made to fit.

In many of those built especially for the work, no attention has been paid to designing for a low insurance rate, and brick stations are found sheathed all over the inside with pine, the one thing that insurance inspectors always criticise. A couple of coatings of whitewash or paint would have been much cheaper, safer, and looked quite as well.

When stations have been remodeled, very little improvement has been made in the smaller ones, but those in large cities have generally taken advantage of all the improvements to date, if not too strongly attached to some one parent company.

MOTIVE POWER.

The selection of motive power has of course been governed by local conditions; in the northern and northwestern part of New York state, water power is abundant and is largely used as motive power for stations, but almost invariably with steam reserve.

Water power alone has been found very difficult to govern for uniform speed, and some of the devices used for that purpose are to say the least ingenious.

When the load is large enough to use part steam there is no trouble whatever, as the wheel takes a steady load and the engine does the governing.

Plants are sometimes placed a long way from the work in order to take advantage of water power and in some cases it seems as if all else had been sacrificed to that one point.

Of engines there is no end to the different design, style and size used. Some use high speed, belted direct to dynamos, others slow speed belted to counter, some simple non-condensing where compound condensing would be decidedly best.

I know of at least three plants located in water works pump-ing stations, using high speed simple non-condensing engines on a practically steady load, all of which have been erected during the past three or four years.

Two stations I remember having an all night and every night load of arc lights and situated on a lake shore which run high speed simple non-condensing engines.

To offset this there is one station that deserves mention as it embodies many points of value. The building is substantial, of brick, two stories high and on a river bank. The boilers are very efficient and well set, the engine is a moderate speed compound condensing, with shaft extended for three dynamo pulleys, and one for the power condenser. There is a heater between the exhaust and condenser and a power pump attached to one side of the condenser. The flow to the boilers is governed by a bye pass valve, as the pump is of course in motion all the time the engine is running. This station has only an arc load and runs all night; it was built entirely under the supervision of a local mechanical engineer with the exception of connecting the lines and dynamo terminals to the switch-board, and would, I think, be hard to beat for results.

Arrangement of Machinery.

The arrangement of machinery is as diverse as the style of motive power; when direct belting is used the arrangement is generally simple and plain, but oftentimes so crowded as to be very inconvenient.

There seems no end to the arrangement of shafting, some have a line shaft through the middle of the dynamo room and belt both ways to dynamos, others a shaft on either side of the room belting to dynamos in the center, others the shaft under the floor belting up to dynamos and occasionally to engines also, others have the shafting overhead, in fact, there is no end to the styles, some good and some bad. In most cases friction clutches are used with shafting for stopping individual dynamos and some few may use loose pulleys on independent sleeve for the same purpose.

The length of belt centers varies greatly, some apparently thinking if long belts are better than short, very long ones must be much the best.

The improvement in switch-boards seems to me more marked than in any other one department, which is probably owing to the pressure of insurance men who look at the switch-board as the most dangerous fire risk of all.

Line Construction.

In line construction I cannot see that any very marked improvement has been made, excepting in some cases, the substitution of larger and better poles for the older ones.

The use of black covered wire in place of white has perhaps made the lines a trifle less conspicuous but that is about all. The lines still have the apparent aimlessness of direction mentioned by Prof. Thomson at Buffalo.

People in the larger interior cities are already agitating the question of underground wires and it seems probable that unless something is done soon by the companies themselves to rid the streets of the more conspicuous of these wires, there will be very costly trouble for them to contend with.

It can no longer be denied that wires are working well every day in sub-ways and the only valid argument against them is extreme cost. Nevertheless when the general public learns this fact, cost will have little to do with the argument.

In many places wires can be removed from the main streets to alleys back of the shops, and the extra cost will be decidedly cheaper than underground work. In such few places as this has already been done, wires are inconspicuous and the underground question is never raised.

In street lighting the favorite method is the cable suspension across the street. Where the work is neatly done this serves very well but it would be difficult to find a more unsightly thing than some of the lamps so suspended.

Considerable trouble is occasioned in the above method by breakage of the wires at the joint with the line, and at the cross bar over the hood. There is no apparent reason why twin or duplex wire should not be more used for this purpose, instead of the kinked and straggly single wires.

There are many other methods, some of them good in principle but bad in the application, and so it goes.

It seems to me that if some action was taken by a non-partisan association like this Institute, an advance toward better engineering might be made, if a few general laws could be suggested to be followed in laying out the different parts of a lighting station. Perhaps it may be said that much of the above work should more properly come before the National Electric Light Association, but as many of that society are members of this Institute, I feel sure they would individually appreciate its backing in the future when the time comes for enlargement, and they have need of combined expert opinion.

DISCUSSION.

MR. H. WARD LEONARD :—Mr. Chairman, I think the points that Mr. Foster has made in his paper are very good ones, and that they will be appreciated by all who have contact with central stations that have been constructed in the past. I know that in my own case I have quite recently had it forcibly impressed upon me in the case of two central stations of considerable size. In one case I remember that a very large central station was to be erected, not a thousand miles distant from here, and considerable time was spent in the selection of a proper site. At that time I remember personally taking sufficient interest in the matter to make calculations as to what would apparently be the best site for a central station to meet the proper demand. The question of the value of the real estate was a matter which proved to be quite important in determining upon the selection, and the first selection had to be abandoned very shortly and a second selection was made, and a very excellent and a very profitable central station was established. But it is a little gratifying to learn, as I have recently, that the central station is about to be moved to within one block of the site that seemed to me personally to be the best, and it could have been placed there originally at a very large saving over what it can be now.

The second instance that has come to my attention recently is one in which a central station has expended something over a quarter of a million of dollars, has made two changes of location, and finally the parties owning the station called me in with the view of learning as to whether certain changes and improvements could not be effected, and it was almost sad to notice that so much money had been expended, and that they were still so very far from economical results. The station was one which had ample space to place apparatus sufficient in capacity to run all of the electrical service for a town of three or four times the size of the one in question. They had abundance of space originally, but they had failed to utilize it advantageously. The building was full of the very long belts which Mr. Foster has very forcibly called attention to, occupying a tremendous amount of space, a large number of friction clutches were used, long steam pipes, and very poor arrangement of all kinds of apparatus—in fact, so perfect a disregard had been evidenced of the proper condensation and arrangement of machinery that although they had but slight capacity they found themselves in such a position that they could scarcely enlarge their facilities without entirely remodeling the station. That was relative to the station itself.

Outside of the station I found that a circuit had been established originally for a very contracted area, and that the system of conductors had been introduced at moderate loss and with a very slight cost in copper, no survey having been made originally that would enable them to judge fairly well as to the location of the probable load. It appears that they got loads at entirely unexpected places, and consequently they got very bad distribution of current relative to the copper which they have installed, with a consequent very bad condition of pressure throughout the system. At this time the question might have been submitted with very beneficial results to some competent engineer. But as soon as they realized that it meant either a readjustment of matters or more copper they came to the conclusion that there was no difficulty about putting in more copper because the territory was limited. and if they got in more copper they realized they would equalize the pressure. Consequently a large number of loops were placed all around their system which made the loss of the system one-third or one-half, perhaps, what it originally had been. In fact, so perfect a disregard had been shown of the question of feeders in that system that they ran out from the station a distance of about 300 feet, three wires of 0000 guage that they didn't have use for, and connected directly on to the mains. Probably the maximum loss of that line did not exceed two or three per cent. Now they want to enlarge. Of course enlarging a direct current plant, as this was, and extending a considerable distance on a basis of two or three per cent. loss in feeders, made the cost of copper prohibitory, and they are now facing the problem of remodeling the entire system in order to put in sufficient loss in those feeders to enable them to operate at reasonable distances with fair economy.

I think that there is one point that Mr. Foster has already touched on which is one of the most conspicuous fallacies in this business. He called attention to the fact that the ordinary purchaser realizes that long belts are better than short belts, and comes to the conclusion that a longer belt is better yet. That seems to be equally true as regards conductors and engines and a good many points. The ordinary purchaser has an impression that you cannot make the engine too large and you cannot make the conductors too large; that the bigger they are the better. But they find that such a plant is operated at very poor economy. They find themselves operating under conditions which make it impossible to enlarge, and altogether find themselves very much restricted as regards their extensions in the future and the profits from their system because of the impression which is so prevalent that it is impossible to make the apparatus you use too large.

There is one thing which I think is essential for any first-class station in starting out which seems not to be considered except by a few, and that is this:—Any gentlemen who are contemplating the investment of money in a central station should have a great deal of money spent under the supervision of a thoroughly competent and experienced person to determine exactly where such a station should be placed, exactly what extent of demand there will be, judging by the existing establishments to be supplied, how large the plant should be to start with, what the arrangements should be for extension, and all such matters as that. But in practice we find that where gentlemen are going to build a station they have a lot that they have selected that is a little ways out of town and they have rented a building, or have made arrangements to do so, perhaps put it in an old factory or an old foundry or something of that kind, and they want a plant of about a thousand lights to start with. The town is about two miles square, and they don't know where the lights are going to be, and they only want to provide in the beginning for conductors, lamps, and so forth, for about two hundred lamps, but they would like dynamos and engines for about a thousand lights, and ask for figures. That is the way they figure at the start. They show a total disregard for the location of the load with reference to the station. They do not care anything about the distance, whereas they would have got far better results in economy had they located centrally.

PROF. ROBERTS:—Because I am not now in construction work I desire to speak in this matter of obtaining proper engineering and paying for it. Architects, as you know, charge 3½ per cent. for plans and 5 per cent. for plans and supervision. How few companies pay such a percentage to a consulting electrical engineer.

With reference to the erratic arrangement of buildings, it is not very long since I had occasion to look at a plant that had been under three different managers, and each manager had put in a boiler room and the boiler rooms were in different places. They started in with an engine room, dynamo room and a boiler room. They had it on the corner of the lot. The next manager wanted more boiler room and put a boiler over here, and the next man put a boiler room down here (indicating) and they had three boiler rooms, three engine rooms and three dynamo rooms; they had no scheme drawn up originally as to what they would do when they extended.

MR. T. C. MARTIN:—Mr. President, I think it is due to Mr. Foster to state that one reason for the somewhat general terms in which he has couched many of the statements in his paper is the fact that he is at present an officer of the government. He has been investigating these things as an agent of the Census Office, and he is not at liberty to go into details as he will at some later time. The paper is certainly as remarkable for that which it does not state as for that which it does state. One of the remarkable features of this paper is that after visiting a hundred central stations, of which I believe nearly the whole were in New York State, there is not the slightest mention made of the use of the storage battery in a single one of them. It seems to me that in that respect at least we must be very much behind our compeers in Europe. As nearly as I can ascertain, at least 10 per cent., if not more, of the central stations in Europe are equipped with storage plants, some of which have been running four or five years. There are not a great many central stations in Europe, but still the fact that so large a percentage of them should have found it profitable to employ storage batteries must convey some suggestion to us. There are some gentlemen on the floor who have had sad experiences in the days gone by with station storage batteries, but it seems to me that we must have advanced a little bit since the days of our pioneer work, and that the time has arrived when we might learn something from what is being done in Europe.

A point Mr. Foster alluded to was painting in stations, and I believe it was once stated by a distinguished expert that dynamos might be painted any color without increasing their efficiency. I believe that the color that the central station is painted is apt to make a great difference in its efficiency. I have heard of one station, I think it is in this state, at Jacksonville or Dixon, where the interior is as sumptuous—well, at least as that of the office of the average electrical engineer. The whole of the interior, is a dazzling, glittering white; and even the engines have been touched up in a style that equals in gorgeousness the splendor of Barnum's circus wagons. Now I understand that that station is paying as much as any station in the state. I have been told, in fact, that its dividends have exceeded those of any other station; and it seems to me that there may be a connection between the cleanliness of that station and the dividends which it pays.

On motion duly seconded and carried, the President appointed as a committee on acknowledgment of courtesies extended to the Institute, Dr. Charles E. Emery, Prof. E. P. Roberts and Dr. E. L. Nichols.

[Recess.]

NOTE.—The proceedings of the General Meeting will be continued in the next issue.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892.

DERIVATION AND DISCUSSION OF THE GENERAL SOLUTION FOR THE CURRENT FLOWING IN A CIRCUIT CONTAINING RESISTANCE, SELF-INDUCTION AND CAPACITY, WITH ANY IMPRESSED ELECTROMOTIVE FORCE.

BY FREDERICK BEDELL, PH. D., AND ALBERT C. CREHORE, PH. D.

The problems arising in the case of circuits containing resistance and self-induction, or resistance and capacity have been treated by various writers and a discussion of such circuits by the authors has recently appeared as a series of articles in the *Electrical World* which form an introduction to the present paper. The treatment of circuits containing all three, resistance, self-induction, and capacity, is not so familiar, and the solutions which have been hitherto given apply only to certain particular cases.

The object of this paper is to treat the problem of a single circuit containing resistance, self-induction, and capacity, in the most general way and to derive a general solution for the current and charge at any time, when there is any impressed E. M. F. acting in the circuit.

All possible cases which may arise can be divided into four divisions according to the nature of the impressed E. M. F. The general solution will, therefore, be discussed in turn for these four cases which arise according to whether, (1) the E. M. F. is suddenly removed; (2) a constant E. M. F. is suddenly inserted; (3) there is an harmonic E. M. F.; or (4) there is any periodic E. M. F. not harmonic. Although many of the particular solutions are familiar, these will be obtained independently from the differential equations, and the results identified with those obtained from the general solution.

Throughout the discussion the following symbols will be used:

R = resistance.
L = coefficient of self-induction (a constant).
C = capacity.
E = (*a*) constant electromotive force; or
(*b*) maximum value of harmonic electromotive force.
e = instantaneous value of electromotive force.
I = (*a*) constant current; or
(*b*) maximum value of harmonic current.
i = instantaneous value of current.
Q = constant charge of condenser.
q = instantaneous value of charge of condenser.
$\omega = 2\pi n = 2\pi \times$ frequency = angular velocity.
$+\theta$ = angle of advance.
$-\theta$ = angle of lag.
T = (*a*) period; or (*b*) time-constant.
$j = \sqrt{-1}$.
ϵ = base of Naperian logarithms = 2.71828.
c = arbitrary constant of integration.

The meaning of other letters when used will be evident.

The starting point will be the differential equation of energy for a circuit with resistance. self-induction, and capacity. This equation is the mathematical expression of the fact, readily derived from the law of the conservation of energy, that the total energy supplied to a circuit is equal to the sum of the several expenditures of energy.

The equation of energy is:

$$(1) \quad e\,i\,d\,t = R\,i^2\,d\,t + L\,i\,\frac{d\,i}{d\,t}d\,t + \frac{i\,d\,t\int i\,d\,t}{C}.$$

The first member of this differential equation $e\,i\,d\,t$ represents the total energy supplied to the circuit in the time $d\,t$. A part of this energy represented by $R\,i^2\,d\,t$ is used in heating the conductor. A second part $L\,i\,\frac{d\,i}{d\,t}dt$ is expended in creating a magnetic field in the space surrounding the conductor. A third part, represented by $\frac{i\,d\,t\int i\,d\,t}{C}$, is expended in charging the condenser. Equation (1) is the general differential equation of energy, in terms of the current which flows in the circuit, the E. M. F. which drives the current, and the time, for a circuit containing resistance, self-induction, and capacity in series.

The equation of energy may be expressed as a differential equation in terms of the quantity of electricity in the condenser, or charge of the condenser, the E. M. F., and time, by means of the relation $d\,q = i\,d\,t$, or $q = \int i\,d\,t$. On substituting in (1) $i = \frac{d\,q}{d\,t}$, we have

$$(2)\qquad e\frac{dq}{dt}\,dt = R\left\{\frac{dq}{dt}\right\}^2 d\,t + L\frac{d^2q}{dt^2}\,\frac{dq}{dt}\,d\,t + \frac{q}{C}\frac{dq}{dt}\,d\,t.$$

Each term in this equation is equal to the corresponding term in equation (1), since it is obtained by direct substitution. The first member, $e\,\frac{d\,q}{d\,t}\,d\,t$, is the total energy supplied to the circuit, and the three terms of the second member represent the three ways in which this energy is expended, *viz.*, in heat, in creating the field, and in charging the condenser.

If equation (1) is divided through by $i\,d\,t$, it becomes an equation of E. M. F.'s, thus

$$(3)\qquad e = R\,i + L\,\frac{d\,i}{d\,t} + \frac{\int i\,d\,t}{C}.$$

If equation (2) is divided through by $\frac{dq}{dt}\,d\,t$, it likewise becomes an equation of E. M. F.'s, thus

$$(4)\qquad e = R\frac{d\,q}{d\,t} + L\frac{d^2\,q}{d\,t^2} + \frac{q}{C}.$$

These are equations of E. M. F.'s, equation (3) in terms of current, E. M. F., and time; equation (4) in terms of the charge of the condenser, E. M. F., and time. Each term in (4) is equal to the corresponding term in (3). The first member e is the E. M. F. impressed upon the circuit. That part of e necessary to overcome the resistance is $R\,i$, or $R\,\frac{d\,q}{d\,t}$. That part of e necessary to overcome the counter E. M. F. of self-induction is $L\frac{d\,i}{d\,t}$ or $L\,\frac{d^2q}{d\,t^2}$. The third part of e necessary to overcome the counter E. M. F. of the condenser is $\frac{\int i\,d\,t}{C}$, or $\frac{q}{C}$.

These differential equations may be written in forms more convenient for solving. Differentiating equation (3) with regard to t, to free it from the integral sign, we obtain

$$(5) \qquad \frac{d^2 i}{d\,t^2} + \frac{R}{L}\,\frac{d\,i}{d\,t} + \frac{i}{L\,C} = \frac{1}{L}\,\frac{d\,e}{d\,t}.$$

By transposition (4) becomes

$$(6) \qquad \frac{d^2 q}{d\,t^2} + \frac{R}{L}\,\frac{d\,q}{d\,t} + \frac{q}{L\,C} = \frac{e}{L}.$$

We know that the impressed E. M. F. has one value at one particular time and is therefore a single-valued function of the time, that is, $e = f(t)$. When we introduce this relation into (5) and (6), the general solution of each of these equations may be readily obtained. The solution of equation (5) will give the value of the current at any time, and the solution of equation (6) will give the value of the charge of the condenser at any time.

If $e = f(t)$, and $\frac{d\,e}{d\,t} = f'(t)$, upon substitution in equations (5) and (6), we have

$$(7) \qquad \frac{d^2 i}{d\,t^2} + \frac{R}{L}\,\frac{d\,i}{d\,t} + \frac{i}{L\,C} = \frac{1}{L}\,f'(t).$$

$$(8) \qquad \frac{d^2 q}{d\,t^2} + \frac{R}{L}\,\frac{d\,q}{d\,t} + \frac{q}{L\,C} = \frac{1}{L}\,f(t).$$

GENERAL SOLUTION FOR CURRENT AT ANY TIME.

In solving equation (7) to obtain the value of the current at any time, it is convenient to make use of the symbolic method for linear equations. (See page 101, Johnson's Differential Equations.)

$$\text{Let } D = \frac{d\,[\;]}{d\,t}. \qquad D^2 = \frac{d^2\,[\;]}{d\,t^2}.$$

Writing (7) in symbolic form, we have

$$\left\{ D^2 + \frac{R}{L} D + \frac{1}{L C} \right\} i = \frac{1}{L} f'(t), \quad \text{or}$$

(9) $$i = \frac{1}{L \left\{ D^2 + \frac{R}{L} D + \frac{1}{L C} \right\}} f'(t).$$

Resolving the inverse operator $\frac{1}{D^2 + \frac{R}{L} D + \frac{1}{L C}}$ into partial fractions, we have the identical equation,

(10) $$\frac{1}{D^2 + \frac{R}{L} D + \frac{1}{L C}} = \frac{L C}{\sqrt{R^2 C^2 - 4 L C}}$$

$$\left\{ \frac{1}{D + \frac{R C - \sqrt{R^2 C^2 - 4 L C}}{2 L C}} - \frac{1}{D + \frac{R C + \sqrt{R^2 C^2 - 4 L C}}{2 L C}} \right\}.$$

(11) Let $$T_1 = \frac{2 L C}{R C - \sqrt{R^2 C^2 - L C}}.$$

and $$T_2 = \frac{2 L C}{R C + \sqrt{R^2 C^2 - 4 L C}}.$$

Placing these values in (10), and substituting (10) in (9), we obtain

(12) $$i = \frac{C}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \frac{1}{D + \frac{1}{T_1}} f'(t) - \frac{1}{D + \frac{1}{T_2}} f'(t) \right\}.$$

The linear equation of the first order, $\frac{d y}{d x} + a y = f(x)$, when written in the symbolic form is $(D + a) y = f(x)$ or

(13) $$y = \frac{1}{D + a} f(x).$$

The solution of this linear equation of the first order is known to be (see Johnson's Diff. Equations, page 31)

(14) $$y = \varepsilon^{-a x} \int \varepsilon^{a x} f(x) \, d x + c \, \varepsilon^{-a x}.$$

Here c is the arbitrary constant of integration, and none other must be added when the integration is performed.

By (13) and (14), we have

$$(15)\qquad \frac{1}{D+a} f(x) = \varepsilon^{-ax} \int \varepsilon^{ax} f(x)\,dx + c\,\varepsilon^{-ax}.$$

If we replace a, in this general formula, by the constant $\frac{1}{T_1}$, and $f(x)$ by $f'(t)$, we have

$$(16)\qquad \frac{1}{D+\frac{1}{T_1}} f'(t) = \varepsilon^{-\frac{t}{T_1}} \int \varepsilon^{\frac{t}{T_1}} f'(t)\,dt + c\,\varepsilon^{-\frac{t}{T_1}}.$$

But this is the value of the first term in the parenthesis of equation (12). The value of the second term in that parenthesis may be found in the same manner, and (12) may be finally written

$$(17)\qquad i = \frac{C}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \varepsilon^{-\frac{t}{T_1}} \int \varepsilon^{\frac{t}{T_1}} f'(t)\,dt - \varepsilon^{-\frac{t}{T_2}} \int \varepsilon^{\frac{t}{T_2}} f'(t)\,dt \right\} + c_1\,\varepsilon^{-\frac{t}{T_1}} + c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

This is the general solution of equation (7) and gives the current which flows at any time in a circuit having resistance, self-induction and capacity.

Since the differential equation (8) for the charge becomes identical with the differential equation (7) for the current when we write $f''(t)$ instead of $f(t)$, and since f denotes any arbitrary single-valued function whatever, we may in the general solution (17) suppress the accents on the arbitrary functions and write the solution for q instead of i. Thus

$$(18)\qquad q = \frac{C}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \varepsilon^{-\frac{t}{T_1}} \int \varepsilon^{\frac{t}{T_1}} f(t)\,dt - \varepsilon^{-\frac{t}{T_2}} \int \varepsilon^{\frac{t}{T_2}} f(t)\,dt \right\} + c_1\,\varepsilon^{-\frac{t}{T_1}} + c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

PARTICULAR ELECTROMOTIVE FORCES.

These equations, (17) and (18), express the values of the current and charge at any time, when the impressed E. M. F. is anything whatever, since f is any arbitrary single-valued function whatever.

There are four cases, covering all possible cases, which arise according to the nature of the impressed E. M. F. These are

Case I. $e = f(t) = 0$.
Case II. $e = f(t) = E =$ constant.
Case III. $e = f(t) = E \sin \omega t$.
Case IV. $e = f(t) = \sum_{E,b,\theta} E \sin (b \omega t + \theta)$.

The meaning of the first assumption is that the impressed E. M. F. is to be zero at every point of time. This condition is fulfilled if we charge a condenser with some quantity Q and then suddenly remove the impressed E. M. F. The impressed E. M. F. remains zero at every point of time after the removal of the source of E. M F. and consequently satisfies the condition $e = f(t) = 0$. The solutions of the differential equations under this assumption give the current at any time flowing in the circuit and the charge at any time remaining in the condenser, when an impressed E. M. F. is suddenly removed from the circuit. It may be any circuit whatever containing any combination of resistance, self-induction and capacity, that is, a circuit containing R and L alone, R and C alone, or R, L and C together. In case the circuit has R and C, or R, L and C, the solutions will give the current i and quantity q at any time during the *discharge* of the condenser. If the circuit contains R and L alone, the solution will give the current at any time as it dies away after the removal of the E. M. F.

When we assume $e = f(t) = E =$ a constant, we mean that the E. M. F. is to be equal to E at every point of time. This condition will be fulfilled if the source of E. M. F. in any circuit is suddenly changed from one constant value to another constant value, either of which may be zero. If the circuit contains R and C, or R, L and C, the solutions give the current flowing in the conductor and the charge of the condenser at any time after the change in the E. M. F. If the circuit contains R and L only, the solution gives the value of the current at any time as it changes to its final steady value.

The third assumption, $e = E \sin \omega t$, means that the circuit contains an impressed E. M. F. varying harmonically with the time. The solutions of the general equations for q and i show that when the impressed E. M. F. is harmonic, both the current and the charge are likewise simple sine-functions of the time, having the same period as the E. M. F.

The fourth assumption, $e = \sum_{E,b,\theta} E \sin (b \omega t + \theta)$ — where b takes in succession any integer values—means that the circuit contains an impressed E. M. F. which is any periodic function of the time whatsoever.

The solution and discussion of these four cases will be considered in the above order.

Case I.—Value of Current and Charge at any Time During Discharge.

Here the E. M. F. is assumed to be zero at every point of time, and the equation expressing this is, as above,

$$e = {}_{t}f(t) = 0.$$

If the value ${}_{t}f'(t) = 0$ is substituted in the general equation (17) for current, and if the value ${}_{t}f(t) = 0$ is substituted in equation (18) for charge, we have

$$i = c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}} \tag{19}$$

$$q = c_3 \varepsilon^{-\frac{t}{T_1}} + c_4 \varepsilon^{-\frac{t}{T_2}} \tag{20}$$

Had the value $e = 0 = {}_{t}f(t)$ been substituted in the differential equation (8), and ${}_{t}f'(t) = 0$ in equation (7), we should have had

$$\frac{d^2 i}{d t^2} + \frac{R}{L} \frac{d i}{d t} + \frac{i}{L C} = 0. \tag{21}$$

$$\frac{d^2 q}{d t^2} + \frac{R}{L} \frac{d q}{d t} + \frac{q}{L C} = 0. \tag{22}$$

It is to be noticed that the form of the differential equation for i is identical with that for q. Hence their integrals (19) and (20) have the same form, although with different arbitrary constants of integration. The solutions of the differential equations

(21) and (22)—which are identical with (7) and (8) when their second members are zero—give what is called the "complementary function." The complementary function contains all the arbitrary constants of integration. The sum of the particular integral—found to satisfy equations (7) or (8) when the second member is not zero—and the complementary function gives the complete integral of the general differential equations (7) or (8).

The particular case of the *discharge* of a condenser through a circuit possessing resistance and self-induction, has been fully discussed by Sir Wm. Thomson and was published as early as 1853 in the *Philosophical Magazine.* His results were obtained from the solution of equation (22), which was solved directly in the usual manner by assuming $q = \varepsilon^{mt}$. This gave equation (20) as his result, which he showed could be expressed in two different forms, according as T_1 and T_2 are real or imaginary.

Writing equation (19) in full, by replacing the values of T_1 and T_2 given in (11), we have

$$(23)\quad i = c_1\,\varepsilon^{-\frac{RC-\sqrt{R^2C^2-4LC}}{2LC}t} + c_2\,\varepsilon^{-\frac{RC+\sqrt{R^2C^2-4LC}}{2LC}t}.$$

If the value of $R^2\,C$ is greater than $4\,L$, the value of i is real; but if $R^2\,C$ is less than $4\,L$, i apparently assumes an imaginary form. It will be shown, however, that i can by a trigonometric transformation be expressed in a real form when $R^2\,C$ is less than $4\,L$.

When $R^2\,C$ is equal to $4\,L$ and we have the critical case, it is evident that the two terms of equation (23) may be written as one, and thus the two arbitrary constants combine into one. The complete solution, which must contain two arbitrary constants, inasmuch as it is derived from a differential equation of the second order, cannot be readily obtained therefore in this case from equation (23); but it will be directly obtained from the differential equations (21) and (22).

If $R^2\,C$ is less than $4\,L$, after factoring out the common factor $\varepsilon^{-\frac{RC}{2LC}t}$, or $\varepsilon^{-\frac{Rt}{2L}}$, we may write (23) in another form, thus:

$$(24)\quad i=\varepsilon^{-\frac{Rt}{2L}}\left\{c_1\varepsilon^{\frac{j\sqrt{4LC-R^2C^2}}{2LC}t}+c_2\varepsilon^{-\frac{j\sqrt{4LC-R^2C^2}}{2LC}t}\right\}.$$

Here j is used to represent $\sqrt{-1}$. If we write

$$(25) \qquad \theta = \frac{\sqrt{4LC - R^2C^2}}{2LC}\, t,$$

then (24) becomes

$$(26) \qquad i = \varepsilon^{-\frac{Rt}{2L}} \left\{ c_1 \varepsilon^{j\theta} + c_2 \varepsilon^{-j\theta} \right\}.$$

The sine and cosine may be written in exponential form thus:

$$(27) \quad \sin\theta = \frac{\varepsilon^{j\theta} - \varepsilon^{-j\theta}}{2j}; \text{ and } \cos\theta = \frac{\varepsilon^{j\theta} + \varepsilon^{-j\theta}}{2}.$$

Therefore

$$(28) \qquad \cos\theta + j\sin\theta = \varepsilon^{j\theta},$$

$$(29) \qquad \text{and} \quad \cos\theta - j\sin\theta = \varepsilon^{-j\theta}.$$

Multiplying through by c_1 and c_2 respectively, and adding, we have

$$(30) \quad c_1\varepsilon^{j\theta} + c_2\varepsilon^{-j\theta} = (c_1 + c_2)\cos\theta + (c_1 - c_2)j\sin\theta.$$

If c_1 and c_2 are conjugate imaginary quantities, they may be written

$$c_1 = \frac{A + Bj}{2},$$

$$c_2 = \frac{A - Bj}{2},$$

where A and B are both real quantities. Taking the sum and difference

$$c_1 + c_2 = A,$$

$$c_1 - c_2 = Bj,$$

and substituting these values in (30), we have

$$(31) \qquad c_1\varepsilon^{j\theta} + c_2\varepsilon^{-j\theta} = A\cos\theta + B\sin\theta,$$

where c_1 and c_2 are imaginary, while A and B are real quantities. Substituting (31) in (26)

(32) $$i = \varepsilon^{-\frac{Rt}{2L}}(A \cos \theta + B \sin \theta).$$

By the trigonometric formula

(33) $$A \cos \theta + B \sin \theta = \sqrt{A^2 + B^2} \sin \left(\theta + \tan^{-1} \frac{A}{B}\right) .$$

we may finally write equation (32), after restoring the value of θ from (25), in the form

(34) $$i = A \varepsilon^{-\frac{Rt}{2L}} \sin \left\{ \frac{\sqrt{4 L C - R^2 C^2}}{2 L C} t + \Phi \right\},$$

where A and Φ are the arbitrary constants of integration. Here A is not the same as in equation (32), but stands for $\sqrt{A^2 + B^2}$, and Φ stands for $\tan^{-1} \frac{A}{B}$.

If $R^2 C$ is equal to $4 L$, then the differential equations (21) and (22) become

(35) $$\frac{d^2 i}{d t^2} + \frac{R}{L} \frac{d i}{d t} + \frac{R^2}{4 L^2} i = 0, \quad \text{and}$$

(36) $$\frac{d^2 q}{d t^2} + \frac{R}{L} \frac{d q}{d t} + \frac{R^2}{4 L^2} q = 0 .$$

Upon substituting $i = \varepsilon^{mt}$, we have

(37) $$m^2 + \frac{R}{L} m + \frac{R^2}{4 L^2} = 0,$$

which is seen to be a perfect square as it stands, and consequently the two values of m become equal, and $m = - \frac{R}{2 L}$. When there are equal roots, the solution is of the form

$$i = c_1 \varepsilon^{mt} + c_2 t \varepsilon^{mt}$$

(see Johnson's Diff. Equations, page 95) or, replacing m by its value $- \frac{R}{2 L}$, we have as the complete solution

$$i = c_1 \varepsilon^{-\frac{Rt}{2L}} + c_2 t \varepsilon^{-\frac{Rt}{2L}},$$

$$q = c' \varepsilon^{-\frac{Rt}{2L}} + c'' t \varepsilon^{-\frac{Rt}{2L}}.$$

Returning to equation (21), we may write its solution (19), the complementary function, in three different real forms, according as the value of $R^2 C$ is greater than, less than, or equal to $4 L$. These forms are

When $R^2 C > 4 L$,

$$(38) \quad i = c_1 \varepsilon^{-\frac{RC - \sqrt{R^2C^2 - 4LC}}{2LC} t} + c_2 \varepsilon^{-\frac{RC + \sqrt{R^2C^2 - 4LC}}{2LC} t}.$$

When $R^2 C < 4 L$,

$$(39) \quad i = A \varepsilon^{-\frac{Rt}{2L}} \sin \left\{ \frac{\sqrt{4LC - R^2C^2}}{2LC} t + \Phi \right\}.$$

When $R^2 C = 4 L$,

$$(40) \quad i = c_1 \varepsilon^{-\frac{Rt}{2L}} + c_2 t \varepsilon^{-\frac{Rt}{2L}}.$$

The value of the charge q given by equation (20), being of the same form as (19), may take three different forms according as $R^2 C$ is greater than, less than, or equal to $4 L$; and these forms only differ from (38), (39) and (40) in the arbitrary constants, thus

When $R^2 C > 4 L$,

$$(41) \quad q = c' \varepsilon^{-\frac{RC - \sqrt{R^2C^2 - 4LC}}{2LC} t} + c'' \varepsilon^{-\frac{RC + \sqrt{R^2C^2 - 4LC}}{2LC} t}.$$

When $R^2 C < 4 L$,

$$(42) \quad q = A' \varepsilon^{-\frac{Rt}{2L}} \sin \left\{ \frac{\sqrt{4LC - R^2C^2}}{2LC} t + \Phi' \right\}.$$

When $R^2 C = 4 L$,

$$(43) \quad q = c' \varepsilon^{-\frac{Rt}{2L}} + c'' t \varepsilon^{-\frac{Rt}{2L}}.$$

The constants of integration in the equations (38), (39), (40) and (41), (42), (43) are determined by the initial conditions imposed by the problem. For instance if a condenser charged with a quantity Q, is suddenly discharged through a circuit with resistance and self-induction, we may count the time from the moment of discharge, and thus have $q = Q$ and $i = 0$ when $t = 0$, and $q = 0$ and $i = 0$ when $t = \infty$.

NON-OSCILLATORY DISCHARGE.

The equations (38) and (41) may be written as in (19) and (20), in terms of the time-constants T_1 and T_2, thus

(44) $$i = c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}.$$

(45) $$q = c' \varepsilon^{-\frac{t}{T_1}} + c'' \varepsilon^{-\frac{t}{T_2}}.$$

The arbitrary constants c_1, c_2, c', c'' of these equations will be determined according to the conditions mentioned above, viz., when $t = 0$, $i = 0$ and $q = Q$; when $t = \infty$, $i = 0$ and $q = 0$.

Substituting in (44) $i = 0$ when $t = 0$, and in (45) $q = Q$ when $t = 0$, we have

(46) $$0 = c_1 + c_2 \quad \text{or} \quad c_1 = -c_2,$$

(47) $$Q = c' + c'',$$

Since we have the relation $dq = i\,dt$, we may differentiate (45) and write

(48) $$i = -\frac{c'}{T_1}\varepsilon^{-\frac{t}{T_1}} - \frac{c''}{T_2}\varepsilon^{-\frac{t}{T_2}}.$$

Equating (48) and (44), we find

(49) $$c_1 = -\frac{c'}{T_1} \quad \text{or} \quad c' = -c_1 T_1.$$

$$c_2 = -\frac{c''}{T_2} \quad \text{or} \quad c'' = -c_2 T_2.$$

Remembering the relation in (46), we may write

(50) $c'' = c_1 T_2$. Adding (49) and (50)

$$c' + c'' = c_1 (T_2 - T_1) = Q. \quad \text{[See (47).]}$$

Hence $$c_1 = \frac{Q}{T_2 - T_1}$$

$$c_2 = \frac{Q}{T_1 - T_2}$$

$$c' = \frac{Q\,T_1}{T_1 - T_2}$$

$$c'' = \frac{Q\,T_2}{T_2 - T}$$

Substituting in (44) and (45) the constants c_1, c_2, c', c'', as finally determined, we have

$$(51) \qquad i = \frac{Q}{T_2 - T_1} \left\{ \varepsilon^{-\frac{t}{T_1}} - \varepsilon^{-\frac{t}{T_2}} \right\}.$$

$$(52) \qquad q = \frac{Q}{T_1 - T_2} \left\{ T_1 \varepsilon^{-\frac{t}{T_1}} - T_2 \varepsilon^{-\frac{t}{T_2}} \right\}.$$

These equations give the complete solution and express the current or the charge at any time after discharge (see Fleming's Alternate Current Transformer, page 376). They show that if we have the relation $R^2 C > 4 L$, the discharge is a gradual dying away without oscillation. Since T_1 and T_2 are each of them positive when $R^2 C > 4 L$, [see (11)], i or q may be represented geometrically as the difference of two decreasing logarithmic curves. To see this more clearly, the values of the time-constants T_1 and T_2 may be substituted in the coefficients of equations (51) and (52). The result is

$$(53) \qquad i = \frac{Q}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \varepsilon^{-\frac{t}{T_2}} - \varepsilon^{-\frac{t}{T_1}} \right\}.$$

$$(54) \qquad q = \frac{Q}{2} \left\{ \frac{R C}{\sqrt{R^2 C^2 - 4 L C}} + 1 \right\} \varepsilon^{-\frac{t}{T_1}}$$

$$- \frac{Q}{2} \left\{ \frac{R C}{\sqrt{R^2 C^2 - 4 L C}} - 1 \right\} \varepsilon^{-\frac{t}{T_2}}.$$

These equations may be more easily explained by referring to figures 1 and 2, which represent the plot of these equations for particular assumed values of R, C and L. The values assumed for the constants of the circuit are

$R = 100$ ohms, $C = 1$ microfarad, $L = .0016$ henrys.

By calculating the values of T_1 and T_2 [equation (11)], $T_1 = 8 \times 10^{-5}$, and $T_2 = 2 \times 10^{-5}$, and the equations (53) and (54), with these particular values, become

$$(55) \qquad i = \frac{Q}{.6 \times 10^{-5}} \left\{ \varepsilon^{-\frac{t}{2 \times 10^{-5}}} - \varepsilon^{-\frac{t}{8 \times 10^{-5}}} \right\}.$$

$$(56)\ q=\frac{Q}{2}\left[1\,\frac{2}{3}+1\right]\varepsilon^{-\frac{t}{8\times10^{-5}}}-\frac{Q}{2}\left[1\,\frac{2}{3}-1\right]\varepsilon^{-\frac{t}{2\times10^{-5}}}.$$

If the condenser was charged to a potential of 2,000 volts, the capacity being .000001 farads, the charge is .002 coulombs. Substituting this value for Q, we have

$$i = 33.33\left[\varepsilon^{-\frac{t}{2\times10^{-5}}}-\varepsilon^{-\frac{t}{8\times10^{-5}}}\right].$$

$$q = \frac{1}{1000}\left[1\,\frac{2}{3}+1\right]\varepsilon^{-\frac{t}{8\times10^{-5}}}-\frac{1}{1000}\left[1\frac{2}{3}-1\right]\varepsilon^{-\frac{t}{2\times10^{-5}}}.$$

where i is in amperes and q in coulombs.

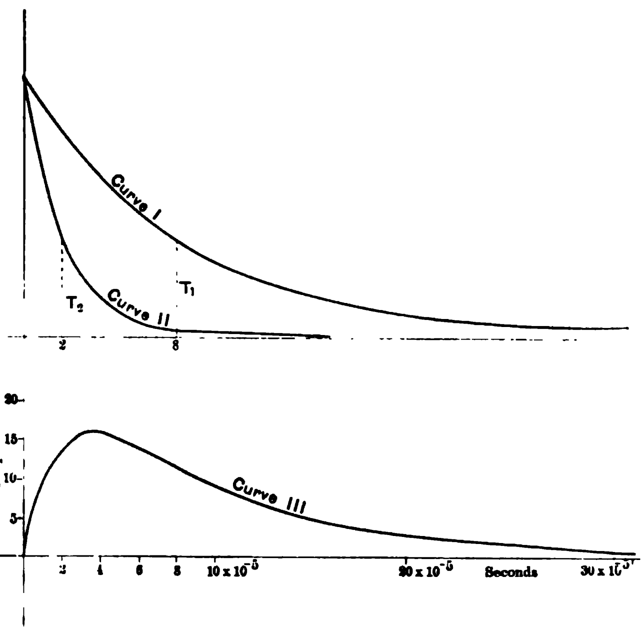


FIG. 1. Curve showing current during non-oscillatory discharge of condenser with capacity $C = 1$ micro-farad, through a circuit with resistance $R = 100$ ohms, and self-induction $L = .0016$ henrys when originally charged to a potential of 2000 volts.

In Fig. 1, curves I. and II. represent the two component logarithmic curves, corresponding to the first and second terms respectively of equation (53), whose difference gives the resultant current curve III. Curve I., corresponding to the first term of equation (53), has the larger time-constant, and is therefore the more important curve. The area included between curve III. and the axis of abscissae is equal to $\int i\,d\,t = Q$, and is therefore independent of the constants of the circuit through which the condenser is discharged.

The current reaches a maximum at a point which may be determined by differentiating equation (53) and equating the first derivative to zero in the usual manner for a maximum. The time t_m at which the current is a maximum is thus found to be

$$t_m = \frac{L\,C}{\sqrt{R^2\,C^2 - 4\,L\,C}} \log \frac{T_1}{T_2}\,.$$

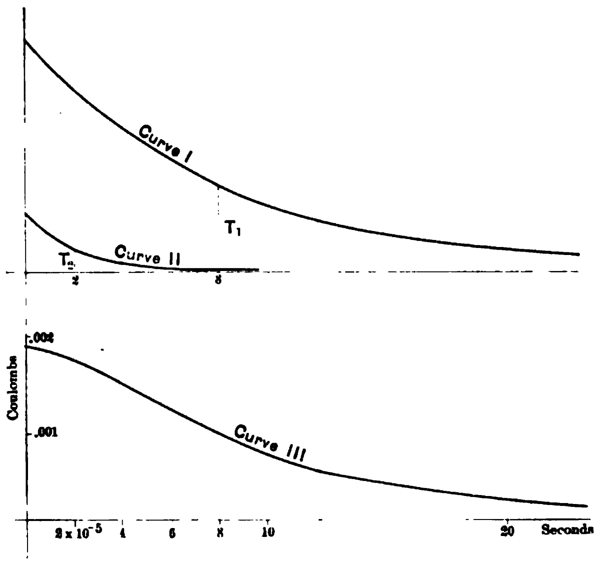


FIG. 2. Curve showing non-oscillatory discharge of a condenser, with capacity $C = 1$. micro-farad, through a circuit with resistance $R = 100$ ohms, and self-induction $L = .00016$. henrys, when originally charged to a potential of 2000 volts.

Substituting the particular values used in plotting Fig. 1,

$$t_m = 3.78 \times 10^{-5}.$$

In Fig. 2 curves I. and II. are the two component logarithmic curves, corresponding to the first and second terms respectively of equation (54) for charge. Curve III. is plotted by subtracting II. from I., and represents the charge of the condenser at any time, according to equation (54). It is noticeable that the upper curve, I., has the larger initial value, and as T_1 is larger than T_2, decreases the slower. It is therefore this curve which is the more important in determining the discharge of the condenser.

Dying Away of Current upon Removal of E. M. F. from a Circuit Containing Resistance and Self-induction.

In this case there is no condenser in the circuit, that is, the capacity is infinite. Substituting $C = \infty$ in the equation (11) for the time-constants, we have

$$T_1 = \frac{2\,L\,C}{R\,C - \sqrt{R^2\,C^2 - 4\,L\,C}} = \infty\,.$$

$$T_2 = \frac{2\,L\,C}{R\,C + \sqrt{R^2\,C^2 - 4\,L\,C}} = \frac{L}{R}.$$

According to equation (19), we have the value of the current at any time

$$i = c_1\,\varepsilon^{-\frac{t}{T_1}} + c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

Substituting in this equation the values of T_1 and T_2 above, we have

$$i = c_1 + c_2\,\varepsilon^{-\frac{R\,t}{L}}.$$

When $t = 0$, $i = I$, that is, the current flowing previous to the removal of the E. M. F. This gives

$$i = I = c_1 + c_2\,I.$$

But when $t = \infty$, $i = c_1 = 0$. Substituting these values for the constants, we have

$$i = I\,\varepsilon^{-\frac{R\,t}{L}}, \tag{57}$$

a result which is well known.[1]

1. Fleming's Alternate Current Transformer, page 102.

Discharge of a Condenser Through a Circuit Containing Resistance, but no Self-induction.

Upon substituting $L = 0$ in the values of the time constants T_1 and T_2, (11), the expressions become indeterminate, but can readily be evaluated by differentiating numerator and denominator, and then substituting $L = 0$ as in ordinary vanishing fractions.

$$T_1 = \frac{2\,L\,C}{R\,C - \sqrt{R^2\,C^2 - 4\,L\,C}}.$$

Differentiating numerator and denominator with respect to L, we have

$$\frac{\dfrac{d}{d\,L}(2\,L\,C)}{\dfrac{d}{d\,L}\left(R\,C - \sqrt{R^2\,C^2 - 4\,L\,C}\right)} = \frac{2\,C}{\dfrac{+\,4\,C}{2\sqrt{R^2\,C^2 - 4LC}}}$$

$$= \sqrt{R^2\,C^2 - 4\,L\,C}.$$

Now letting $L = 0$, we have

$T_1 = R\,C.$ Similarly $T_2 = -\,R\,C.$

Substituting these values in equations (19) and (20), we have

$$i = c_1\,\varepsilon^{-\frac{t}{RC}} + c_2\,\varepsilon^{+\frac{t}{RC}} \tag{58}$$

$$q = c_3\,\varepsilon^{-\frac{t}{RC}} + c_4\,\varepsilon^{+\frac{t}{RC}} \tag{59}$$

c_2 and c_4 must each be zero or else when $t = \infty$ we would have $i = \infty$ and $q = \infty$. When $t = 0$, $q = Q = c_3$. By differentiating (59) and equating to (58), we have

$$i = \frac{d\,q}{d\,t} = -\frac{c_3}{R\,C}\,\varepsilon^{-\frac{t}{RC}} = c_1\,\varepsilon^{-\frac{t}{RC}},$$

and, therefore, $c_1 = -\dfrac{c_3}{R\,C} = -\dfrac{Q}{R\,C}.$

Substituting in (58) and (59) the values found for the constants c_1, c_2, c_3, c_4, we have

$$i = -\frac{Q}{R\,C}\,\varepsilon^{-\frac{t}{RC}} = I\,\varepsilon^{-\frac{t}{RC}} \tag{60}$$

(61) $$q = Q \varepsilon^{-\frac{t}{RC}}.$$

These are the well-known results for the case of discharge through a circuit with no self-induction.

Oscillatory Discharge.

In the case of oscillatory discharge, the equations for current and charge at any time are

(62) $$i = A \varepsilon^{-\frac{Rt}{2L}} \sin \left\{ \frac{\sqrt{4LC-R^2C^2}}{2LC} t + \Phi \right\}.$$

(63) $$q = A' \varepsilon^{-\frac{Rt}{2L}} \cos \left\{ \frac{\sqrt{4LC-R^2C^2}}{2LC} t + \Phi' \right\}.$$

The arbitrary constants A, A', Φ and Φ' will be determined according to the same conditions as those mentioned above, viz., when $t = 0, i = 0$ and $q = Q$; also when $t = \infty, i = 0$ and $q = 0$. Substituting in (62) $i = 0$ when $t = 0$, and in (63) $q = Q$ when $t = 0$, we have

(64) $$0 = A \sin \Phi, \quad \text{and} \quad Q = A' \sin \Phi'.$$

Since A and $\sin \Phi$ are constants, and their product is zero, one of them must be zero. But if A were zero, i would be zero for every point of time, which is impossible. Therefore

(65) $$\Phi = 0.$$

Differentiating (63) and remembering that $i = \frac{dq}{dt}$, we have

(66) $$i = \frac{dq}{dt} = -\frac{A'R \varepsilon^{-\frac{Rt}{2L}}}{2L} \sin \left\{ \frac{\sqrt{4LC-R^2C^2}}{2LC} t + \Phi' \right\} + \frac{A' \varepsilon^{-\frac{Rt}{2L}} \sqrt{4LC-R^2C^2}}{2LC} \cos \left\{ \frac{\sqrt{4LC-R^2C^2}}{2LC} t + \Phi' \right\}.$$

Substituting $i = 0$, when $t = 0$;

$$0 = -R \sin \Phi' + \frac{\sqrt{4LC-R^2C^2}}{C} \cos \Phi'.$$

(67) Hence, $$\Phi' = \tan^{-1} \frac{\sqrt{4LC-R^2C^2}}{RC}.$$

By (64) $A' = \frac{Q}{\sin \Phi'}$. And, by (67),

$$(68) \quad A' = \frac{Q}{\sin \tan^{-1} \frac{\sqrt{4LC - R^2C^2}}{RC}} = \frac{Q}{\sqrt{1 - \frac{R^2C^2}{4LC}}}.$$

To determine the constant A, transform (66) by the formula (33) so as to write it in terms of a sine only. The coefficient of the sine in the equation as transformed will be

$$A' \sqrt{\frac{1}{LC}}.$$

Since equations (66) and (62) are each equations for i, we may equate the coefficients of the sine, and have

$$A = \frac{A'}{\sqrt{LC}}. \quad \text{And, by (68),}$$

$$(69) \qquad A = \frac{2Q}{\sqrt{4LC - R^2C^2}}.$$

Substituting A and Φ, as determined in (69) and (65), in equation (62), and substituting A' and Φ', as determined in (68) and (67), in equation (63,) we have

$$(70) \quad i = \frac{2Q}{\sqrt{4LC - R^2C^2}} \varepsilon^{-\frac{Rt}{2L}} \sin \left\{ \frac{\sqrt{4LC - R^2C^2}}{2LC} t \right\}.$$

$$(71) \quad q = \frac{2Q\sqrt{LC}}{\sqrt{4LC - R^2C^2}} \varepsilon^{-\frac{Rt}{2L}}$$

$$\sin \left\{ \frac{\sqrt{4LC - R^2C^2}}{2LC} t + \tan^{-1} \frac{\sqrt{4LC - R^2C^2}}{RC} \right\}.$$

These equations may be more readily understood by referring to Fig. 3, in which curves showing the current and charge, according to these equations, are drawn for the discharge of a condenser for particular values of L, C and R, assumed. The particular constants assumed are

$R = 100$. ohms. $C = 1$. micro-farad. $L = .0125$ henrys.

If the condenser be originally charged to 2,000 volts, $Q = .002$ coulombs. On substituting these values in (70) and (71), the equations for current and charge become

$$i = 20\,\varepsilon^{-4,000\,t} \sin 8,000\,t, \text{ and}$$

$$q = .00224\,\varepsilon^{-4,000\,t} \sin (8,000\,t + \tan^{-1} 2),$$

where i is in amperes and q in coulombs. Curve I, representing the current, is a sine-curve with a constant period, but with an amplitude decreasing according to the logarithmic curve $20\,\varepsilon^{-4,000\,t}$. The period is $\frac{2\pi}{8,000} = .000785$ seconds; that is, there are 1,275 complete oscillations per second. A very few oscillations are sufficient for a complete discharge.

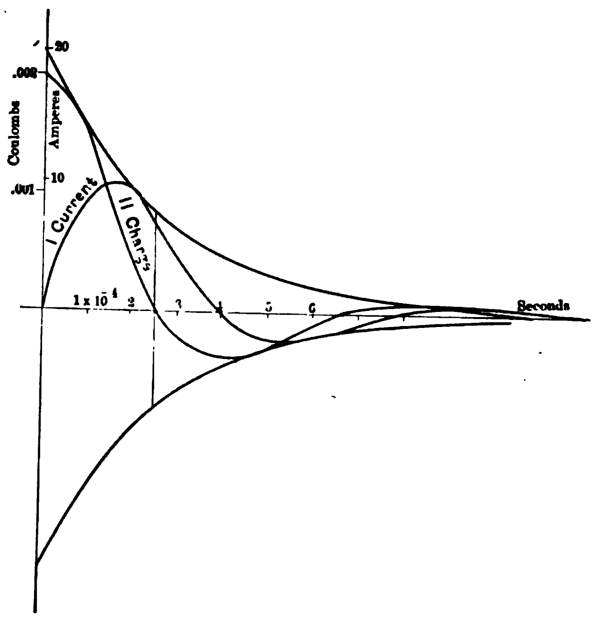


FIG. 3. Oscillatory discharge of a condenser with capacity $C = 1$ microfarad, through a circuit with resistance $R = 100$ ohms, and self-induction $L = .0125$ henrys, when originally charged to a potential of 2000 volts.

The charge at any time is shown in curve II, which is likewise a sine-curve with an amplitude decreasing according to the logarithmic curve, in this case $.00224\,\varepsilon^{-4,000\,t}$. The scale in Fig. 3 is such that the same logarithmic curve is an envelope for the current and the charge curve. The periods of the two are the same, but the curves differ in phase by an angle $= \tan^{-1} 2$, that is, the charge is ahead of the current by an angle of advance of 63° 27′.

When $R^2\, C = 4\, L$.

This is the critical case, when the discharge is just non-oscillatory. The equations for the current and charge, as previously determined, (40) and (43), are

$$i = c_1\, \varepsilon^{-\frac{R\,t}{2\,L}} + c_2\, t\, \varepsilon^{-\frac{R\,t}{2\,L}}. \tag{72}$$

$$q = c'\, \varepsilon^{-\frac{R\,t}{2\,L}} + c''\, t\, \varepsilon^{-\frac{R\,t}{2\,L}}. \tag{73}$$

The arbitrary constants of integration, c_1, c_2, c', c'', of these equations will be determined by the same conditions as in the previous cases, namely, when $t = 0$, $i = 0$ and $q = Q$. Equations (72) and (73) then become

$$\begin{aligned} 0 &= c_1, \\ Q &= c'. \end{aligned} \tag{74}$$

Differentiating equation (73) and substituting Q for c', we obtain

$$i = \frac{d\,q}{d\,t} = \left(-\frac{QR}{2\,L}\,\varepsilon + c'' - \frac{c''\,R\,t}{2\,L}\right)\varepsilon^{-\frac{R\,t}{L}}. \tag{75}$$

But when $t = 0$, $i = 0$; therefore

$$c'' = \frac{QR}{2\,L}. \tag{76}$$

Equating equations (72) and (75) and replacing the values for the constants given in (74) and (76), we have

$$c_2 = -\frac{QR^2}{4\,L}. \tag{77}$$

Substituting for Q its value $E\,C$, and for R^2 its equivalent, in this particular case $\frac{4\,L}{C}$, (77) becomes

$$c_2 = -\frac{E}{L}.$$

Having thus determined the values of the arbitrary constants, the equations (72) and (73) for current and charge may be written

$$i = -\frac{E}{L}\,t\,\varepsilon^{-\frac{R\,t}{L}}. \tag{78}$$

$$(79) \qquad q = \left(1 + \frac{R\,t}{2\,L}\right) Q\,\varepsilon^{-\frac{R\,t}{2\,L}}.$$

These equations give the value of the current and charge at any time during the discharge of the condenser in the case where the discharge is just non-oscillatory. This case is often called the case

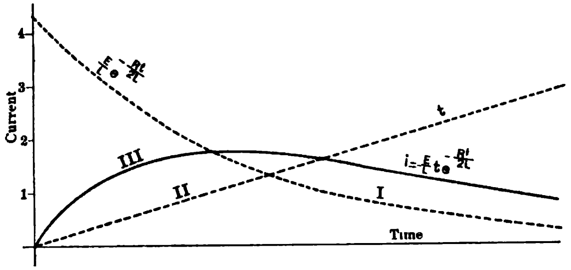


FIG. 4. Showing method of constructing the current curve in the case where $R^2 C = 4\,L$.

of quickest discharge, as was pointed out by Dr. W. E. Sumpner, in the *Philosophical Magazine*, and afterwards discussed by Dr. Oliver Lodge in the *Electrician* for May 18, 1888.

The curve representing the plot of the equation (78) for the current, may be drawn as indicated in Fig. 4. A logarithmic

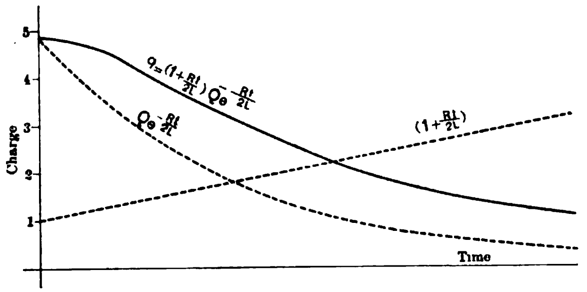


FIG. 5. Showing the method of constructing the curve representing the charge left in the condenser at any time after discharge.

curve I., having its initial value $\frac{E}{L}$ and time constant $\frac{2L}{R}$, is drawn to represent the equation as it would be with t omitted from the coefficient; and each ordinate is then multiplied by the ordinate of a straight line II. which passes through the origin and represents the uniform increase of the time t. The product of the ordinates of curves I. and II. at each point gives the ordinate of the current curve III. at that point. When actual values of R, L and C are assumed, it is found to be difficult to represent these curves to scale, so that Fig. 4 is shown simply as an illustration of the method of constructing the current curve. Curve I., Fig. 6, represents the current in an actual case where $R = 100$ ohms, $L =$ .5 henrys and $C =$ 1,000 micro-farads, the condenser being originally charged to a potential of 2,000 volts. The method of constructing the curve is omitted.

The method of constructing the curve, showing the charge left in the condenser at any time is given in Fig. 5 and is similar to the method just shown for constructing the current curve. The difference is that the straight line passes through a point one unit above

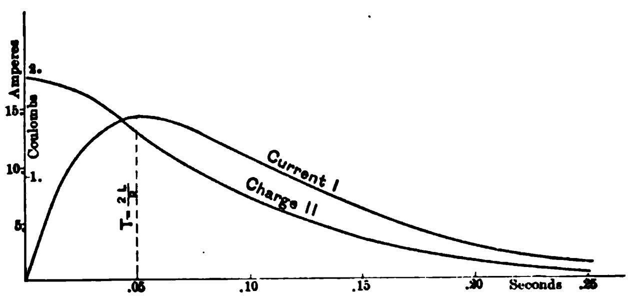


Fig. 6. **Just non-oscillatory discharge of a condenser with capacity $C = 1000$ micro-farads, through a circuit with resistance $R = 100$ ohms, and self-induction $L = 2.5$ henrys.**

the origin, on the vertical axis, instead of through the origin as before. The logarithmic curve has the initial value Q and a time constant $\frac{2L}{R}$. The curve showing the charge for the actual case where $R = 100$ ohms, $L = 2.5$ henrys and $C = 1,000$ micro-farads, the condenser being originally charged to a potential of 2,000 volts, is represented by curve II., Fig. 6.

Case II. Value of Current and Charge at any Time During Charging.

The E. M. F., instead of being zero as in the previous case, is assumed to be a constant E, and

$$e = f(t) = E.$$

This is the case when an E. M. F. is suddenly changed from one constant value to another constant value in a circuit, and it includes Case I. as a particular case, since E may be zero. By differentiation,

$$\frac{d\,e}{d\,t} = f'(t) = 0.$$

Substituting these values in equations (5) and (6), they become

$$(80) \qquad \frac{d^2 i}{dt^2} + \frac{R}{L}\frac{d\,i}{d\,t} + \frac{i}{L\,C} = 0,$$

$$(81) \qquad \text{and} \qquad \frac{d^2 q}{d\,t^2} + \frac{R}{L}\frac{d\,q}{d\,t} + \frac{q}{L\,C} = \frac{E}{L}.$$

It is seen that the equation for current (80) is identical with that of the previous case (21), while the equation for charge (81) has its second member equal to $\frac{E}{L}$, a constant, instead of zero. By substituting a new variable, $q' = q - E\,C$, this equation may be transformed into one having its second member zero; thus,

$$(82) \qquad \frac{d^2 q'}{d\,t^2} + \frac{R}{L}\frac{d\,q'}{d\,t} + \frac{q'}{L\,C} = 0.$$

The solutions of (80) and (82) are, as in the previous case,

$$(83) \qquad i = c_1\,\varepsilon^{-\frac{t}{T_1}} + c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

$$q' = c_3\,\varepsilon^{-\frac{t}{T_1}} + c_4\,\varepsilon^{-\frac{t}{T_2}}.$$

Replacing the value of q' and remembering $Q = E\,C =$ the final charge, we may write

$$(84) \qquad q = Q + c_3\,\varepsilon^{-\frac{t}{T_1}} + c_4\,\varepsilon^{-\frac{t}{T_2}}.$$

These equations, (83) and (84), for current and charge might have been obtained directly from the general solutions (17) and (18) by substituting $e = f(t) = E$, and $\frac{d\,e}{d\,t} = f'(t) = 0$. Upon substituting $f'(t) = 0$ in (17), we obtain (83) directly, and upon substituting $f(t) = E$ in (18), we have

$$q = \frac{E\,C}{\sqrt{R^2\,C^2 - 4\,L\,C}}\,(T_1 - T_2) + c_3\,\varepsilon^{-\frac{t}{T_1}} + c_4\,\varepsilon^{-\frac{t}{T_2}}.$$

But, by the values of T_1 and T_2 in (11), we find that $T_1 - T_2 = \sqrt{R^2\,C^2 - 4\,L\,C}$; and hence this equation is identical with (84), since $Q = E\,C$.

As in Case I, where $f(t) = 0$, the equations just obtained for current (83) and charge (84) when $f(t) = E$, assume three forms.

When $R^2\,C > 4\,L$,

(85) $$i = c_1\,\varepsilon^{-\frac{t}{T_1}} + c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

(86) $$q = Q + c'_1\,\varepsilon^{-\frac{t}{T_1}} + c'_2\,\varepsilon^{-\frac{t}{T_2}}.$$

When $R^2\,C < 4\,L$,

(87) $$i = A\,\varepsilon^{-\frac{R\,t}{2\,L}} \sin\left\{\frac{\sqrt{4\,L\,C - R^2\,C^2}}{2\,L\,C}\,t + \Phi\right\}.$$

(88) $$q = Q + A'\,\varepsilon^{-\frac{R\,t}{2\,L}} \sin\left\{\frac{\sqrt{4\,L\,C - R^2\,C^2}}{2\,L\,C}\,t + \Phi'\right\}.$$

When $R^2\,C = 4\,L$,

(89) $$i = c_1\,\varepsilon^{-\frac{R\,t}{2\,L}} + c_2\,t\,\varepsilon^{-\frac{R\,t}{2\,L}}.$$

(90) $$q = Q + c'_1\,\varepsilon^{-\frac{R\,t}{2\,L}} + c'_2\,t\,\varepsilon^{-\frac{R\,t}{2\,L}}.$$

The constants of integration must be determined by the conditions of the problem as to the previous state of the circuit, the changes made, and the final state.

NON-OSCILLATORY CHARGING.

When $R^2\,C > 4\,L$.

The constants c_1, c_2, c'_1 and c'_2 of equations (85) and (86) will be determined by the following conditions:

When $t = 0$, $i = 0$ and $q = Q_0$.
When $t = \infty$, $i = 0$ and $q = Q$.

This means that the condenser is suddenly charged or discharged from the initial charge Q_0 to the final charge Q. Determining the constants by the same method as in Case I., we find that

$$c_1 = \frac{Q_0 - Q}{T_2 - T_1},$$

$$c_2 = \frac{Q_0 - Q}{T_1 - T_2},$$

$$c'_1 = \frac{(Q_0 - Q)\,T_1}{T_1 - T_2},$$

$$c'_2 = \frac{(Q_0 - Q)\,T_2}{T_2 - T_1}.$$

Substituting in (85) and (86) the values of the constants just determined, we have

$$(91) \qquad i = \frac{Q_0 - Q}{T_2 - T_1} \left\{ \varepsilon^{-\frac{t}{T_1}} - \varepsilon^{-\frac{t}{T_2}} \right\}.$$

$$(92) \qquad q = Q + \frac{Q_0 - Q}{T_1 - T_2} \left\{ T_1\,\varepsilon^{-\frac{t}{T_1}} - T_2\,\varepsilon^{-\frac{t}{T_2}} \right\}.$$

For Q_0, the original charge, we may write $C\,E_0$, and for Q, the final charge, we may write $C\,E$.

These equations, (91) and (92), give the value of the current and charge at any time after the change of E. M. F. from E_0 to E in a circuit with $R^2\,C > 4\,L$. As the equations now stand in their general form, they hold true for either total or partial charge or discharge according to the values of E_0 and E, and consequently Q_0 and Q, assumed. If the final charge is $Q = 0$, we have the case of complete discharge and the equations take the form of (51) and (52). If the original charge $Q_0 = 0$, we have the case of charge from zero to Q.

These equations will perhaps be better understood by referring to Fig. 7, which represents the equations with particular values assumed. These values are the same as in the preceding case, namely, $R = 100.$ ohms, $C = 1.$ micro-farad, $L = .0016$ henrys. The condenser originally had no charge, and when charged to a potential of 2,000 volts, has a charge of .002 coulombs. The current curve I., Fig. 7, is identical with curve III., Fig. 1, which represents the current during discharge. The curve of charge, II., is the same as curve III., Fig. 2, inverted and plotted downwards from the horizontal line $Q = .002$. It is noticeable that the ordinates of curve I., expressing the current, are proportional to the tangents of the angle of inclination of curve II. at every point, since the current $i = \frac{dq}{dt}$, and $\frac{dq}{dt}$ is the tangent of the angle of inclination of the curve of charge II. It is seen that the point of inflection in curve II. comes at the maximum value of the current curve I., as the tangent is the greatest at this point; indeed, curve I. might be constructed geometrically simply from the foregoing consideration.

Establishment of Current upon Inserting an E. M. F. in a Circuit with Resistance and Self-Induction.

In this case there is no condenser in the circuit, that is the

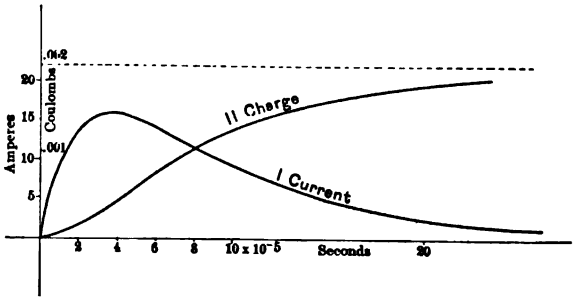


Fig. 7. Non-oscillatory charge of a condenser with capacity C 1 = micro farad, through a circuit with resistance $R = 100$ ohms and self-induction $L = .0125$ henrys when subjected to a potential of 2000 volts.

capacity is infinite. Substituting $C = \infty$ in the values of the time constants (11), we have

$$(93) \qquad T_1 = \infty, \qquad T_2 = \frac{L}{R},$$

as in Case I, where the current dies away after the removal of the E. M. F. Substituting these values in (19), we have

$$i = c_1 + c_2 \varepsilon^{-\frac{Rt}{L}}.$$

$$\text{When } t = 0, i = 0 = c_1 + c_2.$$

$$\text{When } t = \infty, i = I = c_1. \qquad \therefore c_2 = -I.$$

Substituting these values for the constants c_1 and c_2, we have

$$i = I\left(1 - \epsilon^{-\frac{Rt}{L}}\right).$$

I is the final steady value of the current, and is equal to $\frac{E}{R}$;

hence

$$i = \frac{E}{R}\left(1 - \epsilon^{-\frac{Rt}{L}}\right), \tag{94}$$

which is the well-known expression for the establishment of a current in a circuit with self-induction.

Charging a Condenser Through a Circuit Containing Resistance, but no Self-Induction.

Upon substituting $L = 0$ in the values of the time constants T_1 and T_2, the expressions become indeterminate, but can be evaluated as before by differention of numerator and denominator before substituting $L = 0$. We thus find the values, when $L = 0$,

$$T_1 = R\,C. \qquad T_2 = -\,R\,C. \tag{95}$$

Substituting these values in the equations of current (83) and current (84), we have

$$i = c_1\,\epsilon^{-\frac{t}{RC}} + c_2\,\epsilon^{+\frac{t}{RC}}. \tag{96}$$

$$q = Q + c_3\,\epsilon^{-\frac{t}{RC}} + c_4\,\epsilon^{+\frac{t}{RC}}. \tag{97}$$

Q_0 is the previous charge of the condenser, and Q the final charge. The constants c_2, c_4 must be zero, or else when $t = \infty$ we would have $i = \infty$, $q = \infty$. When $t = 0$, (97) becomes

$$Q_0 = Q + c_3. \qquad \therefore c_3 = Q_0 - Q.$$

By differentiating (97) and equating to (96), we have

$$i = \frac{dq}{dt} = -\frac{c_3}{RC}\,\epsilon^{-\frac{t}{RC}} = c_1\,\epsilon^{-\frac{t}{RC}}.$$

Therefore

$$c_1 = -\frac{c_3}{RC} = -\frac{Q_0 - Q}{RC}.$$

Substituting in (96) and (97) the values for the constants c_1, c_2, c_3, c_4, as determined,

$$(98) \qquad i = -\frac{Q_0 - Q}{R\ C} \varepsilon^{-\frac{t}{RC}}.$$

$$(99) \qquad q = Q + (Q_0 - Q)\,\varepsilon^{-\frac{t}{RC}}.$$

These equations are true for the charge or discharge from Q_0 to Q, through a resistance with no self-induction. When the final charge Q is zero, we have the case of complete discharge and the equations become the same as (60) and (61). When the original charge Q_0 is zero, we have the case of charging from zero to Q.

$$(100) \qquad i = \frac{Q}{R\ C} \varepsilon^{-\frac{t}{RC}}.$$

$$(101) \qquad q = Q\left(1 - \varepsilon^{-\frac{t}{RC}}\right).$$

It is noticeable that the current equation is the same as that for discharge equation (60) and that the charge equation is analogous to that in the case of the establishment of the current in a circuit with resistance and self-induction, equation (94).

Oscillatory Charging.

When $R^2\ C < 4\ L$.

The constants A, A', Φ and Φ' in equations (87) and (88) will be determined by the same conditions as before, namely,

When $t = 0$, $i = 0$ and $q = Q_0$.
When $t = \infty$, $i = 0$ and $q = Q$.

The meaning of this supposition is the same as in the preceding case, namely, that the condenser is suddenly charged or discharged from the initial charge Q_0 to the final charge Q. The constants, determined by the same method as in Case I, are

$$A = \frac{2\,(Q_0 - Q)}{\sqrt{4\ L\ C - R^2\ C^2}}.$$

$$A' = \frac{2\,(Q_0 - Q)\ \sqrt{L\ C}}{\sqrt{4\ L\ C - R^2\ C^2}}.$$

$$\Phi = 0.$$

$$\Phi' = \tan^{-1} \frac{\sqrt{4\,L\,C - R^2\,C^2}}{R\,C}.$$

With the constants thus determined, equations (87) and (88) become

$$(102) \quad i = \frac{2\,(Q_0 - Q)}{\sqrt{4\,L\,C - R^2\,C^2}}\,\varepsilon^{-\frac{R\,t}{2\,L}} \sin \frac{\sqrt{4\,L\,C - R^2\,C^2}}{2\,L\,C}\,t.$$

$$(103) \quad q = Q + \frac{2\,(Q_0 - Q)\,\sqrt{L\,C}}{\sqrt{4\,L\,C - R^2\,C^2}}$$

$$\varepsilon^{-\frac{R\,t}{2\,L}} \sin \left\{ \frac{\sqrt{4\,L\,C - R^2\,C^2}}{2\,L\,C}\,t + \tan^{-1} \frac{\sqrt{4\,L\,C - R^2\,C^2}}{R\,C} \right\}.$$

We may write $C\,E_0$ for the original charge Q_0, and $C\,E$ for the final charge Q.

These equations, (102) and (103), give the value of the current and charge at any time after the change of the electromotive force from E_0 to E in a circuit with $R^2\,C < 4\,L$. As the equations now stand in their general form, they are true for either total or partial charge or discharge, according to the values assigned to Q_0 and Q. If the final charge Q is zero, we have the case of complete discharge, and the equations take the form of (70) and (71). When Q is less than Q_0 we have partial discharge; if Q is greater than Q_0 we have partial charging. If the original charge $Q_0 = 0$, we have the case of charge from zero to Q.

Fig. 8 illustrates the case of oscillatory charge through a circuit having the same constants as those of Fig. 3. The current curve I. is the same as that in Fig. 3, and the charge is represented by curve II., which is the same as in that figure, but inverted and plotted from the horizontal line $Q = .002$. It is seen that in charging the condenser, the charge rises at first higher than its final value, and then oscillates about that final value until it has become steady.

When $R^2\,C = 4\,L$.

This is the critical case, where the charging is just non-oscillatory. The equations for current and charge are,

$$(104) \qquad i = c_1\,\varepsilon^{-\frac{R\,t}{2\,L}} + c_2\,t\,\varepsilon^{-\frac{R\,t}{2\,L}}$$

$$(105) \qquad q = Q + c' \varepsilon^{-\frac{R t}{2 L}} + c'' t \, \varepsilon^{-\frac{R t}{2 L}}$$

The initial charge is Q_0, and the final charge Q. To determine the arbitrary constants of integration, let $t = 0$. Then $i=0$, and $q = Q_0$. Equations (104) and (105) then become

$$c_1 = 0.$$

$$c' = Q_0 - Q.$$

Differentiating equation (105) and substituting the value of c', we have

$$(106) \quad i = \frac{d q}{d t} = \left(- \frac{(Q_0 - Q) R}{2 L} + c'' - \frac{c'' R t}{2 L} \right) \varepsilon^{-\frac{R t}{2 L}}$$

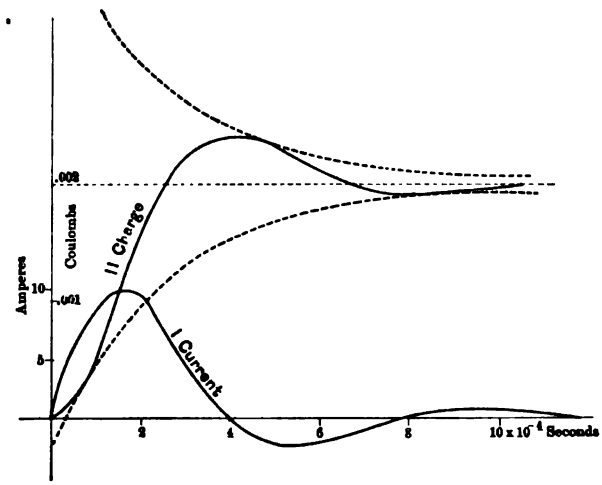


FIG. 8. Oscillatory Charge of a condenser with capacity $C = 1$ micro-farad, through a circuit with resistance $R = 100$ ohms and self-induction $L = .0125$ henrys when subjected to a potential of 2000 volts.

When $t = 0$, $i = 0$, therefore

$$c'' = \frac{(Q_0 - Q) R}{2 L}.$$

Equating equations (104) and (106), and replacing the values for c_1, c' and c'', we have

$$c_2 = -(Q_0 - Q) \frac{R^2}{4 L^2}.$$

If E_0 and E are the initial and final potentials respectively, we may write $E_0\, C$ for Q_0, and $E\, C$ for Q. Making this substitution and remembering that in this particular case $R^2 = \frac{4L}{C}$, we have

$$c_2 = \frac{E - E_0}{L}.$$

Replacing the values of the arbitrary constants, the equations (104) and (105) for current and charge may be written

$$(107) \qquad i = \frac{E - E_0}{L}\, t\, \varepsilon^{-\frac{R\,t}{2\,L}}.$$

$$(108) \qquad q = Q + (Q_0 - Q)\left(1 + \frac{R\,t}{2\,L}\right)\varepsilon^{-\frac{R\,t}{2\,L}}.$$

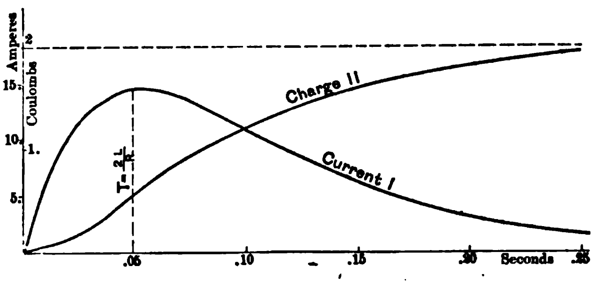


FIG. 9. Just non-oscillatory charge of a condenser with capacity $C = 1000$ micro-farads through a circuit with resistance $R = 100$ ohms and self-induction $L = 2.5$ henrys.

The current curve in the case of charging a condenser, represented by equation (107), is the same as in the case of discharge, equation (78). It is represented in Fig. 9, curve I., and may be constructed by the method shown in Fig. 4. The curve showing the charge represented in Fig. 9, curve II., is constructed in a similar manner to curve II, Fig. 6, and, indeed, curve II. of Fig. 9 is identical with curve II. of Fig. 6, it being inverted and plotted downwards from the horizontal line.

CASE III. HARMONICALLY VARYING E. M. F.

In the preceding cases considered, those of discharge and charge, the solutions for the value of the current and charge at any time were obtained in two ways, first from the general solution, and then directly from the differential equations, by substituting $e = f(t) = 0$, and $e = f(t) = E$, respectively.

The case of a circuit containing resistance, self-induction and capacity, in which there is an impressed E. M. F. varying harmonically, will now be considered, and the solution derived first from the general equations (17) and (18), and then directly from the differential equations (5) and (6). In this case,

$$e = f(t) = E \sin \omega t,$$

$$\text{and } \frac{de}{dt} = f'(t) = E \omega \cos \omega t.$$

Substituting these values in (17) and (18), we have

$$(109) \quad i = \frac{C E \omega}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \varepsilon^{-\frac{t}{T_1}} \int \varepsilon^{+\frac{t}{T_1}} \cos \omega t \, dt - \varepsilon^{-\frac{t}{T_2}} \int \varepsilon^{+\frac{t}{T_2}} \cos \omega t \, dt \right\} + c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}},$$

and

$$(110) \quad q = \frac{C E}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \varepsilon^{-\frac{t}{T_1}} \int \varepsilon^{+\frac{t}{T_1}} \sin \omega t \, dt - \varepsilon^{-\frac{t}{T_2}} \int \varepsilon^{+\frac{t}{T_2}} \sin \omega t \, dt \right\} + c_3 \varepsilon^{-\frac{t}{T_1}} + c_4 \varepsilon^{-\frac{t}{T_2}}.$$

The solution for q being similar to that for i, we will give the integration and reduction of (109) alone, and simply give the resulting expression for q. The integrals may be found by the formulæ of reduction obtained by integrating by parts. The integration of each term in (109) is

$$(111) \quad \varepsilon^{-\frac{t}{T}} \int \varepsilon^{+\frac{t}{T}} \cos \omega t \, dt = \frac{1}{\frac{1}{T^2} + \omega^2} \left\{ \frac{1}{T} \cos \omega t + \omega \sin \omega t \right\}.$$

For convenience in transformation and reduction, put $\tau_1 = \frac{1}{T_1}$ and $\tau_2 = \frac{1}{T_2}$. Integrating the two terms in (109) and making this substitution, we have

(112) $$i = \frac{C E \omega}{\sqrt{R^2 C^2 - 4 L C}} \left\{ \left(\frac{\tau_1}{\tau_1^2 + \omega^2} - \frac{\tau_2}{\tau_2^2 + \omega^2} \right) \cos \omega t \right.$$

$$\left. + \left(\frac{\omega}{\tau_1^2 + \omega^2} - \frac{\omega}{\tau_2^2 + \omega^2} \right) \sin \omega t \right\} + c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}.$$

We may simplify (112) by substituting the values of τ_1 and τ_2 [see (11)].

$$\tau_1 = \frac{1}{T_1} = \frac{R C - \sqrt{R^2 C^2 - 4 L C}}{2 L C}.$$

$$\tau_2 = \frac{1}{T_2} = \frac{R C + \sqrt{R^2 C^2 - 4 L C}}{2 L C}.$$

Then, after a few simple algebraic transformations in the coefficients of the sine and cosine, (112) becomes

(113) $$i = \frac{E R \omega^2}{R^2 \omega^2 + \left(\frac{1}{C} - L \omega^2 \right)^2} \sin \omega t$$

$$+ \frac{E \omega \left(\frac{1}{C} - L \omega^2 \right)}{R^2 \omega^2 + \left(\frac{1}{C} - L \omega^2 \right)^2} \cos \omega t + c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}.$$

This may be transformed into a more convenient form by means of the trigonometrical formula,

$$A \sin x + B \cos x = \sqrt{A^2 + B^2} \sin \left(x + \tan^{-1} \frac{B}{A} \right),$$

and when transformed is written,

(114) $$i = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C \omega} - L \omega \right)^2}} \sin \left\{ \omega t \right.$$

$$\left. + \tan^{-1} \left(\frac{1}{C R \omega} - \frac{L \omega}{R} \right) \right\} + c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}.$$

The corresponding equation for charge, being the integral of this, according to the relation $q = \int i \, d t$, may be written

(115) $$q = \frac{-E}{\omega \sqrt{R^2 + \left(\frac{1}{C \omega} - L \omega \right)^2}} \cos \left\{ \omega t \right.$$

$$\left. + \tan^{-1} \left(\frac{1}{C R \omega} - \frac{L \omega}{R} \right) \right\} + c_3 \varepsilon^{-\frac{t}{T_1}} + c_4 \varepsilon^{-\frac{t}{T_2}}.$$

These equations, (114) and (115), are the complete solutions for current and charge in a circuit with resistance, self-induction and capacity, when there is an harmonic impressed E. M. F.

Let us now proceed to obtain this same solution by solving the original differential equation, with the assumption that the E. M. F. varies harmonically, that is, $e = E \sin \omega t$. Substituting $\frac{de}{dt} = E \omega \cos \omega t$ in the differential equation (5), we have

$$\frac{d^2 i}{dt^2} + \frac{R}{L} \frac{di}{dt} + \frac{i}{LC} = \frac{E\omega}{L} \cos \omega t. \tag{116}$$

This is a linear equation of the second order with constant coefficients. The complete integral of such an equation consists of the sum of two parts, namely, the particular integral and the complementary function. The complementary function is the integral obtained by equating the first member to zero, and contains two arbitrary constants. The particular integral contains no arbitrary constants. The complementary function, obtained by equating the first member of (116) to zero and solving, is

$$i = c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}. \tag{117}$$

To find the particular integral, it is convenient to use the symbolic notation,

$$D = \frac{d\,(\,)}{dt}. \qquad D^2 = \frac{d^2\,(\,)}{dt^2}.$$

With this notation (115) is written

$$\left(D^2 + \frac{R}{L} D + \frac{1}{LC}\right) i = \frac{E\omega}{L} \cos \omega t, \qquad \text{or}$$

$$i = \frac{\frac{E\omega}{L} \cos \omega t}{\left(D^2 + \frac{R}{L} D + \frac{1}{LC}\right)}. \tag{118}$$

Next, to find the value of D^2, we have

$$\frac{d \cos \omega t}{dt} = D \cos \omega t = -\omega \sin \omega t,$$

$$\frac{d^2 \cos \omega t}{dt^2} = D^2 \cos \omega t = -\omega^2 \cos \omega t.$$

$$\text{Therefore} \qquad D^2 = -\omega^2$$

Substituting in (117) $D^2 = -\omega^2$, we have

$$(119)\ i=\frac{E\,\omega}{L\left(\frac{R}{L}\,D+\frac{1}{L\,C}-\omega^2\right)}\cos\omega\,t=\frac{E\,\omega}{R\,D+\frac{1}{C}-L\,\omega^2}\cos\omega\,t.$$

Multiplying numerator and denominator of the coefficient of $\cos\,\omega\,t$ in (119) by $R\,D-\left(\frac{1}{C}-L\,\omega^2\right)$, we obtain

$$i=\frac{E\,\omega\left\{R\,D-\left(\frac{1}{C}-L\,\omega^2\right)\right\}}{R^2\,D^2-\left(\frac{1}{C}-L\,\omega^2\right)^2}\cos\,\omega\,t.$$

Substituting $-\,\omega^2$ for D^2, and separating into two terms,

$$(120)\ i=\frac{-\,E\,\omega\,R\,D\cos\,\omega\,t+E\,\omega\left(\frac{1}{C}-L\,\omega^2\right)\cos\omega\,t}{R^2\,\omega^2+\left(\frac{1}{C}-L\,\omega^2\right)^2}.$$

But $D\cos\,\omega\,t=-\,\omega\sin\,\omega\,t$. Hence,

$$(121)\ \ i=\frac{E\,\omega^2\,R\sin\omega\,t}{R^2\,\omega^2+\left(\frac{1}{C}-L\,\omega^2\right)^2}+\frac{E\,\omega\left(\frac{1}{C}-L\,\omega^2\right)\cos\,\omega\,t}{R^2\,\omega^2+\left(\frac{1}{C}-L\,\omega^2\right)^2}.$$

This is the particular integral, to which must be added the complementary function (117) in order to obtain the complete integral. The complete integral is thus found to be

$$(122)\ \ i=\frac{E\,\omega^2\,R\sin\,\omega\,t}{R^2\,\omega^2+\left(\frac{1}{C}-L\,\omega^2\right)^2}+\frac{E\,\omega\left(\frac{1}{C}-L\,\omega^2\right)\cos\,\omega\,t}{R^2\,\omega^2+\left(\frac{1}{C}-L\,\omega^2\right)^2}$$
$$+\,c_1\,\varepsilon^{-\frac{t}{T_1}}+c_2\,\varepsilon^{-\frac{t}{T_2}}.$$

This solution for the current obtained from the differential equation (5) is seen to be identical with (113), the result obtained from the general solution (17). The solution for charge could be obtained in a similar manner from the differential equation (6).

Discussion of Case III.—Harmonic E. M. F.

These solutions, (114) and (115), show that, after a very short time has elapsed, so that the exponential terms containing the arbitrary constants of integration become inappreciably small and can be neglected, both the current and the charge are simple harmonic functions and may either lag behind or advance ahead of the impressed E. M. F. The current lags behind the impressed E. M. F. when $L\,\omega > \frac{1}{C\,\omega}$, and advances ahead of it when $L\,\omega < \frac{1}{C\,\omega}$. When $L\,\omega = \frac{1}{C\,\omega}$, that is, when $\omega = \frac{1}{\sqrt{L\,C}}$, there is no lag or advance and the current is exactly in phase with the impressed E. M. F. In this case the current equation becomes

$$(123) \qquad i = \frac{E}{R} \sin \omega\, t,$$

which is identical with the current equation obtained from Ohm's law, without considering either self-induction or capacity. When the sine is unity in equation (114), the maximum value of the current, represented by I, is

$$(124) \qquad I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C\,\omega} - L\,\omega\right)^2}}.$$

From the analogy of this equation to Ohm's law, we see that the expression $\sqrt{R^2 + \left(\frac{1}{C\,\omega} - L\,\omega\right)^2}$ is of the nature of a resistance, and is the apparent resistance of a circuit containing resistance, self-induction and capacity. This expression would quite properly be called "impedance," but the term impedance has for several years been used as a name for the expression $\sqrt{R^2 + L^2\,\omega^2}$, which is the apparent resistance of a circuit containing resistance and self-induction only. We would suggest, therefore, that the word "impediment" be adopted as a name for the expression $\sqrt{R^2 + \left(\frac{1}{C\,\omega} - L\,\omega\right)^2}$, which is the apparent resistance of a circuit containing resistance, self-induction and capacity, and that the term impedance be retained in the more limited meaning it has come to have, that is, $\sqrt{R^2 + L^2\,\omega^2}$, the apparent resistance of a circuit containing resistance and self-induction only. Equation (124) may be written

$$(125) \qquad \text{Maximum current} = \frac{\text{Maximum E. M. F.}}{\text{Impediment.}}$$

Since the effective current (the square root of the mean square of the instantaneous values of the current) is equal to $\frac{1}{\sqrt{2}}$ times the maximum value of the current, and since the effective E. M. F. $= \frac{1}{\sqrt{2}}$ times the maximum E. M. F.,

(126) $$\text{Effective current} = \frac{\text{Effective E. M. F.}}{\text{Impediment.}}$$

It is convenient to consider the impediment as a resistance, and we are justified in so doing inasmuch as it has the same dimensions as a resistance, that is, a velocity in the electromagnetic system of units.

$$\omega = \frac{2\,\pi}{\text{Time}}\,.$$

$$L = \text{Length.}$$

Therefore, $$L\,\omega = \frac{\text{Length}}{\text{Time}} = \text{velocity.}$$

$$C = \frac{(\text{Time})^2}{\text{Length}}\,.$$

$$\frac{1}{C\,\omega} = \frac{\text{Length}}{\text{Time}} = \text{velocity.}$$

This gives the dimensions of a velocity to the whole expression for the impediment, which may therefore be considered as a resistance.

The several particular cases of circuits containing various combinations of resistance, self-induction and capacity may readily be found by means of the general solution, equation (114).

Case A. Circuits Containing Resistance and Self-Induction Only.

In this case the circuit has resistance R and self-induction L, and an harmonic E. M. F., $E \sin \omega\, t$. There being no condenser in the circuit, the capacity C is infinite. After the lapse of a very small time the terms containing the constants of integration in the general solution may be neglected as explained above. Substituting in (21) $C = \infty$, we have

(127) $$i = \frac{E}{\sqrt{R^2 + L^2\,\omega^2}} \sin \left\{ \omega\, t - \tan^{-1} \frac{L\,\omega}{R} \right\}.$$

The current must always lag behind the impressed E. M. F. by an angle whose tangent is $\frac{L\,\omega}{R}$. In this case the impediment takes the particular value $\sqrt{R^2 + L^2 \omega^2}$, which is known as the impedance of the circuit.

CASE B. CIRCUITS CONTAINING RESISTANCE AND CAPACITY ONLY.

In this case the circuit has resistance R and capacity C, with an harmonic E. M. F., $e = E \sin \omega t$. Substituting $L = 0$ in the general equation (114), we have

$$(128) \quad i = \frac{E}{\sqrt{R^2 + \frac{1}{C^2 \omega^2}}} \sin \left\{ \omega t + \tan^{-1} \frac{1}{CR\omega} \right\}.$$

The current must always advance ahead of the impressed E. M. F. when there is resistance and capacity only in the circuit, by an angle whose tangent is $\frac{1}{CR\omega}$.

CASE C. CIRCUITS CONTAINING RESISTANCE ONLY.

In this case the self-induction $L = 0$ and the capacity $C = \infty$. Substituting these values in the general solution (114), we have

$$i = \frac{E}{R} \sin \omega t.$$

This result is immediately derivable from Ohm's law. Thus

$$\text{Since } e = E \sin \omega t,$$

$$\frac{e}{R} = \frac{E}{R} \sin \omega t,$$

$$\text{or } i = \frac{E}{R} \sin \omega t.$$

CASE D. CIRCUITS CONTAINING CAPACITY ONLY.

In this case $R = 0$ and $L = 0$. Substituting in the general equation (21), we have

$$(129) \qquad i = CE\omega \sin \left\{ \omega t + \frac{\pi}{2} \right\}.$$

EFFECT OF VARYING THE CONSTANTS OF A CIRCUIT.

The general equation (114) enables us to ascertain the current which will flow in a circuit, when we know its resistance, self-induction and capacity, the value of the impressed E. M. F. and its frequency. It is important to know two things about the current: first, its maximum value I; and second, the angle θ, by which it lags behind or advances ahead of the impressed E. M. F. The mean square value is readily obtained from the maximum value. We are given R, C, L, E and ω. The angle of lag or advance is

(130) $$\theta = \tan^{-1}\left(\frac{1}{C R \omega} - \frac{L \omega}{R}\right),$$

$$\text{or} \quad \tan\theta = \frac{1}{C R \omega} - \frac{L \omega}{R}.$$

This is an angle of advance or lag, according as $\frac{1}{C R \omega}$ is greater or less than $\frac{L \omega}{R}$. The maximum value for the current

(131) $$I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C\omega} - L\omega\right)^2}} = \frac{\frac{E}{R}}{\sqrt{1 + \tan^2\theta}}.$$

It is interesting to note how any change in R, L, C, ω or E affects the value of θ and the current.

First. If the impressed E. M. F. E, is varied and R, L, C and ω are maintained constant, $\tan\theta$ is not affected, and the angle of lag or advance remains unchanged. The value of the current is varied in direct proportion to E.

$$I \propto E.$$

Second. If the resistance R, of the circuit is varied, and L, C, ω and E are maintained constant, as R is increased, the angle of lag or advance is diminished.

$$\tan\theta \propto \frac{1}{R}.$$

The sign of $\tan\theta$ is positive or negative, and the angle therefore one of advance or lag, according to the values of L, C and ω, and is independent of any variations in the resistance. The current is in all cases diminished by an increase of resistance, but the amount of this decrease depends not only upon R, but upon the relation between $\frac{1}{C\omega}$ and $L\omega$.

In Fig. 10 are shown two particular cases of the variation in the current produced by change in the resistance. Curve I. is for a circuit in which

Self-induction $L = 2.$ henrys $= 2 \times 10^9$ C. G. S. units.
Capacity $C = .55$ micro-farads $= .55 \times 10^{-15}$ C. G. S. units.
Impressed E.M.F. $E = 200.$ volts $= 200 \times 10^8$ C. G. S. units.
$2 \pi n = \omega = 955.$

The abscissæ represent resistance in ohms (1 ohm $= 10^9$ C. G. S. units of resistance). The ordinates represent current in amperes (1 ampere $= 10^{-1}$ C. G. S. units). The relation between L, C and ω here taken is such that $\frac{1}{C\omega} = L\omega$, or $\omega = \frac{1}{\sqrt{LC}}$, which is the relation that gives no angle of lag or advance. The relation between current and resistance is the same as in Ohm's law, and when plotted gives the hyperbola curve I. In the same figure, curve II. represents the value of the current with different resistances in a circuit in which

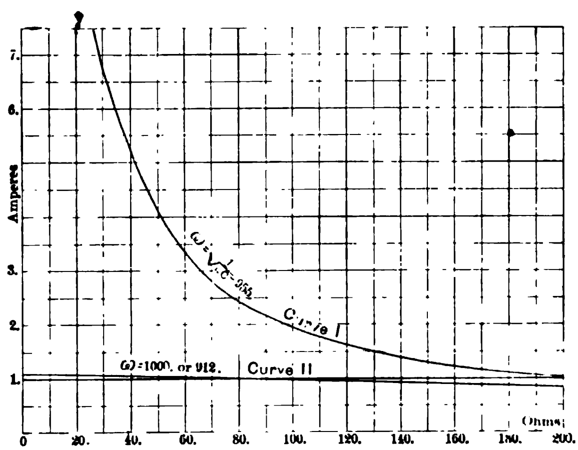


FIG. 10. Variation of Current with Change in Resistance in a Circuit in which $E = 200.$ $C = .55$ $L = 2.$

$L = 2.$ henrys, $E = 200$ volts,
$C = .55$ micro-farads, $\omega =$ either 1,000 or 912.

The constants of this circuit are the same as in the previous case, with the exception of ω, which has been changed from 955, that is $\frac{1}{\sqrt{LC}}$, to either 1,000 or 912. Any change in ω from the value $\frac{1}{\sqrt{LC}}$, whether it be an increase or decrease, causes the curve to depart from the hyperbola, curve I. It is to be noticed that a change in frequency of only seven alternations per second will change the curve from I. to II.

Third. If the coefficient of self-induction L is varied while R, C, ω and E are maintained constant,

When $L < \frac{1}{C\,\omega^2}$, tan θ is positive and θ is an angle of advance.

$$\left.\begin{array}{l}\theta \text{ becomes less} \\ I \text{ becomes greater}\end{array}\right\} \text{ as } L \text{ increases.}$$

When $L > \frac{1}{C\,\omega^2}$, tan θ is negative and θ is an angle of lag.

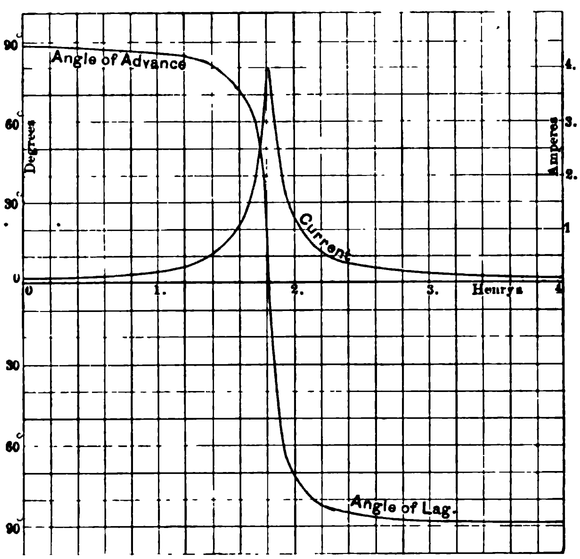


FIG. 11. Value of Current, and Angle of Advance or Lag for different amounts of Self-Induction in a circuit in which $R = 50$. $C = 55$. $E = 200$. $\omega = 1000$.

$$\left.\begin{array}{l}\theta \text{ becomes greater} \\ I \text{ becomes less}\end{array}\right\} \text{ as } L \text{ increases.}$$

These changes in the angle of lag or advance and the current, due to change in the self-induction, are better seen from the consideration of a particular case. In Fig. 11 the values of θ and I are plotted for various values of L in a circuit in which

$R = 50.$ ohms, $\omega = 1000.$
$C = .55$ micro-farads, $E = 200.$ volts.

Where $L = \frac{1}{C\,\omega^2} = 1.82$ the current has its maximum value equal to $\frac{E}{R}$, and $\theta = 0$. This is a critical point, and a slight change of L in either direction will cause θ to reach a considerable value and the current to fall to a small part of the maximum value. If L be increased from 1.82 to 1.92, θ changes from zero to $-63°$, an angle of lag, and the current falls from 4. to 1.8 amperes. If L be made 1.72, θ becomes an angle of advance of 63° and the current will be 1.8 amperes. It is thus seen that an exact balance of self-induction and capacity would be exceedingly hard to maintain in this case, for a slight change in the self-induction would cause a large angle of lag or advance and a large diminution in the current. Just how critical the curves will be in the vicinity of the point of equilibrium depends upon the constants of the circuit. The curves will always be of a form similar to those in Fig. 11, but will often be decidedly modified by the particular values of R, C and ω. The critical parts of the curves may be more or less marked according to these particular values.

Fourth. If the capacity C is varied while R, L, ω and E are maintained constant,

When $C < \frac{1}{L\,\omega^2}$, tan θ is positive and θ is an angle of advance.

θ becomes less, I becomes greater } as C increases.

When $C > \frac{1}{L\,\omega^2}$, tan θ is negative and θ is an angle of lag.

θ becomes greater, I becomes less } as C increases.

These changes of current and lag, with the variation in capacity, are shown in Fig. 12 for a particular case in which

$R = 50.$ ohms, $\omega = 1000.$,
$L = 2.$ henrys, $E = 200.$ volts.

The maximum value for the current is where $C = \frac{1}{L\,\omega^2} = .5$ micro-farads. This is a critical point in the curve similar to that in the curves where the self-induction was varied. Here θ is zero, and so the current, being in phase with the impressed E. M. F., has a value of 4 amperes in accordance with Ohm's law. The critical nature of the curves here is seen by the fact that when $C = .55$ there is an angle of lag of 75° and $I = 1.07$; when $C = .458$ there is an angle of advance of 75°. When C is changed from .5 to .488, the current falls from 4 to 2.83 amperes and is put 45° out of phase in advance of the E. M. F.

Fifth. If the frequency is varied while R, C, L and E are maintained constant, still more marked changes occur in the val ues of I and θ.

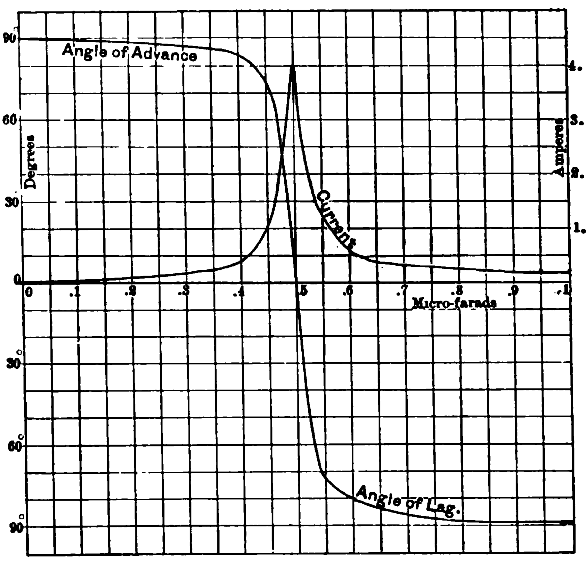


Fig. 12. Value of Current, and Angle of Advance or Lag for different Capacities in a circuit in which $R = 50$. $L = 2$. $E = 200$. $\omega = 1000$.

When $\omega < \dfrac{1}{\sqrt{LC}}$, tan θ is positive and θ is an angle of advance.

$\left.\begin{array}{l}\theta \text{ becomes less} \\ I \text{ becomes greater}\end{array}\right\}$ as ω increases.

When $\omega > \dfrac{1}{\sqrt{LC}}$, tan θ is negative and θ is an angle of lag.

$\left.\begin{array}{l}\theta \text{ becomes greater} \\ I \text{ becomes less}\end{array}\right\}$ as ω increases.

In Fig. 13 the values of the current and angle of lag are shown for different values of ω in a circuit in which

$R = 50.$ ohms, $C = .55$ microfarads,
$L = 2.$ henrys, $E = 200$ volts.

When $\omega = \frac{1}{\sqrt{LC}} = 955$, the current has its maximum value of 4 amperes, in accordance with Ohm's law. Here $\theta = 0$. A change of five per cent. one way or the other in this critical value for ω causes an angle of lag or advance of 75°, and the current falls to one-fourth of the maximum. Just how critical the curves

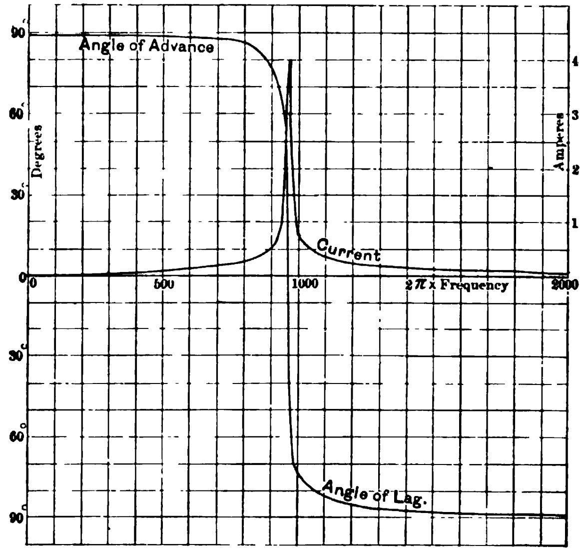


Fig. 13. Value of Current and Angle of Advance or Lag for different Frequencies in a circuit in which $R = 50$. $L = 2$. $C = .55$. $E = 200$.

are, in the vicinity of this point of equilibrium, depends upon the particular values of R, C and L.

In Fig. 14 is shown the E. M. F. necessary to cause a constant current to flow in a circuit in which R, C and ω are constant. In the particular case plotted,

$R = 50.$ ohms, $I = 1$ ampere,
$C = .55$ micro-farads, $\omega = 1000.$

As the self-induction is increased up to the value $L = \frac{1}{C\omega^2} = 1.82$, the E. M. F. needed to drive the current becomes less and less, and when $L = 1.82$ the E. M. F. needed is only 50 volts. As L increases past this critical value, the value of the E. M. F. needed increases. Except very near the critical point, the change in the necessary E. M. F. is almost directly proportional to the change in the self-induction, that is, the curve is formed of two straight lines with a rounded point. This curve is the reciprocal of the corresponding curve for current, with E constant and L variable, as shown in Fig. 11.

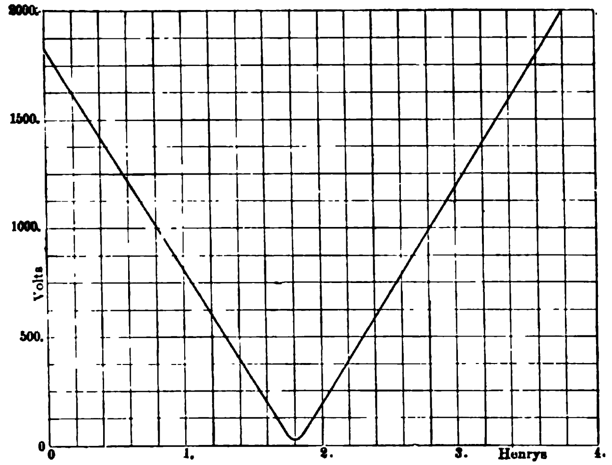


FIG. 14. Relation between Impressed E. M. F. and Self-Induction when 1 ampere flows in a circuit in which $R = 50$. $C = .55$. $\omega = 1000$.

INTRODUCTION OF AN HARMONIC E. M. F. INTO A CIRCUIT WITH R, L AND C.

Returning to the complete solutions for the current [equation (114)] and the charge [equation (115)] at any time after a simple periodic E. M. F. has been introduced into a circuit containing R, L and C, although it has been stated that after a very short time everything comes to a steady state and the complementary function may be neglected, yet it may be interesting to inquire what happens just at the moment of the introduction of the periodic E. M. F. The E. M. F. may be introduced at any point of its phase, that is, it may be zero or may have its maximum or any intermediate value; but, in any case, the complete equations (114) and (115) show just what happens, provided we determine the constants c_1 and c_2 of the complementary function, so that they correspond to the particular hypothesis made.

It has been noticed (39) that the complementary function

$c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}}$ may be written in another form, viz.:

$$A \varepsilon^{-\frac{R t}{2 L}} \sin \left\{ \frac{\sqrt{4 L C - R^2 C^2}}{2 L C} t + \Phi \right\}.$$

This latter form must be used when we have the relation $4 L > R^2 C$, for, under this hypothesis, the time constants T_1 and T_2 of the first form become imaginary. To make this supposition is equivalent to saying that the character of the discharge from the circuit is oscillatory. Inasmuch as this relation $4 L > R^2 C$ is true for most ordinary circuits in which L has an appreciable value, and since the results obtained are rather more interesting under this supposition than under the supposition that $4 L < R^2 C$, which would give "dead beat" discharge, we will confine our attention to the oscillatory case only. The plan to be followed in the discussion of this subject will be to determine the constants c_1 and c_2 of the general equation (114), and write the general result. The application of this result to a particular circuit will then be made, and curves drawn showing the current as it starts in this circuit before it has reached its steady state.

The general equation for current, under the assumption made that $4 L > R^2 C$, may be written

$$(132) \quad i = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C \omega} - L \omega\right)^2}} \sin \left\{ \omega t + \tan^{-1} \left(\frac{1}{C R \omega} - \frac{L \omega}{R} \right) \right\} + A \varepsilon^{-\frac{R t}{2 L}} \sin \left\{ \frac{\sqrt{4 L C - R^2 C^2}}{2 L C} t + \Phi \right\},$$

where A and Φ are the constants of integration to be determined and are each of them real. Likewise, the equation expressing the quantity of charge on the condenser at any moment may be written [see (115) and (42)]

$$(133)\quad q = \frac{-E}{\omega\sqrt{R^2+\left(\frac{1}{C\omega}-L\,\omega\right)^2}}\cos\left\{\omega\,t+\tan^{-1}\left(\frac{1}{C\,R\,\omega}-\frac{L\,\omega}{R}\right)\right\}+A'\,\varepsilon^{-\frac{R\,t}{2\,L}}\sin\left\{\frac{\sqrt{4\,L\,C-R^2\,C^2}}{2\,L\,C}\,t+\Phi'\right\}.$$

Remembering the relation $d\,q = i\,d\,t$, we may differentiate (133) and write

$$(134)\quad i = \frac{dq}{d\,t} = \frac{E}{\sqrt{R^2+\left(\frac{1}{C\omega}-L\,\omega\right)^2}}\sin\left\{\omega\,t+\tan^{-1}\left(\frac{1}{C R\omega}-\frac{L\,\omega}{R}\right)\right\}+\frac{A'}{\sqrt{L\,C}}\,\varepsilon^{-\frac{R\,t}{2\,L}}\sin\left\{\frac{\sqrt{4\,L\,C-R^2\,C^2}}{2\,L\,C}\,t+\Phi'+\tan^{-1}\frac{\sqrt{4\,L\,C-R^2\,C^2}}{R\,C}\right\}.$$

Equating (134) with (132), we obtain the relations

$$(135)\qquad A = \frac{A'}{\sqrt{L\,C}},$$

$$(136)\qquad \Phi = \Phi' - \tan^{-1}\frac{\sqrt{4\,L\,C-R^2\,C^2}}{R\,C}.$$

For simplification make the following substitutions:

$$(137)\qquad I = \frac{E}{\sqrt{R^2+\left(\frac{1}{C\,\omega}-L\,\omega\right)^2}}\qquad \text{[see (131)].}$$

$$(138)\qquad \psi = \omega\,t+\tan^{-1}\left(\frac{1}{C\,R\,\omega}-\frac{L\,\omega}{R}\right) = \omega\,t+\theta.$$

$$(139)\qquad a = \frac{\sqrt{4\,L\,C-R^2\,C^2}}{2\,L\,C}.$$

The frequency of oscillation is $\frac{a}{2\,\pi}$, and the period $\frac{2\,\pi}{a}$. Then we may write, after substituting in (133) the values of A' and Φ', as determined,

$$(140)\qquad i = I\sin\psi + A\,\varepsilon^{-\frac{R\,t}{2\,L}}\sin\left\{a\,t+\Phi\right\}.$$

$$(141)\quad q = -\frac{I}{\omega}\cos\psi + A\sqrt{L\,C}\,\varepsilon^{-\frac{R\,t}{2\,L}}\sin\left\{a\,t + \Phi + \tan^{-1}\frac{\sqrt{4\,L\,C - R^2\,C^2}}{R\,C}\right\}.$$

In these equations time is counted from the point when the impressed E. M. F. is zero. Let t_1 be the time when the E. M. F. is introduced. We know then that the current and the charge of the condenser are each zero at the time t_1, the condenser having no initial charge. These conditions alone, namely, that $i = 0$ and $q = 0$ when $t = t_1$, are sufficient to determine the constants. In equations (140) and (141) make $i = 0$, $q = 0$ when $t = t_1$, and call ψ_1 the value of ψ when $t = t_1$, and we have

$$(142)\qquad 0 = I\sin\psi_1 + A\,\varepsilon^{-\frac{R\,t_1}{2\,L}}\sin\left\{a\,t_1 + \Phi\right\}.$$

$$(143)\quad 0 = -\frac{I}{\omega}\cos\psi_1 + A\sqrt{L\,C}\,\varepsilon^{-\frac{R\,t_1}{2\,L}}\sin\left\{a\,t_1 + \Phi + \tan^{-1}\frac{\sqrt{4\,L\,C - R^2\,C^2}}{R\,C}\right\}.$$

Eliminating A between these equations, we obtain

$$(144)\qquad \Phi = \cot^{-1} - \left\{\frac{2\cot\psi_1 + R\,C\,\omega}{\omega\sqrt{4\,L\,C - R^2\,C^2}}\right\} - a\,t_1.$$

Substituting this value of Φ in (142),

$$(145)\qquad A = -I\,\varepsilon^{+\frac{R\,t_1}{2\,L}}\frac{\sin\psi_1}{\sin\cot^{-1} - \left\{\frac{2\cot\psi + R\,C\,\omega}{\omega\sqrt{4\,L\,C - R^2\,C^2}}\right\}}.$$

This expression for A may be reduced by simple trigonometrical operations to the form

$$(146)\quad A = -\frac{2\,I\,\varepsilon^{+\frac{R\,t_1}{2\,L}}}{\omega\sqrt{4\,L\,C - R^2\,C^2}}\sqrt{(L\,C\,\omega^2 - 1)\sin^2\psi_1 + \frac{1}{2}\,R\,C\,\omega\sin 2\,\psi_1 + 1}\,.$$

Substituting these values of A and Φ in equation (132), we may write the complete solution with constants determined,

$$(147)\ i = I \sin \psi - \frac{2 I \sqrt{(L C \omega^2 - 1) \sin^2 \psi_1 + \frac{1}{2} R C \omega \sin 2 \psi_1 + 1}}{\omega \sqrt{4 L C - R^2 C^2}}$$

$$\varepsilon^{-\frac{R}{2L}(t - t_1)} \sin \left\{ a\ (t - t_1) + \cot^{-1} - \left[\frac{2 \cot \psi_1 + C R \omega}{\omega \sqrt{4 L C - R^2 C^2}} \right] \right\}.$$

There are several general conclusions which can be made in interpreting the meaning of this equation. It is evident that there will be an oscillation of the current when the E. M. F. is first introduced, which gradually dies away, the rate of dying away depending upon the exponent of ε in the equation or, in other words, upon the time-constant of the circuit, namely, $\frac{2L}{R}$. The initial value of this logarithmic decrement curve, which is the value when $t = t_1$, is expressed by the coefficient of ε in the equation. It is evident that this initial value depends upon the value of ψ_1 for its value, or is a function of ψ_1. The initial value of the logarithmic curve has, then, a different value for every value of ψ_1, *i. e.*, for every point of the phase of what the current would have been if it had reached its steady state. Again, at the time $t = t_1$ the value of the last term of the equation becomes $-I \sin \psi_1$. This will be evident upon replacing the coefficient of ε by its value given in (145). The first term becomes $I \sin \psi_1$, when $t = t_1$, and the two terms together show that the equation makes the value of the current zero at the time t_1, that is, at the time the E. M. F. is introduced.

In order to show the meaning of this equation more clearly, a particular example will be assumed. Suppose we have a circuit with a resistance of 50 ohms, a self-induction of 2 henrys and a capacity of .55 micro-farads, all in series. Such a circuit would correspond nearly to the fine wire coil of a small 10-light Westinghouse transformer connected in series with a condenser of .55 micro-farads capacity. Let an E. M. F. of 100. volts (maximum value), having a periodicity of 159, be impressed upon the circuit, (that is the angular velocity $\omega = 2\pi \times 159 = 1000$ approx.) We have, then, with these values assumed,

$E = 100$ volts (max.) $= 100 \times 10^8$ C. G. S. units.
$R = 50$ ohms $= 50 \times 10^9$ C. G. S. units.
$L = 2$ henrys $= 2 \times 10^9$ C. G. S. units.
$C = .55$ micro-farads $= .55 \times 10^{-15}$ C. G. S. units.

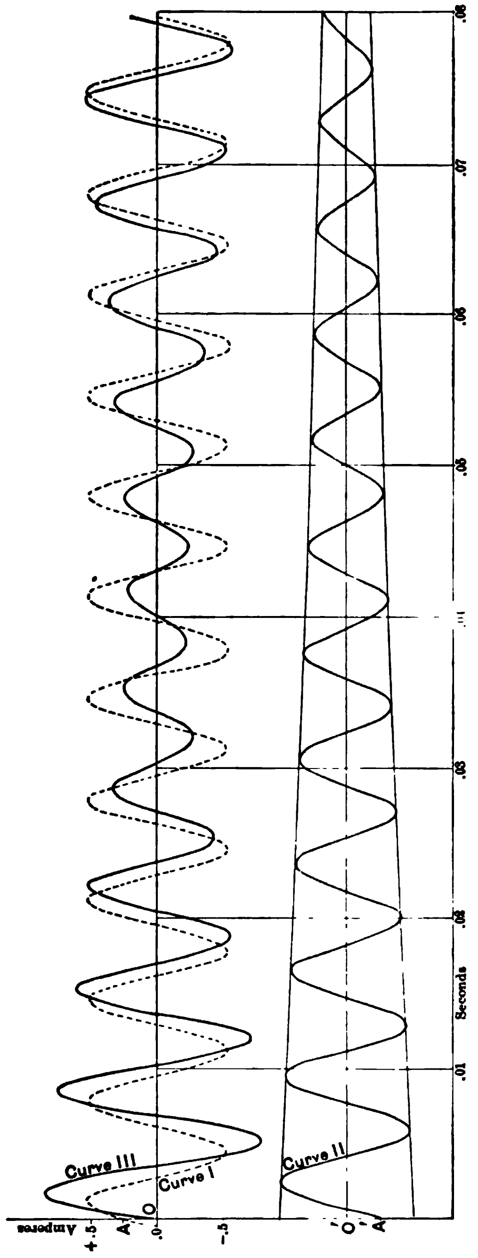


FIG. 15. Curve III. shows the current which flows after the introduction of an harmonic E. M. F. into a circuit with R, L, and C. It is the sum of the two component curves, I. a sine-curve, and II. a sine-curve with an amplitude decreasing according to a logarithmic decrement.

$\omega = 1000.$

$T = \frac{2L}{R} = \frac{4 \times 10^9}{50 \times 10^9} = .08$ seconds.

$I = .53$ amperes (max.) [See equation (137).]

$\theta = -74^\circ\ 30'.$

$a = 955 = 2\pi \times$ frequency of oscillation $= 2\pi \times 151$. [See (139).]

The equation for the current in this particular case is

$$(148) \quad i = .53 \sin \psi - .477 \sqrt{.1 \sin^2 \psi_1 + .0137 \sin 2\psi_1 + 1}\ \varepsilon^{-\frac{t-t_1}{.08}} \sin \left\{ 955\,(t - t_1) + \chi \right\}.$$

Curve III., Fig. 15, represents the plot of this equation when the particular value of ψ_1 is 30°. This means that the E. M. F. is introduced into the circuit at the particular time at which the normal current curve is 30° from its zero value. The value of the coefficient of ε when ψ_1 is 30° is .495, and the equation reads

$$(149) \quad i = .53 \sin \psi - .495\, \varepsilon^{-\frac{t-t_1}{.08}} \sin \left\{ 955\,(t - t_1) + \chi \right\}.$$

Here χ stands for angle of lag expressed in equation (147), and is not expressed in figures inasmuch as it is not necessary to know it in order to draw the curves, because the phase is determined by the fact that we know the distance $O'\ A'$, Fig. 15, it being equal but of opposite sign to the distance $O\ A$. It will be noticed that the initial value of the logarithmic decrement is nearly the same for any value of ψ_1 in this particular case. Moreover, as it happens, the initial value of the logarithmic decrement is nearly the same as the maximum value of the current I. Curve I. is a sine-curve representing the first term in equation (149), and curve II. a sine-curve with logarithmic decrement representing the second term in the equation. The current curve, III., is the sum of curves I. and II. After about one-tenth of a second, curve II. becomes inappreciable and the current follows a simple sine-curve.

As a second example, let us consider the same circuit as before. But now suppose the frequency is just half what it was in the first example, namely, 79.5, or that $\omega = 500$. Furthermore, suppose the E. M. F. is such that it will send a maximum current of .5 of an ampere through the circuit. It will be found, upon calculation, that the E. M. F. must be 1320 volts, maximum. With these values, then,

$$E = 1320.,$$
$$R = 50.,$$
$$L = 2.,$$
$$C = .55,$$
$$\omega = 500,$$
$$T = .08 \text{ seconds},$$
$$I = .5 \text{ amperes},$$
$$\theta = 88^\circ\ 55', \qquad \tan\theta = 52.8,$$
$$a = 955,$$

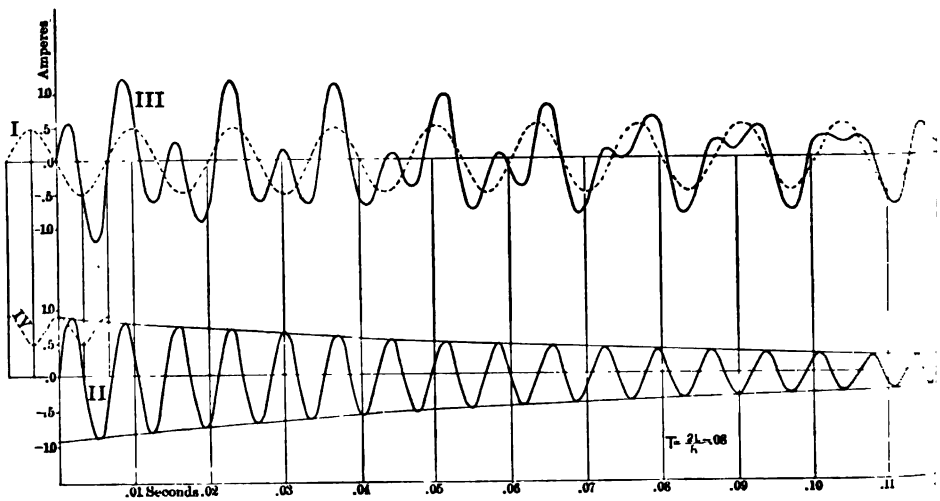


FIG. 16. Curve III. shows the current which flows after the introduction of harmonic E. M. F. into a circuit with R, L, and C. It is the sum of the two component curves, I. a sine-curve, and II. a sine-curve with an amplitude decreasing according to a logarithmic decrement.

the equation for the current becomes

$$(150) \quad i = .5 \sin \psi - .955 \sqrt{-.725 \sin^2 \psi_1 + .0069 \sin 2\psi_1 + 1}$$

$$\varepsilon^{-\frac{t-t_1}{.08}} \sin \left\{ 955\,(t - t_1) + \chi \right\} \cdot$$

The plot of this equation, when ψ_1 is taken equal to 180° (that is the E. M. F. is introduced when the regular current curve is zero) is shown in Fig. 16. It will be noticed that the initial value of the logarithmic curve has considerable variation according to the particular point of time at which the E. M. F. is introduced. This variation is represented in the curve IV., Fig. 16. The initial value of the logarithmic decrement at 0° or 180° is almost twice as much as the maximum value of the current I, their ratio being $\frac{.955}{.5}$. The equation, when ψ_1 is 180°, reduces to

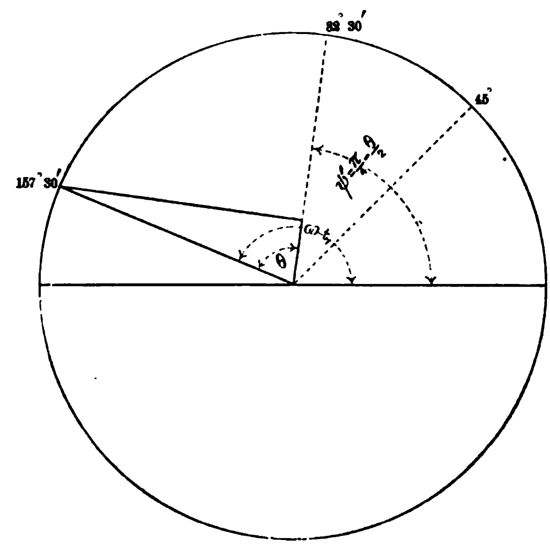


FIG. 17. Showing how to find geometrically the angle ψ, which makes the effect of the exponential term a maximum.

$$(151) \qquad i = .5 \sin \varphi - .955\, \varepsilon^{-\frac{(t-t_1)}{.08}} \sin \left\{ 955\,(t - t_1) + \chi \right\} \cdot$$

In each of the above examples the current follows the sine law in about one-quarter of a second after the periodic E. M. F. is introduced, during which time somewhere in the neighborhood of forty oscillations have been made. It may be interesting to inquire at what point the E. M. F. should be introduced into the circuit to render the effect of the oscillation a maximum. This point may readily be found by referring to equation (147). The coefficient of ε becomes a maximum (for a variation in t_1) when the quantity under the radical sign is a maximum. Differentiating the quantity under the radical, then, with respect to t_1, and equating to zero, we obtain

(152) $$(L\,C\,\omega^2 - 1)\sin 2\,\psi_1 + R\,C\,\omega\cos 2\,\psi_1 = 0.$$

$$\text{Whence}\quad \tan 2\,\psi_1 = \frac{R\,C\,\omega}{1 - L\,C\,\omega^2}.$$

But it will be remembered that [see equation (130)]

$$\tan\theta = \frac{1 - L\,C\,\omega^2}{R\,C\,\omega}.$$

$$\text{Hence}\quad \tan 2\,\psi_1 = \cot\theta = \tan\left(\frac{\pi}{2} - \theta\right).$$

(153) $$\text{or}\quad \psi_1 = \frac{\pi}{4} - \frac{\theta}{2}.$$

And since $\psi_1 = \omega\,t_1 + \theta$ [see (138)], we find

(154) $$\omega\,t_1 = \frac{\pi}{4} - \frac{3\,\theta}{2}.$$

Suppose θ is an angle of lag of $-$ 75°, as in the first example cited, then its sign is negative and $\psi_1 = \frac{\pi}{4} + \frac{75°}{2} = 82°\ 30'$ for a maximum. If θ is $+$ 88° 55′, as in the second example, $\psi_1 = 45° - 44°\ 27'.5 = 32'.5$ for a maximum.

The curve IV., Fig. 16, shows that the maximum point is nearly at the position where $\psi = 0$, and thus agrees with this result. The exact form which the current curve assumes at the introduction of an harmonic E. M. F., depends upon the time of its introduction and the constants of the circuit. The curves shown in Figs. 15 and 16 give an idea of what may be expected in other cases. In all cases, after a very few periods, the current reaches the simple sine form.

The current which flows upon making a circuit which contains resistance and self-induction, but no capacity, is shown in Fig. 18. Its equation is, in general,

$$i = I\sin\psi - I\,\varepsilon^{-\frac{R}{L}(t-t_1)}\sin\psi_1,$$

and is represented in curve III. Curves I. and II. represent the first and second terms of the equation respectively.

It is noticeable that, when there is only resistance and self-induction in the circuit, the E. M. F. may be introduced at such a time that the exponential term will have no effect, whereas if there are all three, resistance, self-induction and capacity, there is no point of time at which the E. M. F. could be introduced so as to make the effect zero.

CASE IV. ANY PERIODIC E. M. F.

If we suppose that the impressed E. M. F. is made up of a number of simple harmonic E. M. F.'s added together, the impressed E. M. F. may be written

(155) $\varepsilon = E_1 \sin(b_1 \omega t + \theta_1) + E_2 \sin(b_2 \omega t + \theta_2) + E_3 \sin(b_3 \omega t + \theta_3) +$ etc.

and, therefore,

$$\frac{de}{dt} = E_1\, b_1\, \omega \cos(b_1\, \omega\, t + \theta_1) + E_2\, b_2\, \omega \cos(b_2\, \omega\, t + \theta_2) + \text{etc.}$$

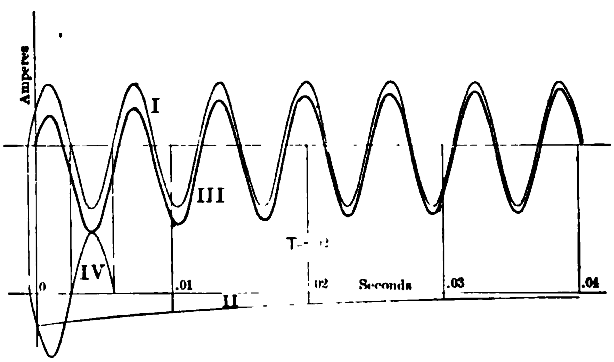


FIG. 18. Curve showing the effect of the exponential term $c\,\varepsilon^{-\frac{Rt}{L}}$ upon the current at the make, in a circuit where $L = 1$ henry, $R = 50$ ohms, $\omega = 1000$, $\psi_1 = 30°$.

Expressed as a summation, we have

(156) $$e = \sum_{E,b,\theta} E \sin(b\,\omega\,t + \theta) = f(t),$$

(157) $$\frac{de}{dt} = \omega \sum_{E,b,\theta} E\,b \cos(b\,\omega\,t + \theta) = f'(t).$$

In this summation it is to be understood that E and θ take in succession any values, fractional or integral, but that b may only have positive integral values as the E. M. F. is supposed to be periodic, and consequently the periods of the component sine curves must be commensurable. It was shown by Fourier, in his treatise on the Analytical Theory of Heat, published in 1822, that such an expression as (155) or (156) represents any single-valued periodic function whatever, and is therefore an expression which represents any possible E. M. F. whatever. If (157) is substituted in the general equation for current (17), and (156) in the general equation for charge (18), it will be found, upon integrating, that each component term in the E. M. F. gives a term in the current or charge similar to that given in equations (114) and (115) in Case III., and consequently the resultant current may be expressed as a summation thus

$$(158)\quad i = \sum_{E,b,\theta} \frac{E}{\sqrt{R^2 + \left(\frac{1}{C b \omega} - L b \omega\right)^2}} \sin \left\{ b \omega t + \theta + \tan^{-1}\left(\frac{1}{C R b \omega} - \frac{L b \omega}{R}\right) \right\} + c_1 \varepsilon^{-\frac{t}{T_1}} + c_2 \varepsilon^{-\frac{t}{T_2}},$$

and the charge

$$(159)\quad q = \sum_{E,b,\theta} \frac{E}{b \omega \sqrt{R^2 + \left(\frac{1}{C b \omega} - L b \omega\right)^2}} \cos \left\{ b \omega t + \theta + \tan^{-1}\left(\frac{1}{C R b \omega} - \frac{L b \omega}{R}\right) \right\} + c_3 \varepsilon^{-\frac{t}{T_1}} + c_4 \varepsilon^{-\frac{t}{T_2}}.$$

In these sums for i and q there must be as many terms in each as there are in the expression for the E. M F., and the values of E, b, and θ must be the same in corresponding terms. In the discussion of Case III., where the E. M. F. was harmonic and the resulting current was shown to be harmonic also, it was pointed out that if the relation $\omega = \frac{1}{\sqrt{L C}}$, existed, the current was the same as if there was no self-induction and no condenser in the circuit, and the same as if it simply followed Ohm's law. This was shown by simply substituting the relation $\omega = \frac{1}{\sqrt{L C}}$, or $\frac{1}{C \omega} - L \omega = 0$, in the current or charge equations (114) and (115) and neglecting the complementary function. Those equations, with these substitutions, become

$$(160)\qquad i = \frac{E}{R} \sin \omega t\ .$$

(161) $$q = -\frac{E}{R\omega}\cos\omega t\ .$$

It is seen that current and charge are the same at every point of time as if the self-induction and capacity were absent. Now, since the current is the same at every point of time, the effects of this current will be the same; namely, the quantity which flows in a half period, being $\int_0^{\frac{T}{2}} i\,d\,t = Q$, is the same as when there is no self-induction and capacity, and the energy expended in the circuit in performing work, or in heating effects, is likewise the same, being proportional to $\int i^2\,d\,t$.

In order to ascertain whether some similar relation between self-induction and capacity would cause them to neutralize each other when the impressed E. M. F. is not a simple harmonic function of the time, consider the case where the E. M. F. is composed of two parts, each a sine function of the time. Suppose

(162) $$e = E_1 \sin a\,\omega\,t + E_2 \sin b\,\omega\,t,$$

where a and b are integers. In the circuit there is resistance, self-induction and capacity. Then at any time the value of the current is [see (158)]

(163) $$i = \frac{E_1}{\sqrt{R^2 + \left(L\,a\,\omega - \frac{1}{C\,a\,\omega}\right)^2}} \sin\left\{a\,\omega\,t + \tan^{-1}\frac{1}{R}\left(\frac{1}{C\,a\,\omega} - L\,a\,\omega\right)\right\}.$$
$$+ \frac{E_2}{\sqrt{R^2 + \left(L\,b\,\omega - \frac{1}{C\,b\,\omega}\right)^2}} \sin\left\{b\,\omega\,t + \tan^{-1}\frac{1}{R}\left(\frac{1}{C\,b\,\omega} - L\,b\,\omega\right)\right\}.$$

Suppose the self-induction and capacity have the relation $a\,\omega = \frac{1}{\sqrt{L\,C}}$. Then they will neutralize each other in the first term of the above expression for the instantaneous value of the current. But in the second term the relation $b\,\omega = \frac{1}{\sqrt{L\,C}}$ is necessary to cause the self-induction and capacity to neutralize each other. Now, if one of the above terms is changed by the introduction of self-induction and capacity, while the other term is unaffected, the value of the current which is equal to the sum of the two terms must be changed. It therefore follows that neither the relation $a\,\omega = \frac{1}{\sqrt{L\,C}}$, nor $b\,\omega = \frac{1}{\sqrt{L\,C}}$ will cause the self-induction and capacity to neutralize each other when introduced into a circuit containing an impressed E. M. F. composed of two simple harmonic E. M. F.'s with angular velocities $a\,\omega$ and $b\,\omega$. If $a = b$, the two terms in the expression for the instantaneous value of the current may be written as one, and we have a simple harmonic function of the time. The relation $a\,\omega = b\,\omega = \frac{1}{\sqrt{L\,C}}$ will then cause the self-induction and capacity to neutralize each other.

If $E_1 = 0$, or if $E_2 = 0$, then we have a simple sine function, and the relation $b\,\omega = \frac{1}{\sqrt{L\,C}}$, or $a\,\omega = \frac{1}{\sqrt{L\,C}}$, respectively, will cause the balancing of the self induction and capacity.

In order to ascertain the conditions under which there may be self-induction and capacity in a circuit, just neutralizing each other so that the instantaneous values of the current will be the same as though there were no self-induction and capacity in the circuit, we will consider the general differential equation of E. M. F.'s

$$(164) \qquad e = R\,i + L\frac{d\,i}{d\,t} + \frac{\int i\,d\,t}{C}\,.$$

[See equation (3).] We wish to ascertain the conditions under which the current will be the same as when there is neither self-induction nor capacity, that is, the conditions under which $i = \frac{e}{R}$ and $e = R\,i$, according to Ohm's law. Substituting in the above equation, we have

$$(165) \qquad L\,\frac{d\,i}{d\,t} + \frac{\int i\,d\,t}{C} = 0\,.$$

This is the same as saying that the E. M. F.'s of self-induction and capacity are equal and opposite. By differentiation,

$$\frac{d^2 i}{d\,t} = -\frac{i\,d\,t}{L\,C}\,.$$

Multiplying by $\frac{d\,i}{d\,t}$,

$$\left(\frac{d\,i}{d\,t}\right) d\left(\frac{d\,i}{d\,t}\right) = -\frac{i\,d\,i}{L\,C}.$$

By integrating, we have

$$\left(\frac{d\,i}{d\,t}\right)^2 = -\frac{i^2}{L\,C} + c.$$

$$\frac{d\,i}{d\,t} = \pm\sqrt{c - \frac{i^2}{L\,C}}.$$

The variables may be readily separated, thus

(166) $$\frac{d\,i}{\sqrt{c - \frac{i^2}{L\,C}}} = d\,t.$$

The integral of (166) is obtained by the formula of integration,

$$\int \frac{d\,x}{\sqrt{a^2 - x^2}} = \sin^{-1}\frac{x}{a}.$$

Upon integration (166) becomes

$$\sin^{-1}\frac{i}{\sqrt{c\,L\,C}} = \frac{t}{\sqrt{L\,C}} + c_1.$$

Taking the sine of each member and writing c' for $\sqrt{c\,L\,C}$,

(167) $$i = c' \sin\left(\frac{t}{\sqrt{L\,C}} + c_1\right).$$

The only two variables in this equation are i and t, and the current is seen to be a sine-function of the time. When the current is a maximum the sine is unity, and we have

$$I = c'.$$

If the time is reckoned from the point where the current is zero, $t = 0$ when $i = 0$, and we have

$$c_1 = 0.$$

Substituting these values for the constants c' and c_1, in equation (167),

(168) $$i = I \sin\frac{1}{\sqrt{L\,C}}t.$$

In an harmonic function, as this, the coefficient of the variable t is the angular velocity which we designate by ω. Equation (168) then becomes

$$i = I \sin \omega t. \tag{169}$$

We have, then, the necessary conditions under which the self-induction and capacity will just neutralize each other at every point of time. The current must be a simple sine-function of the

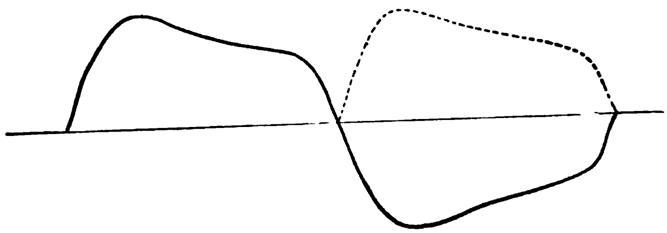


FIG. 19.

time, as expressed in equation (169), and the self-induction and capacity must have such values that $\omega = \frac{1}{\sqrt{LC}}$. Under no other conditions, with self-induction and capacity in a circuit, can the instantaneous values of the current be the same as though the capacity and self-induction were absent.

Since we have found that there is no possible relation that L and C can have so that the *instantaneous* values of the current are unchanged by their introduction into a circuit with an impressed E. M. F. which is not an harmonic function, it is interesting to inquire whether any relation can be given L and C so that the *energy* spent in the conductor in a given time is the same before as after the introduction of L and C.

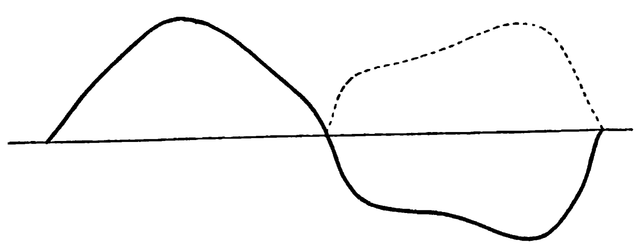


FIG. 20.

Before attempting to investigate such a relation, it will be well to first consider some different classes of current curves, then ascertain the $\int i^2 \, d\, t$ effect for some particular current curves and afterwards consider the energy of any periodic curve whatever.

Fig. 19 represents a curve which has an equal area above and below the axis every period. This means that the integral $\int i\, d\, t$ for one period is zero, that is, the quantity of electricity which flows each period in the positive direction is equal to that which flows in the negative direction. Moreover, if the lower half of the current curve in Fig. 19 is inverted and represented by the dotted line, it is an exact repetition of the first half of the curve. This curve may represent the type of current curves given by alternating generators in circuits with resistance, self-induction and capacity, but no counter E. M. F. For it is evident that as the armature revolves, the number of lines introduced into the circuit every period equals those taken from the circuit. Now, the quantity of current which flows is strictly proportional to the change in the number of lines threading the circuit. This is equivalent to saying that the quantity which flows in the positive direc-

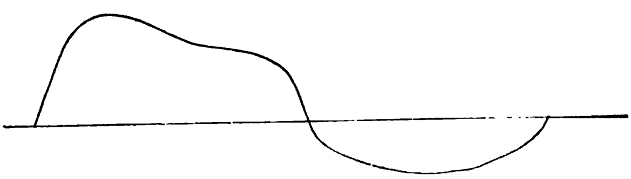


FIG. 21.

tion is exactly equal to the quantity flowing in the negative direction, or the total algebraic quantity per period is zero. Now, if the generator is exactly symmetrical, the current curve in the second half of the period is, if inverted, an exact repetition of the curve in the first half. Any irregularities in the symmetry of the machine might cause slight differences in the two parts of the curve, but hardly enough to prevent this curve from representing the type of curves given by alternating machines. During every complete revolution of the armature, the total algebraic quantity of current flowing must be rigorously equal to zero, no matter how many irregularities there may be in the machine; for, the number of lines introduced into the circuit exactly equals those subtracted from the circuit, because after a complete revolution the number of lines is the same as at the start. It is possible that adjacent positive and negative areas may be unequal in a multipolar machine, due to some irregularity in the machine, but after a complete revolution of the armature the sum of the positive areas equals the sum of the negative

Fig. 20 represents a current curve which has equal areas above and below the axis every period, but the negative area, when inverted, is not necessarily a repetition of the positive area. This represents the type of current curve when there is a non-leaky condenser in the circuit, since the total algebraic flow here is necessarily equal to zero.

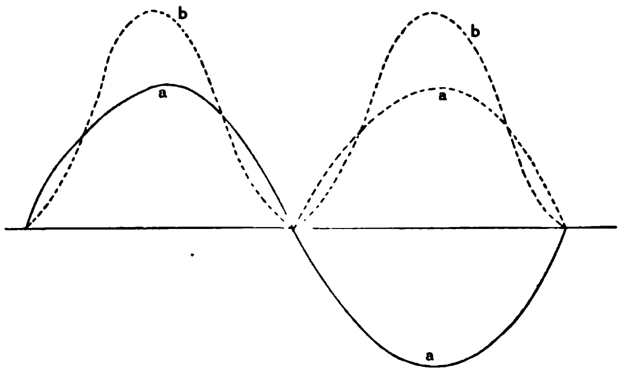


FIG. 22.

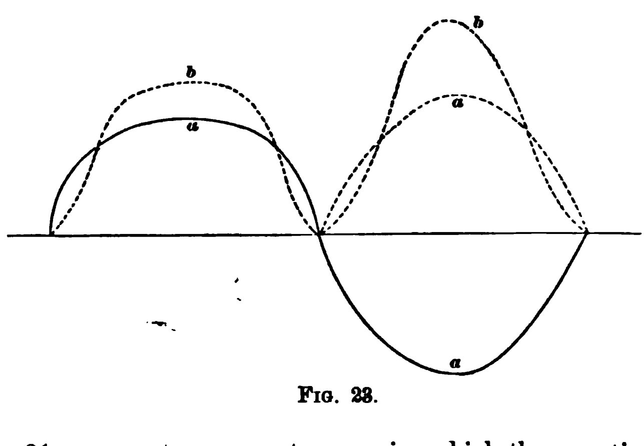


FIG. 23.

Fig. 21 represents a current curve in which the negative area is neither equal to the positive area nor symmetrical with it when inverted.

It is interesting to inquire whether the $\int i^2 \, d \, t$ effect is the same in a circuit while the current flows in the positive direction as it is while flowing in the negative direction. We can see that it is the same for a current of the type represented in Fig. 19, for, squaring the ordinate at each point and drawing a new curve, *b*, Fig. 22, the $\int i^2\,dt$ effect is proportional to the areas of this new curve. Since the current curves *a*, *a* are exact repetitions, these areas, *b*, *b*, are identical, and the $\int i^2\,dt$ effect is the same when the current is positive as it is when negative.

Let us inquire how this is for a current of the type of Fig. 20 where the areas are equal, that is, the $\int i\,dt$ is the same for positive as for negative current), but the negative part, when inverted, is not an exact repetition of the positive part. In Fig. 23 the areas be-

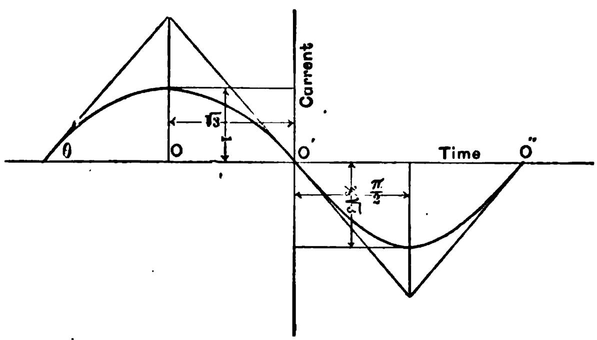


FIG. 24.

tween the axis and the current curve *a*, *a* are equal for each half period. The curve *b*, *b* is drawn by squaring each ordinate of the curve *a*. The areas *b*, *b* represent the $\int i^2\,dt$ effect, and we wish to find whether they are equal.

To show that this $\int i^2\,dt$ effect is not necessarily the same when the current is positive as when it is negative, it will suffice to take one particular case of a current curve. Suppose the positive curve is a parabola [Fig. 24], whose equation, referred to O as origin, is

$$t^2 = -3\,i + 3. \qquad (170)$$

Suppose the negative curve is a sine-curve whose equation, referred to O″ as origin, is

(171) $$i = \frac{2}{3} \sqrt{3} \sin t.$$

It is easily shown that the areas of these curves are equal.

$$\text{Area parabola} = \frac{2}{3} [\text{base} \times \text{height}].$$

One-half of the base of the parabola is found by making $i = 0$ in equation (170) and finding the value of t.

$$\text{Therefore,} \qquad \frac{1}{2} \text{ base} = \sqrt{3},$$

$$\text{Base} = 2 \sqrt{3}.$$

The height is found by making $t = 0$ in equation (170) and finding the value of i.

$$\text{Therefore,} \qquad \text{Height} = \text{unity}.$$

(172) Hence area parabola $= \frac{2}{3} [\text{base} \times \text{height}] = \frac{4}{3} \sqrt{3}$.

The area of the sine-curve is equal to the mean ordinate multiplied by the base; therefore

$$\text{Area sine-curve} = \text{mean ordinate} \times \pi.$$

The mean ordinate of a sine-curve equals twice the maximum ordinate divided by π. By equation (171), the maximum ordinate equals $\frac{2}{3} \sqrt{3}$ and, therefore, mean ordinate $= \frac{4}{3\pi} \sqrt{3}$, and

(173) $$\text{Area sine-curve} = \frac{4}{3} \sqrt{3},$$

which is identical with (172) above. Moreover, the tangents of the angles, which these two curves make at the point O with the axis, are equal, and the curves consequently blend into one another without any abrupt change in continuity. This is easily shown as follows: Differentiating (170) and (171) respectively, we have

(174) $$\frac{di}{dt} = -\frac{2}{3} t = \tan \theta.$$

(175) $$\frac{di}{dt} = \frac{2}{3} \sqrt{3} \cos t = \tan \theta'.$$

Making $t = \sqrt{3}$ in (174), we have the tangent of the inclination of the parabola at the point O. Making $t = -\pi$ in (175), we have the tangent of the inclination of the sine-curve at the point O. These values, it is noticed, reduce (174) and (175) respectively to $\tan\theta = \tan\theta' = -\frac{2}{3}\sqrt{3}$, which is the value of the tangent of inclination of either curve at the point O.

It remains to find the $\int i^2 dt$ for each of these curves respectively. By transposing, the equation of the parabola (170) is

$$i = 1 - \frac{t^2}{3}.$$

By squaring,

$$i^2 = 1 - \frac{2}{3}t^2 + \frac{t^4}{9}.$$

$$\int i^2 dt = \int dt - \frac{2}{3}\int t^2 dt + \frac{1}{9}\int t^4 dt.$$

Integrating between the limits $-\sqrt{3}$ and $\sqrt{3}$, we have

$$\int_{-\sqrt{3}}^{\sqrt{3}} i^2 dt = {}_{-\sqrt{3}}^{\sqrt{3}}\left[t - \frac{2}{9}t^3 + \frac{1}{45}t^5\right].$$

$$\int_{-\sqrt{3}}^{\sqrt{3}} i^2 dt = 2\sqrt{3} - \frac{4\sqrt{3^3}}{9} + \frac{2\sqrt{3^5}}{45} = \frac{16}{15}\sqrt{3}.$$

This is the $\int i^2 dt$ effect for the parabola. For the sine-curve the equation is

$$i = \frac{2}{3}\sqrt{3}\sin t$$

$$\int i^2 dt = \frac{4}{3}\int \sin^2 t.$$

Integrating between the limits 0 and π,

$$\int_0^{\pi} i^2 dt = \frac{4}{3} \times {}_0^{\pi}\left[\frac{t}{2} - \frac{1}{2}\sin t\cos t\right] = \frac{4}{3} \times \frac{\pi}{2} = \frac{2}{3}\pi.$$

This gives the $\int i^2 dt$ effect for the sine curve. Hence we find that, although the area of the current curve is the same for the positive and negative current—that is, the total algebraic quantity of flow is zero—yet the $\int i^2 dt$ effect is different in the positive and negative directions. In the case supposed, the ratio of the two effects is

$$\frac{\frac{2}{3}\pi}{\frac{16}{15}\sqrt{3}} = 1.135.$$

This may afford an explanation for the fact that in many cases one carbon of an alternating current arc lamp is consumed more rapidly than the other, depending upon the way it is connected up.

Let us now return to the consideration of the energy in a conductor when any periodic E. M. F. is applied, and ascertain whether there is any condition under which self-induction and capacity may be introduced into the circuit without changing the energy or $\int i^2\, d\, t$ effect.

The energy expended in a conductor is proportional to $\int i^2 d\, t$. When the E. M. F. in the circuit is

$$(176) \qquad e = \sum_{E,b,\theta} E \sin\,(b\,\omega\,t + \theta), \qquad \text{[see (156)]},$$

which represents any periodic E. M. F., it has been shown that the current is

$$(177) \qquad i = \sum_{E,b,\theta} \frac{E}{\sqrt{R^2 + \left(\frac{1}{C\,b\,\omega} - L\,b\,\omega\right)^2}} \sin\left\{ b\,\omega\,t + \theta + \tan^{-1}\left(\frac{1}{C\,R\,b\,\omega} - \frac{L\,b\,\omega}{R}\right)\right\},$$

neglecting the complementary function [see (158)]. And when there is neither self-induction nor capacity the current is

$$(178) \qquad i_0 = \sum \frac{E}{R} \sin\,(b\,\omega\,t + \theta).$$

Substituting

$$(179) \qquad I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{C\,b\,\omega} - L\,b\,\omega\right)^2}},$$

$$(180) \qquad I_0 = \frac{E}{R},$$

$$\text{and} \qquad a = \theta + \tan^{-1}\left(\frac{1}{C\,R\,b\,\omega} - \frac{L\,b\,\omega}{R}\right),$$

we may abbreviate (177) and (178) as follows:

(181) $$i = \sum I \sin (b\, \omega\, t + a).$$

(182) $$i_0 = \sum I_0 \sin (b\, \omega\, t + \theta).$$

Remembering that the energy is proportional to $\int i^2\, d\, t$, we have

(183) $$W = \int i^2 d\, t = \int \Big[\sum I \sin\ (b\, \omega\, t + a) \Big]^2 d\, t,$$

and

(184) $$W_0 = \int i_0^2\, d\, t = \int \Big[\sum I_0 \sin (b\, \omega\, t + \theta) \Big]^2 d\, t,$$

where W is proportional to the energy expended in the circuit with L and C, and W_0 bears the same relation to the energy when they are absent. In order to find what relation must exist between L and C to cause the energy expended during a certain time to be the same in both cases, we must integrate (183) and (184) between the same limits of time, and equate them. In order to simplify (183) and (184), express as follows:

(185) $$W = \int \Big[I' \sin (b_1 \omega\, t + a_1) + I'' \sin (b_2 \omega\, t + a_2) + I''' \text{etc.} \Big]^2 d\, t.$$

(186) $$W_0 = \int \Big[I_0' \sin (b_1 \omega t + \theta_1) + I_0'' \sin (b_2 \omega t + \theta_2) + I_0''' \text{etc.} \Big]^2 d\, t.$$

Since the square of any polynomial is equal to the sum of the squares of each term separately plus twice the product of each term by every other term, we have as a result to find the integrals of only two forms, thus

(187) $$\int \sin^2 (b\, \omega\, t + a)\, d\, t, \text{ and}$$

(188) $$\int \sin (b_1\, \omega\, t + a_1) \sin (b_2\, \omega\, t + a_2).$$

If the limits are taken from $t = 0$ to $t = T$, a complete period,—the E.M.F. being periodic with a period $T = \frac{2\pi}{\omega}$ —it can be shown that all the integrals of the form of (188) vanish. For, expressing the sine of the sum of two angles in terms of the an gles themselves,

(189) $$\sin (b_1\, \omega\, t + a_1) = \sin b_1\, \omega\, t \cos a_1 + \sin a_1 \cos b_1\, \omega\, t,$$

and

(190) $$\sin (b_2\, \omega\, t + a_2) = \sin b_2\, \omega\, t \cos a_2 + \sin a_2 \cos b_2\, \omega\, t.$$

Multiplying (189) and (190) we obtain terms of the following forms:

(191) $$\int \sin b_1 \omega t \cos b_2 \omega t \, d t,$$

(192) $$\int \cos b_1 \omega t \cos b_2 \omega t \, d t,$$

(193) $$\int \sin b_1 \omega t \sin b_2 \omega t \, d t,$$

which are to be integrated between the limits 0 and T, or $\frac{2\pi}{\omega}$. Substituting for $b_1 \omega t$, $a x$. and for $b_2 \omega t$, $b x$, we have made the integral in (188) depend upon the three forms,

(194) $$\int_0^{2\pi} \sin a x \cos b x \, d x,$$

(195) $$\int_0^{2\pi} \cos a x \cos b x \, d x,$$

(196) $$\int_0^{2\pi} \sin a x \sin b x \, d x.$$

To show that each of these three forms vanishes between the limits zero and 2π, we can reduce as follows:

(197) $$\int_0^{2\pi} \sin a x \cos b x \, d x = \frac{1}{2}\int_0^{2\pi} \sin (a+b) x \, d x + \frac{1}{2}\int_0^{2\pi} \sin (a-b) x \, d x = -\frac{1}{2}\Big[\frac{\cos (a+b) x}{a+b} + \frac{\cos (a-b) x}{a-b}\Big]_0^{2\pi} = 0.$$

(198) $$\int_0^{2\pi} \cos a x \cos b x \, d x = \frac{1}{2}\int_0^{2\pi} \cos (a+b) x \, d x + \frac{1}{2}\int_0^{2\pi} \cos (a-b) x \, d x = \frac{1}{2}\Big[\frac{\sin (a-b) x}{a-b} + \frac{\sin (a+b)}{a+b}\Big]_0^{2\pi} = 0.$$

(199) $$\int_0^{2\pi} \sin a x \sin b x \, d x = \frac{1}{2}\int_0^{2\pi} \cos (a-b) x \, d x - \frac{1}{2}\int_0^{2\pi} \cos (a+b) x \, d x = \frac{1}{2}\Big[\frac{\sin (a-b) x}{a-b} - \frac{\sin (a+b) x}{a+b}\Big]_0^{2\pi} = 0.$$

Since, therefore, the integral in (188) is zero in every case, we only have to find the integral expressed in (187). This is

$$(200) \int_0^{\frac{2\pi}{\omega}} \sin^2 (b\,\omega\,t + a)\,d\,t = \Big[\frac{b\,\omega\,t + a}{2\,b\,\omega} - \frac{1}{4\,b\,\omega} \sin 2\,(b\,\omega\,t + a) \Big]_0^{\frac{2\pi}{\omega}} = \frac{\pi}{\omega} = \frac{T}{2},$$

which is obtained by the formula

$$(201) \qquad \int \sin^2 x\,d\,x = \frac{x}{2} - \frac{1}{4} \sin 2\,x,$$

upon replacing x by $b\,\omega\,t + a$, and $d\,x$ by $b\,\omega$. Returning to equations (185) and (186), and replacing the value of the integral in (200) by $\frac{T}{2}$, as determined, we have now found the values of W and W_0 to be

$$W = \Big[I'^2 + I''^2 + I'''^2 + \text{etc.} \Big] \frac{T}{2},$$

and

$$W_0 = \Big[I_0'^2 + I_0''^2 + I_0'''^2 + \text{etc.} \Big] \frac{T}{2},$$

or

$$W = \frac{T}{2} \sum I^2,$$

$$W_0 = \frac{T}{2} \sum I_0^2.$$

Equating W and W_0, as before explained, to determine the condition necessary to make the energy the same, we obtain

$$(202) \qquad \sum I^2 = \sum I_0^2,$$

which, written in full, is

$$(203) \qquad \sum \frac{E^2}{R^2 + \left(\frac{1}{C\,b\,\omega} - L\,b\,\omega\right)^2} = \sum \frac{E^2}{R^2}\,.$$

[See (179) and (180).] This equation expresses the relation which must be true if the $\int i^2\,d\,t$ effect is the same when the self-induction and capacity are present as it is when they are absent. This equation expressed without the sign of summation is

$$(204) \quad \frac{E_1^2}{R^2 + \left(\frac{1}{C b_1 \omega} - L b_1 \omega\right)^2} + \frac{E_2^2}{R^2 + \left(\frac{1}{C b_2 \omega} - L b_2 \omega\right)^2} + \text{etc.}$$
$$= \frac{E_1^2}{R^2} + \frac{E_2^2}{R^2} + \text{etc.}$$

It is evident that the parenthesis in the denominator of each term of the first member, being squared, is always positive no matter what values L and C may have. Each term, then, of the first member is less than the corresponding term in the second member unless the expression in the parenthesis is zero. And in order that the first member shall be as large as the second member, each parenthesis must be separately equal to zero. That is, we must have

$$b_1 \omega = \frac{1}{\sqrt{LC}},$$
$$b_2 \omega = \frac{1}{\sqrt{LC}},$$
$$\text{and} \quad b_3 \omega = \frac{1}{\sqrt{LC}}, \quad \text{etc.}$$

Therefore $b_1 = b_2 = b_3 =$ etc. But this condition is equivalent to saying that the impressed E. M. F. can only be an harmonic E. M. F., and that we must have the relation $\omega = \frac{1}{\sqrt{LC}}$ in order to have the $\int i^2 \, dt$ effect the same in a circuit when the self-induction and capacity are present as when they are absent. There is, then, no relation between the self-induction and capacity which can be given that will make the $\int i^2 \, dt$ effect the same in a circuit when they are present as when they are absent, if the impressed E. M. F. is not an harmonic E. M. F.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892. President Sprague in the Chair.

ELECTRICITY IN BITUMINOUS MINING.

BY ELMER A. SPERRY.

Many a traveling Englishman on this side turns his eyeglass upon a swift succession of passing trains laden with barely a day's product from some unheard-of western colliery, and thinks that he instinctively recognizes pit coals from Northumberland or Lancashire. He supposes that "all coals come from Newcastle;" nor is this surprising. The average eastern man may be said to be almost unaware of the existence of bituminous fuel. To him anthracite is coal, and Pennsylvania is the place of its nativity. Yet, last year 150,000,000 tons of bituminous coal were mined in the United States, principally in the west.

Of the total anthracite product 78.29 per cent. was shipped to Pennsylvania, New York, New Jersey and New England. To one whose attention has not been directed to the coal industry, it is a matter of surprise that extensive mining operations in coal are going forward in the Mississippi valley. On one of the affluents of the Mississippi river alone, in 1888, was shipped nearly as much coal as was in that year mined in all the continental countries of Europe together. In this valley there are 152,000 square miles of coal area. Illinois alone has 36,000 square miles. In this State $18,000,000 is invested, $11,000,000 is annually disbursed, and about 40,000 miners employed in bituminous mines. These areas of the West are large when compared with those of the Eastern States. The coal area of Great Britain is the same as that of the State of Pennsylvania—9,000 square miles. The coal area in the Mississippi valley is 30,000 square miles in excess of the total superficial area of England, Ireland, Scotland and Wales.

England, doubtless, has the honor of being the first to give up this, the most important of the mineral products. Abundant evidence exists that some of the English outcroppings were worked by the Latins during the Roman occupation. Heaps of debris and cinders from the ancient iron furnaces have been found which were worked at that period, so great in extent that modern furnaces are being supplied from them. While it is not clear that coal was used, yet the fact that the Latins introduced the powerful artifical blast renders its use probable, and may explain the large coal workings of the period.

As to implements and machinery, it is true of the various regions and countries of the old world that if you would know the tools used at an early period you have but to study the tools of to-day. The excavations in the most ancient ruins of civilization show implements used by ancient and contemporary artisans to be the same. Moulds sunk in slabs of limestone used by the most ancient Egyptian silversmiths are identical with those used to-day and sunk in the same limestone. The iron and bronze implements shown in the ancient traceries have been exhumed, together with the drawings, and compare favorably with the picks and shovels used in their discovery. In Nineveh nearly two tons of iron implements were found, among which were bars, shovels, saws, picks, etc. The picks evince excellent workmanship; they are single and double ended, the double in some instances provided with an edge at one end and a point at the other, the eye well formed with extended lips upon the inside for more firmly securing the wooden handle.

There is no doubt but that the implements and tools seen to-day in use in the Lancashire mines, 3,000 feet below the surface, are the same as used by the Latins and Saxons in the ancient coal workings. The motive power has remained unchanged during the centuries; the instrument is good; the method of attack is simply perfect, and cannot be improved. The system, however, has radical defects in point of expense, controllability, protracted effort, want of uniformity, deficient and small power units. The tendency of the times is toward centralization, and a large unit will be the integer of the future. While others among the older industries have adapted improved methods, the mining of coal has remained almost stationary. Ore mining has been revolutionized in many respects; extensive plants of machinery being adopted have been found to increase the capacity and cheapen the product. In isolated cases coal mines have been equipped with labor saving machinery, and the enterprising operator has been richly rewarded.

Veins that were operated at a loss have by the use of machinery been enabled to yield profitable results. In this line doubtless the next decade will witness great advancement. The problem of replacing manual labor in coal mining has engrossed the labors and thought of the ablest engineers of the age. Some of the earliest patents granted by the English monarchs were for mechanical mining devices, with an avowed object of superseding manual labor. These machines were driven by animal or hydraulic power, and more recently by steam and compressed air. They sawed, scraped, cut and plowed, but principally struck a blow. Many, even to a recent date, swung a pick provided with the ordinary transverse handle or power connection. Few, if any of these machines, have been successful under the severe duties required, and none has withstood the test of time. Machines generally employing cutting or scraping devices are of limited application. They are worked with success where the vein is clear; but this, however, is the exception. The presence of iron pyrites or other foreign substances in the strata quickly dulls the knives and requires such heavy driving powers as to preclude commercial use. I have witnessed the operation of this type of machine in strata excellently adapted for machine mining except for a frequent deposit of sulphur about the thickness of a silver dime. The cutters being made of the finest Mushet steel, the entire set required changing every 40 square feet undercut. The current readings would show a power consumption on an average of 27 horse power, whereas in clear coal 10.5 horse power only were required, and one change of cutters for each 250 square feet undercut.

With a more or less friable material, and especially where a cubical or angular crystal exists, great dislodgement and penetration is accomplished by the percussive blow. Its amount is proportional to the stored energy in the projectile. If the energizing motor is deficient, the strokes or impulses must of necessity be feeble; but now that almost unlimited power is at our disposal, the force and work possible is only limited by the rigidity and durability of the immediately attacking medium, namely the tool or cutter. With this form of machine, and especially if organized to be manually directable, the penetration may be pushed at a rapid pace, the foreign substances may be cut about, dislodged and removed without the necessity of directly attacking the substance itself.

These foreign substances are the bane of mechanical coal cutting. They exist in the form of thin layers, thick layers, balls and boulder. The various forms are known to the miner as sulphur balls, lime balls, boulders, bone coal, etc. They are of extreme density, and their hardness is so great that even with the diamond drill they are considered the most difficult mineral substance encountered.

In some instances, especially in the deeper mines and often the thinner veins, it is possible to undermine the coal by excavating in the underlying strata, consisting principally of fire clay and sometimes of a dense slaty and rather heterogenous mass known as "blackjack." In both these materials foreign substances often exist in the form of mineral deposits.

With this foreign matter occurring in irregular forms and in masses of irregular distribution, it will at once be recognized that breakers are ahead of the designer, and that good engineers have been baffled in this field is not a matter of so much surprise.

Successful excavating machinery for bituminous coal is destined to be the product of an evolution, the result of accumulated experiences from various sources and districts, derived principally from the carefully observed action of machines in operation as well as the no less perfect miner, to whose tender mercies the result sometimes of months of work and patience is to be entrusted. This cannot be done by proxy. The environments and conditions are often far from inviting, nor are they entirely free from danger. There seems, however, to be no shorter cut to success. The widely varying systems of mining employed in the different districts render it still farther difficult to construct any single machine which is equally well adapted to all. Such a universal machine is, however, none the less desirable and is doubtless approached most closely by the direct blow or reciprocating action, imitating in this feature the time-honored pick, placing a force behind it never before obtainable. Such a machine may be perfectly guided and directed while in operation. It is the only machine that may be used under almost any condition or quality of coal, foreign substances, underlying strata, or system of mining. It may be used for entry driving, under-cutting, digging, holing or shearing. It may be well here to give a brief statement of the different systems of operation usually met with in the bituminous mines.

After coal is reached, the slope or shaft is divided for ventilation, the air reaching the vein through one division and being exhausted through the other. At this point two or three parallel entries are driven with "break-throughs" at intervals so that the air may be conducted to or near the heading, and at intervals, laterals or "butt entries" are driven, usually at right angles to the main entrance. These butt entries are also driven in pairs, and "overcasts" or "undercasts" are used to connect from one of these entries to the remote main entry. Connections are made through the pillar between these entries in the same manner as in the main entries, multiple distribution being employed throughout. From the butt entries, rooms are turned narrow at first, but widening out from 20 to 60 feet, according to the nature of the roof, leaving a solid pillar of coal between the adjacent rooms approximately equal to the width of the room. As the rooms grow deeper the ribs are broken through for the purpose of ventilation, and curtains are hung in the butt entries which force a small amount of air down through one room, and out through the next, etc. Rooms are usually driven to a depth of 100 yards. It is in these rooms that the mining operations go forward. The product is loaded into pit cars and thus reaches the surface. In rare instances the roof will allow of a number of these rooms being thrown into one, giving a long face of several hundred feet. This is called a "modified longwall" system, as a part of the mine is usually worked ordinary "room and pillar," and in a few places the extended facings are found. In some instances the measure is so dense as to render undercutting out of the question. In these mines the coal is blasted "from the solid," as in anthracite mining. This, however, is not considered good practice in bituminous mines as the product becomes "powder-shot." The slack in this method will run as high as 50 per cent. of the product, and the lump will not bear shipment or the weather without crumbling.

The system of mining employed at the breasts, consists of excavations in the coal or in the underlying strata to a depth about equal to the height of the vein, then by boring near the roof, holes 7 to 15 feet apart, in which light powder charges are exploded for the purpose of tipping out and bringing down the entire breast, which is still farther broken by picks and loaded into cars. After being undermined, in some instances the coal is difficult of dislodgement owing to adherence to the ribs or lateral pillars of the room. To provide against this, machines mounted on high wheels are used to shear in at each side, a depth of 4 or 4½ feet from the floor to the ceiling, so as to entirely separate the portion undermined from the pillars at each side. This operation of shearing is sometimes exclusively employed when the sulphurs are too numerous in the lower strata. The rooms in this instance are sheared in at either end and sometimes in the middle, and the coal is brought down by drilling in an angle and blasting.

Another system of mining prevalent in the northern district of Illinois, and in isolated cases in Iowa, Missouri and Western Pennsylvania is the "longwall" proper. This is among the modern methods of mining. From the shaft "bottom" single entries are driven in four directions through the vein to a distance of about 100 feet, then laterals are taken off each way and driven until they meet. This leaves a pillar of coal to support the top works about 200 feet square. This pillar is never interfered with. After the circuit is entirely completed around this pillar the work is pushed forward on all parts of the facing simultaneously, all the coal being removed; no coal being left, the roof is meanwhile supported by props until at last it gives way and gradually settles down crushing the props, no matter how numerous or how strong they may be. At the same time the floor of the mine "heaves" until the roof and floor practically meet. The rock is taken down overhead in the entries, so that the entries practically consist of tunnels excavated in the "top rock." The long wall facing is pushed forward at all points equally distant from the "bottom," the solid vein of coal ahead supporting the roof in the immediate vicinity, but back from the face a few feet the roof gradually descends until the roof and floor meet, crushing as it would seem the forest of props that is used at the face, entirely out of existence.

The ventilation in this system consists in dividing the air in multiple, taking it up alternate entries and after traveling the face bringing it back through others which are brought together near the "bottom" to the upcast, at which point large furnaces or mechanical ventilators are employed for keeping the air in constant circulation.

Roadways driven off from the main entry like the veinlets of a leaf reach the facing about every 50 feet. The distance between any two of these face entries is called a room, and is worked by two miners. The rock taken from the roof to gain extra height in the entries, is blocked between the floor and the roof near the face, leaving a space for the miners of but from two to three feet from the face. The extreme smallness of this working space may be well understood when it is considered that the thickness or height of the vein is sometimes as low as 18 or 20 inches. Wherever a point of sight may be obtained from these facings back toward the main entries the roof can easily be seen bending downward. The "top rock" is fractured and must be supported at numerous places by props and cap pieces driven in place by heavy sledges. Back a few feet from the face the crushing effect of the enormous weight above can be seen upon these props. The bodies of oak trees six to eight inches in diameter may be seen forcing themselves into the solid rock and curling over at the extremities, exhibiting graphically the enormous pressure at work upon them. Falls of rock are frequent, and constant vigilance is the price of safety at the working face, in a mine of this character.

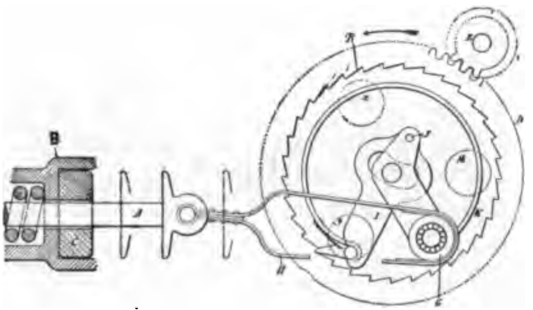


FIG. 1.

The excavating process consists in undercutting in the coal or underlying strata of clay to about the depth of the thickness of the vein, and allowing the constantly descending super-strata to break off the projecting portions of the undermined coal; this occurs from 30 minutes to two hours after the undermining process is completed. This is still further broken up by picks, and loaded as previously described. Drilling or blasting is very seldom resorted to in this system of mining.

I have thus briefly pointed out the methods employed that the conditions may be better understood in the discussion now to follow of electrical machinery as adapted for use in such mines. A diagrammatic outline of the direct blow machine is shown in Fig. 1, the completed machine and parts being shown in Figs. 2 and 3. In this form of machine, a bi-wheeled truck furnished with handles at the rear is provided with a continuously operating electric motor of about four horse power, connected by gearing to a catch or retractor; a longitudinally moving heavy projectile with a pick secured to its outer extremity, is surrounded by a driving spring of about 125 pounds' compression per inch. The line of movement is practically through the centre of inertia of the machine. These springs are preferably made in sections, and an initial pressure is given of about 500 pounds. A retraction then takes place from 6½ to 7½ inches to a pressure of 1,375 pounds whereupon it is released and allowed to make a vigorous forward stroke. This process is repeated from 160 to 225 times per minute. The mean effective of this type of machine is 935 pounds when allowed to strike the cushion, and when striking the work at a distance of one inch from such cushion giving 1,000 pounds mean effective. This is shown in the spring curve diagram, Fig.

FIG. 2.

4. The mean effective in air machinery employed for the same purpose is between 400 and 450 pounds, a 3¾ inch cylinder being the largest employed. The current required for the operation of this machine is between 10 and 10.2 amperes at 220 volts. The projectile weighs between 100 and 150 pounds in the different sizes of machines. Early in the development of this machine it was found that under the action of the intense concussion resulting from the percussive blows and shattering strains throughout the machine, a motor to last under such conditions must be essentially different in its organization from the ordinary commercial machine. After working along various lines it was at last found that by mounting the driving pinion loosely upon the armature shaft, providing it with wing-like projections between which and the armature shaft elastic cushions such as blocks of rubber could

be inserted, the trouble could be averted, and when adopted it was found that the repairs on armatures were reduced to a small percentage of their former value. An elastic medium was also employed in the commutator to account for the difference in expansion of the insulated copper segments and the steel commutator shell. Numerous driving keys or fins, consisting of rawhide, were set in the periphery of the armature and allowed to protude for the purpose of securing the coils against circumferential displacement. The fields were not found to give trouble. With this construction of armature a large number of machines have been made and run successfully in mines in Illinois, Indiana, Ohio and Kentucky. In most instances these machines are run constantly day and night.

A detailed report of each day's work of these machines has been

FIG. 3.

kept from the very first, stating the exact nature of any repairs, the name of the "machine runner," the number of feet undercut, hours of work, etc. These reports are kept on file, and have been of great value in aiding to eliminate the troubles developed. In Ohio alone these reports show that upward of 550,000 square feet of coal strata have been undercut by this type of machine. A somewhat larger amount than this has been excavated in Illinois. In the States of Indiana and Kentucky the operations have not been of so long duration, but at present the daily cutting in the latter States exceeds those in the former.

Beside the elasticity introduced in the armature gear, elastic cushions have also been introduced between the retracting device and the main gear, which is found to still farther reduce the shock to the machine. At an early date it was found that a machine capable of storing in each stroke of the heavy projectile as great an effort as is required for rapid and effective cutting, must of necessity be heavy to be capable of backing up the blow without serious recoil, yet the machine on the other hand should be light for easy handling and direction by a single operator. With a light machine it is found impossible to allow the cutter to strike the work sufficiently back in the stroke for its required penetration, without serious effects from recoil. The operator would complain bitterly of the machine running back upon him, jerking him about upon the floor of the mine, making accuracy of direction impossible, and yet lightness of the machine is important. To combine both qualities I devised a cycle of operation shown in the diagram, the object being to immediately start upon the act

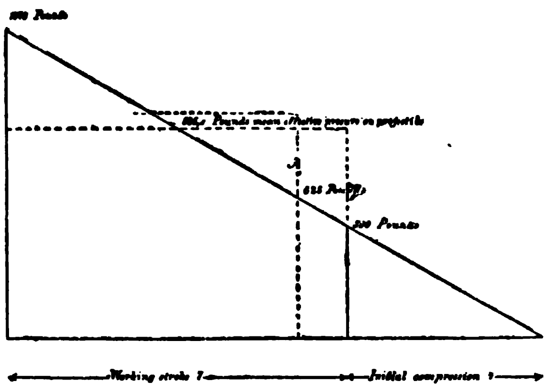


Fig. 4.

of retraction at the moment the projectile had been arrested by the work, no matter at what point in the stroke, eliminating thereby the time element necessary for overcoming the inertia of the body of the machine, and starting it backward in recoil by the intense backward spring pressures. The details are simple and readily understood. [Fig. 1.] The projectile *A* is forced forward by the spring *B*; a cushion *C* relieves the shock when the projectile is not otherwise intercepted. A gear wheel *D* is constantly driven in the direction of the arrow by the motor pinion *E*; this wheel is provided with internal ratchet teeth *R*. A crank *G* is mounted entirely free from the wheel and co-operates with a long slotted pitman *H* connected with the projectile for retracting the same. A light steel crank arm is pivoted, entirely free of the wheel *D*, and an auxiliary arm *I* provided with a dog co-operating with the ratchet teeth *R*, is pivoted to the main crank arm at point *J* and connected with the crank arm through the circular steel spring *K K*. When the crank *G*, reaches the back dead centre at point *M* a reversal of the strains and a free forward movement occurs in the direction of the rotation of the wheel, but very much faster under the impetus of the heavy compression of the driving spring *B*, the pitman and both portions of the crank moving forward together. Suppose now that the forward stroke was intercepted at the point shown in dotted line near the letter *A*; at this moment the crank *G* would be found in the position *x*, also shown in dotted lines, but its momentum and the slot in the pitman would instantly allow it to take up position *y*, also shown in dotted lines, being at an equal angle on the opposite side

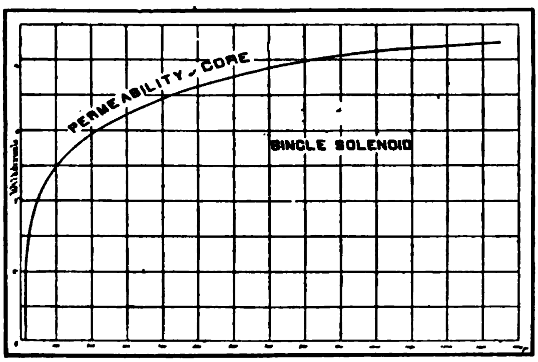


FIG. 5.

of the centre. Its further progress would be intercepted by the remote end of the pitman, and at this instant the dog would instantly fall in the next tooth in the revolving wheel *D*, immediately commencing its work of retraction without the necessity of the full stroke of the pitman being accomplished. The work of the percussive blow is fully accomplished before full retardation, and while being intercepted. Nothing is accomplished by standing and pushing against the face, so that its immediate retraction is not found to interfere in the least with its effective operation, but on the other hand is found to eliminate entirely the serious effects of recoil upon the operator, allowing a light machine to be easily and completely directed while at work. Modifications of the details have been employed, but the general principle has been found to work extremely well in practice. The machine efficiency from the current, on the one hand, and the blow of the pick upon the other has been found to be in excess of 70 per cent.

Another form of the direct blow machine has been constructed, operating upon the solenoid plan; two and three solenoids have been employed in various combinations. It has been found that the return of energy was extremely small until an approximately close magnet circuit was reached. Another point found was that the effectiveness of the blow was materially decreased if the magnetic circuit was closed beyond a certain point, the reciprocation of the solenoid core being dependent upon the non-closure of the magnetic circuit. Diagrams are submitted herewith, showing the various mathematical functions of the machine.

In the Figs. 5 to 8 the ordinates show different withdrawals of

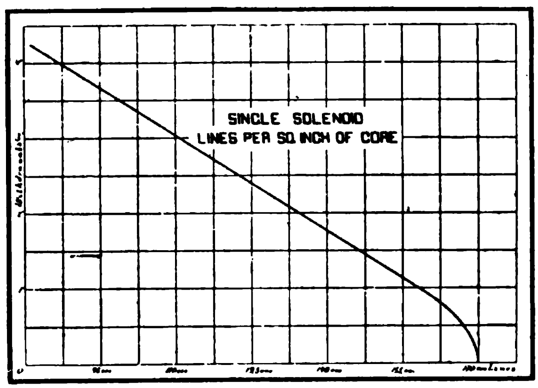


FIG. 6.

the core, and the abscissæ show other functions named in the diagrams. The pressures obtained in case of both single and double coils shown in diagram, Fig, 9. Fig 10 indicates the general arrangement of the solenoid machine. The total weight was about the same as the weight of the spring-actuated machine, and the energy absorbed somewhat in excess. The mean effective pressures, however, are not nearly as great, as diagram 9 indicates; especially is this the case when the work was intercepted, say one inch from the end of the stroke, as at point *A*, in this diagram; the mean effective pressure falls from 259 to 210, decreasing, instead of increasing, as in the case of the spring machine. It was possible to recover in the solenoid machine nearly 10 per cent. of the energy expended during the first few minutes, but the heating effect was found to seriously interfere with its protracted operation.

In drilling holes for blasting, an auger machine is used, shown in Fig. 11. In this case the auger is driven by a single reduction motor, the rod holding the auger being provided with a featherway for driving, and a screw-thread for the feed. An automatic attachment is placed upon the nut of this screw feed, by means of which, when sulphurs or other foreign substances are encountered, the feed is automatically relieved, the progress being inversely to the density of the strata. The machine is made light, and is usually fastened from roof to floor. One machine will drill about 50 holes six feet deep per shift of nine hours. The speed of its penetra-

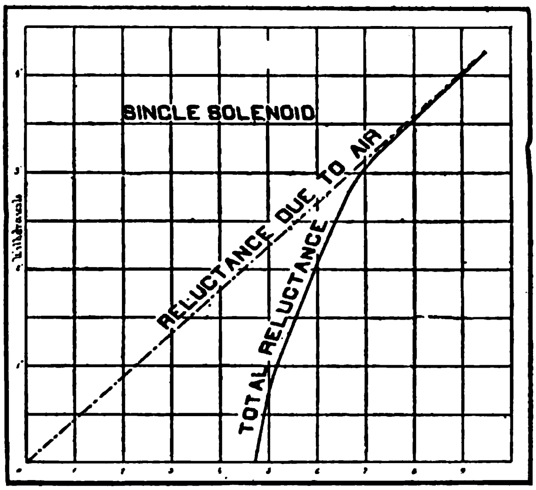


FIG. 7.

tion in ordinary coal is about 3½ feet per minute. It requires about 3½ amperes at 220 volts. Both this and the pick machine are provided with a starting rheostat combined with, or located interior to a cable reel which accompanies each machine. The flexible cable reaches back from the machine to the wires in the entries. The core of this cable is small, and although insulated clamps secured to the ends of the cable for its attachments to the entry wires, have been persistently shipped, it has been found that the miners almost invariably cut them off and prefer to simply bend the end of the cable in the form of a hook, and hang it upon the entry wire. This allows of their being readily pulled off upon the completion of the work, without the necessity of going back to the mouth of the room, and at the same time seems to provide all the contact required.

As to other machines it may be stated that they are divisible into two general classes—the revolving cutter, and the chain machine. In the former the cutters are secured to a revolving bar, which is forced against the substance to be cut. In the latter the cutters are inserted in a chain running over suitable sprocket wheels fastened to a frame, which extend under the coal supporting the entire cutting organization. The chain as it passes out from the coal, goes around a driving sprocket from which the power is obtained. Many attempts at the construction of the former class of machines have been made, which have resulted in entire failure. From my own observation and experience I have

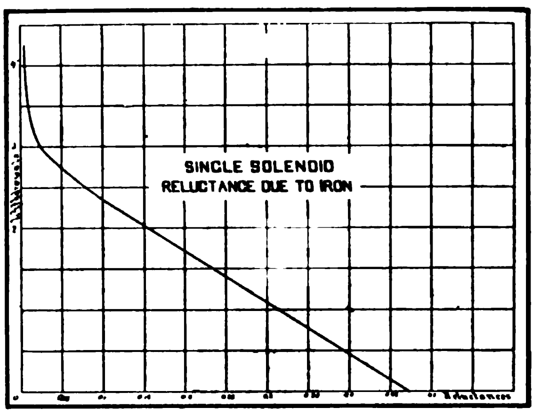


FIG. 8.

found the following to be true with reference to this class of cutters. In Figs. 12 and 13, an outline view of such machine is shown. *A* indicates a rotating cutter bar; *B* the journals of such bar; *C C* the knives or cutters secured to such bar; and *D D* is the coal strata in which the cut is being made. It will be noticed that immediately before the journals, where it is impossible for any cutters to be located upon the bar, there is a solid pillar of coal left. This must be broken up and dislodged by sheer forward pressure of the end of the journal. Furthermore if foreign substances are encountered by the bar, the cutters are usually entirely stripped off at this point. This leaves a pillar uncut as illustrated in the figure, which makes further progress entirely impossible until the machine is withdrawn, new cutters inserted and the pieces of the old ones carefully removed from the kerf. If the machine is not of great strength other portions sometimes break on these occasions, and the machine is laid up for a number of hours and even days for repairs. I have found that in using a chain as shown in the cuts of the long-wall machine now to be described, if some of the cutters are broken, others immediately take their place, and the cutters upon the chain will continue to attack and finally dislodge the foreign substances; in any event the chain will continue to cut so long as any teeth are left upon it, and their absence is easily observed by the operator, inasmuch as all the points in the chain are constantly passing any point of observation outside of the kerf.

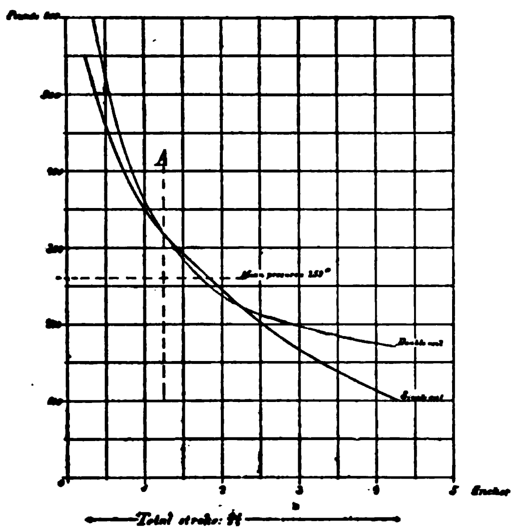


FIG. 9.

The extremely small amount of room between face and props in the long-wall mines sometimes precludes the possibility of even using a very short reciprocating machine. I have therefore resorted to another form of machine to be used in connection with this style of mining, consisting of a mechanism about five feet in length, about 20 inches wide and 18 inches high, from the side of which protrudes a cutting device operated by an electric motor forming part of the machine. This is organized to travel along the face, and undermine to a depth of three feet usually working in the strata below the coal known as "fire-clay."

A number of these machines are in daily operation in the northern district of Illinois. A single machine has repeatedly undermined as high as 1,500 feet per nine hours The machine

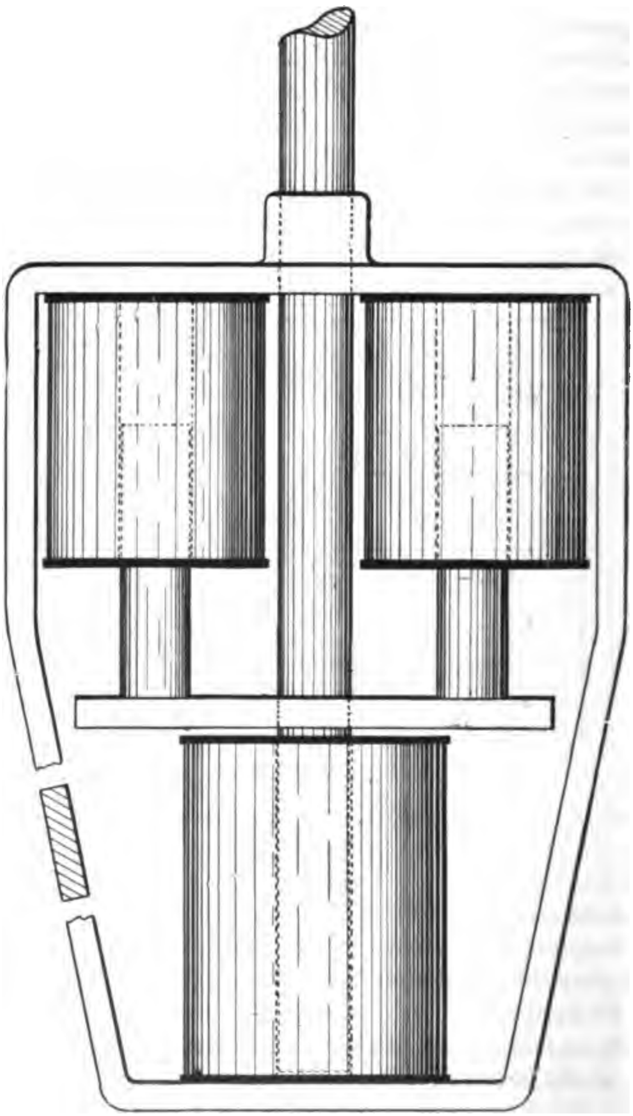


Fig. 10.

weighs somewhat over a ton and travels upon a rail located at one side, which at once provides support for the machine, means for providing against the twisting strains of the lateral cutting device and providing at the same time for feeding in either direction. These rails are in sections, and are taken up after the machine has gone over them, are passed to the front over the machine on rollers provided for the purpose and are laid ahead. The pintles used to connect the rails, form with the other pintles, members of a series by means of which the feeding along the rail is effected in a simple manner, and one that has proven successful in actual work extending over a considerable period of time. The machines are shown in photographs presented herewith and have been in use upward of two years. They require 22 to 35 amperes for their operation at 220 volts. Flexible cable of 150 feet is provided, which, being attached to the live wires ahead, allows the machine to cut 300 feet before readjustment is required.

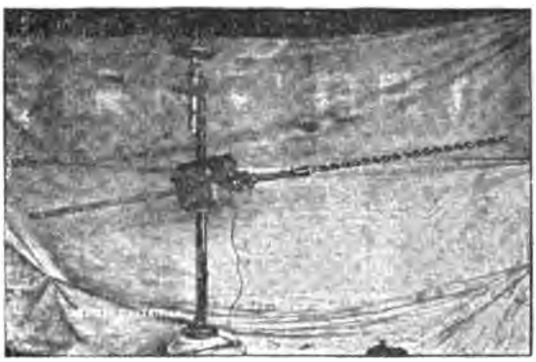


FIG. 11.

After the product has been loaded and the cars massed in trains, their transit to the surface is a problem that has received considerable attention from the mining engineer. There are three prominent systems of mechanical haulage in operation. One in quite extensive use is the tail-rope system, where a main traction rope leads out from a drum over numerous pulleys and rollers to the front of the train. A tail-rope of lighter weight leads from another drum on the same shaft over numerous grooved shives at the side of the track, or suspended from the roof over a "bull wheel" at the farther end of the track, coming back upon the track-rollers and being secured to the rear of the train. Each of the drums is detachably secured to the driving shaft of a powerful engine. The train is only under control of the distant engineer. A trip rider usually goes with the train, and a rather complex system of signals is employed, by means of which he may possibly communicate with the engineer.

Another system of growing importance is the endless rope, which consists of a slowly moving wire cable usually requiring double track and double-width entries, single loaded cars or trains being coupled to the rope by grips at the inner end, which are disengaged at the receiving end and attached to the "empties" standing upon the other track, and are thus gripped to the outgoing cable and sent on their way back. A large number of extra cars are required, owing to the slow movement of the cable. In some instances trip riders are employed to accompany the train. In some mines grip cars are used. In both of these systems a large amount of power is expended compared to the work per-

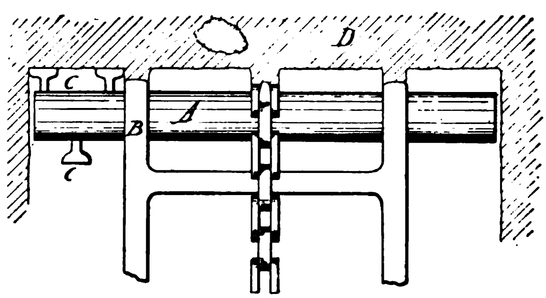


FIG. 12.

formed, and the speed is of necessity limited. Another drawback is the excessive complication necessary in track, innumerable rope sheaves, timbering and entry to provide for turn-outs, crooks, cross-overs, ventilating traps, etc.

Electric haulage has been looked upon by the foremost operators as the coming system, and one which is destined to solve the problem of economical transfer of the heavy product in mines. In studying the problem of electric haulage for mines one is met with the fact that the tracks are poor and light, the roadbed is crooked and irregular as to levels and generally of light construction. The curves, owing to the necessity of leaving pillars, and having connected sight entries, admit only of small radius curves, and excessive grades are often met with in the dip of the vein, which cannot be obviated by cuts or fills as on surface roads without great expense, especially if the entries are timbered, which is usually the case in western collieries. Yet a service of the highest efficiency and greatest capacity in speed and tractive power is required. The motor must work double shifts if necessary, and be at all times under perfect control of a motor man receiving $2.25 per day, and never fail for an instant.

After considering the problem, I have designed a motor shown in the accompanying photographs. A number of plants containing this motor are now in daily operation in Ohio, Indiana, Kentucky and in this state (Illinois). Two of these plants have been installed in one mine in Illinois. The grades are as high as seven per cent., five per cent. being not unusual.

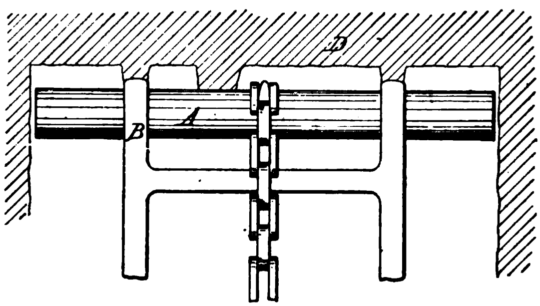


FIG. 13.

The matter of stability of roadbed is a relative one. There are conditions under which a 10 pound rail would be as stable for a light locomotive as the New York Central's 100 pound rail is to the tremendous load per driver in the high speed locomotives recently placed in service on that road. Pounds' pull at the draw-bar is only obtainable by pounds' weights at the rail, yet for a heavy draw-bar pull it is not necessary to have the weight upon any one driver excessive. In designing the locomotive I have employed eight drivers grouped in two swiveling trucks free to turn on the shortest radius curves—as short, in fact, as nine feet radius, measured from the centre of the track. A single powerful motor constituting the frame of the car is coupled to all eight of these drivers, the coupling being simple and of such character as not to be interfered with in the least by the change of the alignment between the truck and the car body, upon irregular track or in making curves. This, while being rather a difficult problem, has been successfully worked out, as shown by the fact that none of the locomotives have ever required repairs as to

FIG. 14.

this portion of their mechanism, although the first has been in operation about two years. Fig. 15 illustrates the central feature. Steel tires of a special grade are employed on all the drivers, and

FIG. 15.

the fact that they are driven from a single motor insures absolute uniformity and harmony in their peripheral speed. It is to this fact, as recently stated in a paper before the Chicago Electric

Club, that I attribute the extremely satisfactory results in traction which have been observed, it being demonstrated both in shop tests and under conditions of actual service that two motors without mechanical coupling do not show results that are at all com-

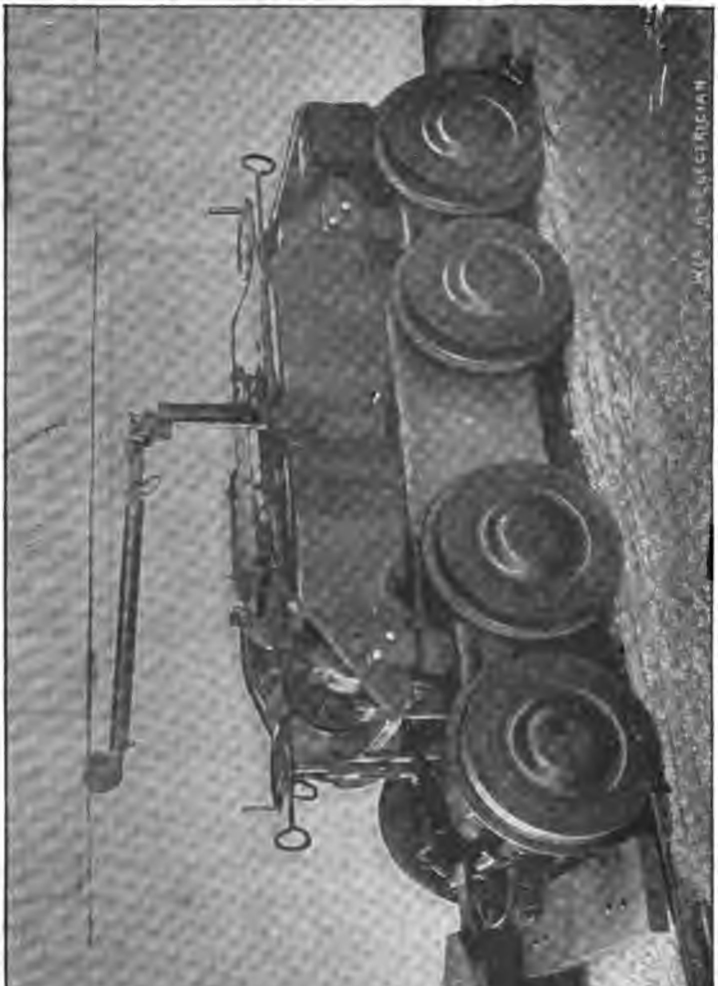


Fig. 16.

parable. In regular service as high as 25 per cent. of the weight of the entire machine may be depended upon for draw-bar pull, and considerably over one-half of such weight has repeatedly been shown on the dynamometer. The wheel base is entirely flexible, distributing equal portions of the total weight upon each driver under all conditions of irregular track. The trains hauled by these locomotives frequently have as high as 200 wheels upon the track. The pit car wheels are constantly oiled, distributing an excellent lubricant from one end of the track to the other, and I have found for rapid acceleration work on heavy grades and quick action of the brakes that sand is almost as indispensable as the current itself. In using the rails as return the sand is found to seriously interfere with the proper electrical connection to the rail, especially where four wheels only are employed. It is the usual practice in this case to use sand upon one side only giving a tor-

FIG. 17.

sional working strain which tends to seriously rack the frame increasing the flange friction and giving uneven wear upon the drivers. With eight wheels, however, I have found it preferable, and in fact this practice is followed in all installations, to sand upon both sides and obtain the " bite " upon the rail through the silicates from at least six drivers out of the eight. The sand, by the time three wheels have passeed over it on either side is sufficiently broken up to allow the fourth pair to get a fairly good contact with the rail for electrical conductivity. This is an accidental feature in the use of the eight wheel car which is of great value. The machines themselves are low and narrow, the height being between 34 inches and 36 inches, accommodating themselves thereby to the lowest entries. Three sizes have been built, namely, eight, ten and twelve tons, Figs. 16, 17 and 18. The motor of the largest of these is of 125 horse power capacity; 250

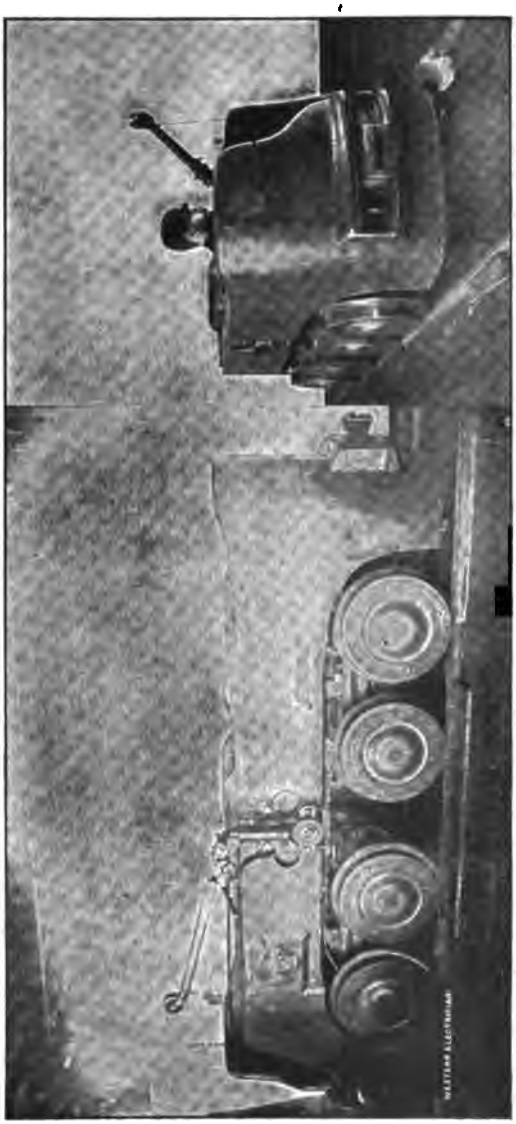


FIG. 18.

volts is the highest that has been used in connection with the machine. The temperature of the machine is very low, not exceeding 60 degrees above the atmosphere on a 10 hour run.

These machines have been operated on as low a rail section as 10 pounds with fairly good results. The heaviest rail that has ever been employed in connection with them is 20 pounds. This makes an extremely inexpensive track, not only eliminating entirely the light track argument used against electricity by advocates of rope haulage but "goes them one better," in that a single track with the most abrupt curves serves better purpose than double track with rope. In Streater No. 3 shaft of the Chicago, Wilmington and Vermillion Coal Company a round trip on a haul of 7 000 feet, including switching at both ends, has been repeatedly run in 8½ minutes, part of the entry being a three per cent. grade against the loads. Thirty seven pit cars of about two tons

FIG. 19.

gross weight have been handled on this grade. The controlling mechanism is extremely simple, a single hand wheel serving the purpose of start, stop, acceleration and reverse. A rheostat and series fields are used. The rheostat is of most durable construction consisting of iron and asbestos. The trolley wire is upon the roof and follows the line of the track at a distance of about six inches outside of the gauge line of one of the rails. Excellent results have been obtained by the use of an elastic medium which is located between the trolley wire and solid mine roof, one form used being among the exhibits. The elasticity prevents concussion of the rapidly moving trolley, obviating thereby the serious sparking often, and most easily observed in mine entries, where nothing but the most intense darkness prevails. To my mind the extreme facility with which electric power can readily be transmitted by the mere contact between conductors has no parallel in any branch of physics. I have often observed the simple contact between trolley wire and wheel while 160 horse power, namely, 480 amperes, was being transmitted to the motor, each of the eight drivers slipping vigorously on the sanded track throwing fire which illuminated the surrounding mine walls, while the trolley, with the exception of slight infrequent scintillations, was perfectly dark and of extremely innocent appearance.

A number of special and automatic devices have been employed in connection with the system with excellent results. Powerful electric headlights are used on each end of the locomotive, and in the 12 ton type Fig. 18, the end is carried out, providing a cab which entirely surrounds the motorman with high walls of metal two to three inches thick, entirely protecting him against collision, piling up of cars, falls of rock, etc. I have operated this motor on tracks which if seen by daylight would be adjudged unsuitable entirely for even the roughest mule service, handling heavy trains at a rate of speed of 2,700 feet per minute, being somewhat over 30 miles an hour. The perfect flexibility of wheel base of the motor is doubtless responsible for these excellent results. Compound-wound dynamos of about seven tons weight are used to furnish current for the machine, Fig. 19. These are designed for sufficient excess of capacity to operate other devices in connection with the mine. In one mine at the south we have coupled to a single dynamo and engine one of our eight ton haulage cars, electric lights at all partings and switches, and on top in engine room and at a store, electric mining machines of the direct blow type, and an electric drill for blasting, by means of which machines, the entire product of the mine is taken out. The mine, which was formerly ventilated by a furnace, at present has its air moved by a fan driven by a powerful electric motor, and an electric pump is at present being installed, all of which are operated from the same feeders. In Kansas a mine pump raising water about 800 feet and two very extensive endless rope hauls are operated from the same dynamo as our electric excavating machinery. The pumps are of simple construction, the motor being geared to the plungers by spur gearing. It has been found with the pumps, long-wall machines and drills, as well as in the case of the percussion machines, that mounting the pinion loosely upon the armature shaft and driving it with cushions, located between it and the armature, has worked a decided economy in repairs, showing its adoption to be along the line of good engineering.

Discussion.

The President:—I am sure the members of this Institute have heard with a great deal of pleasure the interesting and exhaustive paper which Mr. Sperry has read. I wish to express my personal thanks for the information which I have received from it.

The operation of mines by electricity has been a bugbear for all the large electric companies, and it has been almost at a standstill, until some one person has had the energy, the courage and the ability to go into a mine, deal with those who are operating the mines, gain experience from them, learn their present practical or impractical methods of getting out the coal, and then set to work to solve the problems that are presented. I think we may accord to Mr. Sperry the credit of being one of the most successful men who has thus far essayed to operate mines by electricity. [Applause.] I must confess that I am astounded at the care and the amount of work which have been shown in his operations. I did not realize that the business of electric mining had reached the successful condition which it seems to have attained. I think I made an error last night when I did not speak of electric mining as one of the developments marking the vigorous manhood of electricity. To those who have been in mines, whether silver or coal, who are used to going into long headways or down long shafts, the dangers which one has to encounter in dealing with this particular problem must be apparent. It requires on the part of the man who undertakes its solution, more than ordinary courage, and patience to spend as much time, and to run the risks that are necessary to overcome the difficulties that must be met in that way and that way only. The ingenuity which Mr. Sperry has shown deserves special commendation. Personally, I know of no other means which have been more successful in accomplishing the results sought.

In looking forward to the railway work which is to be done in the near future, I take a good deal of comfort in knowing that a single trolley wheel has carried, in actual practice in mines, under the conditions which are there met, half as much current as is required on the very largest class of passenger locomotives when operating at 800 or 1,000 volts, and as much current as would be required by a locomotive in ordinary practice. I confess that there has been a question in my mind whether the contacts at the high speeds operated, and for the current necessary to be carried, would be made without a good deal of difficulty and without a great deal of experimental work. We are under obligations to Mr. Sperry for having demonstrated that large currents at high speeds have been successfully handled without danger to the trolley wire or to the trolley itself.

The paper is open for discussion, and I would be very glad if anybody here, who has had experience in mining, would either criticise the paper which Mr. Sperry has brought forth or advance any arguments for or against this method of operating mines, or if they have any other methods with which they are familiar, that they will bring them forward for criticism and discussion.

Dr. Emery :—I have been very much pleased with the manner in which the mechanical difficulties have been overcome in this work, and it seems to me that with such an adaptation already made underground, where the conditions are much more difficult than upon the surface, there should be no hesitation in pushing forward any work that is desirable, on any scale for which the capital can be secured.

Mr. Nelson W. Perry:—Mr. President, that paper has been very interesting to me. I think it very timely and very fitting that Mr. Sperry should speak of the survival of old methods in the mines. We find that the mining communities are very conservative. They do not change from one method to another readily. For instance, we can illustrate that in our own country here. Our coal miners are fond of using the little coffee pot lamp for lighting, fastened in their hats. They won't use a candle if you furnish it free. You take the gold and silver miner out in the West, and he will take a little piece of candle and daub it up against the wall in any way with mud. You know, in some sections of the country they use a double hand-drill and in other sections you can't hire them to do it—at any rate, where they are doing contract work. And so it goes. When I was mining, one time, in the Republic of Mexico, I received by mistake a shipment of a lot of American picks. Our miners down there use a straight, sharpened bar for doing the same work that we do in this country with the pick. Our foreman looked them over and asked me what they were for. I told him, and he shook his head rather doubtfully. Then I showed him how to use them. They were left there for the men to use if they chose, and I tried to get them to use them, but they wouldn't. They went back to the old bar and I am satisfied did better work with that than they would have done with the pick.

The President has spoken of how much at a standstill we have been in the introduction of electricity in mining. I think that is easily explained. As I said before, the mining communities are very conservative. They have acquired what knowledge they have by hard knocks. They have also had a good deal of experience in this country, experimenting with new devices for treating ores and getting ores out of the earth, and new processes generally; and, as a rule, they have paid very dearly for it. Then, again, electricity being so new, those of us who have lived above ground have been, until recent years, somewhat suspicious of it, and those underground have been still more so. Not to increase their confidence in it, our manufacturers have frequently sent men out to their mines, to tell them how to get their material out, who have never been inside of a mine before. They have sent men out there, to tell them how to place the product in marketable condition, who never saw the product in its crude condition. They have gone further; they have taken coal miners and sent them to the silver fields, and it is a notorious fact that the gold and silver miner has been receiving three to four dollars a day for his work, whereas at the same time the coal miner has been getting 60 or 75 cents, or perhaps a dollar a day for his work.

There has been another drawback to the introduction of electricity in mining operations; that if we come across a mine which is already equipped, we will say, with a compressed air plant for the operation of drills, and we try to induce them to put in electricity, they ask us:—"Well, what can it do? It can't run our drills." Until comparatively recently, we had no electric drill of any kind. Now we have drills to offer them, but the question is one of efficiency. It would be difficult to convince a miner to-day that electric drills are on a par with compressed air drills. So that since we had nothing to offer them in place of compressed air, the miner could not see where it was to his advantage to put in an additional plant which would do only one operation, an operation which has heretofore worked satisfactorily—the oil lamp and the candle. He can detect the quality of his ore with a very dim light. If you offer him an electric light he regards it as a luxury, and we had nothing to offer in the shape of a drill. As it is now, with electric reciprocating drills, they are all too heavy. It requires in operating them about 75 per cent. of the time in moving them from one place to another, leaving about 25 per cent. for actual operation. If we could get a drill which would give sufficient power but only half the weight, which would not eat up the energy in that way, it would be a desirable thing. I regard the attaining of an efficient electrical drill of such a character as being the key to the introduction of electricity into mining operations generally. If we could mine our ore by electricity, it needs no argument to get an introduction of electricity—if we can carry the current as far as may be necessary and do all of the operations from the same plant.

I was a little surprised at Mr. Sperry's statement of the pressure which he found to be most efficient. If I followed him correctly, in the coal drill it was something like a thousand pounds per square inch.

Mr. Sperry:—The projectile is operated by a spring which takes 125 pounds per inch to retract it. It could not be considered in area, or so much per square inch.

Mr. Perry :—In the softer coal it won't do to strike too hard a blow. A more rapid and lighter blow seems to be more efficient. And, in looking at this bit, it occurred to me—and you were speaking of its striking these nodules of various kinds—it occurred to me that it would be better to have a differently shaped bit in coal and other deposits where you will strike those. A drill naturally assumes a certain shape, and we find that the drill is more efficient if we put it, in the first place, in about the shape that it naturally assumes from wear and tear. A drill of this character, lodged in the soft rock, might bind—get in too far. Another difficulty with these drills—the ordinary material that we may strike is not even. It is almost as bad to strike something that is softer than the average material as that which is harder than the average material. It destroys the drill in a different way. It would be difficult to remedy that in a percussion drill.

In this mining locomotive I was very much interested, as I would have anticipated great difficulty in getting around some of the smaller, shorter radius curves which we are liable to meet any time in the mines with an eight-wheels base, and I think your method of coupling the locomotive to make those sharp turns is ingenious. But doesn't the dirt get into that universal joint and affect it at times?

Mr. Sperry :—No, we experience no difficulty in that direction.

The President :—We were all pleased to hear the interesting remarks of Mr. Perry, in which he illustrated the inertia of the mining class and described the character of the men who have been sent out to instruct mine operators how best to handle their products. It is a familiar inquiry, with which we are invariably met, "How much of my system can you operate? Can you operate only part of it, or can you operate the whole?"

There must be sombody else here who has some remarks to make on this paper.

I am somewhat familiar with the inertia of the companies as well, because some time past, when associated with organizations with which I am no longer connected, we made attempts to get into the mining field. We learned at that time that there was not a man in our employ who was sufficiently familiar with mining and electrical practice to discuss questions with the mine operators and those who were interested from a technical standpoint. Every one had altogether too much to do to devote special attention to such matters. It has been necessary for some one to forsake other fields, leave the arc and the incandescent lamp, get away from the ordinary street railway problems, and devote himself individually to the various problems that arise in the solution of mining operations.

Mr. Sperry :—Mr. President, among the points that have been brought up, the one raised by Mr. Sprague is of greatest interest. The fact that we can handle from 300 to 400 amperes through a single contact is one that not only gratifies but astonishes me when I think of the small actual bearing through which such a quantity of current is transmitted. Before we adopted the elastic support we found it quite difficult to do this successfully, because, as the upward pressure exerted upon the wire was brought near the trolley wire support, the trolley wire would assume this shape (illustrating). That is, a series of inverted scallops. This affected only the particular section of the wire, of course, upon which the pressure was exerted at the time, but you will readily see by following the wheel along the line that, as it gets to the point of passing the support, it jumps off, because its momentum has a tendency to make it follow on the curved line, very nearly like the line I have drawn. But on using a flexible trolley wire support, this was largely obviated. That, I may say, was the only trouble we encountered in reference to this point.

Now, as to the wear of the trolley wire under these extreme uses, we have found that the trolley wire which we put in about two years ago is in perfect condition. You cannot feel a difference in section in that wire, one way or the other, with a pair of calipers. I found by a micrometer that on a No. 00 wire that the wear was not in excess of 2½ thousandths of an inch. In some places it was difficult to detect any wear. I suppose that the reason that I could not detect wear, and in some places I could not, was owing to this fact:—Where dirt or oxide covers the wire (in the mine we have an enormous amount of sulphur gas, coming from blasts that take place daily), these fumes corrode the wire, and the trolley, in flashing, leaves protuberances on portions of the wire, and as the micrometer contacts with the top of those protuberances, the wire appears in some cases to be even larger than the original.

As to the use of a pick, I suppose we have tried upwards of a hundred shapes of picks, and we have found that the double-pointed pick was the best. We also find that in even the very softest coal, Indiana block coal, etc., nothing can give too heavy a blow. The heavier the better.

The President:—Hearing Mr. Sperry's description of the action of the trolley wire, recalls to my mind a principle which in early street railroad days was insisted upon at one time. The same difficulty was then experienced, that the trolley wire clamps held by the span wires protruded somewhat, and when the trolley came by, it was thrown slightly from the trolley wire, and left it perhaps for the distance of an inch, and then rebounded. This, after a while, in some cases would melt the solder which was used in the early days to fasten the clamps to the trolley wire. After a while we noticed that the trolley wire showed a very decided wear, and naturally its diameter was increased or diminished in the most varied sort of fashion. So instructions were given to always have the dynamo so connected that the current would pass from the trolley wheel to the wire. We thought if there was going to be any copper deposition, we would have the wheel the sufferer rather than the trolley wire; but the contact is so perfect that nobody pays any attention to which end is grounded and which goes to the trolley wire.

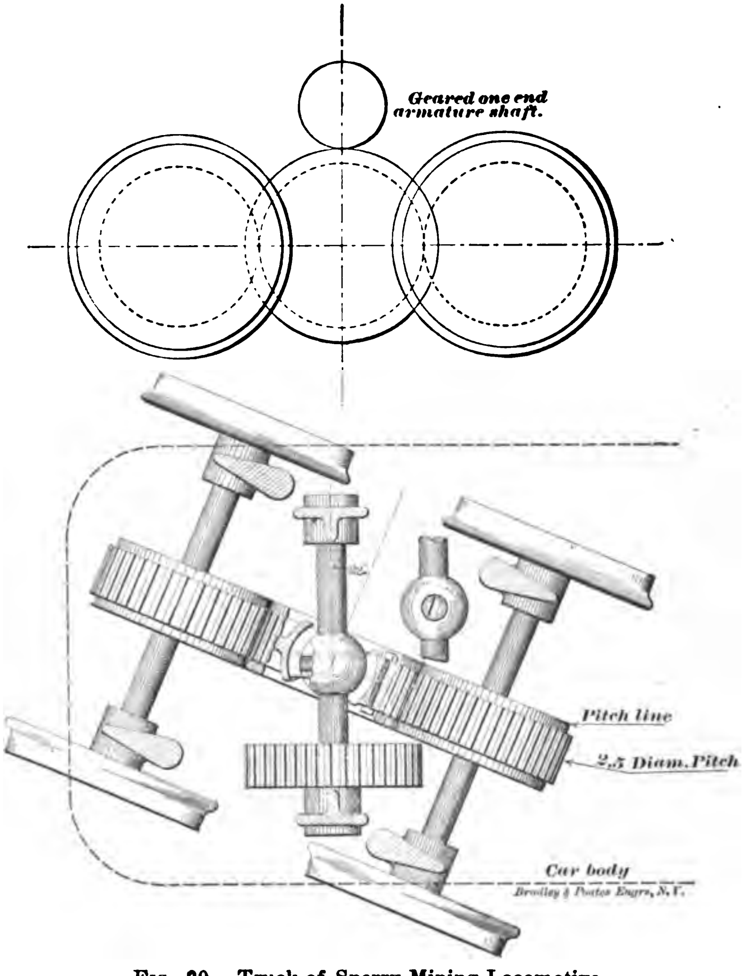


FIG. 20.—Truck of Sperry Mining Locomotive.

DR. EMERY:—Mr. President, I would suggest that Mr. Sperry give us a sketch which will show the way in which the wheels are connected. We would like to see a plan of the whole apparatus grouped together.

MR. SPERRY:—Fig. 20 shows one end of car body with truck turned at an angle of 22 degrees. Gears are placed in the middle of each axle with shrouds on each side. A similar gear is placed in the centre of auxiliary axle which at all times maintains its alignment with the car body and therefore with the motor gearing thereon. The last gear wheel, however, by the abutment of its shroud at all times maintains its alignment with the gears of the truck. The power driving connection with the ball shaft to its gear is made through a heavy rotating stud with flattened ends which work in opposite keyways each side of the gear. The detached portion of the ball shaft shows the direction the flattened ends would take when the ball is turned at right angles to its position as shown within the gear. The rotation of the driving pin within the ball, together with its sliding within the keyways gives the gear upon the ball a universal movement. The ball upon the ball shaft is the only pivot that it is found necessary to give the truck. Roller bearing surfaces are used between the truck frame and the car body to sustain the weight of the latter. Out of five locomotives in practical operation, one of which has been in operation over two years, none of these gears have had to be replaced as yet. Some of these locomotives handle as high as 1100 tons of coal per day.

[President Sprague here withdrew from the Chair, and Manager Leonard took his place.]

THE CHAIRMAN [Manager H. Ward Leonard] :—Before the presentation of the next paper, I wish to call attention to a suggestion made by Mr. Sperry, who informs me that at the works here in Chicago he has an eight ton motor ready for shipment, and if the time at the disposal of the members of the Institute, and the disposition as well, warrants, he will place this motor upon a test track and have it operated over a short distance and give a practical demonstration of how these wheels are connected. I am quite sure, if the time which we have at our disposal permits, that the members of the Institute will be very glad to see that.

The next paper will be "The Electric Percussion Drill in Theory and Practice," by Mr. Harry N. Marvin, of Schenectady, New York. Mr. Marvin's connection with this particular form of drill is well known. He has for the last four years been particularly active in this department. In view of the remarks which have just been made with reference to solenoid motors, I think this paper will be received with a great deal of interest.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7, 1892, Manager Leonard in the Chair.

THE ELECTRIC PERCUSSION DRILL IN THEORY AND PRACTICE.

BY HARRY N. MARVIN.

Wherever rock is to be excavated, in mining, tunneling or quarrying, there of necessity we find the percussion drill. Until about a year ago, two types of drills held the field, the hand drill and the direct-acting steam or air drill. With the extension of electrical methods of power transmission to mining operations, came the urgent demand for an electrically operated percussion drill. The mechanical and electrical requirements of this machine are particularly severe. It is called upon to continuously endure an action that is, in almost all other machinery, studiously avoided, namely, a practically uncushioned reciprocation and a blow upon substances harder than cast-iron. The general requirements of an electric percussion drill for mining work are that it shall be light enough to be quickly handled by two or three men; it must be powerful enough to compete with an air drill that absorbs eight or ten horse power; it must be so simple in its design that it can readily be repaired by an ordinary mechanic without electrical experience; it must be so constructed that the complete machine and its several parts can be soaked in mud and water without injury; it should be incapable of burning out; it must be able to endure almost any amount of the roughest handling without injury, and the materials employed should be as little subject to crystallization as possible. My experience suggests the following elements of construction to be avoided:—Traveling conductors, commutating or current shifting devices, sliding contacts, spring contacts, cotton insulated wire and all insulating material capable of carbonization, switches, lamination of the moving parts, close fittings and joints liable to be impaired by considerable wear, all constructions liable to be impaired by careless or unskilled attention. For the benefit of those unfamiliar with the actions of the air drill, I will state that the general practice at present is to give

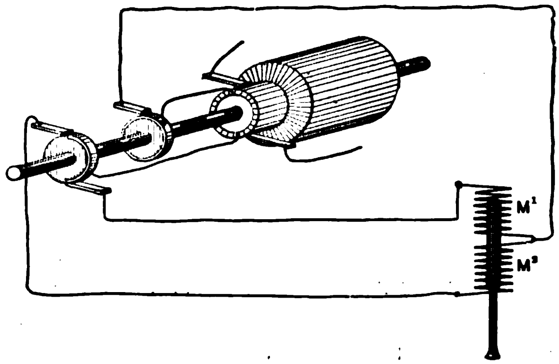


FIG. 1.

the machine a stroke of from five to seven inches, to strike as nearly as possible an uncushioned blow upon the rock and to make as many blows per minute as the power applied will develop, usually from two to four hundred per minute. It is found that a stroke of about five inches is necessary to properly free the hole from mud.

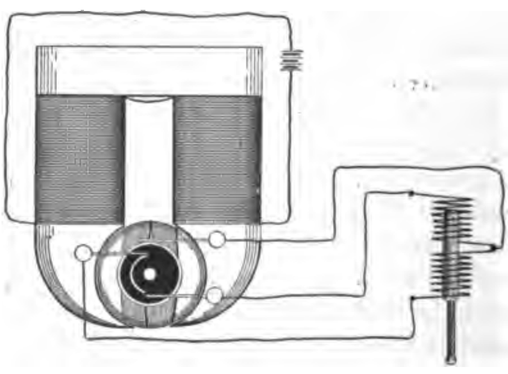


FIG. 2.

In the electrical solution of the problem, the solenoid and plunger affords the simplest method of developing this action, and most of the work in this field has been confined to this line. After much experimental work with divided solenoids and commutating devices mounted on the drill, I abandoned these methods, and in 1888 devised the system of operation that is at present rather well known, but for clearness this may be illustrated.

Fig. 1 shows an ordinary continuous dynamo having two oppo-

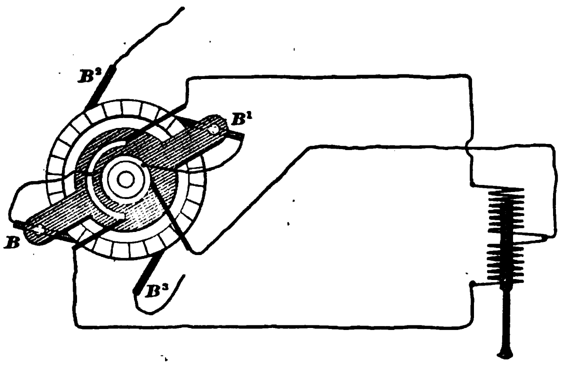


FIG. 3.

site points of its armature connected to a solid collecting ring and a half ring respectively. The outer terminals of the drill coils, M¹ and M², are connected by line wires to the two brushes alternately bearing upon the half ring. The inner terminals of the coil are joined and led to the solid ring. It appears that, as the

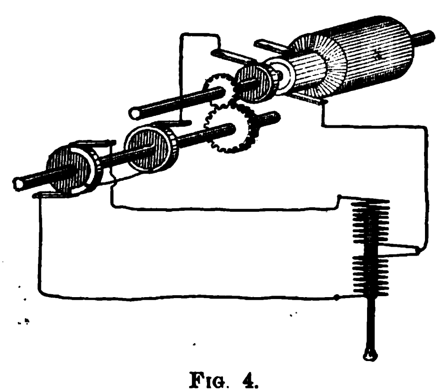


FIG. 4.

armature revolves, current impulses are directed into the drill coils in alternation, causing a reciprocation of the plunger in synchronism with the dynamo armature. It will be noticed that the action here closely resembles the action of a steam engine, force being exerted first in one direction and then in the other, one end of the cylinder being idle while the other end is active. Of course, connections are such that the polarity of the plunger is never reversed. This system simplifies to the utmost the construction of the drill and enables it to be so designed as to satisfy all of the

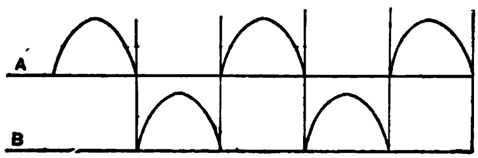


FIG. 5.

conditions before mentioned. The complications of this system are more apparent in theory than in practice. Three wires are required, but once placed they give no further trouble. The generator can be used to develop continuous current and pulsating currents at the same time if desired, but I believe that it is better practice to use a separately excited drill generator without regular commutator. The machine then becomes extremely simple, as shown by Fig. 2. I have found it desirable to run these drills at a speed of about 400 per minute, a rather slow speed for small

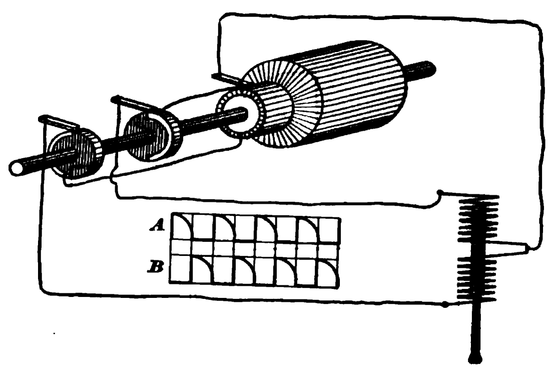


FIG. 6.

dynamos. This difficulty may be avoided at the expense of simplicity in several ways. One method is shown in Fig. 3. The regular commutator of a continuous current armature is equipped with a pair of revolving brushes, B, B[1], one of which connects to the solid ring of the drill circuit commutator and the other to the half ring. In this manner pulsations are developed in the drill circuit as the brushes B-B[1] are rotated, and with a frequency entirely independent of the armature speed. With this arrangement we are also able to take off 100 volt alternating currents from a commutator that is also supplying a 500 volt continuous current circuit, by spacing the brushes B and B[1] an amount less than 180 degrees.

Another method reducing the frequency of the pulsations is shown in Fig. 4, where the drill commutator is geared to the dynamo shaft, reducing the frequency to one-half the speed of the generator.

The general character of the impressed F. M. F. in the two-drill circuit in the above systems is shown in Fig. 5, curve A showing the voltage over the upper coil and curve B showing the voltage over the lower coil.

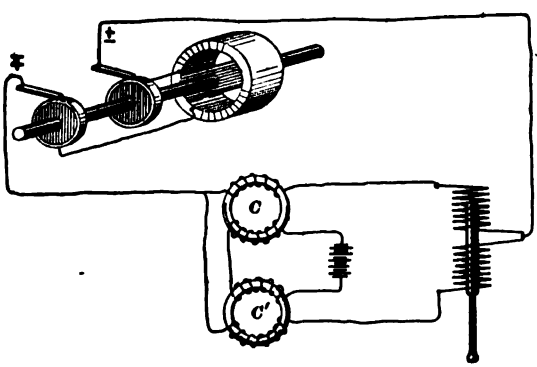


Fig. 7.

A method of operation by which a somewhat different curve is obtained is shown in Fig. 6. It will be noticed that here current is admitted to the drill circuits when the voltage is at a maximum the curve of impressed E. M. F being generally as shown. The general plan of admitting the current alternately to the two drill circuits, one circuit being idle while the other is active, characterize all the above methods. This may be called Plan A.

I have devised a method for effecting this without commutation, as shown in Fig. 7. Here one wire from a simple alternator is led to the drill, while the other wire passes through the secondaries of two converters C, C′. The cores of these converters are continuously saturated by continuous currents in the primary coils, as shown, the windings of the converters being opposite. When current endeavors to pass through these, it is checked considerably in the converter whose magnetism it tends to reduce, and, to a much lesser degree, by the converter whose magnetism it tends to increase. A reverse current is opposed by the other converter, and thus pulsations of one polarity are strong in one coil, while those of the reverse polarity are strong in the other drill coil. This would not probably be a very efficient method.

Another general plan of drill operation, which I will call Plan B, was developed to some extent by the late Mr. Van Depoele. This plan is based on a difference of phase of current in the two coils, and is shown in its simplest form in Fig. 8. The two outer drill wires are connected to the two regular brushes of the armature A and the middle wire connects to the solid ring con-

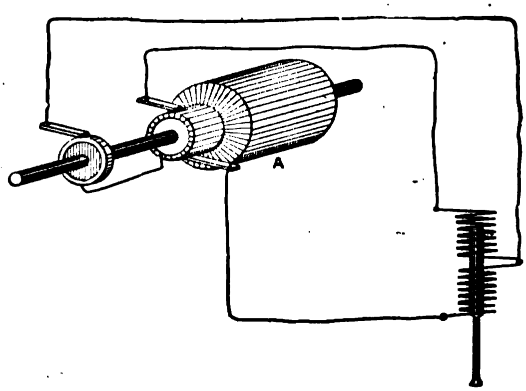


FIG. 8.

nected to one point of the armature. As the armature revolves, current rises in one drill coil and falls in the other, producing the reciprocation of the plunger. The voltage curves for this type of machine are shown by Fig. 9. An armature giving two alternating currents of 90 degrees difference of phase may also be used, but with the disadvantage of reversing the polarity of the drill plunger. The above appears to be less efficient than Plan A, for the reason that the drill coils are constantly working against each other and being heated up by current, opposing the action of the drill.

A third plan of operation, which we may call Plan C, is that devised by Messrs. Siemens and Halske, and shown in Fig. 10. Here three coils are used in the drill, the middle coil being excited by a continuous current and the two end coils by an alternating current of proper frequency. The function of the middle coil is to maintain a constant polarity in the bar, and the motion is effected by the effort of the two end coils. In this system both motor coils are continuously excited as in Plan B, but there

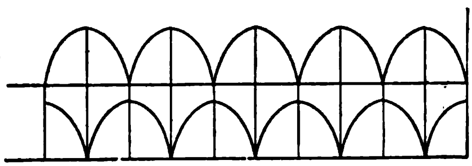


FIG. 9.

appears to be less waste of energy. Aside from the extra complication of drill construction, it is questionable if as much power can be obtained from a given weight of wire with this arrangement as can be realized on Plan A. It must be borne in mind that in these machines it is necessary to get the utmost power possible out of a given weight of copper and iron, and the heating limit is the only practical consideration. The efficiency of the machine is secondary.

Plan C was reduced to practice in this country by the late

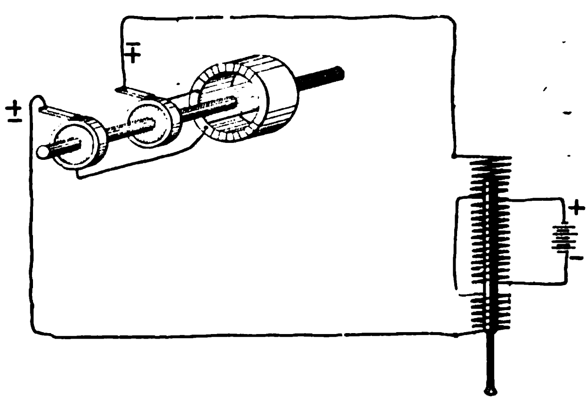


FIG. 10.

Mr. Van Depoele, who avoided the use of a fourth wire in the system by an ingenious method, shown in Fig. 11. The regular commutator A is supplied with rotating brushes B^2, B^3 in addition to the regular brushes B, B^1. It appears that as the rotating brushes revolve, a simple alternating current flows through the

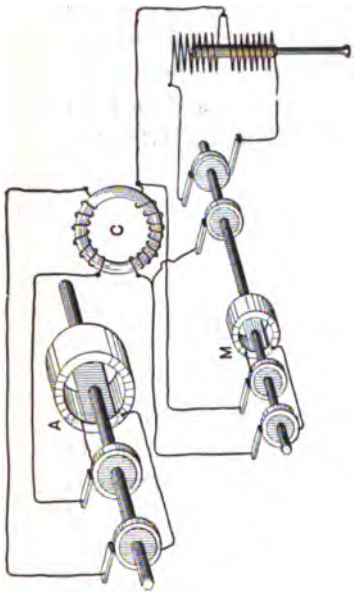


Fig. 12.

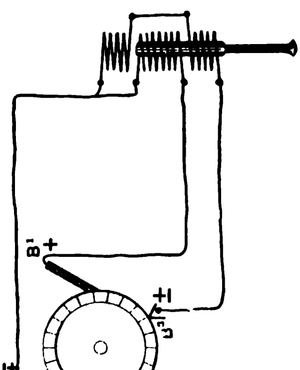


Fig. 11.

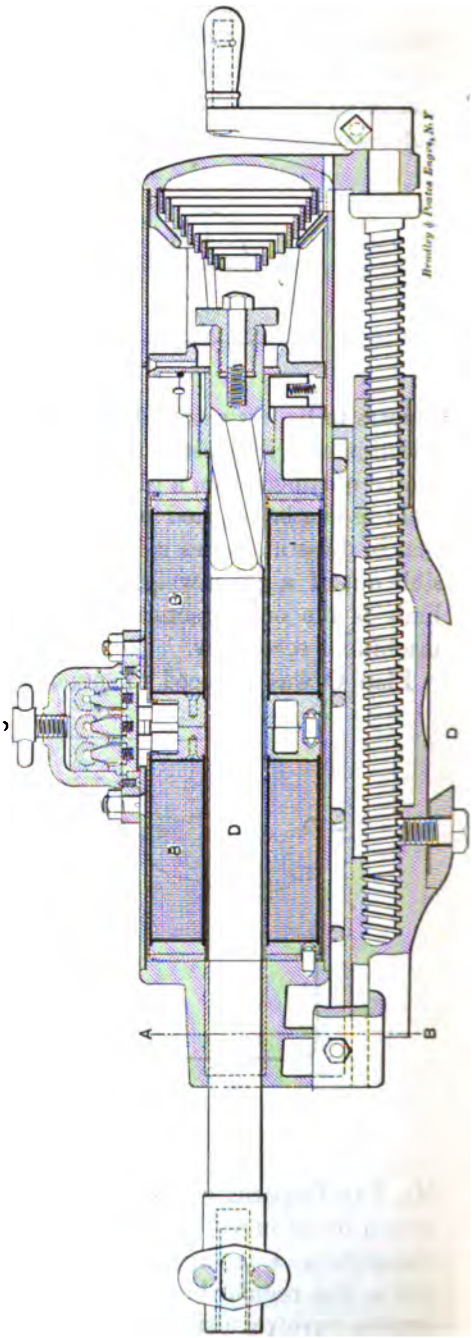
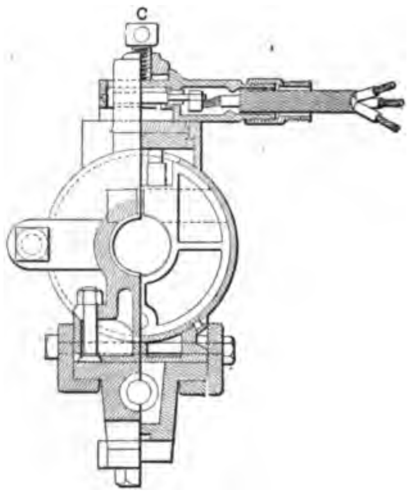


Fig. 13.

end coils of the drill, while a unidirectional pulsating current of one-half the frequency circulates in the middle coil.

The requirements of construction and service have thus far in-



SECTION A B. SECTION C D.

FIG. 13A.

duced me to employ a rather low voltage in the operation of drills, our present practice being to use about 100 volts alternating upon the drill. I have employed several methods of operating drills from high voltage circuits.

Referring to Fig. 3, if the regular brushes, B^2, B^3, be connected to a 500 volt circuit, the armature will run as a motor, and if the

FIG. 14.

rotating brushes B, B^1 be spaced by a suitable amount, less than 180 degrees, they will take off the pulsating current for the drill circuit at, say, 100 volts.

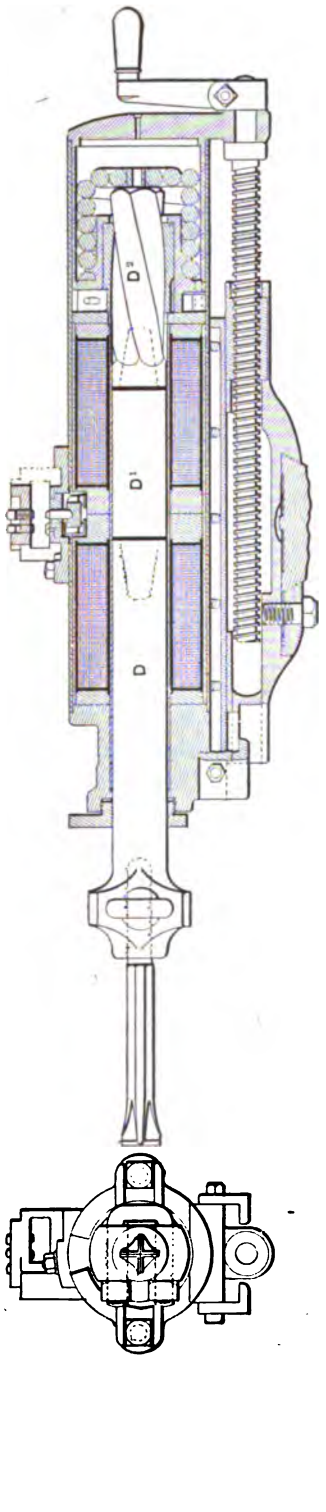


FIG. 15.

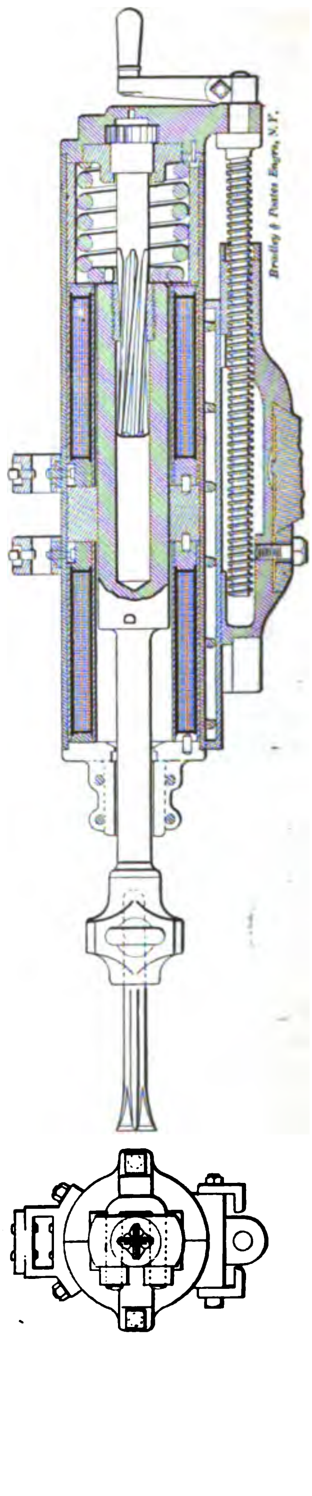


FIG. 16.

Another method is shown in Fig. 12, where a 1,000 volt alternating circuit is led from the prime generator A to the vicinity of the mine, where it passes through the primary of a converter, C, in which the voltage is reduced to 100 volts. A small motor, M, running in synchronism with the generator A, directs the alternate pulsations into the drill circuits.

Turning now to the drill construction, Fig. 13 shows the first form in which the percussion drill was put upon the market. This I call a Type A machine. As appears in the sketch, the machine consists of a 7 inch boiler tube provided with a suitable mounting. Within the tube are two solenoids, B, B[1], a rotating device on a cushion spring. Traveling through the coils is a 2 inch plunger, D, the middle portion of which is of iron; the upper end is of brass and is rifled, as shown, to fit the rotating device;

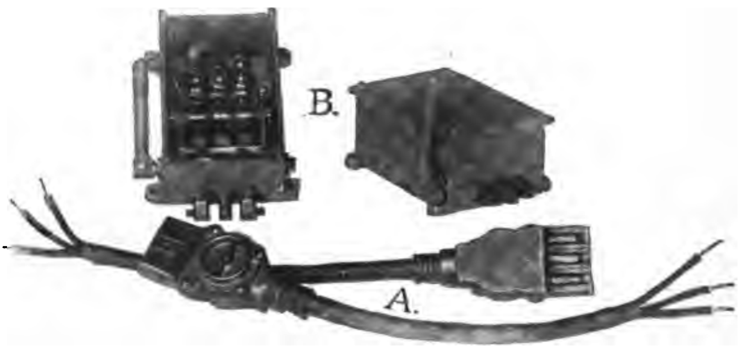


FIG. 17.

the lower end is also of brass and is enlarged at the end into a chuck to hold the bit. The three sections of the plunger are welded together. The weight of this plunger was 38 lbs. This machine was designed to make 600 blows per minute with a 3 inch to 4 inch stroke. The first of these machines to be put into a mine was that started in May, 1891, in the Black Bear Mine, at Gem, Idaho. This was, I believe, the first commercial electric percussion drill plant ever operated. During the next few months several other mines and quarries were equipped with these drills, with the general result that where the rock was not excessively hard, the work was fairly satisfactory, but in extremely hard rock several defects developed. The brass portion of the plunger would crystallize and break, a short distance above the chuck. Under the severe strain of continuous work in hard rock, the coils would become so heated as to ground, and the spring connections between the cable and the coils would give out. The construction of these drill coils deserves special description. Fig. 14 shows a coil complete, ready to be put into the drill. The coil is constructed as follows:—Upon a brass spool, the body and heads of which are insulated with mica, is wound a bare copper wire of square section. This wire is insulated as it is wound, with mica. The complete coil is wrapped with mica and a metal tube slipped over the whole and soldered to the coil heads, making the completed coil water-proof and heat-proof, as it is insulated with mica alone, nothing but mica and metal being used in its construction. The trouble with our first coils was that they were soldered up with a comparatively soft solder, and when the coils got very hot this solder softened, the joints opened, and oil and dirt getting in

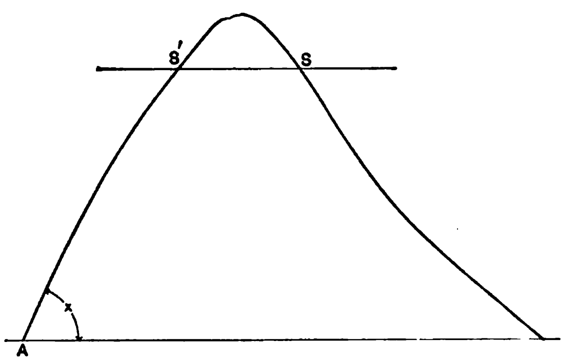


FIG. 18.

carbonized and developed a ground. As an example of the treatment these drills received, I will state that while visiting one of our drill plants that was used for railroad grading on the Great Northern Railroad, in Idaho, I saw the men dump one of these drills bodily off from a flat-car onto a dump of broken stone, down which the drill rolled some twenty feet. I might add that this was one of our most successful plants, 18 foot holes being regularly drilled in granite rock. In view of the defects mentioned, the design of the machine was altered, as shown in Fig. 15, which shows a Type B machine. The plunger has been enlarged to 2¾ inches and is what I call the double magnet type. The forward part, D, is now made of steel; the rifled part, D^2, is also of steel, and the connecting piece, D^1, is of brass. This design gives a solid steel chuck and brings the brass part of the plunger within the drill body. The coils are now incased in boiler tube jackets brazed up with hard spelter, and are heated to a bright red in process of manufacture. The spring connections have been abandoned, and solid set screw connections now connect the cable

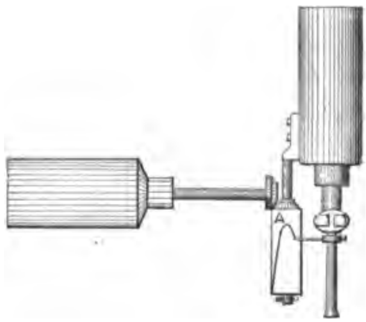


FIG. 19.

to the drill. A switch is inserted in the cable near the drill. This machine seems to overcome the defect of the old drill, and has thus far proved very satisfactory. This machine takes a stroke of about five inches and runs at about 380 blows per minute. This longer stroke is found more effective in keeping the hole free from mud.

Fig. 16 shows a still later type of drill that I have recently built and which promises to be much better than the others. The outside dimensions of this machine are about the same as the Type

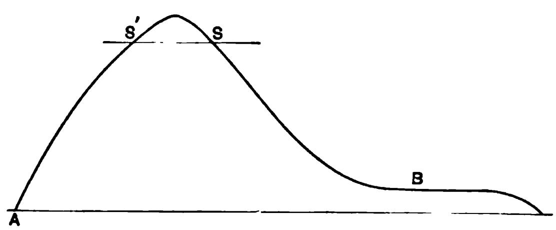


FIG. 20.

A machines, but the plunger of this machine is a solid steel forging and four inches in diameter. No brass is used in the plunger, the metal being reduced in section where it passes through the front head. The ratchet device is similar to that used in air drills and, in fact, the whole design of the machine quite closely follows the air drill construction. This machine takes a stroke of from 6½ to 7½ inches, and makes about 380 blows per minute. The plunger weighs 80 lbs.

Fig. 17 shows the cable connection and switch A, and the cable fuse box B, through which connection is made from the

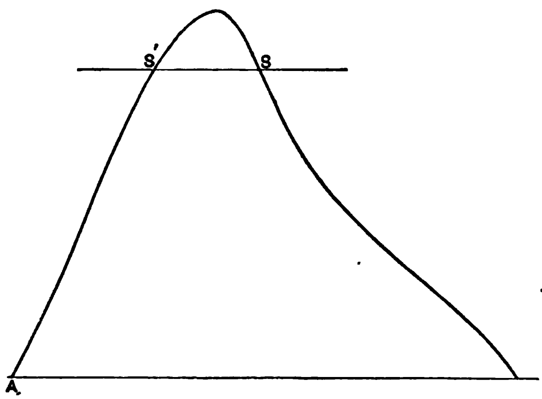


FIG. 21.

mains to the cable. A study of the operations of these machines presents many interesting features. In Fig. 18 is shown what I term an energy curve of the machine. This curve is obtained in a manner similar to an indicator card of a steam engine. Referring to Fig. 19, A is a cylinder mounted parallel to the drill rod. This cylinder is geared to the armature shaft in such a manner that it rotates in synchronism with it. A pencil carried by the drill rod rests upon the cylinder A. It appears that as the drill rod reciprocates and the cylinder A rotates, a curve will

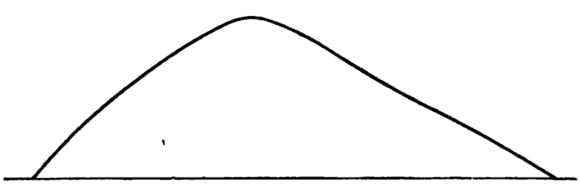


FIG. 22.

be traced by the pencil. Fig. 18 shows such a curve. The direction of motion of the paper being from left to right, it appears that the angle x of the curve at any point indicates the velocity of the plunger at the instant; A is the point where the plunger strikes the rock, and the sharp rebound is show by the angle. The concave character of the curve shows the backward acceleration of the plunger. The buffing spring is encountered at S, and the angles at S and S′ show that there is little loss in the spring. The angle X gives the final velocity of the plunger when it strikes the rock. A simple calculation gives the energy of the blow in foot pounds. This affords a good method of comparison between different machines and conditions. The general character of the curve reveals the general action of the forces during the stroke. The curve in Fig. 20, for example, shows that the drill rebounded sharply at A, and then stood still for a considerable time at B,

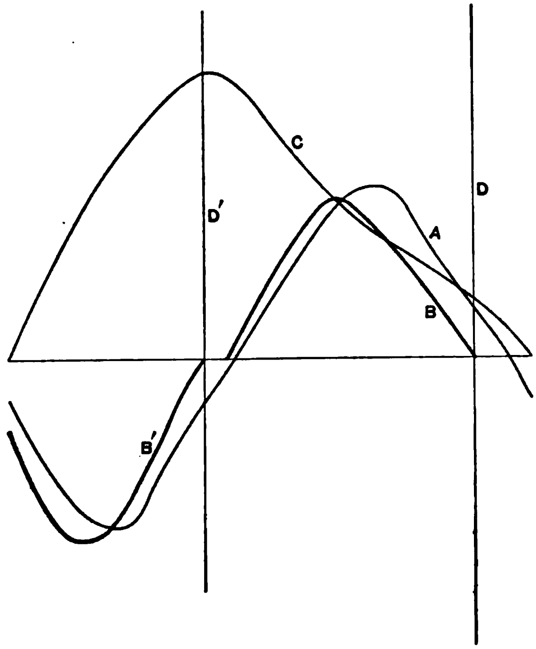


FIG. 23.

indicating that the stroke was too short for the power applied and the frequency of the stroke. On Fig. 21 we have shown the reverse conditions, where the concave character of the curve at B indicates a loss of velocity, and the length of stroke is evidently too great for the power applied. Fig. 22 shows a curve taken on a Type A drill with an 18 foot bit, drilling downward in slate rock.

The energy of the blow being determined, it can then be decided whether the drill delivers the greater amount of energy upon the rock by a few long strokes, or by a greater number of shorter strokes.

Some other interesting curves are shown in Fig. 23. Curve A shows the vol age on the drill circuit. Curve B and B′ the current in the two coils. Curve C is the energy curve. The lines D, D′ indicate where the brushes make contact with the half ring.

The efficiency of the above machines, compared with other form of electro-motors, is of course low, but this factor is of comparatively little moment in percussion drill work. It is far more important that the machine should be able to endure the development of a large amount of power with a small weight than that it should be highly efficient. It would seem that the general mechanical design of these machines admits of greater durability and simplicity of construction than air drills, as there are no steam-tight joints required and a very great wear upon the moving parts does not reduce the effectiveness of the drill. The general flexibility of the electrical system and its peculiar adaptation to mining work are well recognized, but it has been urged that for drill work compressed air is a necessary factor for ventilation. A careful investigation of this matter reveals the fact that there is little or no weight in this objection. The instances are extremely rare where compressed air is relied upon for ventilation, and I have found few miners who considered this matter of importance.

Although the introduction of the percussion drill has been attended with many difficulties, I believe that the obstacles have been so far overcome that the machine is to-day in thoroughly practical shape.

Discussion.

Mr. Sperry:—Mr. Chairman, I have been deeply interested in the paper that has been read, and we all know Mr. Marvin's enterprise in this line for some years past, and we feel very much indebted to him for being the first one, so far as I know, to prove that a solenoid had the capacity to do the work. I remember quite a long trip I made to see one of the machines in operation. The first part of the paper is interesting as giving accurate data as to the earliest methods of circuit connection.

I also think that, among the others, the last chart presented is one of great interest to us, as presenting for the first time a curve which has been made by the machine itself. Of course, the area of the curve cannot possibly be figured in the same sense as an indicator card, but, as I take it, the deviation from a straight line of the upward or downward curve is the feature that is to be studied.

I would like to hear Mr. Marvin's statement with reference to the comparative merits of the three-coil and two-coil systems of operation in practice. This would be interesting and would add to our knowledge upon this point.

MR. MARVIN:—Mr. Chairman, I would say that in operating a machine with an intermittent current in the end coils, I have found very little advantage to be derived from a constant energizing coil placed between the two end coils. Of course, upon the system shown in the drawing, Fig. 9, the third or central coil is necessary to give any motion at all. You must polarize the plunger, and then one coil is supposed to pull, and the other coil to push, but my experience has led me to believe that the same amount of iron and copper will not do the same amount of work when thus distributed as when disposed in only two coils. In the three-coil drill shown, the coils are constantly energized and the heating is continuous. In the two-coil drill the coils are energized intermittently and the heating occurs only half the time.

MR. SPERRY:—Mr. Chairman, I notice that the tendency in perfecting the machine, was to make a space between the coils. Have you any measurement as to the increased reluctance incurred in thus distributing the coils?

MR. MARVIN:—I would say that the increased space between the coils in the last form of drill shown, is not an especial feature of the magnetic circuit. It is a mechanical element to afford a bearing for the plunger of the drill. I do not think that a sufficient gain in the magnetic circuit is obtained to counterbalance the increased weight of the plunger necessitated by such a construction. In fact, I have a drill about completed, with no space between the coils, but I think it will give better results.

MR. PERRY:—Mr. Chairman, I would like to ask Mr. Marvin a little further about those curves. What are the ordinates?

MR. MARVIN:—The horizontal distances represent the successive positions of the dynamo armature in its rotation. The vertical distances represent the successive positions of the plunger in its stroke.

MR. PERRY:—Then it is not a power curve?

MR. MARVIN:—No, it does not show directly the power of the stroke. It simply shows the velocity of the plunger at any instant. The shape of that curve shows the acceleration of the plunger under the force of the coils. If you had a straight line there, it would indicate a constant velocity without acceleration, and the more the curve departs from a straight line, the more acceleration or retardation is shown.

MR. PERRY:—One feature of Mr. Marvin's drill he did not refer to, which is exceedingly interesting. It is quite as bad sometimes to strike something which has less resistance than the average, as it is to strike something harder than the average. Now, Mr. Marvin's drill has a peculiar property. If it strikes nothing the drill does nothing but tremble a little in space. I presume the explanation of that lies in the sluggishness of the magnetization, does it not? When it is driven in one direction the other coil holds it.

MR. MARVIN :—The coil starts to pull it back, and you really have there an electric cushion.

MR. BRADLEY :—How much power does it take, and how many inches of hard rock can you go through per minute?

MR. MARVIN :—With that last drill we absorb on the machine about 6½ H. P., that is, the large plunger drill, and we have made a record in very hard blue lime rock of drilling 56 feet in six hours, using a 2⅝ in. starter and drilling the holes 10 feet deep.

The following paper on "Long Distance Transmission for Lighting and Power" was then read by Mr. Charles F. Scott, of Pittsburg:

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, Manager Leonard in the Chair.

LONG DISTANCE TRANSMISSION FOR LIGHTING AND POWER.

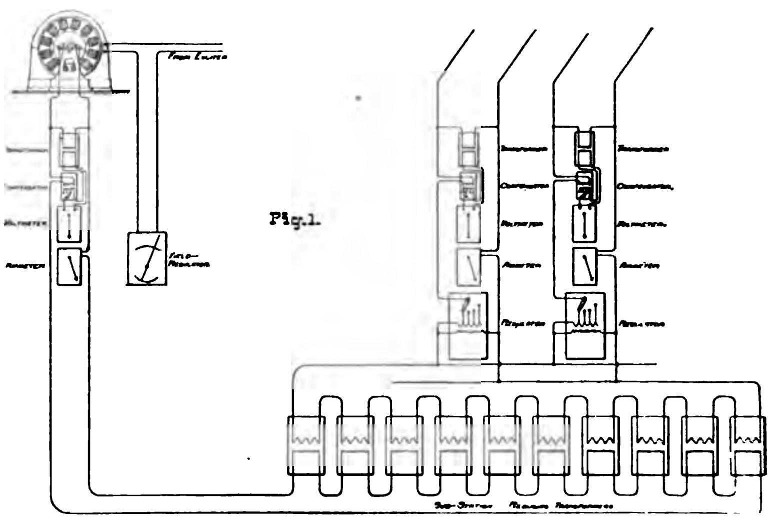
BY CHARLES F. SCOTT.

The public interest in electrical subjects is continually sustained by the announcement of discoveries and projects which border upon the wonderful and extreme. In power transmission, one of the most inviting and promising fields, popular expectation often rises to operation over distances and at pressures which exceed the limits of commercial engineering. But many schemes which are readily planned with glowing outlines to accomplish wonderful results are defeated by difficulties encountered in details and unforseen obstacles.

The test of practical operation in long distance transmission has been applied in but few cases, and the severe test of continued operation over a considerable length of time is of rare occurrence. The latter is the crucial test, and its commercial significance gives it the highest importance. The continued and successful operation of one plant for a year, under extreme conditions of situation and service, is of higher value in testimony to the practical development and possibilities of electrical work than many elaborate projects, or the operation of novel apparatus for a short time.

It is with this idea in mind that a description is here to be given of two plants, one for lighting and the other for the transmission of power. The conditions which have been met include a very considerable distance, extreme difficulties of climate and roughness of country, exacting requirements in continuity of service, and a pressure above that ordinarily used in the class of machines employed. The plants to be described are the first of their type installed in this country, and the apparatus in the power plant is of a kind that has not been heretofore used. The type and construction of the machines, and the arrangement of apparatus are new in many particulars, and as they have contributed largely to successful operation they will be described with some minuteness. Alternating current machinery is employed, constructed by the Westinghouse Electric and Manufacturing Co., the pioneer company in alternating work in this country.

The lighting plant was first installed. It is operated by the Willamette Falls Electric Co., of Portland, Oregon. The

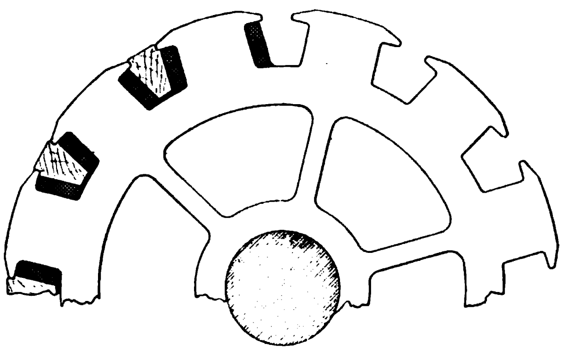


Lighting plant at Portland. Diagram of apparatus and connections.

general requirements are those which electrical transmission is admirably adapted to meet. Portland, a city marked for its prosperity and rapid industrial growth, has not the great advantage of proximity to developed coal fields, so that power, the fundamental requirement for industrial activity, cannot be obtained cheaply from this source. Another supply of energy, however, is found in rich abundance. The falls of the Willamette river at Oregon City, in the combined points of size, accessibility and nearness to the seaport, are unequaled. These falls, estimated at from 200,000 to 250,000 H. P., are about 13 miles from Portland, and it requires but a moment's thought to appreciate the value of an agent which can make this power available in the city.

The Willamette river is about one-quarter of a mile wide, and the fall is about 40 feet. The present station is located on an island at the middle of the river. Victor wheels of 300 H. P. are geared to horizontal shafts, from which the dynamo belts pass to an upper floor at an angle of 45 degrees. Two alternating current dynamos for incandescent lighting are driven by each wheel. The current, at a pressure of 4,000 volts, passes directly to the line of No. 4 B. & S. wire, which is carried on ordinary double-petticoat glass insulators across the level country to a sub-station in Portland. The current is received at 3,300 volts by transformers in the sub-station and is reduced to 1,100 volts, for distribution by various circuits through the city to ordinary transformers, by which it is reduced to 50 or 100 volts.

Fig. 2.



Section of armature showing iron disk with 8 coils in place.

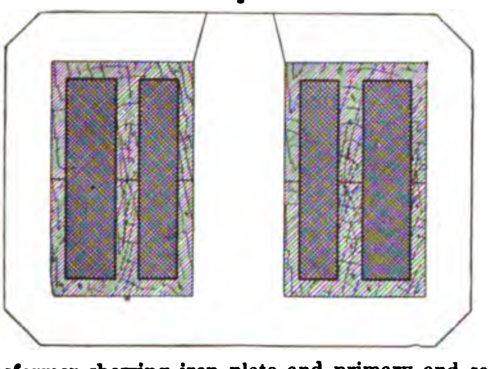
When the apparatus was designed, it was not considered practicable to generate 4,000 volts with the ordinary type of machine, in which the wire is wound upon the surface of the armature, on account of the difficulty of insulating for more than 1,000 or 2,000 volts. The work was undertaken with a new type of armature, which is specially noteworthy, as it has rendered high potentials practicable in a machine of simple construction.

The field of the dynamo is of the ordinary type of alternating current machine in use in this country. The casting is circular in form, with 12 inwardly projecting poles of laminated iron, on which the field coils are placed. This type of machine combines simplicity with rigidity and strength, as both bearings and the lower field are in one casting.

The armature is built up of laminated disks, which are punched with 12 T-shaped teeth. The armature coils are wound in a lathe, are carefully taped and insulated, and are then placed over the teeth and sprung in under the projections. The space between adjacent coils is filled by a block of wood, which holds them in place securely. This form of construction gives all the advantages of machine winding over hand work, allows ample insulation between coils and core, protects the coils from mechanical injury, holds them in position without the use of band wires, and makes the replacing of a damaged coil comparatively simple. The field current is supplied from a direct current machine, and the main current is taken from two collecting rings on the armature shaft. The reducing transformers are placed in a vault in the sub-station at the city. They are arranged in banks, or units of ten. Each bank is supplied by a separate dynamo, and has a capacity of 1,250—16 C. P. lights. The coils of the transformers are separately wound and taped, and are separated from one another and from the iron by strips of wood. The primaries are connected in series for receiving 3,300 volts, and the secondaries are in series for delivering 1,100 volts, so that there are 330 volts in the primary, and 110 volts in the secondary of each converter. This method of connection throws small differences of potential in any single coil and permits the use of conductors of good size. The necessity for special insulation is between the coils, where there is ample room for placing it. A transformer may be readily cut out of circuit by short circuiting its terminals, and in case of an accident in which a coil becomes short-circuited, the E. M. F. on that transformer disappears and the others are called upon to do a larger share of the total work, without interfering with service. The efficiency of the transformer at full load is 96 per cent.

The operation of the system is simple. The voltmeter or potential indicator is supplied by the secondary of a converter reducing in the ratio of 30 to 1. In the voltmeter circuit there is placed a compensator, which is a small transformer with its primary in series with the main circuit, and its secondary in series with the voltmeter circuit, and connected in such a way that the compensator pressure, which is proportional to the main current, is opposed to that of the converter. The compensator is so adjusted as to introduce into the voltmeter circuit a counter E. M. F. proportional to the loss in the conductors, so that the voltmeter indicates the potential at the distant end of the line. The compensator effects the same result as pressure wires run from the point of supply back to the station. The E. M. F. at the dynamo is adjusted for each load by regulating the field current so that the voltmeter shows the proper indication, thus keeping the pressure at the sub-station constant at 3,300 volts. The pressure at the dynamo is slightly in excess of this at light loads, and is increased to 4,000 volts at full load, to cover the loss of transmission. The secondary current from the reducing transformers is treated as if it were received directly from a dynamo. On each supply circuit from the station there is a voltmeter with a compensator set for the loss in this circuit. The exact adjustment of E. M. F. on a circuit is made by a regulator, consisting of a transformer with its primary connected directly across the

Fig. 3.



Section of transformer showing iron plate and primary and secondary coils surrounded by wood.

main terminals, and a secondary divided into small sections, each having an E. M. F. equal to one per cent. of the primary. Any number of these sections may be placed in series with the supply circuit, thus varying the E. M. F. at will. This form of regulator is of high efficiency, as it converts but a small percentage of the total energy, and the loss is a small fraction of this percentage.

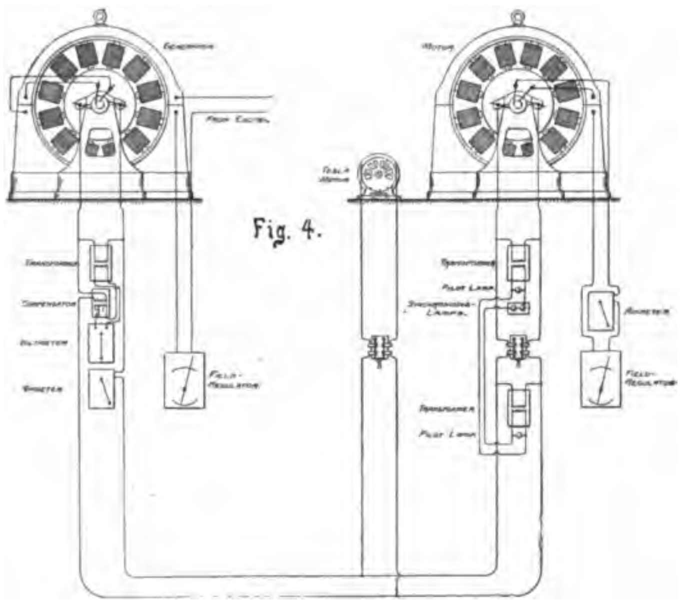
The simplicity of the system, and the perfection of its operation, both from theoretical and practical standpoint, are noteworthy. The electrical system receives mechanical energy, converts it into electrical energy, in a form suitable for transmission over a distance too great for other agents, and by the simplest form of conductor, and transforms it to a pressure suitable for commercial lighting. And yet, in the whole system, there is but one element in which there is mechanical motion, and that motion is simple revolution. The only wear and friction is in the dynamo, and its bearings are large and easily lubricated. The one point at which the high-tension conductors need be exposed is at the dynamo, where the brushes and fittings are of the simplest sort. The line does not deteriorate by carrying current, and as a piece of apparatus the transformer, in simplicity of construction and operation, is unrivaled.

The plant was first installed with two incandescent machines and started nearly two years ago. Since that time, five additional machines have been added, so that there are now seven, each with a capacity for supplying 1,250 16 C. P. lights, in Portland. The total capacity is 8,750 lights. The dynamos run admirably. There was one night when several armature coils were burned out, which was attributed to an iron wire falling across the main line and connecting several of the circuits, grounding them. Otherwise there have been no difficulties to speak of with regard to the operation of the machines. The superintendent of the plant states that the line has given very little trouble, much less than would ordinarily be expected from a city line. He also says, that "the converters in the sub-station have not given one minute of trouble, and have not cost one cent for repairs." One explanation of the success of the plant is the intelligent policy of the general manager, in harmony with his statement that, "It is not the first cost which counts, but the cost of throwing out and replacing apparatus."

The same policy has happily governed the installation of the second plant to be described—the power plant. This is located near Telluride, Colorado, and is owned by Mr. L. L. Nunn. The Gold King mill requires power for operating its crushers and stamps, and fuel can come only from long distances at enormous costs. A few miles from the mill there is a water power, but the country between the two points is steep and rough, and for many months in the year is covered with snow. Electricity is the one means of getting the power from its source to the mill. The conditions are of the most favorable character for demonstrating the value and possibility of electrical transmission.

In this plant a Pelton wheel receiving water through a two foot steel pipe, under a head of 320 feet, drives an alternating current generator. The current is carried over a line of bare wire to the mill, which is nearly three miles distant, and drives an alternating current synchronous motor of 100 H. P. The generator and motor are machines of the same size and form of construction as the dynamos at Portland, already described, and differ from these only in some minor modifications.

The generator is provided with a composite field winding. A part of the magnets are excited by direct current from a separate machine, and the rest are excited by a current from the generator armature, which is proportional to the main current and is commutated by the equivalent of a two-part commutator. The adjustment is such that the E. M. F. on the main terminals rises as



Synchronous motor plant at Telluride. Diagram showing apparatus and connections.

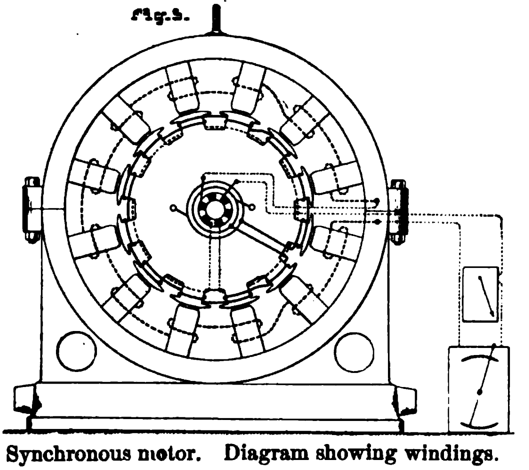
the current delivered by the machine increases, compensating for line losses and keeping the pressure at the motor 3,000 volts. The speed is 833 revolutions, giving 10,000 alternations per minute. The switchboard and regulating appliances are similar to those in the station at Portland. Ordinarily no adjustment is required after the machine is started. and the attendant has little to do besides looking after the mechanical running of the apparatus.

The motor is similar to the generator except in the manner of exciting the fields. The field current is obtained, not from a separate machine, but from a second winding parallel with the main coils around the teeth of the armature. This current is commutated and passes through the field coils. The motor, as already stated, runs in synchronism with the generator, and although the general theory of the synchronous motor is well known, it may be briefly outlined. If the terminals of two alternating current machines giving the same number of alternations per minute be connected together, and one be driven by an engine or other source of power, the second will run as a motor and will do work. The impulses of E. M. F. which are generated in each machine occur simultaneously and are opposed in direction, so that only a small current flows through the circuit joining their armatures. As the motor is loaded, its armature is held back slightly and its impulses of E. M. F. do not exactly oppose those of the generator. This causes an increased current to flow which prevents further change in the position of the motor armature and holds its speed in synchronism with that of the generator.

A motor of the synchronous type requires an auxiliary device for starting, which, in the present plant, is a small motor—a special modification of the Tesla type. This has a laminated field with inwardly projecting poles, on which coils are placed which receive current directly from the main circuit. The coils on the revolving armature are short-circuited. There is, of course, no commutator or collector, nor is there any exposed contact or auxiliary apparatus except the switch. This motor comes quickly to its normal speed and then has ample capacity for bringing the armature of the large motor up to speed. Both of the machines are belted to a countershaft, and the ratio of the pulleys is such that the speed of the large motor is a little greater than than that of the generator. The large motor is then excited and runs as a self-exciting alternating current dynamo at the normal E. M. F. of the circuit. The small motor is then switched off and the speed of the large machine gradually falls until it is approximately equal to that of the generator. The relation between the speeds of the two machines is indicated by the fluctuation in the intens ity of lamps, which are connected in series with the secondaries of two converters, whose primaries are connected with the generator and motor respectively. When the E. M. F's. of the two machines are in the same direction, current will pass through the lamps, and when they are opposed there will be no current.

If the motor is running a little faster than the generator its E. M. F. will be in the same direction as that of the generator at one moment, and will be opposed at the next moment, causing a corresponding variation in the intensity of the lights. At the time of slow variation and proper phase relation the machines are connected by closing the switch. The small motor is disconnected by its friction clutch and comes to rest, and the load is then thrown upon the large motor by a second clutch. The operation of starting requires but one man, and is accomplished in about two minutes. The rheostat in the field circuit is adjusted to give the proper field current as indicated by the ammeter. This is done when the motor is started and it may then run in-

Fig. 5.



Synchronous motor. Diagram showing windings.

definitely with varying loads without requiring any adjustment whatever.

When the motor is running, the only things to be cared for are the brushes and the bearings. The high tension brushes—the only point besides the switches where the high tension is exposed —will run for a week without adjustment, the exciter brushes run without sparking and the lubrication of the bearings is well provided for. The construction and operation of the motor is strikingly simple in comparison with the steam engine, which it replaces, with its many moving parts and intricate motions.

A few points illustrating the characteristics of the synchronous motor may be mentioned, as they are of both theoretical and practical interest. The connection of the motor to the generator is not a delicate operation. If the motor is running above synchronous speed at the time of connection with the generator it instantly adapts itself to the proper speed. If the motor speed is slightly lower than that of the generator it may fall into step when the switch is closed, but if it be running considerably slower it will not come into synchronism, but will further decrease in speed. When this occurs, the switch of the large motor is opened and that of the starting motor is closed, bringing the machine up to full speed again without any injury to the apparatus. If the E. M. F. upon each of the machines before connecting them be 3,000 volts it will remain unchanged when they are connected. If the field current of either machine be increased the E. M. F. will be raised, but the field current of the other

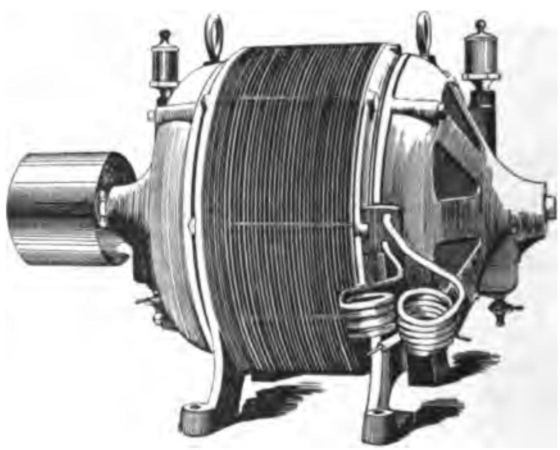


FIG. 6.—Tesla starting motor.

machine may be lowered and the resulting E. M. F. made equal to 3,000 volts. The current flowing between the machines depends upon the relative field charges, and is least, whatever the load may be, when the two machines are equally, or very near equally excited. The field current of either machine may be made zero, and the motor will still run, but with greatly reduced capacity. In a test with machines of a smaller size the E. M. F. was 2,000 volts when the two field charges were equal. When the field charge of either machine was cut out it fell to 1,200 volts, and the current increased very considerably.

The explanation of the fact that the two machines may run together with widely-differing field charges is easily understood when the extra flow of current at that time is taken into account. If the field charges are different the E. M. F. tends to be different also, and a current flows between the generator and motor, which is of such phase that it tends to strengthen the weaker field and to weaken the stronger one. Thus, when the tooth of the motor is in front of a field pole, the current flowing at that time is in such direction as to weaken or strengthen the field as may be required to make the E. M. F. equal to that of the generator. Difference of phase between E. M. F. and current has an effect upon the regulation of a dynamo which is easily shown by changing the character of the load. If a dynamo, with a constant field

FIG. 7.—Machine used as generator and motor at Telluride.

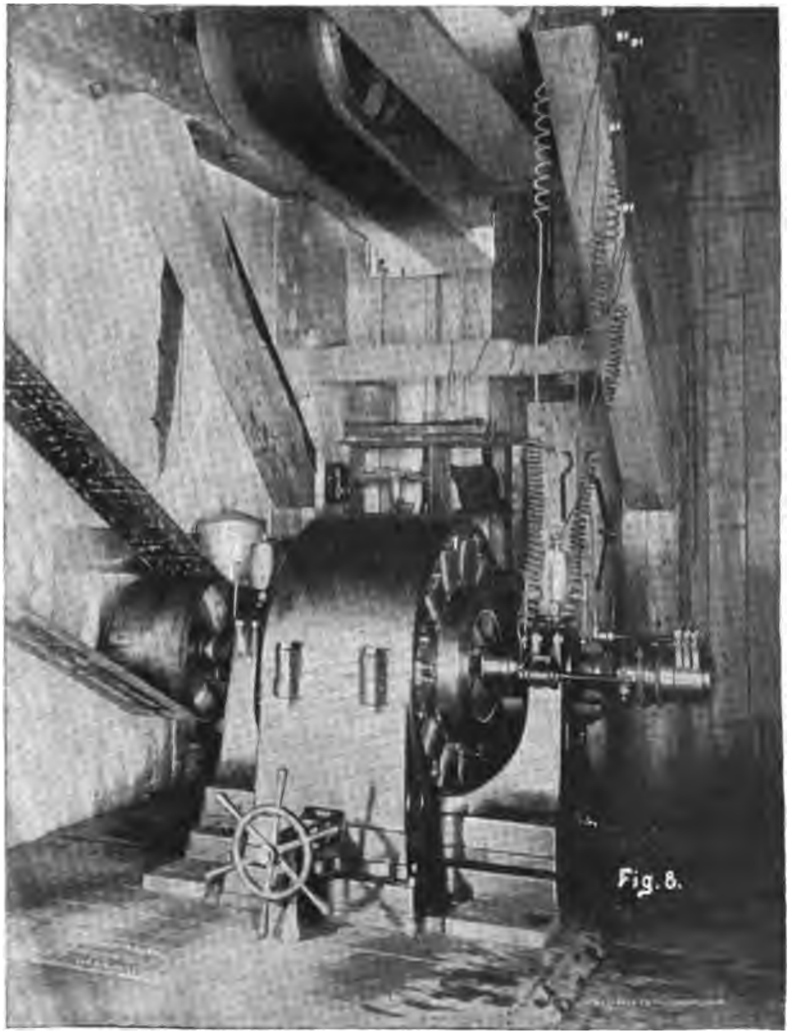
charge, is used for carrying an ordinary load of incandescent lamps, a certain drop in E. M. F. will result. But if the same current be delivered to an inductive resistance, such as a coil of wire, the starting motor, or a synchronous motor, when its armature is at rest or its field is not charged, the drop in E. M. F. will be considerably greater than with lamps. On the other hand, when the generator is supplying a synchronous motor running under normal conditions, the drop in one test was about half that which resulted from the same current to incandescent lamps. The current to the motor when running without load is quite small and increases in proportion as the load is added. With any definite load the current between the machines, as already pointed out, depends upon the relative field charges of the machines as well as upon the E. M. F.; but there is, however, a considerable range through which the field charges may be varied without materially affecting the current. If the load on the motor be increased to about twice its rated capacity it will fall out of synchronism and come to rest. The current, however, is held back by the self-induction of the motor armature and is not sufficient to cause immediate injury.

An efficiency test of the motor was made before shipment by driving a dynamo which was loaded. The current and E. M. F. received by the motor and delivered by the dynamo were measured and an allowance made for the loss in the dynamo. The full load efficiency in this way was found to be 93 per cent. In a test upon smaller machines of similar type the efficiency of the motor at full load was found to be 91.5 per cent. The efficiency of the synchronous motor system, leaving out loss in conductors, but including losses in generator and motor, in the plant for the delivery of 50 H. P. was found to be 83½ per cent. at full load, and 74 per cent. at half load.

Full load may be thrown on the motor suddenly. In the Gold King mill the stamps, which are operated by the motor, are usually left raised when the plant is stopped, in order to avoid the extra strain of lifting them when the plant is started. It sometimes happens that the stamps are left down and the motor is required to raise them all at once. When the clutch is thrown in, the current indicates that the load is considerably above the normal capacity of the motor, and yet it is started without difficulty or apparent strain.

The excellent current regulation with different loads, the tendency of the machines to normal adjustment when there is ordinary variation in the field currents, the small liabilty to injury when the motor is greatly over-loaded, the high efficiency and ease of attendance, are points of great value in the practical operation of the system.

The pole line runs from the power station up the mountain to a height of 2,500 feet, and then crosses a rough but comparatively level country to the mill. The line at some places is at an angle of 45 degrees, and many of the poles had to be set in solid rock. The surface of the snow in winter is occasionally at a level with the tops of the poles, and parts of the pole line are practically inaccessible during some months of the year. This region is peculiarly subjected to lightning discharges, and special precautions are necessary to protect the apparatus In one instance there were 42 discharges of the lightning arresters in as many minutes.



The Synchronous motor in the Gold King Mill.

The plant was started for regular work in June of last year. An accurate record was kept from the middle of July to the first of May, showing the actual number and the length of the delays caused by electrical machinery. During these nine and a half months the system was in regular continuous operation six and a half days each week, with but few intermissions. The difficulties which were encountered were insignificant in amount and have resulted, not from any fundamental difficulty in the system, but have been caused by incidental defects or accidents which usually indicated their own remedy. The stops due to the electrical machinery resulted from a variety of causes and comprised the replacing of an armature coil damaged by lightning, renewing of fuses, fixing loose contacts, the examination of the line after a storm, and sundry other slight mishaps. The aggregate time lost on account of the electrical apparatus was, by actual count, less than 48 hours during three-fourths of a year. A recent report from the superintendent of the plant covering the time from December 13th to May 1st, shows that the plant was running 127 days with a loss of 19¾ hours, or, as he puts it, an average of about nine minutes in a day of 24 hours. Although the plant was generally shut down each week for 12 hours on Sunday this was not practicable during a part of the winter, and the motor on one occasion was run continuously for 27 days without any stop whatever.

Such a record as this, with a new type of machinary, in a country where line construction and maintenance are peculiarly difficult, with practically continuous service, with attendants who were not electricians, with a high voltage, a considerable distance and large power, places transmission by the alternating current synchronous system beyond the stage of experimental trial and gives it the stamp of commercial success.

This success is confirmed in a substantial way by the immediate extension of the plant. A 50 H. P. motor is now being installed at a mill a few miles from the Gold King. An order has been entered for a 750 H P. generator to be located in the power station, and a 250 H. P. motor for operating a mill about 10 miles distant. Lighting at Telluride, eight miles from the station, which has been heretofore done on a small scale on a circuit from the power generator is being extended.

The large generator is a new design, and is notable as it has more than three times the capacity of any alternating current dynamo previously made in this country. Two machines of this size have been running for some months for incandescent lighting in St. Louis.

View of Gold King Mill illustrating character of country across which pole line is run.

This dynamo is of a type similar to the machines at Portland and Telluride. The field has 28 poles, requiring a speed of 570 revolutions for 16,000 alternations, the conditions of running at St. Louis, and 357 revolutions for 10,000, as it will be operated at Telluride. The armature has T-shaped teeth, as in smaller machines. The diameter of the armature is slightly over four feet and its length is about two feet. There is a third bearing at the end of the shaft outside of the pulley to relieve the other bearings from the severe strains resulting from belt tension. The total height of the machine is eight feet and its weight is 40,000 pounds. The electrical efficiency at full load is over 95 per cent.

The extension of alternating current working, both for lighting and power, by the use of larger machines is therefore already provided for.

The extension to greater distances is largely a question of E. M. F. Nearly everyone is familiar with the rapidity with which the cost of copper diminishes as the voltage is increased.

If the cost be $100 with 500 volts it will be $25 at 1,000 volts, and $1 at 5,000 volts. The higher the] tension, however, the greater the difficulty and cost of construction and the greater the liability to accident with apparatus and line. There are a few points in connection with this subject which may be noted without entering into a general consideration of it.

The smallest size of wire that can well be used for line work on account of its mechanical strength, is about No. 6 B. & S. This wire will transmit with 20 per cent. loss 100 H. P. 10 miles at 4,000 volts, or twice the power half the distance. Unless these distances or powers are to be exceeded an increase in pressure would result in no saving in copper but simply in a less line loss, which is already not excessive.

The use of 4,000 volts at the motor and a line loss of 20 per cent. requires an outlay for copper of only about 10 per cent. to 15 per cent. of the total cost of the plant when the distance is 10 miles. Unless, therefore, the cost of copper is to bear an insignificant proportion of the total cost it is unnecessary to exceed this pressure unless the distance be greater than about 10 miles.

These simple considerations show that pressures practically the same as those employed in the plants which have been described are ample for considerable distances. The same type of apparatus which has been successful in them is available for larger capacities. The fundamental elements required for electrical transmission in a very wide range of cases have therefore been tried and their success demonstrated.

For considerably longer distances, where pressures higher than about 5,000 volts are required, good practice indicates the use of transformers for raising the pressure at the generator and reducing it at the motor, similar in general to those employed at Portland. The increased pressure thus available greatly reduces the cost of copper required, and this reduction must, of course, be more than sufficient to cover the cost of the transformers.

The prime requisite in a system for power transmission or distribution is simplicity. In this point electrical appaatus is scarcely to be compared with any other class of machinery. There is a marked difference, however, between the classes of electrical apparatus. In direct current machines the commutator is the characteristic featúre. It is expensive to make, to maintain, and to renew. The insulation of the armature is much more difficult, because it is necessary to connect a hundred points in the winding to exposed pieces. The commutator is the part requiring the most careful adjustment and attention both in construction and operation, and yet it is ordinarily the source of more difficulty than all other causes combined. It is, moreover, the principal element which limits the E. M. F. at which this class of apparatus may be operated, and, in order to secure the advantages of a high E. M. F., systems are planned in which the generator and motor is each composed of three or four distinct machines to be run in series, thus avoiding an excessive E. M. F on any single commutator at the expense of many machines and multiplied parts. The alternating current machine substitutes for the commutator the simplest kind of contact—brushes sliding on plain rings.

The alternating current is anomalous. For years it had little place in literature and less in practice. Theoretically, it is intricate and complicated, and the earlier difficulties in its application caused it to give way to direct current. But the direct current is reaching its limitations in conditions which alternating current apparatus readily meets. The alternating current motor has been one of the most complicated and difficult electrical problems, and yet the first large alternating current motor installed in this country excels direct current apparatus in simplicity of construction and operation, in perfection of regulation, and handles with simple sliding contacts, running for a week without adjustment, a pressure which with commutators is impracticable.

There is another class of alternating current apparatus to which no reference has been made. The multiphase, or Tesla system, which has attracted much attention of late, possesses the characteristics of this type of apparatus, which readily adapt it for combining simple construction with the use of high pressures. There are also marked advantages in the characteristics of the motor which are of especial value where distribution of power is to be combined with transmission. Motors of this class are self-starting with load, and may be run either as synchronous motors or with one winding short-circuited and no commutator or brushes. The latter is the ideal motor in point of mechanical construction.

The simplicity, and flexibility, and range of the alternating current system make its possibilities the sole dependence of the largest enterprises, toward which the public and engineers are looking. The records of the plants at both Portland and Telluride, demonstrate that these possibilities are being realized, and that work in this field is fast passing from experimental investigation into practical electrical engineering.

Discussion.

The Chairman:—The paper is now open for discussion, which I trust will be free, and that we will pay to this subject the consideration which it certainly deserves. Personally, I am the strongest kind of a believer in the general practicability of the synchronous alternating current motor for long distance transmission, and it is a subject upon which there exists such a difference of opinion that I think a general discussion by the Institute of the features of its use and its present applicability will be of great benefit to users.

Mr. Hering:—Mr. Chairman, I would like to ask Mr. Scott whether he has tried starting the motor and generator together. I am told by European engineers, who have put up quite a number of installations with alternating current motors, that if the motor and generator are first electrically connected and then started up together, there is no difficulty and no need of a special starting motor.

Mr. Scott:—Mr. Chairman, the generator will have to run at a speed sufficient to give some electromotive force in order to send the current through the motor. If the motor be given a slight initial speed, so that the system will really be running in synchronism at the start, it can of course readily be brought up to synchronism, as the speed of the motor will increase as that of the generator increases.

In experimenting with these machines in the factory, it is always very interesting to let the connection between the generator and motor remain when the engine is shut down. As the speed becomes slower, the motor continues to maintain the exact speed of the generator almost to rest, and if the engine is then brought up to speed again, the motor would of course follow.

MR. BRADLEY :—I think that the answer to Mr. Hering's question is that the motor must be separately excited in order to accomplish that result. In this case, where the motor has to get the field excitation from itself, it must have a speed in order to generate its own field. I think this paper is a very valuable one, because it is full of facts, and those are what we are all in search of.

I would like to call attention to Fig. 1, which might be of interest as showing one arrangement of a bank of transformers. Now, in this case my criticism does not fully apply, because the electromotive forces are as 3300 to 1100, that is, three to one, and where the transformation is very great, say, from 5,000 down to 100, then the secondary being the low tension and being connected throughout the whole number of transformers, at the end of the bank of transformers it brings primary and secondary very close together, and the insulation must be sufficient between the primary and the secondary to stand the whole voltage. You can readily see that by following it through. We ourselves made the mistake of putting up some twenty in series, and they knocked out the end ones in succession as we ran the voltage up.

MR. SPERRY :—Mr. Chairman, as I recollect, the installations abroad have been run by synchronous motors, and both generator and motor have been excited, so that, on the least turn of the generator armature, sufficient electromotive force can be given to the motor armature to start it and keep it in synchronism. I can voice the sentiments of the last speaker as to the value of the paper. I have been deeply interested in the engineering features. I think it is splendid practice to have a single circuit and some mechanical means of starting the motor. The plan, as shown in the figure in the paper, has an advantage over the method used abroad , due to the fact that no separate excitation is necessary in either motor or generator, and that by the simple addition to the ordinary system of a small motor which must have capacity to generate the field of the motor, besides overcoming the mechanical friction of the generation, the whole system may be set in operation. I think, as one follows through all the details and compares each with the same element existing in the foreign system, we certainly have an advantage in this system. The method by which the two are brought into step exactly and by means of which that step can be observed easily, is as simple as it can be made.

MR. BRADLEY :—I would like to ask Mr. Sperry if abroad they run any motors in multiple arc, and operate some of the generators in synchronism.

MR. SPERRY: —I have not seen any installations myself, but I am told by an engineer that he does that right along without any difficulty whatever, with motors of different sizes and capacities. At the Frankfort Exposition, last year, there was a small dynamo coupled with a large dynamo, but I don't remember seeing any synchronous motors run that way abroad.

THE CHAIRMAN:—I should like to point out one possibility which seems to me to be applicable, and that is that very frequently in a transmission of this nature it may be desirable to have some character of fixed current in the shape of a dynamo of a continuous current type, which may perhaps be operated by an alternating current motor for some other purpose. If so, it would be very readily possible to keep charged a sufficient number of cells of storage battery, such as to enable us to secure the original excitation of the motor field, which would be desirable and sufficient to bring it up gradually into synchronism with the generator in full step as the original power is started. Is there any further discussion on the paper?

MR HERING:—Mr. Chairman, I agree with the other speakers that this is an exceedingly interesting paper, but I cannot help thinking that the multiphase current system has about as many advantages over this one, as this one has over the continuous current; at least, it seems so to me at present. I have seen a large 100 horse power three-phase motor started without the use of any auxiliary apparatus whatever other than a liquid rheostat. It started beautifully. I also had the pleasure of seeing a small two horse power motor of the same kind, loaded with 100 per cent. overload (that is, with four horse power), reversed as rapidly as the switch could be turned while it was running at full speed. It took but a few seconds before it was up to speed again. It therefore seems to me that a three-phase current has very great advantages in starting as well as in running, because if overloaded the speed will simply diminish slightly, but it will not come to rest suddenly any more than a continuous current motor would.

THE CHAIRMAN:—We will take up next the paper by Mr. A. H. Bauer, of Chicago, on "Railway Train Lighting." Mr. Bauer being absent, the Secretary will read his paper.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7, 1892, Manager Leonard in the Chair.

RAILWAY TRAIN LIGHTING.

BY A. H. BAUER.

The first successful system of railway train lighting is that invented by Houghton, and adopted by the London, Brighton and South Coast Railway of England, in 1881–2. Since then the many improvements suggested by other inventors have made it almost automatic.

The system consists of a Brush dynamo carried inside the baggage compartment, and directly connected by link belting to pulleys on the axle of the car. Attached to the dynamo is a ball governor, rotating vertically, whose office is as follows:

1st. To control the movement of a switch, which, when the speed and therefore the E. M. F. of the dynamo reaches a predetermined value closes the circuit, and also opens it again when the E. M. F. approximates that of the secondary battery, which is always in circuit.

2d. The adjustment of a resistance which maintains the current constant, and

3d. To shift the position of the brushes as the neutral point is changed by the varying speed of the armature.

But one set of brushes is used, carried in rectangular holders, at right angles to the commutator, and always in contact with it.

When the rotation of the armature is reversed by a change of direction of the train, the brushes are carried forward or backward by the friction on the commutator and a connection with the governor until the quadrant passes but a fraction beyond the vertical, when it is drawn to the proper position by a spring, the action being similar to that of the snap switch. Limiting stops are provided to prevent the quadrant going too far.

The same movement of the quadrant also changes the position of a switch controlling the connection of the field coils, and therefore the polarity of the dynamo. It therefore follows that the current is always in the same direction, no matter which direction the armature may rotate. One set of accumulators, consisting of 25 cells, is provided for each train, and placed in the baggage compartment. The maximum number of lamps in a train is 70, of 10 candle power each, at 50 volts.

No attendant is necessary, but at certain stations on the line an examination of the plant is made, and required repairs attended to. I am informed the system is so reliable that since the year 1888 but two failures have occurred.

It will be noted that the key of this system is the convenience with which the connection between the armature pulley and that on the axle can be made.

Throughout Europe the rigid wheel base is universally employed under railway baggage cars; consequently, by setting the dynamo across the car, the armature shaft will always be parallel with the axle, and the connecting belt run in practically the same plane.

In this country the bogie truck is exclusively used. Several attempts have been made to drive dynamos by connections with the axle of bogie trucks. All, however, have failed, for the reason that no provision was made for maintaining the armature shaft and axle parallel at all angles of the truck, and because sand, dirt, etc., gathered by a moving truck will soon destroy any mechanism that may be used for the purpose under the car. The problem, however, has not been abandoned, and I am in hopes that within a very short time a solution will be found.

Numerous propositions have been made to use primary batteries for car lighting, but I am not informed of a successful installation of that character.

Secondary or storage batteries have been more or less employed for the purpose, with varying success. The first attempt in this direction was made in 1887–8 on two Pullman limited trains, of six cars each.

Each car was equipped with thirty cells of battery, having a capacity of 150 ampere hours, and weighing 50 lbs. per cell, or 1,500 lbs. per car. Duplicate sets were kept charged at each end of the line, and on arrival of the train, exchanged for those that had been exhausted while on the road. The average number of lamps per car was 26, of 16 candle power, at 60 volts, or a total of 156 in the train. After sixty days' trial, it was clearly demonstrated that, under existing conditions, the system could not be made successful, and it was abandoned.

The reasons for its failure were—1st, that the capacity of the battery was insufficient to maintain the number of lamps required for the proper lighting of Pullman cars on long runs.

For example, the current required for 26 60 volt, .8 ampere lamps, is about 20 amperes. Therefore $\frac{150}{20} = 7\frac{1}{2}$ hours, that is to say, 1,500 lbs. of battery was able to maintain 26 lamps but $7\frac{1}{2}$ hours. These trains departed east-bound at 5 P. M., but the light is required at 4 P. M. for inspection, receiving passengers, etc. Consequently the batteries would become exhausted at 11 P. M.; in fact, it would be earlier, as will be explained. Therefore the oil lamps would have to be used when light was required during the remainder of the trip. West-bound the same reasons held good, although not to the same extent, because the train leaves that end in the morning and passengers will, as a rule, after 12 hours' traveling, retire earlier than those going east, leaving at 5 P. M. Consequently less light is required, and a certain percentage of the charge is not used.

A second reason was the deterioration of the batteries themselves, which were of the pasted grid type. It was found that the constant agitation of the acid solution in the jars, as well as the unavoidable rough usage to which they were subjected when changing, caused a loss of the paste or active material, proportionately reducing the capacity. In fact, close observation indicated the loss during one handling to be equal, if not more, than that caused by 1,000 miles travel on the car. The paste, when separated from the grid, accumulates in the bottom of the jar, or lodges between the plates, forming a circuit through which the cell is discharged, resulting in the buckling and sulphating of the plates, and the destruction of the positive elements within a short time. This was five years ago. Since then, improved methods of manufacture, as well as more intelligent care in handling, has, to a great extent, overcome these objections and thereby increased the life of the battery. It may be asked—why not increase the size and therefore the capacity of the cell? The reply is—that to properly light a train of six Pullman cars, for instance, between Chicago and Jersey City, with the number and kind of lamps above stated, would require 30 cells, each weighing not less than 100 pounds—a total of 3,000 pounds per car, or 18,000 pounds for a six car train. The expense of handling and changing such a weight would make its use almost prohibitory, for each cell would have to be handled singly. The weight on the car would also be objectionable. Since these experiments were made, car lighting for short distances only, from storage batteries, has been made successful. For the past two years four cars, each equipped with 32 cells of 150 ampere hours capacity and 26 16 C. P. 60 volt lamps have been running between Chicago and Cincinnati, and Chicago and Indianapolis. Two of these cars are charged every day at Chicago for about nine hours with sufficient current for a round trip. The batteries, however, are not changed; the cars are always placed on the same side track to which wires from the dynamo are led, and the charging is done without removing them. The average length of time the light is required during a round trip is six hours; the cars leave each end of the line at 8 and 9 P. M. respectively. Repairs are made by removing the defective cell and substituting another if necessary.

The cost of repairs and renewals of all kinds from Sept., 1891, to January, 1892, inclusive, per month, was as follows:

September, 1891	$ 36 44
October, "	108 82
November, "	51 24
December, "	79 21
January, 1892	38 31
Total	$314 02

An average of $62.80 per month.

$\frac{62.80}{30}$ = $2.09 per day for the four cars.

$\frac{2.09}{4}$ = 52.25 cents per car per day.

$\frac{52.25}{26}$ = 2 cents per lamp per day of hours.

$\frac{2}{6}$ = .33 cent per lamp per hour.

As the engine and boiler are used for furnishing power for other purposes while running the charging dynamo, it is difficult to get the cost of the power for charging these batteries, that factor, therefore, is not included in the above statement

In January, 1888, a solution of the problem of lighting six-car trains for long distances was sought for in another direction. Two trains running between Jersey City and Jacksonville, Florida, a distance of 1,100 miles, were selected for the experiment. At first an attempt was made to utilize the power of the axle, but for reasons already stated did not prove successful.

The next step was the substitution of a vertical single-stroke engine, located in the baggage car, for the axle connection. This engine was belted to the dynamo, and was supplied with steam from the locomotive boiler.

While this plan seemed to be a step in the right direction, it still had its objections, due to the fact that the upward and downward movement of the driving-rod acted in the same manner as would a heavy blow on the car body, so that the latter would vibrate in unison with the stroke of the engine.

After a few trials, the vertical engine was removed and a three-cylinder reciprocating engine, with three-inch cylinders and four-inch stroke, was substituted. It was connected direct by a flexible coupling to a 75 volt 60 ampere dynamo of the ordinary open frame type, and both run at 1,000 revolutions per minute.

The working of this combination clearly demonstrated that a solution of the problem was attainable, and it was now possible to guarantee a fairly successful lighting of the two trains. A fault soon developed, which could not be anticipated. It is well known that all railway trains, while running, gather more or less dust and dirt, but it was not known until train lighting was attempted, that this dust and dirt contain certain quantities of carbon and metal which adhere to armature and field wires, and being conductive form short-circuits. So frequently did this occur, that it became necessary to carry an extra armature with each plant, and make changes while the train was in motion. Later in the year these dynamos were removed, and the Eickemeyer installed. The Eickemeyer dynamo seems to be perfectly adapted for train lighting. As both the armature and field coils are protected by the iron of the machine, dust and dirt does not reach the wire, except in small quantities, and by removing it every six months, when the car is shopped for repairs, short-circuits have been prevented. Its strong construction is such that it will successfully withstand the general rough usage to which machinery of this character is subjected to on railway trains.

The system which has been used for the past five years on all Pullman trains, consists of a Brotherhood three-cylinder engine and Eickemeyer dynamo, bolted to a cast-iron bed-plate, and located in the forward end of the baggage car, occupying an enclosed space of 6 feet 6 inches by 3 feet 3 inches. The engine and dynamo are connected by a flexible coupling which allows for the irregularity should they not be in perfect line. A two-gallon sight-feed pressure lubricator bolted to the end of the car, furnishes oil to all wearing parts of the engine. The average consumption of oil is about one gallon every 20 hours of actual running of the engine.

Steam is taken from the locomotive boiler, a tap being made at the dome, the pipe passing under the tender and car, between which a flexible rubber hose makes connection. It has been found that with a 1¼ inch pipe between the boiler-head and car, there is a loss of 15 pounds pressure due to friction and condensation; therefore, to run the engine with 50 pounds, requires 65 pounds at the supply pipe on the locomotive. With 50 pounds pressure, the dynamo will, at 900 revolutions, generate 80 amperes, at 72 volts, when all the lamps and batteries in a six-car train are in circuit, and 50 to 75 amperes, at 80 to 85 volts, at the same speed when the batteries alone are connected, depending on the counter E. M. F. of the batteries.

On the side of the car is placed an automatic switch, which will break the circuit when the E. M. F. of the dynamo equals that of the batteries. A voltmeter and ammeter are kept constantly in circuit while the plant is in operation. A tachometer, belted to the armature shaft, is also provided for noting the speed of the engine and dynamo. This plant is enclosed by a tongue-and-groove partition surmounted by a wire screen.

The system of wiring adopted is the equi-potential, in which the pressure is practically equal at each lamp and battery. One wire leads from the positive pole of the dynamo to the rear end of the rear car, where it is coupled to a second that returns to the baggage car—but not to the dynamo—being tapped, however by the positive pole of each battery and one side of each lamp, A third wire leads from the negative pole of the dynamo to the rear end of the rear car, where it ends. This third wire is tapped to the negative pole of each battery and the remaining side of each lamp.

All the batteries and lamps are therefore in multiple arc. Double pole, fusible cut-outs are placed in each circuit, and, with the switches, are located in the closets of each car. The wires are always placed on the roof of a car. For this purpose, white-wood moulding, thickly coated with asphalt paint, is nailed from end to end as near the center as possible, usually one and three-quarter inches from the edge of the smoke-jack if the car is equipped with center oil lamps, and from six to 24 inches when gas lamps are applied. Branch mouldings extend to all points on the roof through which it is desired to run wires to the lamps, switches, etc., inside the car. For instance, the drops to the center lamps in the body of the car pass directly through the center of the roof into the air chamber of the oil lamp, from where they are suitably connected. Those leading to the switches, cut-outs and batteries pass through the panels between the ventilators and into the closets where the switches are located, the battery wires continuing on through the floor to the boxes under the car. After being run in the moulding, the wires are covered with wooden capping and the whole tinned over, practically forming part of the roof. The grooves in the moulding are made of such size as to hold the wire rigidly, so that its movement or abrasion is impossible. Wire so applied has, after five years' service, shown no deterioration whatever, and is apparently serviceable for at least five years more. As the tin covering of the moulding is cut and worn away by cinders and the action of the elements, it is found necessary to renew the moulding about once a year. The sizes of wire used are all of B. & S. gauge, and consist of No. 2 for those leading from the dynamo, Nos. 6 and 10 for the lamp mains and No. 14 for the lamp drops. The connection between cars is made by bringing the wires from the roof through the hood to the inside of the vestibule, where they terminate in square brass tubing called connectors, which are permanently attached to the vestibule frame. The connection between these connectors is made with three conductor flexible cables, each conductor of No. 6 gauge. To the ends of each conductor, brass springs are attached which fit closely inside the tubing, giving about eight square inches contact. If cleaned occasionally this connection will carry 100 amperes without sensibly heating. As the connectors are placed horizontally it is evident that should the train from any cause be parted, the connection will be severed without damage to any part of the system, except to throw the load off the engine and cause it to race. Should this occur, which, in fact, is very seldom, the attendant is at hand to cut off steam and stop it until the connector can be replaced. With a No. 2 wire the average fall of potential in a six-car train is nine volts.

When the batteries alone are in circuit, the E. M. F. of the dynamo will be from 67 to 83 volts, which, minus the loss, will overcome the counter E. M. F. of the batteries, viz., 57.6 to 73 6 volts. When both lamps and batteries are in circuit the external resistance is of course reduced and the E. M. F. of the dynamo falls in proportion, and that at the lamps will be from 60 to 66 volts.

It is unnecessary to use a resistance in the lamp circuit, as when the lamps are first turned on, the E. M. F. being say 66, a greater candle power is had just at the time when most needed, which, however, gradually falls and ordinarily reaches 60 to 61 volts in from two to four hours, depending upon the amount of charge in the batteries. It is true that this is at the expense of the life of the lamp, but as the handling of the switches is done by the porters and conductors, the use of rheostats or regulators, no matter how simple, would complicate the system and probably cause the total extinction of the light. Each car is provided with 32 cells of storage battery, placed 16 in each of two boxes, securely fastened under the center of the car, and directly over the truss rod. The weight of batteries and boxes complete, is about 2,000 pounds. As already stated, with the system of wiring adopted the batteries and lamps are permanently connected in multiple arc, so that should the train be parted and connection with the dynamo become broken the batteries will supply current necessary to maintain the light; or should the batteries under one car become disconnected, its lamps will be supplied from batteries under other cars in the train.

The lamp equipment of a six-car Pullman train is as follows:

Combined smoking and baggage car	21	lamps
Dining car	32	"
Three sleeping cars	90	"
Combined observation and sleeping car	29	"
Total	172	lamps.

Of this number, 98 are 16 candle power and 74 are 8 candle power. The latter are placed in hallways, toilet-rooms and vestibules.

During six months of the year, seven $\frac{1}{8}$ H. P. fan motors are added, viz.: 3 in the dining, 2 in the smoking and 2 in the observation cars, each absorbing the current of four 16 candle power lamps, or a total of 28, which, added to the 172, makes the total, 200 lamps in the train. To maintain the 200 lamps requires 144 amperes. As the dynamo will generate but 80, the batteries must supply 64 amperes, or 44 per cent. This is effected by charging the batteries during the day and part of the night *en route*, and while the train is standing in the yards.

The following, taken from the January records of a train, will give an idea of the number of lamp hours required:

CHICAGO TO JERSEY CITY.

Time.	Hours.	No of Lamps.	Lamp Hours.	
4 A. M. to 9 P. M.	5	172	860	Leaving Chicago.
9 " 11 "	2	140	280	
11 " 12 "	1	42	42	
4 " 7 "	3	172	516	Arr. at Jersey City.
During day in tunnels and depots ..	1	172	172	
Total	... .	....	1870	

JERSEY CITY TO CHICAGO.

Time.	Hours.	No. of Lamps.	Lamp Hours.	
4 P.M. to 9:30 P.M.	5½	172	946	Leavg. Jersey City.
9:30 " 11 "	1½	140	210	
11 " 12 "	1	42	42	
6 A.M. to 7:30 A.M.	1½	32	48	Arriving at Chicago.
During day in tunnels and depots ..	1	172	172	
Total	. ....	....	1418	

Total, 3,288 lamp hours during the round trip.

The cost of an installation for a six-car Pullman train—consisting of one combined baggage and smoking, three sleeping, one dining and one combined sleeping and observation car is as follows:

COMBINED BAGGAGE AND SMOKING CAR.

1 Brotherhood Engine	$500 00
1 Eickemeyer Dynamo	500 00
32 Cells Accumulators	392 00
Wiring	100 00
1 Set Wire Connectors	11 00
Battery Boxes, Crates and Connections	71 00
Steam Piping, Lubricator Gauges, etc	155 00
Voltmeter and Ammeter	77 50
Safety Switch	12 00
Lamps and Sockets	17 00
Switches and Cut Outs	17 50
Shades—Holders and Fixtures	10 80
Partition for Dynamo and Engine	38 00
Two ⅛ H. P. Fan Motors	76 00
Miscellaneous	50 00
	$2,027 80

SLEEPING CAR.

32 Cells Accumulators	$392 00
1 Set Wire Connectors	11 00
Wiring	90 00
Battery Boxes, Crates and Connections	71 00
Lamps	15 00
Sockets, Receptacles, etc	47 00
Switches and Cut Outs	17 50
Shades and Shade Holders	9 00
Berth Lamps	90 00
Miscellaneous	20 00
	$762 50

DINING CAR.

32 Cells Accumulators	$392 00
1 Set Wire Connectors	11 00
Wiring	70 00
Battery Boxes, Crates and Connections	71 00
Lamps	16 00
Receptacles and Fixtures	32 00
Switches and Cut Outs	17 50
Three ½ H. P. Fan Motors	114 00
Miscellaneous	20 00
	$743 50

COMBINED SLEEPING AND OBSERVATION CAR.

32 cell accumulators	$392 00
1 set wire connectors	11 00
Wiring	90 00
Battery boxes, crates and connections	71 00
Lamps	14 50
Sockets, receptacles and fixtures	19 50
Shades and holders	10 40
Berth lamps	45 00
Two ⅛ H. P. fan motors	76 00
Miscellaneous	20 00
	$749 40

A total of $5,808.20, or an average of $968.00 per car.

As the fan motors are used but six months in the year, the average number of lamps will be $172 + 14 = 186$. Therefore, the cost of equipment per lamp will be $5,808.26 ÷ 186 = $31.22.

The average cost of labor and material for maintaining the lighting of three trains, or 18 cars for 19 months, from August, 1890, to February, 1892, inclusive, was as follows:

Average total cost per month			$1265 95
"	"	per car per day	1 99
"	"	of labor per month	712 39
"	"	" per car per day	1 11
"	"	of material per month	511 51
"	"	" per car per day	87
"	"	per lamp per day	07.17
Average number of lamps in use			558

The item of labor includes the wages of five attendants on the train, at $3.00 per day each, and two men at each terminal station, at $90.00 and $55.00, and $75.00 and $50.00 per month respectively.

That of material includes the cost of renewal of batteries, etc.

The cost of labor is practically constant, while that of material varies from 12 cents to $2.04 per car per day, the average for 19 months being 87 cents. The cost per lamp per day varies from $3\frac{8}{10}$ cents to $12\frac{5}{10}$ cents; the average is 7.17 cents.

The cost of power furnished by the locomotive boiler is not included in the statement, for the reason that a satisfactory measurement of the quantity of coal and water used has never been made.

So long as the dynamo can be run, and the batteries properly charged, the system is reliable.

During the coldest part of the winter, or as sometimes happens, when a poor quality of coal is furnished, it is difficult for the locomotive to supply sufficient steam to run the dynamo. In such cases the batteries are called upon to maintain the light. As a rule, they have sufficient charge to do so for about four hours. Trains so equipped have been run between Jersey City and St. Augustine, Florida, during the months of January, February, March and April of each year since 1888.

The conditions there are decidedly more favorable, for the reason that the trains leave both terminals early in the morning. In consequence, the dynamo is run nearly all day, and the batteries are therefore fully charged and in condition to furnish current for the maximum number of lamp hours. So successful has been the electric lighting of these two trains, that it is rare for other sources of illumination to be used. The system has also been used on other trains, viz., between New Orleans and the city of Mexico, Omaha and San Francisco, Chicago and Portland, Me.

Several specials have also been similarly lighted, notably—the Presidential, from Washington to San Francisco and return; the National Electric Light Association trains, between Jersey City and Chicago, and Jersey City and Kansas City; the National Telephone Exchange Association train to Minneapolis, and that of the Pan-American delegates, which was almost constantly on the road for three weeks.

A duplicate of this system was tried for a short time on the Chicago, Milwaukee, and St. Paul Railway. I must look to others to explain the causes for its being abandoned, and also describe that which has been substituted and which it is understood has proven very satisfactory. One of the most serious sources of trouble met with in train lighting was the effect of the vibration of the car on different members of the plant. At first it was almost a daily occurrence to have lamps drop out of sockets—the shade-holders, which were made of thin sheet brass, were broken at the rate of eight or 10 during one trip. Trains would arrive at terminal stations with two or three batteries out of circuit caused by connections between cells being broken. In the earlier days it was the practice to use a rigid connection between battery cells, as it was considered best to prevent the elements moving in the rubber jar. It was soon discovered that the element would move irrespective of the rigid connection, and in doing so would break the terminal, and in a majority of cases the fracture was next to the plates. As we had no means of burning the lug on again the element was useless. To overcome this difficulty flexible connections were substituted. Contrary to all expectation no damage was done by the movement, and since then should a terminal be broken, which however is seldom, it is in every instance due to a defect in burning on at the factory. Cast brass shade holders were substituted for those of sheet brass. To prevent shades working loose and dropping out, ordinary rubber bands were placed under the lip, against which the holder screws were driven, and they having a soft foundation were prevented turning and held the shade in place. The cause of the lamps falling out was due, in a great measure, to the socket rings working loose. This was overcome by the invention of a tool that would drive the ring into place much tighter than was possible by hand. Many minor causes of trouble that could not be foreseen were eliminated as fast as they developed.

A system of safety cut-outs was devised that protect each wire in the car. They are placed on the same baseboard with the lamp switches, and are located in the locker or closet, convenient for inspection and renewal. Later on portable lamps were demanded that could be placed in the sleeping car sections, either before or after the berths had been made up. For this purpose No. 18 wire was connected to one of the lamp circuits on the roof, and led to a connecting block placed over the mirror between the windows in each section. Connection with the block was made with a plug, to which flexible lamp cord was attached. On the other end of the cord a frosted 16 candle power lamp was connected, the lamp hanging from an arm which was placed in a receptacle in the corner formed by the side of the car and the partition between sections, and immediately over the shoulder of the passenger, the most favorable position for the lamp when used for reading.

It was early seen that the only uncertainty connected with the system is due to the absolute dependence upon the locomotive boiler for power to run the dynamo, for, as explained, there is a constant liability of the failure of the steam supply which, if prolonged beyond the capacity of the battery will result in the use of oil or gas for light. As many other problems connected with the system have been successfully worked out, it is believed that the solution of this one will also be found.

There is no doubt that the ideal way of running the dynamo is by a connection with the axle. Many apparent solutions have been suggested, only to be condemned as uncertain or impracticable. It is, however, thought that within the next year a reliable connection will be had, after which I believe the lighting of railway trains by electricity will be universally adopted.

DISCUSSION.

MR. C. R. GILMAN:—Referring to the cost of installation for a six-car Pullman train, given in Mr. Bauer's paper, for comparison with ours, that is, the Chicago, Milwaukee and St. Paul system, I give the following:—Cost of equipping one ten-car train, consisting of one baggage car, two mail cars, two coaches, three sleeping cars, one dining and one parlor car. Baggage car, including one Westinghouse 6x6½ automatic 15 horse power engine, one No. 4 compound Edison dynamo, switches, meters, etc., $1,183.19. Two mail cars, $119.84 each—$239.68. Two coaches, $147.92 each—$295.84. Three sleeping cars at $299.88 each—$899.64; one dining car, $192.23; one parlor car, $205.50; making a total of $3,016.08, or an average of $301.61

per car, a total cost per lamp of $15.82. Our cost of labor and repairs on four trains, 35 cars for one month, is as follows:—Labor, $650; material, $175.86—total, $825.86. Cost per car per car day, 78.6 cents; cost per car per car day for labor, 61.9 cents. The cost per car per car day for material, 16.7 cents. Cost per lamp per day, 5 cents. Average number of lamps in use, 542.

THE CHAIRMAN:—How much is that per lamp per hour, roughly, Mr. Gilman?

MR. GILMAN:—I will have to figure that out.

THE CHAIRMAN:—While Mr. Gilman is getting some additional figures, is there any discussion on the paper that any gentleman would like to participate in? This is a very important subject, and one which is receiving a great deal of attention from companies which are lighting trains by gas, recognizing the demand for electric lights and the necessity for their having electric lighting systems in order to protect their already established gas lighting industries. The figures which Mr. Gilman has given us would indicate an extremely low rate for the production of light on the trains of the Chicago, Milwaukee and St. Paul Railway, and he will have for us presently the exact figure per lamp hour, which is perhaps the best way of making comparisons as to economy with other systems.

PROF. SHEPARDSON:—I would suggest, Mr. Chairman, that possibly the plan Mr. Sperry has used for coupling together four axles on his mining locomotive could be used for transmitting power to the dynamo on our trucks. I understand that plan has been quite successful in Europe, where the car axles are not swiveled.

MR. WILLYOUNG:—Mr. Chairman, Mr. Bauer was talking about this matter, Sunday, and I asked him whether he had finally secured the results that he was after, and he said he had; he had plans in his office, but he said it was not an original plan. He said it was a plan that has been used in Europe for some time with considerable success, and it may be that it is a similar plan to that to which the gentleman refers.

MR. SPERRY:—Mr. President, I would like to call attention to the fact that it would be impossible in such a system, although on the face it cost about half to install, to detach any of the cars without leaving them in darkness during the time that they are so detached.

MR. HERING:—I would like to ask also what you would do when the cars are in the station?

MR. GILMAN:—Oil lamps are used during stops.

THE CHAIRMAN:—The figure that Mr. Gilman presents is five cents per lamp per day. He says the average burning is about nine hours a day, and it brings the cost of the lamp hour down to approximately a half a cent per lamp hour. That is extremely low, as the cost of the production per lamp hour of the largest central stations to-day is in the neighborhood of a quarter of a cent. But it is natural to suppose that the cost of production per lamp hour by a system such as this, would be much less than in a system which would involve storage batteries, although this system would be applicable only to through trains, on account of inability to take care of breaking up the trains.

MR. CLEMENT F. STREET:—Mr. Chairman, there is one criticism I wish to make regarding this paper. The average total of material per car per day is given as 87 cents. Now, it seems to me that is the cost per day while this plant is in existence. It is not the cost per day of 24 hours, of 12 hours during which the light is being used, and I do not think this is the proper basis on which to figure. If the number of hours which the plant was in use had been taken and the figures derived from that, it seems to me it would have given more information. As I understand it, he has given the cost of the 24 hours during which the plant is in existence, whether it is in use or not.

There is another point, in regard to breaking up the train. Of course, in the system which is in use on the St. Paul road the statement was made that when the train was in the depot it was necessary to use oil lamps This occurs only at points when the engines are changed and when the baggage car plant is used. When the light and heat tender is used in connection with the system, it is never necessary to use the oil lamps at all, because the light and heat tender has an independent engine and boiler. This is used in the winter, when it is necessary to supply steam heat to the cars. In the summer the same engine and dynamo are transferred from the light and heat tender to the baggage car, and steam taken from the locomotive, consequently it is necessary to shut down the plant during the time of taking one engine off and putting another on, which will be every 100 or 150 miles, depending on circumstances, and only in rare cases more than once during a single period when the lights are in use.

THE CHAIRMAN:—I would like to say in this connection that I have had brought to my attention a system which is likely to be put into commercial use, in which the number of storage batteries which will be used will be very much reduced, so that there will be but two or three batteries per car, although the lamps which are in ordinary service will be lamps of 110 volts, and the main lighting of the train will be direct from the dynamo engine, upon the locomotive probably; although in case of the removal of the locomotive or separation of cars the storage batteries will act automatically, lighting by electric lamps of different voltage from the main lamps in the car, which will obviate the necessity of lighting up some other lamps by hand means, which would be troublesome.

MR. GILMAN:—I would like to say that Mr. Gibbs has already got that system started. We have three cars equipped on the road with small batteries and an automatic switch that throws them in when the train is cut off from the locomotive.

[Recess.]

EVENING SESSION.

At the Chicago Electric Club, June 7th, 1892, at 8.30 P. M. President Sprague in the chair.

THE PRESIDENT:—The first business before the meeting this evening will be the consideration of the report of the committee appointed at the New York meeting, to make some changes in the Rules with reference to the election of officers. It has been concluded, and I think very reasonably, that the method we now have of electing our officers is not a satisfactory one, that is, it does not necessarily represent the choice of the Institute as a whole. At that meeting a committee was appointed, consisting of Dr. Herzog, Mr. Upton and Mr. Martin, which was instructed to submit recommendations for such changes in the Rules as would make the election of officers somewhat more representative of the feeling of the Institute.

The report will be read by Mr. Martin.

REPORT OF COMMITTEE ON REVISION OF THE RULES REGARDING THE ELECTION OF OFFICERS.

V. ELECTION OF OFFICERS.

During the first week in February of each year the Secretary shall mail to each full and associate member of the Institute a list of members; a list of the offices to be filled at the ensuing annual election in May, giving the names of the incumbents, and a copy of this rule, with the request that nominations, propositions and suggestions as to desirable candidates be made promptly and prior to March 1st.

The Secretary shall submit all answers to the Council, who during the month of March shall prepare a complete ticket to be headed "Council Nominees," containing the names of members whom they deem best suited, all circumstances considered, for the offices falling vacant. This ticket shall be printed on the same sheet with a "General Proposal list" containing the names of all eligible members proposed, with a memorandum stating the reason of ineligibility of all other names proposed, and with a statement that the nominations by the Council are in nowise governing, but are intended only to assist members in making a choice. The voting shall be restricted to the names on this sheet This sheet, together with an envelope, on which shall be printed the address of the Secretary, and the words "Voting Envelope—Enclosing a Ballot Only," shall, not later than the 15th of April be mailed by the Secretary to every member in good standing.

Each member may cast three votes for Vice-Presidents and he may cast all three votes for one candidate or two for one and one for a second, or one for each of three. Each member may cast four votes for Managers, which he may in like manner divide between from one to four candidates. This division shall be specified by the appropriate numeral marked opposite the desired name.

All names voted for shall be written, printed or otherwise marked on a single ticket or ballot, which shall be enclosed in a sealed, unmarked and unidentified envelope of any suitable size to be in its turn enclosed in the voting envelope received from the Secretary. On this outer envelope the member shall add his signature, and the postage stamp.

At the annual meeting, these outer "Voting Envelopes" shall be opened in the meeting room by two tellers, then and there appointed by the presiding officer. After all the inner envelopes shall have been thoroughly commingled, they shall be opened and the votes shall be counted by the tellers, who shall report the results in writing. The eligible persons receiving the greatest number of votes for the respective offices shall be declared duly elected. The tellers shall reject all names that do not appear on the "Council Nominee" list or the "General Proposal" list, and they shall also reject that part of a ballot which shall name for any office or offices more candidates than there are vacancies.

This method of election shall apply to the offices of President, Vice-President, Treasurer and Manager. No unsalaried officer except the President and Treasurer shall be eligible to immediate re-election to the same office (as provided in Rule IV). The Secretary and any other salaried officer shall be chosen each year from among the members of the Institute by the Council. The Secretary shall be a member of Council, but shall have no vote in its proceedings.

New York City, June 4, 1892.

Committee to report on Improved Plan of Election and Change of Rules for that purpose.	F. BENEDICT HERZOG, Chairman, FRANCIS R. UPTON, T. C. MARTIN, Secretary.

APPENDIX.

The following is the section of the existing Rules, which it is proposed to amend:

V. ELECTIONS.

The annual election shall be held in the city of New York, on the third Tuesday in May of each year. Nominations of officers may be made in writing to the Secretary at any time previous to the meeting, but the votes shall be by ballots deposited only by members actually present. *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until the said arrears shall have been paid. If for any reason it is deemed proper to postpone the election, it may be adjourned from day to day with the consent of two-thirds present or voting.

The following is the existing Rule regarding Amendments:

VIII. AMENDMENTS.

The Rules may be amended at any regular meeting by a two third vote of the members present, provided that written notice of the proposed amendment shall have been given at a previous meeting.

It was voted that the report be printed and a copy mailed to each member, but that action upon the report be postponed until the first regular meeting in New York City. After considerable discussion an informal vote showed that the sentiment of those present was entirely favorable to the proposed plan.

The following papers were then read by Professor R. B. Owens on "Electro Technical Education," and by Professor Dugald C. Jackson. on "The Technical Education of the Electrical Engineer." They were discussed jointly.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, President Sprague in the Chair.

ELECTRO-TECHNICAL EDUCATION.

BY R. B. OWENS.

In his presidential address before the American Society of Mechanical Engineers, in 1883, Professor R. H. Thurston, in speaking of the policy and work of the mechanical engineer, claims electrical engineering as "the last established branch" of his profession. And again, in 1887, President Geo. Babcock, referring to electricity, says:—"Yet another great force . . . is yielding its neck to the yoke prepared for it by the mechanical engineer;" and a great number of similar quotations from the writings of other engineers might be made to show that when the importance of the industrial applications of electricity were fully recognized, the mechanical engineers claimed such electrical work as a branch of their profession. But the very existence of this body to-day, evinces the uselessness of such a claim. Again, it is not unusual to hear it asserted by some members of our profession that electrical engineering will, in time, absorb all engineering professions, although I believe those more familiar with the extent and variety of the work which might be called purely electrical are rather of the opinion that life is all too short in which to deal with the electrical problems, presented and are glad to refer the problems of mechanics to the mechanical engineer. Indeed, the field of work seems amply large for both professions, and, as remarked to the writer some years ago by Professor W. P. Trowbridge, "A definite and amicable understanding should be reached between them, so that we do not duplicate each other's work."

My object in presenting this paper at this time is to induce, if possible, a discussion which will throw more light on the relations which should exist between our profession and other engineering professions, as well as to learn by an interchange of opinion the best methods of instruction to be adopted in the training of electrical engineers. The subject of the technical training of mechanical engineers has been very fully treated by the American Society of Mechanical Engineers, and the Transactions of the American Institute of Mining Engineers contain valuable suggestions as to methods of training mining engineers, and so on with other engineering societies. But as yet the subject of the technical training of electrical engineers has, I think, hardly received the attention it deserves from our society, and in view of the fact that it includes managers of manufacturing companies, members of engineering firms and a number of men prominent in educational circles, I shall venture to hope the subject will receive the exhaustive treatment it well merits. We can consider ourselves fortunate in having a society such as this, where engineers engaged in every variety of work may meet on common ground and learn from each other, and I might here suggest, if indeed it has not been already suggested, that subjects be chosen by a suitable committee and appointed for "Topical Discussion" at certain meetings, as the mechanical engineers have done, and in this way still further increase the sphere of our usefulness.

Having stated my reasons for presenting this paper, I shall try to show the necessity of making technical training in general, graduate instruction and electro-technical training in particular.

A moment's reflection will show, that to the man of pure science or to the engineer, we owe all our methods of rapid communication and transportation, our supplies of metals and the necessities of daily life, as well as the utilization and adaptation of the latent and wasting powers of nature, but it is difficult to say to which one we owe most. "To have the application of a science, we must have the science itself," as remarked by Professor Rowland, in his address before Section B of the American Association, in 1883; but how often are the inquiries of such physicists confined to the simple enunciation of a physical or chemical principle which remains practically unproductive of good for centuries, and perhaps has to be discovered again, as witness the work of Lord Henry Cavendish. But I would not depreciate the work of the man who so often foregoes wealth and ease, to devote his life to that highest of human efforts, the study of nature's secrets and the enunciation of her laws. His mission is a high one and rarely appreciated as it should be, or else the "lucky inventor, who is lauded in every newspaper, would not receive more praise than him who perhaps discovered the principle upon which the invention is based, and died in obscurity and want."[1] Not that the trained inventor deserves no credit; the world owes him much, but not more than the man of pure science.

Between the scientist and skilled mechanic or handicraftsman is the engineer—the man who, familiar with the results of scientific investigation and methods, uses both, by the help of the mechanic's skill, to minister the more effectively to the wants and will of an ever increasingly exacting public. To him alone, we look for the solution of the problems of transmitting and distributing the power of waterfalls and fuels, the tunneling of our mountains, the building of our railways and steamships, as well as the more delicate work of flashing our thoughts and words from town to town and from continent to continent. This field of work is so vast that of necessity it must be divided among specialists and sub-specialists; but since the "Vril" of Lord Lytton's "Coming Race" has shown itself so marvelously well fitted to do our every bidding, I believe a great portion of the work hereafter will be done by the electrical engineer. And as so much will be expected of him, the duty devolves upon us to give him such training in his youth as will most effectively enable him to grapple with the problems to confront him in his future work. I have said the engineer uses the mechanic's skill in the accomplishment of his aims, and if so, he must possess a certain familiarity with tools and shop methods, or else he will not always be using such skill to the best advantage. But, evidently, it is not expected of every engineer that he spend sufficient time on shop practice to attain the same degree of efficiency in the use of tools as acquired by the mechanic who devotes his whole life to their use without attaining the highest skill in manipulating them. And experience, both at home and abroad, has shown that systematically conducted elementary schools where the "manual element" has been introduced "are far more efficient in developing and training of youth than the best managed mill or shop,"[2] for in the latter, despite the good intention of the manager or president, the learner is kept months by the foreman stamping out armature disks, if

1. Professor Rowland.
2. Professor R. H. Thurston.

there were need of armature disks, or punching holes, if there were need of holes, while in the school the variety of equipment is greater than in the best shop, and every operation is taught with the object of making the student familiar with the principle involved, and no more time is spent on one operation than is sufficient to insure a thorough understanding of it.

Until within the past few years, the value of the manual element in education has been sadly overlooked in elementary instruction in this country. Special and distinct schools, called variously; manual training schools, schools of mechanic arts and developing schools, have arisen, where those elements which underlie all industrial pursuits have been introduced into general elementary education, not because students leaving such schools expect always to enter upon some trade or into some "trade school," but because such instruction is eminently "desirable for the roundness and unity of general education, and valuable no matter what the future of those so educated may be."[1] The Massachusetts Institute of Technology, the Washington University, St. Louis, and others, have attached to themselves schools of mechanic arts and manual training schools, for the reason, I take it, that the elementary public schools do not afford such instruction, and they recognize the great educational value of their training.

But as soon as such instruction is given, as it should be, in the public or preparatory schools, the universities will find it no longer necessary to devote their energies to such elementary work, but will reserve their whole force for the higher instruction for which they are originally designed. Aside from the educational value which instruction in the use of tools, wood turning, pattern making, forging, metal working, etc., has, and which alone would justify it, "simply on the ground of the discipline it gives,"[2] such instruction becomes of double value to a student intending either to learn a trade or become an engineer. If he intends to learn a trade, and perhaps be a shop foreman, he probably knows, due to the manual instruction already received, whether he will become a watchmaker, carpenter or machinist, and enters a trade school where the technique of his chosen trade is taught.

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1. President J. D. Runkle, "Manual Element in Education."
2. President Runkle, "Report in Developing Schools."

If his aspirations are higher, he pursues his studies still further and enters a technical school whose primary province is the training of engineers.

The necessity of trade schools has arisen from two facts which make it particularly difficult to learn a trade to-day. First, the "abandonment of the old apprenticeship system," and, second, "the division of labor occasioned by the general introduction of machinery."[1] Many of these schools are doing excellent work and turn out workmen in two or three years, quite as skilled and possessed of very much more general knowledge than the apprentice of fifty years ago after spending "seven years learning his trade."[2] And all engineers should be glad to see such schools prosper, as they produce another tool which, to them, is of almost inestimable value, the skilled handicraftsman. In nearly every profession which makes applications of the teachings of science "manual operations of exceeding delicacy have to be performed,"[3] and it is but just to the skilled handicraftsman to acknowledge our great indebtedness to him. It is difficult to say whether the science of astronomy owes more for the discovery of the moons of Mars to Asaph Hall, or to Alvin Clark who made the instruments by which the moons were discovered. And just in proportion as the progress of the world requires a superior training of engineers, it will require the better training of the handicraftsman. Engineers should naturally, then, give all the encouragement in their power to apprenticeship and trade schools, since the instruction given in such schools unquestionably produces in time, better and more skilled mechanics than those not receiving such instruction.

Professor Huxley, in an address before the Workman's Club of London, I think, says:—"Technical education" in "good vernacular English would be called the teaching of handicrafts." But I think, in this country at least, we have attached a different meaning to the term. Here we generally mean by technical education the training of engineers, and in that sense I will use it.

"Technical schools are not indigenous to this country."[4] They have generally been copied from European models and cannot claim as yet to equal the schools of the old country. Yet, due to

1. President Barnard, *Century Magazine*.
2. Mr. Hale, "Report on Developing School."
3. Professor Huxley, *Fortnightly Review*.
4. T. M. Drown, *Journal Franklin Institute*.

the exceptional skill, ingenuity and enterprise of our people, the engineering works of America are, with few exceptions, unexcelled. And I hope that, in order to demonstrate our ability in long distance electric transmission, much of the energy wasting at Niagara will drive the machinery and light the halls of the World's Fair buildings in 1893.

In studying the various courses given in the best technical schools in this country and abroad, and the opinions of educators and engineers, I take it that a technical school is primarily a place for the preparation of men who expect to earn their living as engineers. It is not a school of general culture, nor is it a school of abstract science. It is a device to save time, and teaches the applications of pure science to industrial purposes.

A technical school is also, I claim, a post-graduate school in the ordinary sense, and in this respect should rank with schools of law and medice. If the engineer is a man who uses both the results of science teaching and mechanical skill, he must certainly have great familiarity with both, and the attaining of such familiarity will constitute his undergraduate work. But after such general knowledge is acquired, no time should be lost in fitting each student to be of the greatest immediate value to those who employ him. Unfortunate as it may be, we must reconcile ourselves to the necessity of becoming specialists. It may be argued that "the more a man knew of all the related branches the better he could perform his special work, but this is only arguing the advantage of omniscience."[1] Time was when all known about electricity would not greatly tax the ordinary intellect, but now each student can only hope to become an expert in one very narrow department, and I believe we must shape the courses, as far as possible, in our electro-technical schools to meet the requirements of the times.

Of course, to employ a number of specialists and to give each student the opportunity to choose the work he is best fitted for, will be expensive, but if our country is to keep apace with others in industrial progress she must educate her engineers. When private generosity fails, state aid must be forthcoming, or we will have to witness others surpass us in the race for international position. "It is in consequence" of superior industrial and technical education "that Germany is gaining a better industrial posi-

1. T. M. Drown, *Journal Franklin Institute.*

tion daily."[1] And the same might be said of several other foreign countries, so that on the score of economy no more profitable expenditure of public money is possible than for the support of technical schools. Education is not a money-making business. "No fact is more firmly established all over the world than that higher education can never be made to pay for itself.[2] No considerable income can be anticipated from student fees. Higher education must look for its support to private munificence or public help, and, as suggested to the English Institution of Electrical Engineers by Professor Ayrton, it would seem to be the duty of such a body as this to influence, as far as possible, public opinion in favor of advanced electro-technical education.

"How many of our people," says President C. K. Adams, "know that one of the minor universities of Great Britain has recently completed a college building at a cost of more than £500,000 ($2,430,000), not to speak of the four millions that were put into the Polytechnicum at Charlottenburg? How many have had their attention called to the fact that the little Republic of Switzerland, with a territory not a third as large as the State of New York, has recently, from its public treasury, built a chemical laboratory for the Polytechnic school at Zurich, at a cost of 1,337,000 francs ($267,400)? And of those who suppose that needless sums are expended at Harvard, Yale and Cornell, how many know that the little Kingdom of Saxony, only half as large as Vermont, gives from its public treasury annually $400,000 to its university, although the institution itself has great wealth? . . . Let us not cherish the erroneous supposition that there is a single well-endowed university in America. Let us remember that the richest of our institutions has an income not much larger than that of a single one of the twenty-four colleges of Oxford."

Having seen the importance of manual training as a factor in elementary education, and knowing its special value to those intending to become either handicraftsmen or engineers, I would recommend that a fair knowledge of forging and foundry work, pattern making, wood and metal turning and drawing be required of every student for matriculation into any college course. Such an elementary knowledge can readily be acquired by the average

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1. Professor R. H. Thurston.
2. Professor Rowland.

student by the age of 16 or 17, along with the elements of English education, such as given in our high schools and academies.

The importance of drawing can hardly be overestimated. It is rightly called "the shorthand language of modern science," and every one can learn to draw with a fair degree of accuracy, although the "negative faculty of drawing in some people is almost miraculous."[1] I no not mean artistic drawing, painting and perspective, but the elements of orthogonal projection can be as easily acquired as the art of writing, and for some purposes it is just as useful. Indeed, "drawing is now regarded by many educators as an established factor in elementary education, and destined to work its way into all classes of public schools."[2] At the age of 16 or 17 a boy having had good advantages should be able to enter any of our best American colleges, and here, if he intends becoming an electrical engineer, I would have him study for three years mathematics, chemistry and physics, with German and French. These apparently few subjects will absorb the greater portion of his energy. Nothing is gained by working at excessive pressure in early life, and, as to knowing anything about engineering itself, it would seem best to leave that alone until a thoroughly good scientific education had been first acquired. When electrical engineering is taken up in earnest, the student should have such a command of physical and chemical facts and methods, and be such a master of mathematical analysis as to leave him free to discuss engineering problems without the necessity of first acquiring the facts and methods he may wish to make use of.

A good course in modern geometry, differential and integral calculus, say, according to Williamson, and differential equations, say, Forsyth or Craig, would be sufficient to pursue with advantage nearly any course in electrical engineering given in this country at the present time, and when, in reading Maxwell, it becomes convenient to have quaternions or spherical harmonics, they can be studied in connection with such reading. But to attempt to analyze the action of alternating current apparatus without the use of differential equations, is, to say the least of it, no very easy task. We admit the value of geometrical methods and especially as expressing in convenient form the result of algebraic analysis.

1. Professor Huxley.
2. President J. D. Runkle.

Indeed, in the hands of Mr. Kapp, Mr. Blakesly and a few others, they have been used with excellent analytic effect, but their general weakness, as compared with modern methods, is too well known to need comment. As regards the amount of general physics required, I should say the student ought to be familiar with the theory of heat measurements, thermo-dynamics, the principles of fluid motion, the dynamics of a particle and of solid and rigid bodies, the theory of sound and physical optics, and the facts and principles of magnetic and electric actions. Above all, he should be able to apply mathematical reasoning to physical problems and be skilled in the art of experiment.

In ordinary electrical work, a knowledge of inorganic chemistry would perhaps suffice, but if one expects to make a specialty of electro-chemistry, then both organic and inorganic chemistry should be required.

Besides mathematics, chemistry and physics, which must be considered as principal subjects of the directly preparatory course, German and French should be acquired, as so large a part of our best electrical literature is in these languages. Sanscrit and psychology might be classed as electives, as affording variety.

Indeed, aside from the three principal subjects of the preparatory course, it would seem best to allow as wide range of choice in the remaining subjects as one is capable of carrying, for engineering is "a narrow life which concerns itself solely with building bridges or making analyses,"[1] building, erecting and testing electric and magnetic machines. Unless his general education is gotten in early life, I believe it is the experience of engineers that such culture is doubly difficult to attain after entering upon strictly professional duties.

Many colleges give, for the completion of the course I have outlined, as preparatory to electrical engineering, the degree of B. Sc.; but, irrespective of degrees, I believe the subjects above named should be thoroughly mastered before electrical engineering can be taken up with the best advantage.

Assuming, however, that a thorough working knowledge of mathematics, physics and chemistry is possessed by the student, then I believe he should spend three years in studying the applications of his acquired facts and principles before attempting to practice his profession.

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1. T. M. Drown.

We must, I think, recognize three classes of electrical engineers in this country at this time. First, the installing engineer, who superintends the equipment of central or isolated electric light or power plants, electric railways, mining plants, etc., and runs the same when completed. In this class of work, more than a knowledge of electricity is required. It becomes essential to have a thorough knowledge of steam engineering, track and pole line construction as well. He should be as well able to choose the best engine and boiler for a given set of conditions, and to install and operate them economically, as he is able to choose the best dynamo, motor, line wire or lightning arrester. A practical knowledge of building foundations, laying out railway curves, running pole lines, is to this engineer a matter of greatest importance.

The next distinct class of electrical engineers I would recognize, are designing engineers, who rather have to do with the manufacture of electric apparatus than its installation. Such men design and superintend the construction of the apparatus put on the market by the several manufacturing firms, but rarely also have to do with steam engines, track construction or pole lines. To this second class, a correct knowledge of machine design is of equal importance with a knowledge of magnetism and electricity, and it was perhaps of such men that Lord Kelvin was thinking when he said an electrical engineer should be nine-tenths mechanical and one-tenth electrical.

The third class of engineers are employed by standardizing bureaus and in laboratories, to make tests of electric and magnetic constants, calibrate instruments, etc. For such work, neither a knowledge of pole lines, foundations or machine design is so important as familiarity with delicate methods of measurement and skill in manipulating sensitive instruments.

It would seem best, then, to shape the course, in any electrotechnical school, as far as possible to meet the requirements of these distinct classes of engineers.

The proportions of the three kinds I have named vary greatly in different parts of the country. With us, at the West, the greater part of electrical work consists in installing and operating the apparatus manufactured by Eastern firms. In some few cases, electric factories started west of the Mississippi have been successful, but their number is not great, and the proportion successful is less. The time will undoubtedly come when the mineral wealth of the

West will be mined and manufactured by Western waterfalls, but so long as the East continues the centre of manufacturing interest, the principal work of the electrical engineer in the West will be installing and operating Eastern manufactured apparatus. Therefore, to meet the immediate home demand for engineers, I believe our Western schools of engineering must make a specialty of training installing engineers. In the East the case is different. More men are employed by manufacturing firms, testing and standardizing bureaus than by construction and engineering companies, so that the course given in the Eastern schools of engineering, and which are largely for the designing engineer, are justified.

After an inspection of the engineering departments of the University of Nebraska some months ago, Professor R. H. Thurston declared the electrical equipment to be "the finest, considering the size of the institution, in the United States,"[1] so that a word about the electrical department may not be without interest.

Our apparatus for instruction and experiment consists briefly of one Sterling water tube boiler, 125 H. P. at 150 pounds pressure; one 100 H. P. tandem compound, high speed, condensing engine, arranged to run either cylinder high pressure; one Worthington independent condenser, one 25 H. P. single cylinder high speed engine, also one 5 H. P. Otto gas engine, a line of countershafting with clutch pulleys and couplings throughout; one 500 light, 1,000 volt alternating current machine with converters and regulating apparatus; two 15 K. W., 120 volt continuous current machines complete; two 25 light, 10 ampere arc machines, and six smaller machines of various types; seventy-five 200 ampere hour storage cells; Prony friction brakes, cradle spring and hydraulic dynamometers, standard electric and magnetic measuring instruments, the greater part of which were imported; steam calorimeters, indicators and other instruments for steam measurement. The equipment, which is entirely new and of the latest and most approved design and construction, is valued at about $45,000. All the heavy machinery is placed in a separate building, 50 by 60 feet, designed for the purpose, while wires lead from it to the physical laboratory, where the more delicate instruments are placed on brick piers, as usual.

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1. *Nebraska State Journal*, March 19th, 1892.

The requirements for entrance into the college course preparatory to the electrical course are:

English—Spelling, capitalization, punctuation and pronunciation, and thorough, logical and historical study of English grammar, two hours.

History—Mediæval and modern, three hours.

Hygiene and physical training, one hour.

Language—French, five hours. German, five hours; 10 hours.

Mathematics—Algebra, five hours. Algebra and geometry (alternating,) five hours. Plane trigonometry, two hours; 12 hours.

Science—Botany, chemistry, physics, five hours.

Second year:

English—Continuation of the work of the first year, two hours.

History—Mediæval and modern completed. English history, three hours.

Hygiene and physical training, one hour.

Language—French, five hours. German five hours; 10 hours.

Mathematics—Algebra and geometry (alternating), ten hours. Plane trigonometry, two hours; 12 hours.

Science—Botany, chemistry, physics, five hours.

Manual training, three hours.

Each "five hours" represents full time for one subject for one semester or one "course." After completing the matriculation requirements, about six years are required for the degree of "Electrical Engineer."

The first three years are given mainly to a study of mathematics, chemistry and physics, and the last three years to engineering proper.

The course is as follows:

Chemistry—(1) Study of the metallic elements, their compounds and characteristic reactions. (2) The elementary principles of chemical philosophy. Two courses.

Mathematics—(1) Solid geometry and trigonometry. (2) Higher algebra and analytic geometry. (3) Conic sections and calculus. (4) Calculus and differential equations. Four courses.

Physics—(1) Experimental physics; lectures and recitations on mechanics, sound and heat; light, electricity and magnetism;

supplemented with exercises in the laboratory. (2) Advanced physics; application of calculus to the solution of physical problems; thermo-dynamics; physical and geometrical optics; dynamics of solids and fluids; theory of elasticity; problems in sound; theory of electricity and magnetism; supplemented with work in the laboratories. Three three-fifths courses.

Graphics—Descriptive geometry; orthographic projections of points, lines, planes, surfaces and solids. Four-fifths course.

English—(1) Lectures on the principles of rhetoric; practical exercises in criticism and composition; themes and studies in style. (2) Advanced course in rhetoric and oration; studies of the best styles in models, etc. One and three-fifths courses.

English Literature—English literature from Chaucer to the modern period. One and one-fifth courses.

Germanic Languages—Cohn's Ueber Bakterien; Helmholz's Ueber Gœthe Wissenschaftliche Arbeiten. One course.

Romance Languages—Scientific French; reading of scientific authors. Four-fifths course.

Military Science. Two-fifths course.

Physiology and Hygiene. Two-fifths course.

Shop Work. One and one-fifth courses.

Applied Mechanics and Strength of Material and Structures. One one-fifth courses.

Mechanism and Mechanics of Machinery. One one-fifth course.

Machine Design—In connection with mechanical drawing. One one-fifth course.

Steam engineering—Study of types of boilers and engines; their design, construction and erection; boiler and engine trials; fuels. One one-fifth course.

Theory of Prime Movers—Theoretical study of the principles underlying the action of steam and hot air engines; hydraulic and pneumatic machinery. One one-fifth course.

Theory and Practice of Electrical Measurement—Special problems involving exact measurement, supplemented by readings on problems assigned. Four-fifths course.

Electromagnetic Mechanism and Machinery—Includes a discussion of the principles of design and construction of dynamos, motors, transformers, lamps, telegraph instruments, telephones, etc.; the effects of self and mutual induction, capacity and hysteresis are considered.

Electro-Thermal Apparatus and Thermo-Generators—In this course are discussed arc and incandescent lamps, electric welding, thermo-generators, etc. Two-fifths course.

Chemical Generators, Electro-Chemistry and Electro-Metallurgy—Includes a discussion of primary and secondary batteries, electroplating and electrotyping, electric refining of metals, etc. Two-fifths course.

Mathematical Theory of Electricity and Magnetism—Requires a thorough knowledge of the calculus. One three-fifths course.

Principles of Electric Installation.—In this course are discussed the design and equipment, care and management of electric light and power stations, electric railways, telephone and telegraph systems, electricity in mining and hoisting, pole line construction, inside wiring, underground conductors, problems in the transmission and distribution of power by electricity. Two two-fifths courses.

The last year of the course is given up mainly to theses and electives in electrical engineering. Besides the regular course above outlined, leading to the degree of "Electrical Engineer," short and special courses are given to undergraduate and special students, who for various reasons cannot complete the full course for the degree.

No attempt has as yet been make to teach telegraphy practically, and as we have here some members who have had much experience in practical telegraphy, I hope they will express their opinions as to the advisability of introducing it into electro-technical schools. Some declare it properly belongs to engineering, and others contend, with much truth, I think, that it properly belongs to a trade school. Similarly with wiring, electroplating and electrotyping. Is a practical knowledge and skill in them to gotten in or out of the school? I trust the discussion on such points will be full.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, President Sprague in the Chair.

THE TECHNICAL EDUCATION OF THE ELECTRICAL ENGINEER.

BY DUGALD C. JACKSON.

Perhaps it would be well to call my subject the "College Education of the Electrical Engineer," for it is strictly of the technical college course that I shall speak. We can truly affirm that the technical education of an engineer does not end until his work is ended, and the college course is but the commencement of it. That the college course can be made a very important fundamental part of this education, is becoming more thoroughly appreciated as the work of the technical schools comes into closer harmony with the demands of the profession, and it is now generally agreed that a technical college course of the proper kind forms a valuable aid towards the success of the average young man who wishes to enter the engineering professions. It therefore becomes a matter of no little moment to so arrange the course that its usefulness will be a maximum. A few years back, a college course entirely devoted to the training of electrical engineers was unknown. At the present time there is no dearth of such courses, and their organization is progressing right and left, whence it is well to carefully consider what requirements of the electrical engineer's profession they may be made to meet, in order that no powder be wasted. It is neither possible nor desirable that the courses of study of electrical engineering students in the various schools should be alike, but a certain unity of purpose and treatment should be observed, and all can profit by the suggestions made by the practical man.

With this in view, I present the subject to your attention as it is looked upon at the Engineering School of the University of

Wisconsin. There is no originality claimed for the ideas presented, as they are based upon the recorded experience of some of the country's most successful practical men, and are virtually followed in such other engineering schools as make their courses thoroughly practical, and therefore, in the true sense, professional. I trust, however, that a discussion will arise that is in proportion to the wide importance of the subject to the electrical profession and that must result in a considerable increase in the efficiency of the electrical engineering courses in our various colleges, nearly all of which are still in process of crystallization.

In order to enter the freshman class of the best engineering schools, the applicant must have a thorough common school education, including mathematics through ordinary algebra, a fair knowledge of English, a reading acquaintance with German or French, a little elementary physics and chemistry. This can be gained in the high schools of most of the cities of this country. The high school timber (some of it quite green) the college is required to work, and to work it to the best advantage requires no little careful designing. In order that an engineer may use his abilities and training most advantageously, he should have a good general education, including a fair knowledge of literature, history, economics and certain elements of law. This cannot be expected to come from the high school, and you can readily appreciate that an attempt to give a general education in an engineering course can only result in sacrificing the good of the students by omitting essential fundamentals. Thus, to have an average chance of proving successful, an electrical engineer must be well grounded in three sciences besides those gained in the common schools, and which connot be classed as engineering. These are: Higher mathematics, as far as it may be practically applied in engineering; chemistry and physics (including elementary electricity and magnetism); and manual training. A few students enter college who have been given a fair start in these, but they are the exception. Consequently the subjects must be taught from the ground up, with a common sense view to their practical applications. Unlimited time could be given to these preparatory subjects, but it is necessary to clear them away in the actual time of two college years. With this requirement, it is impossible to give a very thorough knowledge of analytical chemistry, or of physics, but they are taught so as to give the student a good working knowledge and so that he can readily go deeper if he finds it to advantage in his future practical experience. The higher mathematics require all the time that can be afforded, especially in its last division, that of applied mechanics, where the student gets his systematic knowledge of the properties and uses of materials.

With the preparatory studies cleared away, the student must enter into professional studies in earnest, but there is little time for true engineering. The developing electrical engineer must expand his physics and his chemistry and mathematics into the laws of electro-magnetism, alternating currents, electrolysis and electro-metallurgy, and study the conditions of their numerous practical applications in engineering and the arts, each of which may demand months of constant effort before an intelligent mastery is attained. Neither can he confine his attention to these during two full years, for he must gain an elementary but practical knowledge of thermo-dynamics and hydraulics, with an efficient working knowledge of their applications in steam and water power plants. He must also get a *common sense knowledge* of the principles underlying the design, manufacture and selection of machinery.

This is a great deal to expect a student to efficiently absorb in four years, and it requires a most judicious selection in order that nothing unessential be allowed to enter and that nothing essential be omitted. Let us see how the selection is made at the University of Wisconsin. The arrangement of the fundamentals will first claim our attention.

During the first year the student is given a course of four subjects, continuing through the year. These are:—1st, English and rhetoric, with such reference to technical forms as seems desirable so early in the course; 2d, mathematics, beginning with higher algebra, passing through trigonometry and descriptive geometry, and into analytical geometry; 3d, advanced French or German, grammar and reader; 4th, manual training. In the latter, which continues during the following two years, we do not think it necessary or desirable for the student to spend sufficient time during his course to become a carpenter, machinist, blacksmith or foundryman. His future calling will probably not demand that his wages be earned in either of these trades, but they are tributary to his profession, and he must have an intelligent mastery of the tools and an appreciation of shop requirements. In order that some future day he may become a successful designer, or a useful shopman or superintendent, it may be desirable for him to take a properly arranged apprentice course in a first-class commercial shop, after completing his college course. Mathematics are also continued through the second and third year, during which time analytic geometry, calculus and applied mechanics are passed through. All mathematics are taught with especial view to future *practical* applications, and good use is made of the laboratory in applied mechanics. During the second year of the course, elementary chemistry and physics are disposed of, and here again the laboratory is put to good service. At the same time, work in draughting and the elementary designs of machines is begun. The third year is about half, and the fourth year wholly devoted to what may properly be called professional studies. The arrangement of the latter in the electrical engineering course, we will examine later.

Upon completing his technical college course of four years, an average student has spent at least 144 weeks of hard study, much of it of a practical workday nature. During this time he has been called upon to spend upwards of five hours per day in class-room and laboratories, and about as much more time in individual study. No one is likely to go satisfactorily through such a course unless he has a decided taste for engineering work, but many students find themselves capable of doing a considerable amount of extra work and yet have sufficient time for recreation to keep their health and spirits. It is well for an engineering course to stand beyond the reach of students without a taste for the work, for a successful engineer must be pre-eminently an enthusiast, while he is at the same time a candid and careful *thinker*. Those who are not fitted by nature to become engineers, are better placed in a general educational course at college, and they are then more likely to become useful to society and to themselves than if passed through the technical mill.

It may here be asked:—Of what use is the severely specialized education to the successful student in the engineering courses? The graduate does not become an engineer merely because he has successfully met the college examination. College cannot make an engineer, however practical the course of study may be. Practice has made thousands of good ones without the aid of the college, but I venture to say that these would frequently have become more eminent if they had received a thorough technical college course. While theory alone, wherever learned, can not make a practical man, it is the one who can follow the guide of theory along the paths of practical work and experience, who makes the fully developed engineer. In order, however, that neither theory nor practice may lead him astray, he must have a *well-educated common sense.* The eminent and eloquent engineer, Alexander L. Holley, well illustrated this in one of his addresses, when he said:

"Mere familiarity with steam engines is not, indeed, a *cause* of improved steam engineering, but it is a *condition.* The mechanical laws of heat were not developed in an engine house, yet without the mechanism which the knowledge derived through this familiarity has created and adapted, the study of heat would have been an ornamental rather than a useful pursuit. So in other departments. . . . When one in any art can make a diagnosis by looking the patient in the face rather than by reading about similar cases in books, then only may he hope to practically apply such improvements as theory may suggest, or to lead in those original investigations upon which successful theories shall be founded."

The true object of the technical college is here outlined. It is to teach the fundamental theories, with a common sense view to their practical applications, in such a way as to aid in a diagnosis, not by the application of a mathematical formula, but by comparing the accumulated experience of the practical world. Take two young men of equally *good* ability and equal age. Put one through a thorough technical college course and the other through an apprenticeship of the same length of time. Finally, put them side by side in a working position, where they must work out their own salvation, and the college man will usually have more ambition and adaptability, and will outstrip his mate, though perhaps not at once. The college man may fall behind at first, but, having worked through the transition period, he will prove the winner. I venture to say this is the well-nigh universal experience of those who have had the opportunity of dispassionately trying the experiment.

Another illustration of the advantage of the technical college course, lies with the designer. To design good machinery is a natural gift, and to become thoroughly successful requires long experience, in order that the widely varying requirements may each be given due weight. Proper instruction at the technical school may here do much toward stimulating an appreciation of the lessons of experience. The considerations of primary importance to be followed in designing machines, are admirably divided by Professor A. W. Smith into four:—1st, adaptability; 2d, strength and stiffness; 3d, economy; 4th, appearance. In developing the design of a machine, the practical but highly sanguine inventor often forgets all the considerations except the first. A theoretical draughtsman may figure the strength to great precision by formulas that may not fully cover the required conditions, and in the meantime forget the other considerations. When the design reaches the shopman, it must be altered to suit his views of economy, as the prime factor. A machine is thus produced that has lost part of its adaptability as designed, and has neither sufficient stiffness to properly do its work, nor a thoroughly substantial, workmanlike appearance. The economical shopman has been defeated in his object, for the machine is hard to sell or requires costly repairs at the expense of the maker. A proper college course should sufficiently broaden a man, so that he can quickly appreciate the demands of the prime considerations of practice, and will apply his formulas with common sense and moderation. If we replace our three men in the machine transaction, by men of equal experience and a technical college education of the right sort, the work of each should supplement the work of the other, and the product can be predicted, with some confidence at least, to be a satisfactory commercial one. The fault of much of the college training for engineers has been the lack of this *education of the common sense* or judgment. The result has often been graduates with as great a contempt for the practical man as the latter could return. These graduates have, it is needless to say, been a failure in their calling, and it is such men that technical colleges should not turn out. The best engineering schools desire to, and do, turn out men who have a *capacity for practical* work and research, and who are in a fair way to make useful engineers.

It is comparatively easy to properly teach the fundamental theories, hence it is so frequently overdone. It is not so easy to educate the judgment of a student in electrical engineering, whose entire knowledge of his future profession has been acquired from the electric bells in his father's house, and who may never have examined a dynamo or storage battery until he visited the college laboratories. But it is wonderful how rapidly such students, when of good timber, absorb a beginner's information and a thirst for investigation. In this part of the student's education, the manufacturers and large users of electrical apparatus, who have become directly or indirectly interested in the work of the graduates, can assist with little direct inconvenience and much indirect advantage. In a properly organized technical school, as shown above, the student gains his fundamental theory during the first three years, and, if of good timber, he will absorb much of the practical methods of thought required for successful after-work. Moreover, a considerable part of the third year is spent in practical instruction. As the fourth year is wholly spent in practical training, or the education of the common sense, the student must have some acquaintance with the methods of commercial work before entering it, in order that he may properly profit by the instruction. It is impossible for many, and doubtless undesirable for the majority, to take a year from the midst of their college course for outside work. The summer vacation between the third and fourth years should, therefore, be occupied in some such employment as wireman on electric light or telephone construction, or better, in the station and repair room of an electric railway, under the eye of an appreciative superintendent. Three months spent in this work may seem very little, but it will do a deal of good in giving an apt student a fair idea of how far exact formulas will carry him. It is only by the generous co-operation of employers that students can obtain this summer's work. At first thought it appears that the employer gains no advantage from it, but upon careful consideration, an advantage is evident. To begin with, the properly trained student will not prove useless during the summer, and the satisfactory one will usually find employment after graduation with the interests of those who afforded him summer work, and who thus gain the benefit of his greater advancement during his last year at college. In a similar manner the manufacturer gains an advantage from placing his apparatus in the technical school laboratories for *proper* use in instruction.

Suppose a student has completed the prescribed college course, and has done a proper portion of repairing armatures, stringing wires, or similar work, at some interval between his terms at college, what shall we call him? A few of the technical colleges of the front rank call their graduates engineers, but we have already seen that they must pass through a transition period, during which the claim to the title can be proved. To call an untried graduate an engineer does not seem proper respect for himself or the successful workers in his profession. The transition period may never end for some graduates, while its length must always depend upon the man. Until the graduate has been in practical life a sufficient time to show his capacity, and has reached a position of responsibility, he has no right to claim from his college an engineer's degree. Upon this ground, the University of Wisconsin, as do many others, confers degrees in engineering upon graduates of its engineering school of not less than three years' standing, who have held engineering positions of trust for at least one year. The minimum transition period is thus tacitly recognized as three years. Upon completing his college course, the student is given a graduating degree of Bachelor of Science by the engineering school, which is simply an endorsement by the University that he has received a good technical college education and is in a fair way to profit by it.

That the rigid specialization required in the technical school may not diminish the graduate's field of vision, and thus his usefulness to society, is a matter of much concern. With the college left behind, there is little opportunity to gain a broadening culture, except that received by contact with broad men, while we have seen how little opportunity for this can be afforded in the technical course. With this in view, we recommend, at the University of Wisconsin, that all who can afford the time and money complete a four years' undergraduate course in the University School of Arts and Sciences before entering the School of Engineering. By proper elections during the general course, the studies of an engineering course can be completed in two additional years. By this plan a solid educational foundation is laid for the specialized studies of the engineering student, and the best conditions are developed for his ultimate success in professional work. The plan offers two other points of advantage. First, the student comes to his professional studies in the engineering courses with a more matured mind, which is of much importance; second, students without the taste for hard engineering work, which is required for their future success in technical industries, will not often attempt a technical course after having completed a general course.

We can now usefully inquire into the specialized work that should be prescribed for the average electrical engineering student during his last two years at college. Up to this point, students in mechanical and electrical engineering courses have received virtually the same instruction. Here, we hold, with several others, their paths should diverge. The student of mechanical engineering goes into careful study of shop practice, designing and utilizing various types of machinery and similar subjects. The electrical engineering student must receive a good working knowledge of the problems of the mechanical engineer, but he must, above all, be trained in the practical problems of electrical engineering. He, therefore, goes into a study of that which will aid most in making him truly an electrical engineer. His knowledge must all be based on mechanical laws, but he must be much more than one-tenth electrical.

Before reaching his truly professional studies, the student should gain, during his course in physics, a common sense grasp of the elementary notions of electricity and magnetism and of the "all-pervading law of Ohm." The latter can be properly enforced in the laboratory by placing in the student's hands ordinary electrical instruments, such as bridges, galvanometers, amperemeters, voltmeters, etc. Before beginning his specialized work, the student's knowledge of Ohm's law and its common results should have become almost instinctive.

With due regard for his preparation, it seems best to arrange the professional studies for the average electrical engineering student in four divisions, thus:

1st. Electro-magnetism and its application to practical uses, with special reference to dynamos and motors.

2d. Electro-chemistry (including primary and secondary batteries) and electro-metallurgy.

3d. Alternating currents and alternating current machinery, including dynamos, converters, condensers, etc.

4th. The special application of the preceding divisions in electric light, power, railway, mining and other types of plants.

The last division is allotted about twice the amount of time given to each of the others.

While higher mathematics is a useful aid in each of the divisions, its limitations as an agent must be carefully set forth in the class room and laboratory. For the purpose of educating the judgment and fully defining the limitations of theories and mathematical deductions, the laboratory is indispensable. As much as one-half of the total time spent by the student under the direct instruction of the professors of electrical engineering should be devoted to the laboratory. This work, moreover, should as far as possible deal with commercial instruments and machinery, and actually follow the methods of testing and research used in practice. Physics, chemistry, mechanics, steam-engine, hydraulics, dynamos, electrolysis, alternating currents and other subjects should all be properly represented by a commercial laboratory equipment, which is made useful in everyday instruction under the direction of a man who has had experience in similar commercial work. The laboratory method of educating the student is unfortunately too little developed in many of our engineering schools, but a strong movement has begun in most schools to increase it in efficiency and amount. At the University of Wisconsin we carry the laboratory instruction as a part of the required work in every subject in which it is possible.

While the specialized course of the electrical engineering student during the last two years is largely devoted to strictly electrical engineering, he is also given proper class room and laboratory instruction in useful allied subjects, such as the steam-engine, boilers, water-wheels, laws of contracts, etc., as has been already explained.

Students who are mature and show that they can usefully specialize more severely than is done in the regular prescribed course are permitted, by election, to devote a greater proportion of their time to either of the first three divisions already enumerated. Thus, a student may have reason to know that a thorough course in electro-metallurgy will be specially useful to him. In this case, his work in the second division is increased beyond the course requirements, and his work in the first and third divisions is proportionately decreased. Other things being equal, a student who has thus arranged his course may graduate with his classmates who have followed the fixed course as laid down. In the same way, a student of sufficient maturity, who feels assured of special advantages in the field of electric transmission of power or electric railways, may increase his work in the first or third divisions and proportionately decrease it in the second.

The student who satisfactorily completes a *proper* professional course at college, whether laid down in the college catalogue or carefully elected from that prescribed, is not likely to become one who "turns out results like a cornsheller, and never grows wiser or better tho' it grinds a thousand bushels of them." In order that he may have a fair opportunity of growing "wiser and better" in the practice of his art, he should be given reasonable encouragement. As Mr. Holley one time said, an understanding should obtain—

"among the owners, directors and commercial managers of engineering enterprises that it is not a matter of favor, but a matter of as much interest to themselves as to any class, that young men of suitable ability and of suitable preliminary culture, however acquired, should have an opportunity and encouragement to master the practical features of technical education *in works*, not as mere apprentices, but under reasonable facilities for economy of time and completeness of research."

A legend on the cover of a circular lately issued by the Engineering School of the University of Wisconsin, gives the true object of the technical college, when it says, "We do not aim to produce engineers, but to produce men with great capacity for becoming engineers." If our product is accorded the treatment advised by Mr. Holley (himself an experienced manufacturer), we feel sure the work of our school and of similar technical schools will not be useless.

Madison, Wis., May, 1892.

Discussion.

THE PRESIDENT:—The two papers are before you for discussion, gentlemen. I ask that the discussion be brief, pointed and that those who have anything to say upon these papers will be prompt in responding. I take the liberty of calling upon Professor Crocker to open the discussion.

PROFESSOR FRANCIS B. CROCKER:—Mr. President, these papers have quite fully treated this very important subject, but I do not think it could be exhaustively treated short of a large volume. We are simply experimenting at all the colleges at which electrical engineering courses are given, to find out the best method, just exactly as we are experimenting in the various branches of electrical industry to find out which form of dynamo, or which form of lamp is the best. The work of this investigation can be greatly facilitated, I think, by just such discussions as these. I consider the matter is worthy of as much time as we can give to it this evening.

In regard to what electrical engineering is, strange to say, that point has been the most unsettled of all, because such men as Sir William Thomson and one or two others have stated very definitely—in fact, in mathematical language—that an electrical engineer is *not* an electrical engineer. They say he is nine-tenths mechanical engineer. When I entered into the profession of teaching electrical engineering, I took the stand that that was not true, and could not be true. I have no occasion to regret having taken that position. We all know that an electrical engineer has his hands full to know even a part of electricity. I would turn the figures around. Instead of spending one-tenth of his time learning electricity, I consider that the time has come or will come very shortly when men will have to specialize in electrical engineering; and that entirely disposes of the idea that a man can be nine-tenths mechanical and one-tenth electrical.

No one appreciates more than I do the importance of the mechanical side of electrical engineering. But I claim that it is incidental: it performs exactly the same function and occupies the same position as mathematics or chemistry. We must know these subjects in order to be finished electrical engineers. It is a necessary part of the profession, but the problems that present themselves are primarily electrical. I have only to refer to the papers that have been read before the Institute at this meeting, almost all of which are electrical. Look over our programme, and you will find that nine-tenths of the papers are electrical, which is certainly proof of what I say.

In electrical engineering we do not have complicated mechanics; we have simple rotary motion in most of our apparatus, and we have reason to thank heaven that such is the case. If we had reciprocating motion, the mechanical engineering of which is infinitely more complicated than uniform velocity, our problems would be correspondingly complicated, and it is largely due to the fact that we have simple mechanics, that electrical engineering is so successful. Ours is a sister science to civil engineering, to mining engineering, to mechanical engineering. Each one of these borrows from the others, but each is independent.

Now, in regard to a course of instruction in electrical engineering, I agree with Professor Owens and Professor Jackson very thoroughly, that a man must have a taste for the subject. It is absolutely essential, I think, that a man should be born for it, and the course should be so designed that the man who is not cut out for the profession will find it out, and will give up the attempt to be an electrical engineer.

The preparatory course should be simply a first-class high school education, carried as far as possible. At Columbia College, we are trying to raise our standard, at the lower end as well as the upper. That is one way to get around the difficulty of putting so much in a short time. Instead of beginning at sixteen or seventeen years, as stated in these papers, we do not allow a man to enter until he is eighteen or perhaps nineteen years of age, when he is supposed to have pretty well mastered the elementary subjects in mathematics, and so forth, and to have really begun on higher work. The first two years of the course, as both papers have stated, are largely preparatory. They are spent in going further with mathematics, chemistry, physics, mechanics, particularly laboratory work in chemistry and physics, and bringing the student right up to the point where he can begin the truly professional part of the course which is carried on during the last two years, and can be completed pretty thoroughly in that time, provided the preparation of the first two years has been substantial. That has been my experience. In fact, I will guarantee that in two years I can make an electrical engineer out of a man who has been thoroughly over those preparatory subjects, provided he has the taste for it. That is a short time, but it can be done with first-class preparation. By an engineer I do not mean an experienced engineer, but one who is thoroughly familiar with the subject, and more familiar with it than the practical electrical engineer. His general knowledge is far superior to that of the average electrical engineer in practical work. But, of course, his experience is much less extensive. That is the principal difference between them. After a few years, he has not only the scientific and general knowledge, but the practical experience, the combination of which makes the finished and really valuable electrical engineer.

I agree with Professor Jackson heartily in his strong recommendation of the education of common sense. The mere teaching of principles is not enough. A man must be taught to use his judgment, and he can be taught to do so. You can put a man through one course where the principles are perfectly taught, but very little of the practical or common sense part is given, and the result will be that he is a good abstract thinker, perhaps. You put the same man through a course where at the same time he learns the principles, he also acquires common sense and judgment, and he will be a first-class, useful man. I claim that the college can turn out a man who is useful immediately, but of course not a finished, experienced engineer.

The papers, I say, are so satisfactory that all I can do is to endorse them. The points that I have given are the ones that occurred to me as being particularly important.

The President:—I think that the definition which has been given of the electrical engineer may, from practical experience, perhaps be slightly varied so as to be as follows:—One-tenth electrical, one-tenth mechanical and eight-tenths I don't know what.

I have been in the unfortunate position sometimes of having a great many people come to me for employment. Some of them have been young men fresh from technical schools—not those which pretend to give an electrical engineering education, but which have been sending out great numbers of graduates with no special electrical training. Oftentimes they seek employment in electrical work because it seems to them to be the coming profession. The first question I generally asked them was:—"Why do you want to go into the electrical field? Have you any particular fitness for it?" "Well, I have worked with batteries, I have put up the bells at home and I like to use the telephone." "That is a somewhat restricted training for an electrical engineer. At what school were you educated? Have you had a common school, high school or collegiate education? What was your principal bent? Have you mathematical tastes? Have you studied differential calculus and, if you have, do you still know that two and two make four?" [Laughter.] After I had learned something about a man in that way, I asked him:—"Have you mechanical tastes? What salary do you think you would be able to earn when you start out? Are you aware that the average man, when he enters into the electrical field will do his employer more damage, unless he is reasonably well trained before he starts, than he can possibly earn in salary the first year?" For I oftentimes had in mind an experience which I once had with a technical graduate, now happily successfully filling an important position. He watched a motor with its commutator and brushes going to destruction as rapidly as possible, because he didn't have the knowledge to move the brushes to the neutral point. I watched him about five minutes until my ire began to rise and I had to unbosom myself. That was simply because he had not had that preliminary instruction which one single week in any respectable technical school should have given him. He was not a handicraftsman, in any sense of the word, and he certainly was not an electrical engineer.

After I had learned something about a man, if he looked promising, I would say:—"Now, when you go out on the road, you will run across a number of men, perhaps younger than yourself, who have had more or less of a mechanical training. They have not had the advantages, perhaps, of a technical school such as you have been in, but they have been in the shop; or if they have been in an ordinary school, they have been for six months or a year getting practical experience under a clear-headed superintendent of an electric railway. Are you willing to go in there and put yourself on the same level with, or below, them, take off your coat, get on your back in the pit, underneath a car, and hustle?" When a man said he was ready to do that, was anxious to start in and did not expect an exorbitant salary, and realized that the experience he was going to get in the first six months would probably be quite as valuable to him as the work he would do would be to his employer, I concluded there was something in him.

Now, going back to the training which I had to go through some years ago in the Naval Academy, at Annapolis. I find that there is there a course of instruction, as there is also in the Military Academy at West Point, which, it seems to me, carries out in a practical way some of the results which may be attained in a manual school, in schools for handicraftsmen. A man to know how to teach another man to pull a stroke oar, must get on the stroke oar himself; to be safe on the quarter-deck, to give orders for reefing a topsail in a gale of wind, he must himself have reefed a topsail in a gale of wind. To know how to tell a man to ease a weather sheet or to work the running gear of any part of a ship, he must have had the practical experience on that same gear. He cannot instruct his men properly, he cannot command them safely and efficiently, unless he has been through three or four years of hard, practical experience, hand-in-hand with the men in the forecastle. The same thing is true of electrical engineering. No man is fitted to be superintendent of a road or works, no man is able to carry on large engineering operations, until he has had the practical experience and the necessary education which fits him to pass judgment upon what will be the results of the directions which he may give to others.

MR. LOCKWOOD:—Mr. President, it has been a source of pleasure to me to see that you yourself appreciate the importance of a full discussion of these very valuable papers. I am especially obliged to you, sir, for your definition of the term "electrical engineer." I may perhaps be pardoned if I add to that definition the reason that it came to be so universally used. After the first race of electrical men had to some extent outlived their usefulness, there sprang up another, a mushroom generation, who advertised themselves as electricians. They were not electricians in any sense of the word; they were not even medical electricians. [Laughter.] They were mechanical bell hangers who had appreciated the necessity of being in the swim, and who had therefore added electricity to their former means of obtaining a livelihood. But they so universally called themselves electricians that the word fell into some disrepute, and therefore it was necessary to coin another and more euphonious one. And thus it came about that before we had any institutions for learning in that line, we had electrical engineers.

With you, sir, I am extremely obliged to the authors of the papers now before us, because I think, in the first place, the subject of technical education has been by this Institute in some measure neglected. It seems to me that education should be the pursuit of every man's life, from its beginning to its end, therefore being a life work. Education, as I think every gentleman present will agree, is not a mere matter of the four or five, or perhaps ten years that we may spend, first at the common school, then at the high school, then at some academy or college, and perhaps by and by in a technical institute. If a man concludes that his education is finished when he leaves the institution where he is being drilled and fitted for practical life by his preceptors, I hardly think that the education of that man as far as it had gone, will be worth anything to him or to any other member of the human race. It does seem to me, therefore, that any paper which calls our attention to the importance of education, and especially such education as is discussed in these papers, deserves our hearty thanks.

Having said so much, perhaps I may be pardoned if I say a few words regarding the papers as they were read; not page by page, because that would take too long, but by reference to certain points to which my attention was especially attracted. In Professor Owens' paper I notice that on the first page he speaks of the rather premature assertions of some mechanical engineers whom he mentions. It seems to me that, even setting aside the fact that those assertions were not founded on fact, mechanical engineers had very much to do with electrical engineering, as we know it now, than had either civil or mining engineers. For if we look at the poles, outside wiring and cable running, or anything of that kind connected with outside construction and the construction of conduits, it seems to me that that is very much more the work of the civil engineer than of the mechanical engineer. If we look at the appliances for the utilization ef electricity in which ingenuity is manifested, there the mechanical engineer plays his part. But when we come to the construction of conduits, it appears quite proper that we might class it as the work of the mining engineer. [Laughter.]

Passing on to page 464, I find that he says, near the top of the page: "Between the scientist and skilled mechanic, or handicraftsman, is the engineer—the man who, familiar with the results of scientific investigation and methods, uses both, by the help of the mechanic's skill, to minister the more effectively to the wants and will of an ever increasingly exacting public. To him alone we look for the solution of the problems of transmitting and distributing the power of waterfalls and fuels, the tunneling of our mountains, the building of our railways and steamships, as well as the more delicate work of flashing out thoughts and words from town to town and from continent to continent. This field of work is so vast that of necessity it must be divided among specialists and sub-specialists." This statement may be true at the present day—no doubt it is partially true—but in this connection it seems to me to be proper to point out that it is not necessarily so. During the early part of my career with my present employers. I had as an assistant a gentleman who had been a professor, or partial professor, at some institute, and the one thing that he seemed to have thoroughly learned the power of saying, was "Not necessarily," when a proposition was put forward by that part of the inferior human race that we call "the practical man." There was not a single thing that was put forward by myself or any other gentleman there, but what he would at once give utterance to the shibboleth "Not necessarily," after which he would proceed to prove why it was not necessarily the case, and then would finish by following my way of doing it.

In this connection, I would say that I do not think it is alone to the skilled engineer, who is most familiar with scientific investigation and methods, that we look for these great achievements. That is partially disproved by the history of the lives of such engineers as Metcalf and MacAdam, the road makers; Stephenson, the railroad builder; James Watt, who made the steam engine what it is; Telford, the bridge and canal builder; and Brindley, who made the first modern canal—these were all self-taught men who did not regard their education as finished when they learned to spell "cat," but who carried on their education all their lives.

Professor Owens says that schools are far more efficient in developing and training youth than the best-managed mill or shop. With that statement I most cordially agree. When I was thirteen years old I had to go to work in a machine shop in Birmingham, where I was to remain for seven years. Fortunately for myself, I left when that term lacked three years of its completion and three years of the four during which I worked there, I was drilling holes in iron plates. It was a foot drill which I had to work, and I think had it not been for that hard work, I might have been three inches at least taller than I am to-day.

At this time in the history of electrical applications, I think we must all agree with the statement that the time was, when it was possible for men to be generalists in electrical science and electro-technology, but that time has passed. That part of the science which relates to electro metallurgy alone is enough for one man. Telephony is enough for one man; telegraphy is enough for one man, even with but one company in the United States. Although the Western Union Telegraph Company does not now depend largely upon electrically educated engineers, the time is coming and is not far distant, when it and all other companies must employ educated men or must fall behind in the race. [Applause.]

As we heard last night, there is so much to be done and so few people at present to do it, that there is enough in the field for all the first-class men that we can get for at least the next ten years. The way our colleges and schools have been run in the past is, that they usually send out men with such exaggerated ideas of their importance that they want $5,000 a year for their electrical energy, and they haven't got very much of it at that. That leads me to ask what I regard as a pertinent inquiry:—Will it be possible for all these engineers who so far have been educated to this point in the schools, to find sufficiently lucrative employment? And would it not have been better, for many of them at least, to have been educated in pharmaceutical establishments and turned out as druggists? [Laughter.]

Professor Owens says that besides mathematics, chemistry and physics, which must be considered as proper subjects for the course of preparation, German and French must be acquired, "as so large a part of our best electrical literature is in these languages." Yes, I think there is no electro-scientific man who can afford to dispense with German and French. Some of our best periodicals are written in German and French to-day—and some of the others might as well be. The professor says:—"German and French should be acquired, as so large a part of our best electrical literature is in these languages." Then I find a phrase that is rather mystifying to me, namely:—"Sanscrit and psychology might be classed as electives affording variety." At first I thought that was written seriously. I had some conversation this afternoon with the distinguished authors of both of these papers, and in the course of the conversation, one of them, I do not remember which, remarked that Maxwell was a great author. and that a great many things which were coming out as new to-day, were to be found in Maxwell, and it was further stated by one of the party that there were a great many jokes in Maxwell, if people could only find them. And that remark, with what I have heard to-night, convinces me that the gentleman who wrote this paper was having a quiet little joke to himself. I have not the slightest objection in the world to jokes, but would suggest that to these elective studies the gentleman may very properly add the study of Volapuk and Christian Science. [Laughter.]

Upon page 473, in the third line of the page, is something which recalls to my mind an incident that is related by Sir Edwin Arnold, when in Boston, of a visit to the Zoological Garden. He said that while he was visiting the Zoological Garden in London, once, he listened to the conversation of some of the people who were looking at the animals, and he heard a little girl ask her mamma "if she thought it would hurt the elephant if she offered him a chocolate drop." In the same guarded and respectful spirit, I desire to call attention to the third word in that line, on page 473, "capitalization," by which it appears that Professor Owens has not neglected that important part of the electrical engineer's education. Capitalization has, of course, been one of the most successful branches of the profession, and any electrical engineer of the latter part of the nineteenth century who does not know how to capitalize a large company upon a carbon brush, is hardly worthy of notice. [Laughter.]

Briefly referring now to the paper of Professor Jackson, I noticed something which struck me rather forcibly, and that is that the engineer to be successful must be a trained and careful thinker. I believe it is the lack of independent and careful thinking which keeps us—I was going to say as far behind as we are in the attainment of knowledge, but I would rather say—no further advanced than we are in the attainment of knowledge. When I was a very small child, certainly not more than ten years old it was my fortune to fall upon a book entitled "Learning to Think;" and what little success I may have achieved in life, I regard as being largely attributable to my perusal of that book, because it led me to think upon various subjects in many ways, and I think it taught me to think with some degree of vigor and independence; and I hope that the school and college training of our young men, whatever else it neglects, will not fail to teach them to think for themselves—to teach them at all times to put to themselves—no matter what they may be studying—the question represented by the little monosyllabic word "Why?"

It is impossible to put everything in a paper, or even in two papers, but I was a little surprised that there was not any mention of the literature which students of electricity and electrical engineering might profitably peruse. It is not an easy thing to direct a course of reading, because the literature of the subject is changing so rapidly that what is new to-day may be old to-morrow, and certainly what is now before us was not in existence as long as ten years ago. Ninety-nine one-hundredths, at least, of the books which have been written upon electricity, magnetism and electrical science might just as well never have been written, except for this one thing—that while they were new they served the purpose of keeping alive interest in the art and science, and thus helped to give us those wonderful discoverers, Ampere, Arago, Oersted, Faraday, and many others too numerous to mention, all of whom were careful thinkers, great readers and intelligent experimenters. And I say to every one who has the care of those who are still studying, "Not only should you teach them to learn to think, but to learn to read, and, above all, to ask questions of nature by experimenting."

DR. EMERY:—Mr. Chairman, I had fully determined not to say anything this evening, until the remarks of my friend Lockwood caused me to change my mind. I think that each of the engineering societies should avoid the assumption of superiority which is evinced at times by some members of particular organizations, the architects, perhaps, being the greatest offenders. I belong to all the principal engineering societies, and have unfortunately heard such remarks in nearly every one of them. I do not think there is really any such feeling among the better class of members, but some are incautious and choose such language as they think will please some of the persons assembled. Evidently, therefore, the language should never be repeated in other circles. There are individuals who would reduce the members of all other special professions than their own to the plane of artisans, because solicited to use their manufactures or brains, while perhaps the very person who thinks himself superior is the most skillful in making himself "the servant of all" among rich families "that he may win the more." An assumption of superiority can only be sustained by an organization like the Institution of Civil Engineers. In England all the engineers of reputation, from all branches of engineering—civil, mechanical, electrical, sanitary and otherwise—must belong to the Institution to have a good standing. That arises from its age, from the high character of its work from the beginning, and especially the high standing of its members of all grades. Full membership is given only to those who have actually done practical work for a considerable period, not to those who have theorized upon it, or who are going to do it, but the latter can generally enter other classes of membership and be heard by all. I was very much pleased with the remark of Dr. Duncan, at our annual dinner, in which he urged that there should be no antagonism between theory and practice. One is a necessity of the other. It is only the ignorance of the one class of the value of the work of the other, that makes it possible for remarks to be made, such as are sometimes heard. We must have those with the brains to conceive, and those with the muscle to execute. Knowledge is power, but its foundation is the practical work of others. It is well to think often of the legend in which King Solomon is said to have assembled all the workmen, at the completion of the temple, and asked which was entitled to greatest honor, when the dirty blacksmith stepped forward and took his position on the right, and when the cutters of the massive but beautiful stonework disputed the propriety of his action, the blacksmith asked what they could have done if he had not made and mended their tools. On the other hand, we may say that those who study principles and develop theories to be applied by others, really aid in the march of civilization. They should, however, claim no superiority for this, as there would have been none to civilize if the brawny sons of toil had not perpetuated the race. In the stone age our ancestors were but animals, using the advantages which reason gave them to conquer other animals on land and ensnare those of the sea, but reason and necessity taught them to work with their hands in cultivating the ground; and in seeking tools, the earth was robbed of its various treasures; and by combined manual and mental labor, civilization was developed and we were brought from the stone age to that of electricity. Now, all must be considered workers and each has his place. He that has the most skill and the most knowledge which can be usefully applied, is strictly superior, but one whose information is entirely in one branch of engineering, may be excelled by one who knows as much of that branch and much also of other branches. Much knowledge or superior skill should, however in all cases bring due modesty. Again, with Dr. Duncan, I say there should be no antagonism between theory and practice; there should be none between the different branches of the engineering profession. Any assumption of superiority is unseemly. and all branches of the profession should co-operate in the general advance to a higher plane of civilization. At the same time it may be entirely proper to believe and state among ourselves that in the field of electrical engineering there promises to be a greater opportunity than in any other, for the utilization of all branches of engineering for the benefit of mankind. [Applause.]

PROFESSOR ROBERTS:—Mr. President, I wish to quote a remark made by Professor Coleman Sellers, whom I had the pleasure of hearing speak on this subject the other day. He said that he had been investigating the technical schools of Europe, when he was over there recently for the Niagara Falls company, and he decided that the technical schools of this country were in some respects better. If I recollect correctly, he was judging from results along the line of independent thinking which Mr. Lockwood spoke of.

I was going to ask our President to speak upon the subject which he has just touched upon. We also have Mr. Upton with us, and he certainly has had to do with a great many of the technical school graduates. I think the graduates should be advised not to go to the large shops, but to go to small first-class shops that do all-around work—go to some small constructing company or small repair or manufacturing company—and get their all-around experience there, and then they will be of more value to the larger companies. I know how it is with one or two of the larger companies, and I think it is the same with a great many others, that it is difficult to find any position where they can even earn anything for the company, until they have gone through some such course either in the works or out of it. They are shoved off to one side to do routine work until they have grit enough to go out and take hold of the dirty work and then come back. The gentleman by my side thinks that Mr. Lockwood left out one branch of engineering—sanitary engineering—which could be utilized in ventilating armatures.

THE PRESIDENT:—I do not know but he left out another branch of the profession, that of entomologists, or bug hunters.

MR. LOCKWOOD:—I have no doubt, Mr. President, that I did omit some of the branches, because I did not undertake to go through all the sciences.

MR. UPTON:—Mr. President, Professor Owens asked me if I would not make a remark on his paper. I, of course can only speak from one point of view at present, and that is from the standpoint of the employer. In the company with which I am engaged, the question has often come up, "What use shall be made of the graduate?" And I have had some little experience with men coming to me and asking for advice. I have given them the advice as suggested by Prof. Roberts, to go into a small shop first—go into some repair shop, in a small town, where they can learn a great many parts of their work, so that they will get experience. The trouble with the large corporations is that the work is subdivided. They have men in the large factories who sit in darkness year after year, repeating one operation. I know one man who for nine years has been doing one operation in darkness. He earns his living there, it is true. It is sad to see a man laboring under those circumstances, with no possible opportunity of learning anything but the one operation that he is kept at, and we have got to look to the technical schools for men trained in different branches of the business. Take Schenectady, for example. Everything there to-day is divided so that each man performs one operation, and of course he becomes very skilful at it. I would say to the technical schools that they should bear in mind one thing, always to exercise and drill their students in the rudiments of the art. I do not think there is anything more useful to a man in ordinary electrical work than to know Ohm's law, when twisted around in every way it can be. I have known men, who came out of technical schools, who could not tell you anything about the multiple arc, nor could they answer two or three simple questions about Ohm's law. I think the students should be so trained in these things, exactly as children are trained in mental arithmetic, that they become part and parcel of their mental make up. I do not think anybody can deal with alternating currents to-day, unless he is well up in mathematics. I have given up the study of alternating currents, though I had an excellent mathematical training, because I haven't had time to follow it up, and I have had to drop it except upon the mere theory of alternating apparatus. It is not in my line. Of course my line is specialized, but I consider myself a sufficiently competent judge of literature to be certain that the technical schools must carry a man well up in mathematical and technical training to make him master of that part of the art.

Another thing which I would like to add, the progress that is now being made in electrical work is being made in the United States, and it is being made by men who are in this Institute of Electrical Engineers, and I think that any man that takes a broad view of progress will say that a meeting like this marks an important advance in electrical knowledge. There are many things brought out here, many things entrusted to your hands, and that are being given to us here, which are ahead of anything in the world. The foreign papers do not compare with ours. Progress in the alternating current is being made in this country.

I have been pleased with these papers, and especially with the purpose that has been evinced by them to put the students in a position to be well-grounded in their chosen profession. I think the students should be given a post-graduate course and should have special instructions to fit them for the requirements of the different sections of the country.

Mr. Perry:—Mr. President, with Mr. Upton's last remark I most fully agree, in regard to the education of the engineer whether he be an electrical engineer or other engineer, that our object should be to give him breadth. School education is to my mind a preparation for future education in practical life. The broader we can make that education the more useful have we been in the instruction of the to-be-engineers. It is not long since, that a man was not considered liberally educated unless he had spent a number of years in the study of classics, but the views of educators have changed very radically during my time. Now for a man who is to enter the engineering profession,—time is limited as we all know,—how can we in that limited time give him the broadest education possible? It seems to me if we could devote our time to but one study that there is none that could give us such a broad foundation for any scientific pursuit as that of chemistry; and in both these papers this evening the study of chemistry is a part of the course recommended to the young engineer. It is practically significant in the electrical profession just now, since in our profession we are turning our attention to molecular action. We have an explanation of molecular magnetism by Mr. Tesla, and of the molecules striking each other to give us light. We hope the time will come when we can produce light without heat, as the fire-fly does.

Then there is another branch of the electrical profession which is very important. I refer to metallurgy. A man without a thorough knowledge of chemistry cannot hope to do much in metallurgy. It seems to me that to make metallurgy even a subordinate study it is necessary to give chemistry as full time in the course as possible.

Mr. Bradley:—Mr. President, the gentleman speaks of chemistry, but I will say that I should think general physics would cover the subject and cover it better, a good understanding of general physics. Chemistry then comes under that head, and a man must necessarily understand it.

Mr. Upton suggested an idea to me when he said that he had to drop out of the consideration of the alternating current. I am dealing with questions of alternating currents myself, and I am not educated in higher mathematics. I have an assistant who is pretty well educated. I think that I am able to form a pretty correct idea of the actions that take place without the use of any great amount of mathematics. I think I can get it in my imagination and I have done it oftentimes, because I could not do it mathematically, and if I had mathematics it would be in my way. That is the education that makes of it what the general public can use. We think of the wonderful things in connection with electricity, and we think of electricity as being a profession now. In a few years it will be within the knowledge of the general public.

My two boys, one is twelve and the other is eight, and there are some things that they know about it that I haven't thought of. They fooled with the lamps and broke the carbon by scuffing their feet over the floor, and got their bodies charged, and all such things as that they are trying. They know more about electricity now than I did at 25 years of age; they understand it better; they have got the theory more thoroughly in their heads than I had at that time. Now I think that the boys or young men growing up ought to get an education without taking the regular course. Of course the selective studies are a great advantage, they help a great deal. It is a step in the right direction, but it does not go far enough. Our boys ought to have a chance to get a galvanometer and work with it. I actually believe my boy in a year's time will handle a galvanometer, if he is allowed to. Of course there are lots of them that won't do this, unless they take naturally to that direction. It makes all the difference in the world whether a child naturally inclined that way. If he had a chance and takes a great interest in astronomy, for instance, and goes up and watches the professor in the observatory, he would gather a great many ideas. Give him a chance at the observatory. That is what we want. It is a bold idea, I know, but that is what we want. If there is danger of their breaking it, they can be watched the more carefully. I often think if I could take two or three boys and bring them up and attend to their education and pay no attention to anything else whatever, I could fix them in ten year's time so that they could earn so much more than I can, that it would pay in the long run to apply one's time and attention to it. [Laughter.]

PROFESSOR JACKSON:—Mr. President, Mr. Owens states that he does not care to reply. I have no reply to make, except to thank the various gentlemen who have taken part in the discussion. Their recognition of the advantages of an engineering education is very gratifying.

I wish to add a remark to Lieutenant Sprague's definition of an electrical engineer, that he should be one-tenth mechanical, one-tenth electrical and the rest he didn't know what. Dr. Nichols says the rest should be man. I want to add to that, what is left should be good, manly common sense. [Applause.]

I want to especially thank Mr. Lockwood for his remarks, which were evidently very pleasing to us all, and I want to assure Mr. Lockwood that we consider one of the necessities of an electrical engineering course is to teach the students how to read technical journals without wasting too much time, and also how to make references to current books of the day which it is impossible to thoroughly read but which must be used more or less.

I also wish to thank Mr. Upton for his recognition of the necessity of practical instruction in engineering education. I feel that the practical is demanded at the present day. The theoretical side has been developed. I do not think it is necessary for an electrical engineer to be able to read Maxwell through all its parts. I would scarcely claim that distinction myself. In fact, there are very few pages in Maxwell that would be enjoyed as reading matter.

As to the question of shop apprentices, I think it is well, under certain circumstances, for a student to enter a properly arranged apprentice course in a first-class commercial shop. The size of the shop may be of little importance, but if it is not *first-class* the student will probably be wasting his time.

Finally, I want to say a word about our universities. If a man comes to a university with the view of learning something special, and doing good work, and making use of what he can learn, he will receive every attention and fully as much assistance as any man who takes the regular prescribed course.

The following paper on "A New Rheostat" was then read by the author.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, President Sprague in the Chair.

A NEW RHEOSTAT.

BY CHARLES E. CARPENTER.

It is a well-known fact that an insulated wire suspended in the air, will carry a given amount of current at a lower temperature than the same wire without this covering of insulation under the same conditions. This is obviously due to the fact that while the cross-section of both conductors is the same, the one which is insulated has a much larger radiating surface than the bare wire, and therefore dissipates the heat conducted through the insulation more rapidly. Suppose, for convenience of illustration, we conceive a conductor to be first covered with some insulating substance, and then enclosed within a metallic tube so that its insulated surface shall fit perfectly within and against the inside surface of the tube, as shown in section in Fig. 1. We thus have a comparatively small conductor with a largely increased radiating surface, and the insulation between the two metallic bodies does not materially obstruct the flux of heat from the conductor to the outside metallic shell.

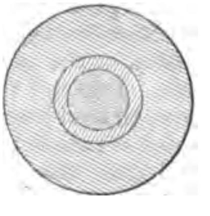
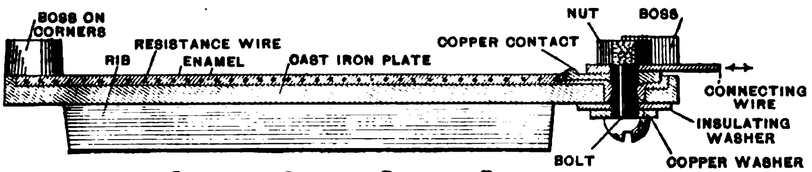


FIG. 1.

One of the early experiments of the writer in electric heating —in fact, his first successful apparatus—consisted of two iron plates, between which was interposed an iron resistance wire of the "reflex" or "zig zag" type insulated from both plates by means of thin sheets of mica or asbestos paper, with screws passing through one plate and engaging the other. By this means the plates could be pressed into close relation to the resistance wire. By connecting this apparatus to a constant potential system, the current at first would be comparatively large, but would gradually decrease as the temperature of the plates increased until a point was reached where the heat was dissipated as fast as generated. By tightening or loosening the screws, the current could then be either increased or decreased. This increase of the current by increasing the mechanical pressure is due to a reduction of temperature effected by the more intimate heat conducting relations between the resistance and plate, facilitating the flux of heat.



SECTION OF STANDARD RHEOSTAT PLATE

FIG. 2.

The better the conduction for heat is made, the less will be the difference of temperature between the wire and the outside radiating surface plate, and it follows that the larger the surface of the radiating plates which are closely impressed upon the conductor, the larger will be the current-carrying capacity of the latter.

These experiments are cited as an illustration leading to a thorough appreciation of the extent to which the current capacity of a resistance wire may be carried, as it is upon this principle, but with modifications of construction, that the new and improved rheostat herein described is based, that is, a resistance wire of small cross-section is used, but a large radiating capacity is secured by placing the wire in such relations to a metal plate as to practically increase its radiating surface to a very great extent.

The results of the experiments described above suggested a modified form of construction, one in which the resistance would be entirely covered by a medium which would protect the wire from oxidation and yet act as a good insulator of electricity and a good conductor of heat, and which will permanently attach the wire to, but insulate it from, a radiating plate. A special enamel was finally found by the writer to be suitable for this purpose. A section of this construction is shown in Fig. 2.

The injurious effect of linear expansion of the resistance wire, due to heat, is avoided in this method by the "reflexed" or "zig-zag" form in which the wire is bent, as shown in Fig. 3, and it has been demonstrated by experience that this linear expansion is thereby so distributed as not to injure or crack off the enamel in practice.

On this principle, since we are able to greatly reduce the cross-section of the conductor, it follows that its length is also proportionately shortened for any required resistance, and no consideration of mechanical strength of the wire enters into this construction, since it is so perfectly confined and supported on all sides.

Practice has demonstrated that 20 watts of electrical energy may be dissipated continuously to each square inch of resistance surface, without injury to the apparatus. However, on account of the excessive temperature of the plate used in close proximity to the other materials, it is not practicable to dissipate over 8 or 10 watts to the square inch in continuous service.

By placing one surface of the plate in contact with water, so that its heat is dissipated in this manner, we are able to continuously dissipate about 25 watts to the square inch. From this it will be seen that by means of water we are able to increase the capacity of a certain plate to about three times that of the same plate dissipating its heat directly into the atmosphere, or we may decrease the size of the plate to one-third for the same capacity where water is used.

In many applications, especially in railway work, apparatus is often subjected to a load far beyond its rated capacity. Rheostat plates for such service are made with narrow ribs, between which the resistance wire and enamel are placed. It is found that by means of these ribs, the safe carrying capacity of a wire is greatly increased, while the ribs serve also to protect the insulation and wires from mechanical injury.

In adapting this construction to meet practical requirements in its several applications, it is necessary to alter only in detail the general construction and distribution before explained, and shown in Fig. 3, which shows the usual plan of distributing the wires in a simple rheostat plate. Connection to the resistance wire is made by means of a sheet copper contact strip, one portion of which is folded back upon itself, and after inserting a portion of the wire this sheet copper is crushed about it. The joint so formed can not oxidize, since it is completely sealed by the enamel fused about it.

To divide the resistance so formed into steps, it is only necessary to place contacts for connection to the resistance wire at convenient points where the loops approach the edge of the plate, as at *a*, and so on, in Fig. 3. This particular way of locating the connecting points on one side of the plate is especially convenient in using these plates with small motors, where only few steps or divisions of the resistance are required. A modification of this

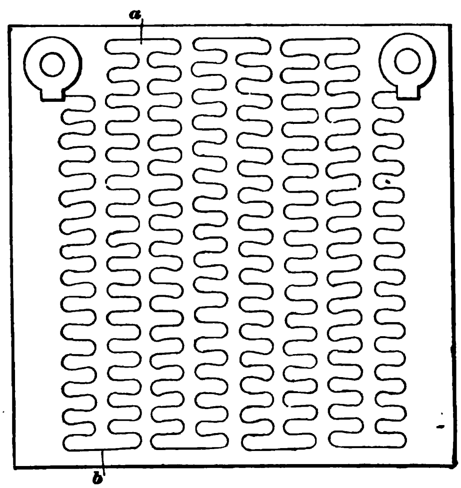


FIG. 3.

arrangement is to have the connecting points alternate from one side of the plate to the other, as at *b*, *a*, etc., Fig. 3. A distribution best adapted for stage or field-controlling rheostat, or one in which a great number of steps are required, is secured by arranging the resistance in a similar manner around the entire outer portion of a disk with contact connections near the circumference. Another arrangement is required in a plate of low resistance and high ampere capacity. In this case, several coils are placed in parallel and connected to a common contact piece.

The plates, with their coils and contacts distributed as above described, are well suited for use in connection with rheostat switches. They are provided with ribs or blades for extending their radiating surface, and lugs at the corners for convenience in attaching them to the back of the switch. Each contact of the resistance plate is connected by a very short wire or strip, to the corresponding contact piece on the rheostat switch.

A very simple and complete rheostat is made by placing the switch contacts and lever, properly insulated directly upon the radiating plate, on the surface opposite the resistance face. With this arrangement as shown in Fig. 4, a rheostat is obtained which is no larger than the switch parts alone of existing rheostats.

To make a single plate large enough to dissipate the energy

FIG. 4.

wasted in the rheostat in starting a large motor, would make it necessary to have a surface so large as to be objectionable. To avoid this difficulty, a number of plates of, say, 10 inches square, are placed in parallel with each other, but separated by sufficient space to admit of proper ventilation, and connection made from the switch contacts to the contacts upon the various plates as required With this arrangement, a rheostat of very large watt capacity may be placed within a small cubic space.

This form of rheostat, by reason of its compactness, is well adapted for use with arc lamps on constant potential circuits. In this application, the resistance plate may be attached directly to the outside of the casing, leaving just sufficient space between the casing and the plate for ventilation. Where the casing is cylindrical, the plate may be disk-shaped and placed on top of the cylindrical casing, with holes in the plate for the hooks and chimney to pass through. A valuable feature of this rheostat in this application is that it will endure exposure to the weather while in use. As an example of this, the writer knows of a case where one of these plates has now been in use on a pair of lamps for over seven months, where the plate is in a horizontal position, with the enameled side up and water dripping upon it continually.

In some places the heating effects of rheostats should be avoided. For example, in stage controllers, 5 to 10 kilowatts continuously converted into heat is extremely objectionable in warm weather. This may be remedied by conveying the heat away through the agency of running water. To accomplish this the resistance plate may be hollow, with inlet and outlet pipes connected directly to a source of water supply. By this means and with proper circulation, the plates will always be comparatively cold, and no sensible amount of heat will be given off to the surrounding atmosphere, while the size of the apparatus is so reduced as to occupy no considerable amount of space.

It is evident that numerous modifications of this general design may easily be made to adapt the apparatus to the requirements of practice.

The following facts are true regarding this form of rheostat:

1st. It is fireproof, as no combustible material enters into its construction, and it can never be submitted in normal use to a temperature so high as that towhich it is subjected in the process of manufacture.

2d. It is durable, since the resistance wires cannot deteriorate from oxidation, electrolysis, etc.

3d. It is compact, as it requires less than 5 per cent. of the cubic space required by the ordinary coiled wire rheostat of the same capacity.

4th. It is simple, the three necessary elements, resistance wire, insulation and radiating surface plate, being fused into one integral mass.

5th. It is cheap, for a certain resistance and carrying capacity can be obtained by the use of a wire whose cross-section and length will both be but one-tenth of that required for a wire used in the air. That is, the total weight of wire, and hence the cost of the same, will be but one per cent. of that usually required.

6th. It is unaffected by heat, cold, acids, alkalies, oils and other chemicals, and for this reason is especially adapted for use in mines, breweries, marine vessels, etc., where chemical action rapidly destroys ordinary insulators. It is even practicable to operate these plates submerged in flowing water, in case it is desirable to carry off the heat in this way.

Another and important application of this method of converting electric energy into heat in a compact form is for the operation of various heating devices.

The requirements of a commercially successful electric heating device are:

1st. The concentration upon the working surface of the apparatus, of practically all of the heat produced in the resistance, thus preventing as far as possible the dissipation of heat by radiation or conduction to other bodies or parts than those it is required to heat.

2d. The ability to rapidly supply a large amount of heat energy from the resistance to the working surface, through a medium having a high conductivity for heat, thus keeping the working surface at the proper temperature even when a large amount of heat is rapidly drawn from it.

3d. The protection of the resistance wire from deterioration by chemical and electrical action, so that its life shall be indefinitely prolonged.

All the above requirements are fulfilled in this device.

DISCUSSION.

THE PRESIDENT:—Gentlemen, you have heard Mr. Carpenter's interesting paper. I am sure those who have had anything to do with rheostats will appreciate the very practical and simple form in which this rheostat is presented. I see many applications of it which are of interest, and may be made practical. If there is any discussion on this paper, we shall be glad to hear it.

MR. SPERRY:—Mr. President, I would like to call out some points with reference to it. I would like to know if the rheostat has been designed for heavy currents, and if so what is the heaviest that has been used?

MR. CARPENTER:—We are manufacturing resistance plates of low resistance and high ampere capacity. In these low resistance plates, several wires are in parallel or multiple, and have a capacity depending upon the kind and size of the wire, from 25 to 200 amperes or more. A 50 kilowatt 500 volt motor-starter is made up of a number of these low resistance plates connected in series. Each plate has 4 wires in parallel, and each plate forms a step or division of the rheostat. The plates for this size of motor are 18 inches long and 3 inches wide, and weigh about 4 pounds. Twelve or 14 of each are used for this size of machine.

These series plates have the coils or wires enameled between ribs for increasing the adhesion of the enamel to the plate. It has been found by experience that 50 per cent. more current may be passed through a wire when placed between the ribs in this manner, without breaking the enamel, than where the wire is simply enameled on a plain surface. It is also a fact that these plates used in this way, will endure splashing of water about them without breaking the enamel, when the temperature is as high as will be reached in normal use.

MR. UPTON:—Mr. President, I would like to add one word, that I believe that at the Exposition at the Crystal Palace in London the invention of Mr. Carpenter's is one of the leading features That is, it is most talked about and most noticed by far. There is a large exhibition there, and it is meeting with a great deal of success.

[Adjourned to June 8th.]

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8, 1892, Manager Webb in the Chair.

PRACTICAL NOTES ON THE ELECTROLYTIC REFINING OF COPPER.

BY LIEUTENANT F. B. BADT.

There are a good many books extant on the art of electrolytic separation of metals and a good deal has been, and is being written in scientific journals on the same subject, but, strange to say, most of it has been published in the foreign press and very little can be found in American publications.

From this it might appear that but little interest is taken in this subject and that copper refining is being done on a very small scale in this country, while, as a matter of fact, quite the reverse holds true. We cannot explain the dearth of information on this subject any better than by quoting from Mr. Gore's latest book:

"Much of the information heretofore published on the subject lies scattered about in short articles and fragmentary accounts, in periodicals and books; and statements more or less inaccurate have been made, owing to the writers not having access to the manufactories, the processes in which they have attempted to describe. M. Kiliani and others have observed the privacy with which electrolytic refining works are conducted; he says that 'its effect has been to some extent to make people believe that the operations carried on are based upon discoveries known only to a few and are surrounded by difficulties of a very special and complicated nature.' He writes with 'the object of dissipating this wrong impression, and of convincing all those interested in the subject that whatever is done inside these works can be done by anybody who gives a little attention and study to the subject, the only secrets being slight and immaterial details of practice.' The probable explanation of this is, that each electro-refiner, in consequence of being imperfectly acquainted with the literature of the subject, and of how his fellow refiners were working, has been obliged to ascertain by means of experiments in his own works the practical details of the process; and has thus independently arrived at the same general plan of operating as other refiners, whilst considering his own method a secret."

The foreign books above referred to naturally contain descriptions of plants and processes in vogue in Europe, and very little can be learned concerning the art of electrolytic copper refining in the United States.

It is the object of this paper to give a few practical data in relation to American practice, and to give a short description of the processes in vogue in this country. While the writer has erected some of the largest copper refineries in the United States and examined a few of the other plants, it is for the very reason that Mr. Gore gives, that the data which the writer submits in the following are not claimed to be either complete or to be absolutely correct. The writer has endeavored to tabulate the electrolytic copper refineries in the United States.

This, to his knowledge, is the first attempt ever made, and he hopes that considering the circumstances, his endeavors in this direction will not be misconstrued, but be properly appreciated.

In the following we give a list of electrolytic copper refineries in the United States. It shows us that there are at present 36 dynamos of a total capacity of 1,814 kilowatts used for the electrolytic refining of copper, and that the total output of these refineries (when all are completed) will amount to 3,650 tons per month, or 43,800 tons per year. A capital of over $1,000,000 is invested in these refineries.

The Census report, dated Washington, D. C., July 15, 1891, shows the United States to be the largest producer of copper in the world, its product for the year 1889 being 226,055,962 pounds, or 113,028 (short) tons. The total expenditures involved in this production were $12,062,180, of which there was paid in wages, $6,096,025; in salaries, $120,896; to contractors, $334,-443; for materials and supplies, $4,067,970; for taxes, rent, etc., $1,442,846, the total capital invested being $62,623,228, and the total number of employes, exclusive of office force, 8,721. The same Census Report gives some statistics on "copper refining," but unfortunately fails to state how much copper was refined by the electrolytic process.

It is interesting to note that only a part of the furnace material produced in the United States, a small quantity of ore, and nearly all of the mineral from the Lake stamp mills are refined in works, the majority of which are controlled by firms and corporations not directly connected with the mines. In some works copper refining is incidental to the working of other base and precious metals, and in others it is part of a general chemical business One concern failed to report. The returns cover establishments which produced 159,693,252 pounds (79,847 tons) of refined copper, valued at $19,686,561,86. Hence if our list is approximately correct only about 25,000 tons out of 79,847 tons of refined copper were treated electrolytically.

We might construe the following paragraph in the Census Report as referring partly to electrolytic refineries:

"It is interesting to segregate one group of refiners, which treats exclusively high grade, pure material, like Lake mineral, Arizona bars and Montana blister copper. Works which produced 105,400,664 pounds of refined copper incurred the following total expenses:

EXPENSES IN COPPER WORKS TREATING HIGH-GRADE MATERIAL.

Wages	$326,687
Salaries	42,056
Paid to contractors	4,735
Supplies and material	305,679
Rent, interest, etc	40,462
Total	$719,619
or 0.68 cent per pound.	
Total refined copper, pounds	105,400,664

These figures will demonstrate conclusively that the subject is an important one. It is not intended to tire you with the details of the ordinary process for the electrolytic refining of copper, as this has been described in many books, and the theory and practice are well known. In the above table, however, I mention, in the fourth column, the names of certain processes in vogue in the United States, and it might be well to show the main features of each. The crude material used in the anodes is black copper, or blister copper, containing from 97 per cent. to 98 per cent. of copper. The electrolyte is a solution of sulphate of copper.

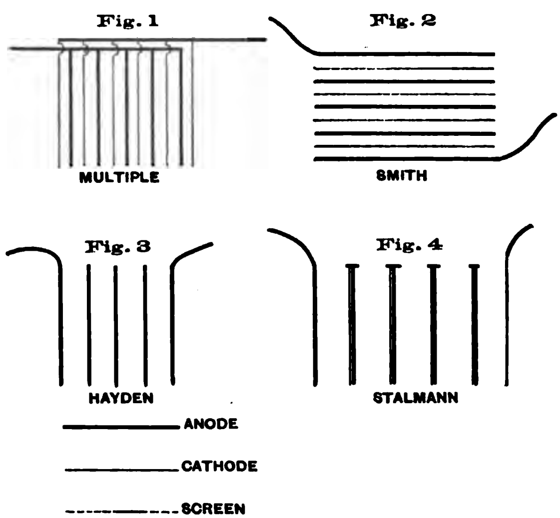
In some processes refined copper is a by-product only, especially when it appears in a concentrated form in the mattes of lead smelters and refiners. In the process which we call the "multiple process," anodes and cathodes in each vat are arranged in multiple, in about the same manner as the plates in a storage cell. (See Fig. 1.) In this process there is usually one more cathode than there are anodes. The electrodes are suspended in a vertical position in wooden vats, usually lined with lead. The vats themselves may be arranged either in series, multiple, or in multiple series. For simplicity's sake and for numerous other reasons well known to the electrical engineer, an arrangement of vats in single series is most advantageous.

LIST OF ELECTROLYTIC COPPER REFINERIES IN THE UNITED STATES.

Name of Company.	Generators	Number of Vats.	Process (Arrangement of Vats).	Output in Electrolytic Copper per Month, Tons.	Remarks.
1. Anaconda Mining Company, Anaconda, Mont.	5 Edison - 60 volts, 1,100 amperes.	320	Partly multiple, partly Stalmann.	350	Plant being extended for ultimate capacity of 900 tons per month.
2. American Nickel Works (Jos. Wharton), Camden, N. J.	1 Excelsior—6 volts, 1,000 amperes.	48 in series.	Multiple.	30*	* By-product.
3. Balbach Smelting a d Refining Company, Newark, N.J.	7 Excelsior—15 volts, 2,000 amperes. 1 Excelsior—30 volts, 3,000 amperes.	7 series of 48; 1 series of 96	Multiple (18 anodes, 18 cathodes).	650*	* They refine the product of the Orford Copper Company, whose smelters are in New Jersey, and who are general purchasers of copper ores, matte and bullion.
4. Baltimore Copper, Smelting and Rolling Company, Baltimore, Md.	6 Edison*—150 volts, 400 amperes.	....	Hayden.	800	* Generators have sectional fields, which can be plugged for different voltages.
5. Baltimore Refining Company, Baltimore, Md.	2 Edison—80 volts, 700 amperes.	....	Hayden.	300	
6. Boston & Montana Consolidated Copper and Silver Mining Company, Great Falls, Mont	3 Thomson-Houston—multipolar separately excited, 165 volts, 1,000 amperes.	288	Multiple (19 anodes, 19 cathodes).	550	Plant in construction. Dynamo capacity in excess of present requirements.
7. Bridgeport Copper Company, Bridgeport, Conn.	1 Thomson-Houston, 1 Mather, 1 Edison—150 volts, 460 amperes.	3 series of 10	Hayden (100 electrodes in each vat).	400*	* They refine the entire product (black copper) of the Parrott Silver and Copper Company, Butte, Mont.
8. Chicago Copper Refining Company, Blue Island, Ill.	2 Edison—80 volts, 800 amperes.	165	Multiple.	150	
9. Electrolytic Copper Company, Ansonia, Conn.	3 Mather—100 volts, 300 amperes.	75	Smith.	100	
10. Lewisohn Bros.,† Pawtucket, R. I.	1 Excelsior—15 volts, 2,200 amperes.	60 in series.	Multiple (19 anodes, 19 cathodes).	110	
11. Omaha & Grant Smelting Works, Omaha, Neb	1 Excelsior—6 volts, 1,000 amperes.	48 in series.	Multiple.	30	
12. Pennsylvania Salt Manufacturing Company, Philadelphia, Pa.	....	.. ..	Smith.	30*	By-product.
13. St. Louis Smelting and Refining Company, Cheltenham, St. Louis, Mo.	1 Excelsior—16 volts, 2,400 amperes.	48 in series.	Multiple.	60*	* This plant is operated in connection with an electrolytic silver refinery, using the Moebius process.
14. Washburn, Moen & Company, Worcester, Mass.	....	....	....	90	Plant burnt, being erected.

† Agents for the following mining companies: Boston & Montana Consolidated Copper and Silver Mining Company, Montana; Butte & Boston Mining Company, Montana; Arizona Copper Company, Arizona; Huron Copper Mining Company, Lake Superior, Mich.; Tamarack Mining Company, Lake Superior, Mich.; Osceola Mining Company, Lake Superior, Mich.; Kearsarge Mining Company, Lake Superior, Mich.; Santa Fe Copper Company, New Mexico; Peninsula Copper Mining Company, Lake Superior, Mich.

Another process is the "Smith process" (United States patent No. 393,526, Nov. 27, 1888. In this process there are no cathodes of pure copper. The plates of black copper (anodes) are not suspended vertically in the solution, but are placed horizontally. As it would not be practical in many places to cast the plates large enough to give a sufficient amount of surface, several plates are placed side by side so as to form one large plate. These layers are then placed one above the other, at a distance of about 1½ inches, the layers being supported by strips of wood running lengthwise of the vat. The top plate is connected as an anode to the generator, and the other pole of the dynamo with the bottom plate. The spaces between the plates are filled with the solution



of sulphate of copper, which forms the only connection between the plates. The copper is dissolved from the under surface of each layer and deposited on the upper surface of the next layer below. The insoluble foreign matters in the copper, including gold and silver, fall upon screens of cotton cloth which are stretched between each two layers. The process is kept up until all the black copper is dissolved and nothing remains but plates of electrolytic copper.

Fig. 2 shows the relative position of plates in one vat. The inventor claims several important advantages over the common vertical multiple arrangement. He claims that the silver or other foreign insoluble matter is removed, that the space required for a given amount of depositing and the amount of solution required are relatively small, that the connection between the plates in one tank is made by the solution only, and that the copper is easily handled and prepared for the vats. The following is his patent claim:

"A vertical series of horizontal electro-depositing cells formed by horizontal plates of the metal to be deposited, separated and supported by insulating supports, and immersed in an electrolytic solution, with screens interposed between the successive plates, substantially as described, whereby insolub.e matters are arrested as they are liberated from the lower surface of the upper plate in each cell by the combined action of the said solution and the electric current."

Smith arranges all vats in series.

Another process mentioned in the list is the "Hayden (Fig. 3, United States Patent No. 465,525, Dec. 22, 1891). The Hayden process differs materially from that of the Smith only in that he places his plates in vertical position instead of placing them horizontally, and that he does not use any screens. He uses removable grooved vertical wooden strips to hold the plates in proper position. He also states that it might be advantageous in many cases to cast the plates in small sizes and arrange them one above the other.

Mr. Hayden's patent claims are as follows:

1. In an electrolytic bath having a number of plates unconnected electrolytically, excepting through a solution in the bath, and having narrow partitions extending from opposite sides of the bath adapted to hold the plates in a vertical position and out of contact with each other, stops wholly between the partitions supporting the plates above the bottom of the bath, substantially as specified.

2. In an electrolytic bath having a number of plaets unconnected electrolytically, excepting through a solution in the bath, and having independent grooved side pieces in the bath, the side walls of the grooves forming narrow partitions engaging the lateral edges of the plates to be treated and holding said plates out of contact with each other, stops at the lower ends of said grooves, supporting the plates above the bottom of the bath, the said stops not projecting beyond the faces of the partitions, substantially as specified.

3. In an electrolytic bath having a number of metal plates unconnected electrolytically, excepting through a solution in the bath, a series of grooved strips removable from the tank, driven tightly on to the side edges of the plates and constructed so as to be capable of sustaining the plates within the bath above its bottom, substantially as specified.

Hayden also arranges his vats in series.

Another inventor, Stalmann (United States Patent No. 467,-

350, Jan. 19, 1892, and No. 467,484, Jan. 19, 1892), practically uses the same process as Hayden, only instead of using single plates, he uses, with the exception of the initial anode and the terminal cathode, pairs of plates of crude and refined material, but bringing the two plates together by connecting them by one or more bolts or rivets, so that they become practically a pair of anode and cathode plates with no electrolytic solution between them (Fig. 4).

The claim in the first patent is as follows:

"An electrode consisting of a plate of refined copper material and a plate of crude material with insulating material interposed between said plates and metallic connection between said plates,"

The claims of the second patent are as follows:

1. The method of separating from copper and like metals foreign matter which may be incorporated with them, which consists of arranging in an electrolytic bath an initial anode connected to the positive pole of the source of current supply, and a terminal cathode connected to the negative pole, securing together by conductors, intermediate anodes and cathodes in independent pairs, each pair consisting of an anode of crude material and a cathode of refined material, interposing said independent pairs between the initial anode and terminal cathode of the bath, and passing an electrolyzing current from the initial anode to the terminal cathode through the bath and paired plates, substantially as described.

2. An electrolytic bath comprising a containing vessel, an electrolyte, an initial anode, a terminal cathode, and intermediate pairs consisting each of an anode of crude material and an independent cathode of refined material removably connected thereto and in metallic conductive connection therewith, the several pairs being independent of each other, substantially as described.

3. An electrolytic bath, comprising a containing vessel, an electrolyte, an initial anode, a terminal cathode, and intermediate pairs consisting each of an anode of crude material and an independent cathode of refined material removably connected thereto and in metallic conductive connection therewith, the several pairs being separated on their sides and bottoms from the containing vessel, substantially as described.

3. An electrode, consisting of a plate of refined material and an independent plate of crude material removably connected thereto and in metallic conductive connection therewith, substantially as described.

Stalmann's patent drawings show the vats arranged in either series or multiple. The inventors of the series processes, like the Smith, Hayden, Stalmann and others, claim for their processes very much cheaper first cost of plant, very much less copper carried as idle capital in the vats, much less floor space and higher efficiency in operation, that is, a larger recovery per horse power hour. Whether or not these claims can be demonstrated in practice is yet an open question. One pound of copper will be deposited theoretically in one hour, by a little less than 386 amperes out of a solution of sulphate of copper. If we, therefore, pass 386 amperes through one vat we will deposit one pound every hour, and if we pass the same current through a series of 100 vats, we will deposit 100 pounds per hour. The amount of power expended in each vat, however, is $C^2 \times R$, but as it is always possible to reduce the resistance of a vat by increasing the surface of the plates, we can greatly reduce the amount of power required for the same output in copper per horse power hour. We may also reduce the amperage for a given production by joining more vats in series, or we may combine both methods.

It is therefore always possible to largely reduce the expenditure of electrical energy, and consequently that of the motive power. As a matter of fact, theoretically, any amount of copper may be refined with any given horse power, but as soon as we attempt to largely increase the production of copper with a given power, we find it necessary to largely increase the size and the number of vats and the quantity of copper under treatment. These conditions have been thoroughly examined, and the laws governing them have been explained in the several hand-books extant.

As a resumé it may be stated that if power is cheap we may make the internal resistance of the vats greater, employ small vats and less copper under treatment, requiring less floor space, thus decreasing the first cost of the establishment materially. If, on the other hand, power is expensive, we must make the internal resistance of the vats as small as possible, have a large amount of copper under treatment, requiring a larger floor space and materially increase the first cost of the plant. It can easily be seen that in each special case these conditions must be carefully determined in accordance with principles very similar to those laid down in Sir William Thomson's law.

From these statements, however, we may infer that the claims of the promoters of the so-called series processes are not well founded; because no matter how the plates in the vats may be arranged, we can always arrange the plant for conditions of minimum first cost or minimum operating expenses. It is true that both Smith and Hayden do away with cathodes of refined copper, and thus save quite an item for copper under treatment. On the other hand, there is the disadvantage that particles of the original anodes will stick to the final cathodes of refined copper, and that it will be found difficult to separate them.

As a matter of fact, it is claimed by some assayers and selling agents that electrolytic copper obtained by these two processes is not so pure as copper obtained by a process employing anodes and cathodes arranged in multiple. Mr. Stalmann in his arrangement obviates the latter disadvantage by attaching removable plates of refined material to his anodes.

Another important item in order to obtain a pure deposit is the density of the current. American copper refiners usually adopt 10 amperes per square foot of active cathode surface as a maximum. I am told, however, that some of the refineries operated on the "series" processes go even beyond 15 amperes per square foot, which may account for certain impurities found in the electrolytic copper, and for a greater efficiency of the plant; that is, a larger output of copper for a given number of vats and amount of copper under treatment.

High voltage in an electrolytic plant of course means considerable saving or less drop in conductors, less trouble from poor contacts, etc., and it is probable that for these reasons the so-called series processes show a greater efficiency per given horse power than the processes employing electrodes in multiple. For refineries using this latter process low tension machines and comparatively few vats in series are employed. By adopting as high voltages in the multiple process as in the series process, of course, the same advantages may be obtained.

One advantage of the series process is the fact that each electrode will get its proper amperage per square foot as all the plates are in series, and are of uniform size. In the parallel process some trouble is always experienced in properly subdividing the current in each vat so that each plate will get its share, or, in other words, that the current density will be the same for each square foot of active cathode surface. By proper precautions, however, trouble in this direction may be easily avoided.

Another important item for the obtaining of pure deposits is a good circulation of the electrolyte. This insures a uniform specific resistance in the solution between the parts of the plates. Inasmuch as a solution of sulphate of copper is of greater specific gravity than the acid, which is liberated by the decomposition of the copper upon the surface of the cathode, such acid rises to the surface of the liquid while the solution of sulphate of copper settles toward the bottom. Where plates are arranged vertically, therefore, there is an ascending current before the surface of the cathode, and a descending current before the surface of the anode. If there is not a sufficient circulation of the electrolyte, the free acid attacks the upper portion of the plates more rapidly than the lower portion, and the deposition goes on most rapidly on the lower portion of the cathode.

In American practice, the electrolyte is sometimes kept in circulation by arranging the tanks on the cascade plan, and having each higher vat siphon through a pipe whose orifice is near the bottom of the next lower vat. A better plan now usually adopted is to have a trough run through the whole refinery, and have each vat fed independently by means of a rubber hose. The electrolyte is raised from the collecting tank into the troughs by means of lead pumps or steam injectors. Both, however, are objectionable. The pumps are always getting out of order, and the steam injector means waste of steam, besides having the disadvantage of putting too much moisture into the electrolyte, which again necessitates the adding of free acid continually. A better plan is to have two collecting tanks, which are to be used alternately. Just as soon as one is full it is made air-tight, and a small air compressor driven by an electric motor compresses the air above the solution and drives the solution under a pressure of, say, 25 pounds through a pipe up into the troughs. Smith claims that in his arrangement no artificial circulation of the electrolyte is required. He claims that the free acid liberated over the whole horizontal surface of the cathode in each cell, rises directly through the solution and the screen to the surface of the anode above, and acts uniformly over its whole surface. As the deposition also takes place uniformly over the whole surface of the cathode, uniform electrical and chemical conditions are secured over the whole surface of each plate and uniform liquid resistance between the parts of the plates and the action of the cells is entirely automatic. Smith also claims that less heat is wasted by this arrangement than in installations which require the circulation of the liquid.

We might mention another incidental advantage of the multiple process over the series processes. Some of the patentees claim one-fourth of a cent per pound of refined copper as a royalty. In one instance one plant gives the patentee, under this arrangement, an income of over $100 per day. Taking this in combination with the very doubtful advantages claimed for the series process, we need not wonder that there exists prejudice against erecting electrolytic refineries employing these patented operations.

As to the value of the patents from a legal point of view, I do not care to express an opinion. Some legal authorities state that anybody may arrange the electrodes in series within a vat without infringing, if he omits some of the minor details of the combination patents whose claims have already been quoted.

The power installations of some of the electrolytic refineries which the author had an opportunity to visit, reminded him very much of electric light stations put up about ten years ago. The old motto, "Cleanliness is next to godliness." he found missing, and the plants usually excelled by a total absence of voltmeters or ammeters or other electrical testing instruments showing the conditions under which the plant was operating. Such statements, therefore, as "working current of a thousand amperes," or "density of current of 10 amperes per square foot," which we get from electrolytic refiners, must be taken with several grains of allowance.

I could enumerate a long list of defects that exist to-day in almost all of the electrolytic refineries, and which all may be traced to one cause, and that is the imperfect knowledge of the refiners, of matters electrical. Large amounts of money may be saved in the erection and operation of such plants by considering all the conditions carefully, before making the final plans. One case came to my knowledge where the lead lining was put in the tanks, and plumbers were commissioned to wipe the seams in the ordinary way instead of having the edges of the lead melted together by means of the hydrogen blowpipe. The latter plan should always be followed, as wiped joints will be destroyed by the electrolytic action of the solution in a very short time.

This is not by any means a small matter, as repairing of the lead lining involves large expenses and great loss of time. In one installation, the conductors leading from the dynamos to the tanks are undergound, but run in such a careless manner that they are permanently grounded, often get short circuited, and in a few instances the wood conduit was set on fire. As a matter of fact, all the experiences which we have gone through for the last ten years in constructing electric light and power plants have been of no benefit it seems to most electrolytic refiners. Even in the few installations where a voltmeter is used to indicate the proper working condition of the vats, this voltmeter is carried by two men from vat to vat, and the voltage of each vat is taken in this cumbersome manner.

In a plant just being erected, the writer proposes the erection of a potential board in the office of the superintendent. Both terminals of each vat are to be connected with two contact points of the potential board, and a voltmeter is to be so arranged that by simply turning a switch handle the potential of each vat can be taken almost instantaneously. As a matter of fact, the working condition of each vat may be thus ascertained in a few minutes, while it would take hours for two men to do the same by carrying the voltmeter from vat to vat. One of the occurrences which has to be guarded against is the short-circuiting of an anode and a cathode which, in the multiple plan, means the short-circuiting of a whole vat. Such an occurrence should be detected immediately, as otherwise the contents of the vat may be spoiled. The author proposed, for a plant just being erected, an electric tell-tale in connection with the potential board. This tell-tale might be constructed somewhat after the fashion of a hotel annunciator. Each magnet might be permanently in circuit with its corresponding vat and the tension of the armature spring so adjusted that at the proper potential the armature would be held up, but just as soon as the vat is short-circuited no current or but very little current will flow through the magnet, and the armature will drop, ringing an alarm bell and indicating the number of the vat in which the trouble occurred.

All such appliances are labor-saving devices, and their installation would pay well in a plant where many thousand dollars worth of copper and solution is under treatment and liable to be spoiled. In a number of refineries there are T-rails suspended over the vats in such a manner that a pulley carrying a block and tackle can be used for lifting the plates out of the vats and moving them in the gangways for either washing off the slime or for substituting new anodes for the old ones. Some of the electrolytic refineries in the United States buy copper matte of from 45 to 54 per cent. of copper from the mining companies. In these cases they own their own smelters, resmelt the copper matte, producing black copper of from 97 to 98 per cent. of copper. This black copper is then cast into anodes and subjected to the electrolytic process. Other refineries buy the black copper direct from the smelters owned by the mining companies. For instance, the

Bridgeport Copper Company, of Bridgeport, Conn., buys the entire product of the Parrott Silver and Copper Company, of Butte, Mont., as black copper.

There is another matter which should be mentioned, as it is very often misunderstood by the public and the electric companies. If copper matte contains, according to the assay, 30 ounces of silver or less per ton of matte, no extra charge is made for the silver, but the copper matte is sold at the reigning market price. If it contains, however, over 30 ounces, the silver is to be paid in accordance with the assay. Thirty ounces of silver per ton of matte, of course, means almost double that amount per ton of electrolytic copper. It can easily be seen that electrolytic refineries prefer to buy copper matte containing just a trifle less than 30 ounces of silver per ton.

There are quite a number of points which need the attention of electrolytic copper refiners. There are, for instance, only a few of the refineries which manufacture their own sulphate of copper, but buy it at high rates in the market. Sometimes the cost of freight and haulage doubles its cost. Each copper refinery should have a little installation of its own for the manufacturing of the necessary sulphate of copper, which it can do at a small fraction of what it has to pay for it. The same holds good in relation to the refining of the slime or mud which collects at the bottom of the vats, and which contains the precious metals. Each copper refinery should have its own little plant for the refining of the mud. These little installations can be run at a small expense in connection with copper refineries, and it is almost nonsensical to have other concerns make large sums of money which could be saved by the refiner himself.

A few words as to electric generators may not be out of place. The author prefers separately excited machines for the reason that they cannot be reversed and for other incidental advantages. When water power is used as prime mover a good deal of trouble has been experienced in the regulation of the wheels. As a matter of fact there is no water governor in existence which will regulate so perfectly as the governor of a modern automatic engine under varying loads. By running all the exciters from an independent prime mover (either water or steam) the strength of the fields of the generators will be uniform at all times, whether there are fluctuations in the external circuit or not. The strength of the field of the generators which, with self-exciting machines, is subject to the fluctuations in the external circuit, and is a variable, becomes a constant. The author proposed this arrangement over three years ago for railway and power stations with the very best results.

Before closing, we might mention some processes which have not been introduced in the United States yet, but about which a good deal has been said during the last few years. There are in Europe processes by which electrolytic copper is produced direct from the "matte," containing from 35 to 55 per cent. of copper. From the reports that have appeared from time to time, it seems that these processes have not been a great success. There are other processes which contemplate the extraction of copper direct from the ores by means of electrolysis. The best known are the "Siemens" and "Hoepfner." If we are correctly informed, the Siemens process is now being used in one experimental plant only, which is owned by the Siemens firm. This is at Martinicken fields, near Berlin. Another one which they have in the Caucasus, at their own copper works, is said to have been abandoned because it did not give satisfaction. Dr. Hoepfner's process, it is claimed, is now in operation in three plants; one at Schwarzenberg, which began operations in September, 1890, and two others about which very little has been published. Mr. Hoepfner uses in his process a cuprous chloride solution, out of which a current of one ampere will deposit 2.35 grammes per hour, while out of a solution of sulphate of copper, only one-half of this amount of copper can be deposited per unit of current per hour.

As it was the object of the writer to give practical points on the refining of copper, and as he does not know anything about these two processes from personal observation or from practical experience, he does not wish to comment any further, but prefers to wait until he can see one of these plants in operation in the United States. While these processes do away with the smelting and resmelting of the ores, and while they would make unnecessary the large, expensive plants now used for this process, they seem to be very complicated. Their commercial value certainly should be investigated much more closely by American mining companies before they should be willing to invest large amounts of money.

We finally give below, the approximate cost of a refinery with a capacity of 1,000,000 pounds of electrolytic copper per month :

Building	$30,000
Pavement (asphalt)	2,000
Pipes for steam heating	4,000
Vats	6,000
Lead for lining vats, collecting-tanks and troughs	28,000
Lead burning	1,500
Copper conductors	11,000
Rails for overhead blocks for handling plates	2,000
Sulphate of copper	3,500
Sulphuric acid	1,000
Steam injectors or pumps or air compressors.................	1,000
Electric generators, switchboard, instruments	30,000
Shafting and belting............	3,000
Total	$123,000

To this sum must be added the copper under treatment, which in this case will amount to at least $80,000, and if a steam plant should be required, another $20,000 must be added, bringing the total of this plant up to $223,000. The above items include labor of erection, but do not include freights. These figures, although approximate and true only under certain conditions, will demonstrate that electrolytic copper refineries are expensive plants and should be erected on carefully prepared plans and under the supervision of responsible and competent engineers.

CORRESPONDENCE.

[*From the Engineering and Mining Journal.*]

BLACK COPPER AND BLISTER COPPER.

Editor Engineering and Mining Journal. Sir: In the issue of the Engineering and Mining Journal of the 6th inst., I read with much interest the "Practical Notes on the Electrolytic Refining of Copper," by F. B. Badt.

In these he speaks repeatedly of treating "black copper" by the electrolytic process, while he surely means "blister copper." As I have met a number of metallurgists to whom the difference between these two terms is anything but clear, and it seems desirable not to get technical terms mixed, I think it would be desirable to have the *Engineering and Mining Journal* clear up things. This is the excuse for this letter.

BLACK COPPER (from the German schwarz kupfer) shows in the break a dark appearance; hence the name, and may contain from 75 per cent. to 92 per cent. copper. It contains, besides other impurities, such as iron, lead, etc., always several per cent. sulphur; it is produced in a blast furnace together with matte of 52 to 65 per cent. copper (German, dunnstein or lech). The English copper smelting in Wales does not produce "black copper," unless one would call the "buttons" produced in the "best selected" method by that name. I understand that repeated attempts of refining "black copper" electrolytically, made some years ago, resulted in failure, as the electrolytic copper produced, usually carried from 0.68 to 2 5 per cent. sulphur.

Blister Copper shows, when broken, a true copper color. It carries from 97 to 98.5 per cent. copper and is practically free from sulphur, and it is this metal that is now nearly exclusively used as anodes in electrolytic refining. "Blister copper" can be made by oxidizing matte (or "black copper") in a reverberatory furnace or by the Bessemer process, for the latter process I obtained a U. S. patent in 1865 or 1866. A. Raht.

State School of Mines, Golden, Col., Sept. 8, 1892.

F. B. Badt, Esq., Manager Mining Dept.,

General Electric Co., Chicago.

Dear Sir:—Yours received, and after careful perusal have the honor to reply that I am in accord with what you say regarding the use of "black copper" as anodes in the electrolytic process. I do this not because I desire to agree with you necessarily, but because authorities are rather of the same opinions as those expressed by you, and opposed to the general criticism Mr Raht makes. I have high regard for Mr. Raht, who was Superintendent of the Parrott Copper Works in Montana. If he desires to suggest a distinction of terms as defined by him, well and good, let the criticism be so announced, but if he wishes to "clear up" what he chooses to term confusing, I do not think he is starting on the right track. If he intends to limit the use of "black copper" and "blister copper" in the manner he defines, then he is merely endeavoring to prescribe Montana practice for that of the world.

"Black copper" is the result of a blast furnace fusion, contains over 95 per cent. of copper, and is practically an ingot copper, with an admixture of some oxide of copper; the compound is perfectly homogeneous as a scratch over its surface or fresh fracture will show. It may, and often does, contain other impurities than the oxide, as iron, etc., but it does not as he says "always contain several per cent. sulphur." When toughened it makes the copper of the market.

"Blister copper" is the result of a reverberatory treatment of copper matte and, as may be expected, contains some sulphur. It may carry as high as 92 per cent. of copper, but rarely does. A fracture of the "blister copper" pigs will show a porous surface with pellets or globules of the metal scattered over it. The pig is not so homogeneous as in the "black copper" ingot.

Doubtless Mr. Raht, who used both blast furnaces and reverberatory furnaces at his works, employed the two terms in question to designate the separate products thereof in the manner he mentions, but I am sure the larger number of metallurgists will not agree with him. Mr. Pierce, whose ability as a metallurgist is as unquestioned as Mr. Raht's, ships "black copper" of the character I mentioned above. The Arizona smelters, those of Trinidad, Colorado; and others that might be mentioned in Europe, call the impure ingots I have described, "black copper." I speak now of copper producers, not refiners, as the Orton Works in Baltimore, Md., who may perhaps take greater liberties with the designation of the several grades of intermediate products between matte and pure metal. Freiburg smelters (reverberatory) produce a matte such as Mr. Raht described, and call it "black copper." At Altenau, Clausthal and Andreasberg 600 tons are produced annually of "black copper" averaging 95 per cent. Cu, 2 per cent. lead, 0.085 silver. At Agordo, the blast furnaces fuse mattes till a black copper is produced with 95 per cent. copper.

See Phillip's "Elements of Metallurgy," p. 406.

"Smelting of Copper," Col. Grant-Frances, p. 27.

Greenwood, "Metallurgy of Copper."

All of these refer to "black copper" as the result of blast furnace fusion, which same is refined to ingot copper.

Trusting that this may be clear, and with the remark that the operators of Siemens' electrolytic process call their metal "black copper," I am,

Yours truly,

M. C. IHLSENG.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

THE REVERSAL OF POLARITY IN PLATING DYNAMOS.

BY PROFESSOR HARRIS J. RYAN.

Shunt machines used for copper plating carbons are frequently found to have their polarity reversed after being stopped. The cause can be ascribed only to voltaic action of the unplated or partially plated carbons, copper anodes, and the plating solution. Any electromotive forces in the bath that would result from the electrolytic action of the dynamo current must be counter to the E. M. F. of the dynamo. Any current that these counter E. M. F.'s might set up through the dynamo when at rest, as is well known, could tend to only maintain the same polarity.

To determine the extent of the voltaic action Messrs. Thayer and Warner, of the Senior class in Electrical Engineering at Cornell, made a copper plating bath of the density that is found to do best for copper voltmeter work. This solution was increased 20 per cent. by the addition of commercial sulphuric acid so as to obtain a solution practically the same as that used by the carbon platers for good tough deposits. In this bath an unplated electric light carbon formed the cathode and good commercial copper the anode. With this cell the observations given in the following table were made.

The E. M. F.'s of the cell due to voltaic action were observed by the deflection of a galvanometer, connected to its terminals immediately after the circuit of the electrolytic current was broken.

The table explains itself, and shows that the difference of potential between the unplated carbon and copper is .17 of a volt. After the deposit of a thin film of copper on the carbon this E. M. F., immediately after stopping the current, was .004 of a volt, and was rising so that at the end of 10 minutes it was .138 volts. When a marked deposit was made by the application of the electrolytic current for one minute the cell gave a counter E. M. F. of .085 of a volt immediately on stopping the current. The return of the voltaic E.M.F. was evident, for two minutes later the E. M. F. of the cell was zero, and sixteen minutes from the time of stopping the current the voltaic E. M. F. of the cell was .130 of a volt. At this point the application of the current for but five seconds produced a momentary return of the counter E. M. F. of the cell. Even after the carbons had been well plated by the application of the electrolytic current for fifteen minutes, when the counter E. M. F. of the cell at the moment of breaking the circuit

Time.	Volts.	Remarks.
11:20	—.170	Carbon unplated.
11:20½	—.004	Current on 30 seconds; lower part of carbon plated; plating on the upper part scarcely perceptible.
11:28	—.012	
11:30	—.138	
11:32	+.085	Current on 1 minute; well-marked deposit on carbon.
11:34	.000	
11:36	—.022	
11:40	—.064	
11:48	—.130	
11:50	+.064	Current on 5 seconds.
11:52	—.124	
12:15	+.138	Current on 13 minntes.
12:20	+.064	
12:36	+.053	
12:55	+.021	
1:45	+.006	

+ indicates a counter E. M. F.
— indicates a voltaic E. M. F.

was .138 volts, there was a strong tendency manifested for the return of the voltaic E. M. F.

It is seen, therefore, that with a shunt electroplating machine at work on a bath for plating carbons, there is danger of reversing its magnetism whenever it is stopped before the carbons are well coated. It may be avoided by breaking the main circuit before shutting down, and making it again only after the machine has been brought to full speed. This method would generally require the use of a large and expensive knife switch. Breaking and making the field circuit in the same manner would do just as well.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

SELECTIVE OR INDIVIDUAL SIGNALS.

BY THOMAS D. LOCKWOOD.

Among the many subordinate branches of invention in auxiliary appliances which surround and form a suitable setting for that grand central figure, the Electric Speaking Telephone, none represents more painstaking thought, has been more thoroughly ransacked, or has constituted a more attractive pursuit than the study of selective signaling.

The problem it presents is both electrical and mechanical, is sufficiently difficult to create the excitement always attending the pleasures of the chase, and sufficiently promising and hopeful of a practically successful issue to be retentively fascinating. Hence its solution has been attempted alike by prominent and capable electricians, by practiced electro-mechanicians and by amateurs; has, from the laboratory and workshop point of view, already many times been achieved in as many different ways, although commercially it yet hangs like the fabled bundle of hay, just a little in advance of the enthusiastic aspirant who strives to clutch it.

THE USE OR FUNCTION OF SELECTIVE SIGNALS IN TELEPHONY.

The business of the average user of the telephone keeps a line employed but for a very small part of the entire business day, and for the remainder of the time the line wire is idle and earning absolutely nothing. If by any means it could be made possible to place several sub-stations in connection with the same circuit, without materially affecting the efficiency of the service rendered, it is obvious that the earning power of the circuit would be largely increased. But a call-bell or other signal is clearly necessary in order that the attention of the station may be attracted when some other station desires to communicate, and as we add stations to a circuit we also necessarily add call-bells; thus introducing two practical objections, viz.:

1. A most incessant and annoying ringing, because a call sent to any station is heard at all stations.
2. The necessity of distinctive signals, whereby when the bell at any station is rung the attendant may know whether the call is for his or for some other station.

At this juncture the selective signal steps in, and its special work or function may be thus stated: That two or more stations being electrically connected with the same circuit, the call-bell at any predetermined or desired one of such stations may be operated, and the call given there, to the exclusion of the call-bells at the other stations, which at the same time remain quiescent, or are silent. We therefore see that the thing to be done is not merely to ring a bell over an electrical circuit; but to select and ring from a distant point a *given* bell on a circuit with which more than one are connected; and at the same time to ensure that the bells at the other stations which are not intended to be rung, shall not be rung.

This statement of function justifies the term "*selective signal*" which I have adopted, and which I conceive to be more appropriate than the old term "individual signal" because more descriptive.

Historical Sketch of Selective Signals.

The idea of producing a practical selective signal is not (as might from the introductory remarks of this paper have been supposed) one which made its first appearance subsequent to the advent of the telephone.

Appliances possessing the same characteristics, appeared in England many years ago, and several forms have from time to time been patented in that country for use in connection with telegraphy, which closely resemble some of the forms which within the last ten or twelve years have been re-invented and patented here.

One of these[1] is based upon combinations of a plurality of line wires, two or more of which extend from a terminal to each two sub-stations.

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1. Br. Patent 12039, January 25, 1848, H. and E. Highton.

A second[1] involves two wires together with the use of both directions, and varying strengths of current; and states itself to be "for sounding any particular alarm in a set of telegraph stations."

The third,[2] quoting from the published abstract, is for "transmitting secret intelligence to any one or more stations without the use of extra wires. At each station a metallic disk suitably inlaid with non-conducting portions, is brought to the required position in order to complete the circuit or not, by any electromagnetic step-by-step movement, thus excluding or including the telegraph instrument at any particular station or set of stations as required."

Three other British patents prior to 1876 are of this class, one of which[3] speaks of "an apparatus comprising a main line, a series of independent branch or station lines at each end, and clocks at both ends working synchronously, which, by means of revolving cams, place the main wire in consecutive connection with corresponding branches at the two ends for definite times."

Another[4] speaks of "apparatus placed in a continuous circuit; the bell at any particular station being caused to ring by the simultaneous advance in all the line wire apparatus, of a cam disposed in a way peculiar to each station, which is instrumental in closing a local circuit by which the bell is sounded."

The final instance[5] of this series is a mechanism in which a disk slotted or perforated at but one point, the location of such point differing for each station, opposes itself to the forward motion of an armature lever, at all times, except when the slot or hole is immediately opposite a pin on the end of the lever. This occurs at no two stations at the same moment, but when it does occur at any station, the pin passes into the slot and the armature is thereby permitted to complete its advance and to close a local circuit and ring a bell.

Several of these suggestions will no doubt be recognized as being found also in some of the more modern selective signal appliances.

In France, too, in connection with railway telegraphy, this

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1. Br. Patent 12959, February 7, 1850, E. Highton.
2. Br. Patent 13427, December 27, 1850, Dering.
3 Br. Patent, No. 3006, December 1, 1863, Wilde.
4. Br. Patent, No. 910, March 31. 1865, De Bonneville.
5. Br. Patent, No. 1801, June 11, 1869, Lyttle.

class of invention was formerly very popular; and as might be expected, is not neglected by that indefatigable chronicler, the late Count du Moncel, who devotes considerable space to the subject in the "Expose des Applications de L'Electricité."[1]

It is unnecessary to recapitulate much of what he states, and it is perhaps sufficient to say that the plans of no less than thirteen different inventors are described, in which the achievement of selective signaling is at least aimed at; and that some of them evince as thorough an appreciation of the merits of the question, as do many of the appliances patented for the same purpose in America since 1876; while one or two actually are based upon ideas which are found in comparatively recent patents also.

In the plan of Lamothe, for example, which is discussed by M. du Moncel, the gong which is to be struck is by one electro-magnet brought within range of a bell hammer, which then by a second electro-magnet is caused to strike the bell.

Another inventor, Bizot, has a plan for selectively ringing bells by means of pendulum hammers placed at the different stations, and adjusted at each station to a different length.

An electro-magnet at each station in the main circuit controls the swing of the pendulums by its alternate magnetizations and demagnetizations brought about by the makes and breaks of the main line current; these being effected by a vibratory circuit breaker at the transmitting station, operated by a similar electro-magnetic pendulum there, which can be adjusted when desired, to the same length as the pendulum at any one of the other stations which it is desired to operate. Only that one to which it is adjusted, will be operated; the others remaining inert. By so arranging *all* of the station pendulums that they can be adjusted, any station is enabled to selectively signal any other.

This apparatus I have described at considerable length, because it is founded on the harmonic principle which later was introduced into telegraphy, and because it contemplates the use in selective signaling of that principle, subsequently more elaborately worked out by German and American inventors and described in their several patents.[2]

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1. Expose des Applications de L'Electricité, Vol. iii, 1874, pp. 510-528.
2. German Patent, No. 1944, Maron, December 5, 1877.
   Br. Patent, No. 5078, Blake, December 11, 1879.
   U. S. Patent, No. 251,097, Currier, Dec. 20, 1881 and others.

Martorey's system, which likewise is described by M. du Moncel, also contains the elements of many subsequent forms. In it, by an electro-magnetic step-by-step motion, an escapement wheel having a number of teeth at least equal to the number of stations on the circuit, to give the signal, is brought to a given position by a given number of pulsations, differing for each station. All the teeth are metallic, and all, except one, are insulated. That one connects with the axis and mechanism, and is part of the alarm circuit. When brought into position, the ringing circuit which it appears is open normally at two points, is closed at one of these points, and at this juncture a single impulse sent over a second wire closes the second break in the local circuit, causing the bell to ring.

In addition to the foregoing examples of the condition of the art, it is not, I conceive, out of order to point out that the principles which govern printing telegraphy are closely related also to selective signaling. Consider for example, the House, Hughes, and Phelps telegraphs, and the form of stock quotation recorders now so universally employed; in all of these a given letter or figure is brought to a suitable point and is then pressed by a final operation against the paper to make the impression.

Now a little careful thought will show that the two problems:

A. To bring a number of typewheels at different stations all to the same predetermined point, and then press the paper against them so that the same letter will be printed at all stations, and

B. To bring a number of wheels at different stations carrying local circuit closing devices (placed at a different point for each wheel) all to the same predetermined point, where any particular one of them will be in position to close its local, and ring its bell when the press movement is made; are not in principle by any means far distant from each other.

They are further related, in that both must have a unison, zero, or starting point, to which they can be brought periodically for a fresh start, to forestall a lack of harmony between the different stations, or to provide means for bringing back an errant wheel which has strayed away from the path of electro-mechanical rectitude.

A good stock of knowledge thus was at the disposal of those interested, even at as early a date as 1876, when the career of the telephone was only beginning. We had the electro-magnetic ratchet and pawl, step-by-step, movement. We had electrically controlled clocktrains.

It was old to trip clockwork electrically; and also to use wheel circuit changers. The unison device in connection with step-by-step devices was old, and its use well known; the relay and its function of closing local alarm circuits was already a classic; wire combinations of various sorts were customarily employed; and the harmonic field had already been well threshed by Helmholtz, Bizot, La Cour, Varley, Gray, Bell, and others.

Why then was it not easy to make at once a thoroughly satisfactory and efficient selective call?

One reason is, that the average inventor or would-be inventor generally refuses, tacitly it is true, to recognize that there is any material of which he may make use. He does not know the state of the art; does not want to know the prior art; does not care anything about the prior art, and often feels affronted when he is necessarily brought face to face with it; and then he gives utterance to the pathetic plaint that "the people of former times were a dishonest race, they have stolen all my new inventions."

It is however clear from what has been stated, that the principles which underlie the problem in its many phases had to a great extent been elucidated, and that much had been done in working out scores of electro-mechanical contrivances, capable of being utilized in apparatus embodying such principles; and for these reasons there has in this branch of electro-mechanics been little scope for the exercise of original broad invention, and consequently little reasonable expectation of substantial pecuniary reward, even for him who might produce a thorough practical success in selective signaling.

These considerations have without doubt had effect in preventing many inventors and mechanicians of the first rank, or of great experience, from vigorously grappling with what was left of the problem. Yet from January 1879 to December 1891, 161 U. S. patents were granted for forms of Telephonic Selective Signaling appliances, all of which I have examined.

A careful analysis shows that quite a large number of general plans have been proposed, and that each of these has been developed in several ways, with greater or less care, and to many degrees of perfection. Several sub-methods can be utilized in many of the general plans, and in a number of cases attempt has been made to provide for several additional functions.

Though at one or two points selective signals embodying a few of these different plans are even yet employed, every telephone man knows that it cannot truly be asserted that success has attended such appliances.

One reason why, has been detailed. Some other reasons may now be given.

1. Some forms of promising selective apparatus have been put into use before being mechanically perfected, and their faultiness has given a figurative black eye to the entire race.

2. Some have been inherently defective, either in principle or construction.

3. Many as soon as crudely devised, have been employed as beasts of burden on which to organize a heavily capitalized stock company, and it has therefore been the great object of the advocates of these, to sell stock, instead of to make a practically successful apparatus.

4. To be commercially successful, a selective signal for a telephone system must be of low cost. In every form which has been put out and which has come under my observation, this requirement has been too prominently insisted upon, and the attempt has been made first of all to make not merely a *low priced*, but a really *cheap* signal. This attempt, I may note, *en passant*, has met with uniform success.

5. Excellency has not been insisted upon.

6. In many instances the apparatus has been required to do too much, or to perform too many functions, and has therefore become complicated; and

7. Usually the places where such signals have been tried, have also been places where intelligent supervision has been at a minimum.

Under the above circumstances, good results need not have been expected, and although they were expected, they did not arrive; and the user, after trying successively many of the different kinds of signals from time to time placed before him, has with the few exceptions already noted, discarded all; and for a long time now has refused to listen further to the voice of the charmer; alleging and with some show of reason, that "the only trustworthy individual signal is an individual line."

Desirability of Selective Signals.

This epigrammatic saying is however in some sort losing its attractiveness, in face of the multitude of conductors which it implies; and to a keen observer of the signs of the telephonic times, it is evident that a very extensive return to party lines in some form will bye and by be inevitable; at all events for residential districts, and from this point of view, it appears that the demand for a simple and trustworthy, but not costly, selective signal is as great as ever, and that, if such a thing is made, and its merits proved, many more party lines could and would be arranged and satisfactorily operated.

To reach practical success, by which is meant to devise a really trustworthy selective signal, economical, simple and easily kept in order, invention is not so much needed—keeping the prior art in mind—as is electro-mechanical skill to mould a homogeneous and perfect apparatus from the immense amount of material we have to choose from; an apparatus in fact which will operate perfectly, not only when the several circuit signals are ranged up alongside each other on the testing room wall, where a screw may be adjusted here, a spring tightened there, and a bell hammer rod bent in another place; but equally well when they are distributed over the circuit, and all at a distance from the operator.

And to aid the adventurer who intends to construct such an apparatus, I will outline the principles upon which this class of work in its several proposed plans, have so far been founded, reference being made in brackets to a single U. S. patent exemplifying each of the several plans.

General Plans.

1. *To operate the several signals at each sub-station on a circuit with differing strengths of current.*

Bells depending for their proper operation on a margin of current are however generally untrustworthy. [U. S. Patent—No. 221,512, Nov. 11, 1879, Buell.]

2. *Signals arranged to respond to currents of opposed direction.*

This implies of course polarized bells, and for a line with but two stations, it is probably as good an arrangement as can be provided. [U. S. Patent—No. 218,153, August 5, 1879, Anders.]

3. *Signals involving changes both in strength and direction of currents.*

These are apt to be unreliable for the same reason as are those of No. 1. [Patent No. 242,408, May 31, 1881, Anders and Vail].

4. *Electro-magnetic step-by-step devices, acting to bring the sub-station signals to a ringing point differing for each section, and then to close a local, branch, or shunt circuit, including the local bell, to operate ringing mechanism, or in some way to introduce the bell magnet into the circuit.*

Figure 1, taken from a patent of E. N. Dickerson, Jr., illustrates a ratchet and pawl step-by-step movement operating to close a local circuit in which is placed the bell. Successive pul-

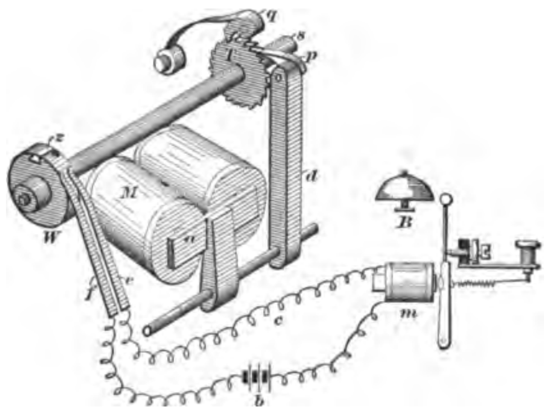


Fig. 1.

sations sent from the central station, cause the electro-magnet M in the main line circuit to attract its armature *a*, which after each pulsation is pulled back by a suitable spring (not shown).

The non-conducting wheel W on which presses the two springs *e* and *f*, has at one point on its periphery an inlaid piece of metal *z*. When the wheel is rotated till the plate *z* comes under the two springs, the local circuit of the battery *b* is closed through the bell magnet M, and the bell B, which in practice would be vibratory, rings.

The wheel W can be adjusted on its shaft *s*, so as to be in a different position at each station, and is operated by the main magnet through its armature *a*, lever *d*, pawl *p*, and ratchet wheel T, the retaining pawl *q* holding the shaft *s* between the several forward impulses.

There are of course many other ways of utilizing these principles, one being shown in Fig. 2, which is one of the drawings of a patent taken out by Messrs. Curtis and Crocker.

In it, the main line L comes to the binding screw *b*, passes by the wire *a* to the main electro-magnet A, which acts through its armature *h*, lever H, and pawl I on ratchet wheel K, held at any point by the retaining pawl *l*, and provided with a zero spring *p* and stop *o*. The ratchet wheels K are metal and at a point on their disk surfaces, differing for each station, have a non-conducting piece *n* let in, flush with the said surface.

A contact spring M presses also on the conducting surface.

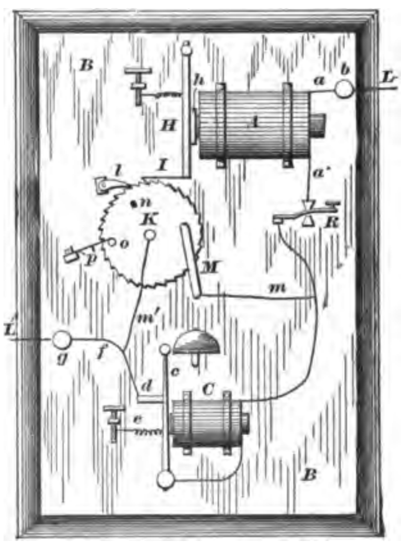


Fig. 2.

After passing the magnet A, and continuing by wire *a'* to a key R, used to call the central station, the circuit divides, one branch passing through the magnet C of the call-bell and thence by way of the bell hammer lever *c*, back contact *d*, and point *f*, to the terminal *g* and thence to the outgoing line L'.

The second branch passes by wire *m* from the point of division to the contact spring M, thence to the ratchet wheel and through the mechanism and by the wire *m'* to the reuniting point *f*, binding screw *g* and outgoing line. Thus as long as the contact spring M presses on the metal face of the ratchet wheel, the bell magnet is short-circuited; but when as the wheel is revolved, the end of the spring presses on the non-conducting piece *n*, the shunt circuit is broken and the bell introduced and rung.

This general plan No. 4 has been much favored by inventors, admits of almost indefinite variation, and is easily associated with auxiliary devices such as unisons, "busy" signals, and lock-outs for apparatus at other stations. If mechanism properly designed and made, be employed, there is no reason why satisfactory results might not be expected. Cheap apparatus has however invariably been tried and the system besides is slow. [No. 212,792, March 4, 1879, E. N. Dickerson, Jr. No. 230,530, July 27, 1880, Curtis and Crocker].

5. *Clockwork Bells.*

a. Those in which a constantly running clock-train brings the bells at the different stations into circuit successively, or re-

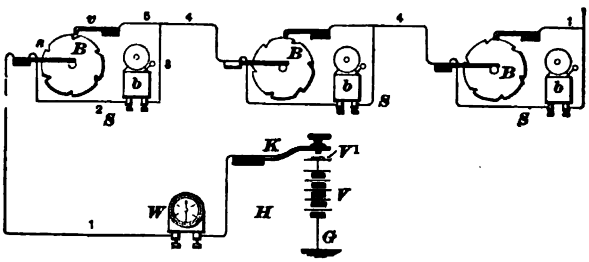


Fig. 3.

moves a mechanical holder from their hammers; when only they can be rung. These are not reliable; it being impossible to keep the clocks together; the clocks also require too frequent winding. [Patent 223,469, January 13, 1880, Bliss].

b. Those in which at each station is a normally stopped clock-train. All clocks are started by the same initial pulsation, and bring their signals to ringing points, or their bells into circuit at different times.

This idea is one of the most practical that has been advanced, and if the apparatus is well designed, and put together in a good mechanical form, it ought to do good work; unfortunately first-class apparatus is costly enough to remove the gilt from the economical side of the selective signal.

This plan is indicated by the diagram Figure 3, in which however the clockwork is not shown. In the diagram, H is supposed to be the signal transmitting, and S the signal receiving station, at each of which is a metal circuit wheel B, by which in conjunction with the circuit springs *s* and *v*, the bells *b* are when at rest short-circuited. At the transmitting station is a circuit closing key K, a battery V having one pole united to earth or return G, and the other extended to the front contact V′ of the key, and a duplicate W, of the several sub-station instruments.

The first pressure of the key through suitable mechanism starts the clock-works at all stations, and introduces the bells at

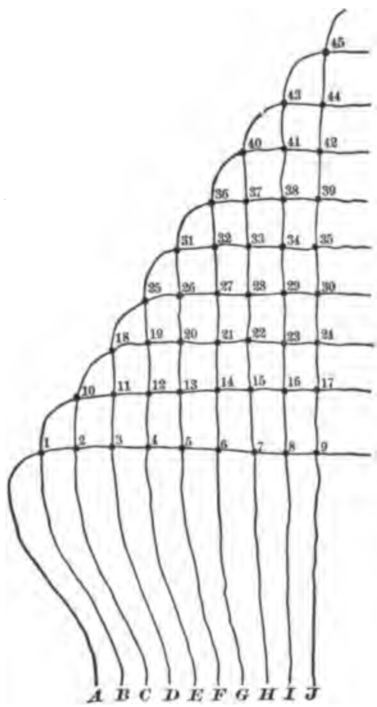


Fig. 4.

each station successively, as the wheels B bring their notches under the springs *v*. The wheels are in the present instant supposed to be slow moving, and to have six ringing notches for each complete revolution. They can by suitable mechanism be stopped on each notch to ring a given bell as long as may be desired; and they come to rest after one notch at all stations has passed under its spring.

Of course the notches are arranged to pass under the springs at different times for the several stations, and this is indicated in the figure, where the bell at the nearest station is introduced into the circuit; the springs *v* of the others being at different positions on the periphery of the wheel. [Patent 232,442, Sept. 21, 1880, Blake].

c. Those in which a normally quiescent clock-train is controlled by an electro-magnetic escapement, and permitted to move by successive beats, as a key at the central station alternately makes and breaks the circuit. [Patent 228,047, May 25, 1880, Eaton].

This could doubtless be made to work all right by putting excellent apparatus into it, but like nearly all step-by-step devices, would generally be slow.

Note.—All of the sub-divisions of class 5, may either have the signaling device directly in the main circuit, or in a local circuit to be closed by the action of the main circuit.

6. *Bells in which all the hammers move forward to strike at the same time, but except the desired one are prevented from striking by an interposed mechanical obstacle, which in the bell of the wanted station is removed.*

This has been faithfully tried. It was operated by an electro-magnetic ratchet and pawl, and was uncertain in operation. It also developed another fault: viz, that even the bells which are not to respond, make a considerable rattling. [Patent No. 219,059, Sept. 2, 1879, Anders.]

7. *Bells in which the ringing is done by circuit arrangement, or conductor combinations. Two series of circuits may radiate from a central to a number of substations, and one of each series caused to enter all stations. No two stations however have the same two circuits. Only when the current traverses both circuits does the bell ring at the station they enter.*

This is very promising. It can not however be applied to a multiple switch-board system. It requires relays and a local circuit bell; but no specially constructed apparatus.

It is also very speedy, the single pressure of a given key will always ring a given bell, and no mistake can be made.

This system is roughly illustrated by the diagram, Fig. 4, in which each outgoing conductor is shown to intersect each other conductor at some one sub-station, and thus afford facilities for producing a selective signal for 45 stations by using but 10 main lines.

For example, if it be desired to signal station 41, it will be necessary to manipulate the lines G and I.

The diagram Fig. 5, more fully illustrates one way in which the idea is worked out, although there are several plans, all of which are more or less advantageous.

A battery B, branches its two poles to each of a series of keys k, each of which controls the terminals of two lines; for example, key k may control terminals of A and B, k^2 those of A and C, and so on.

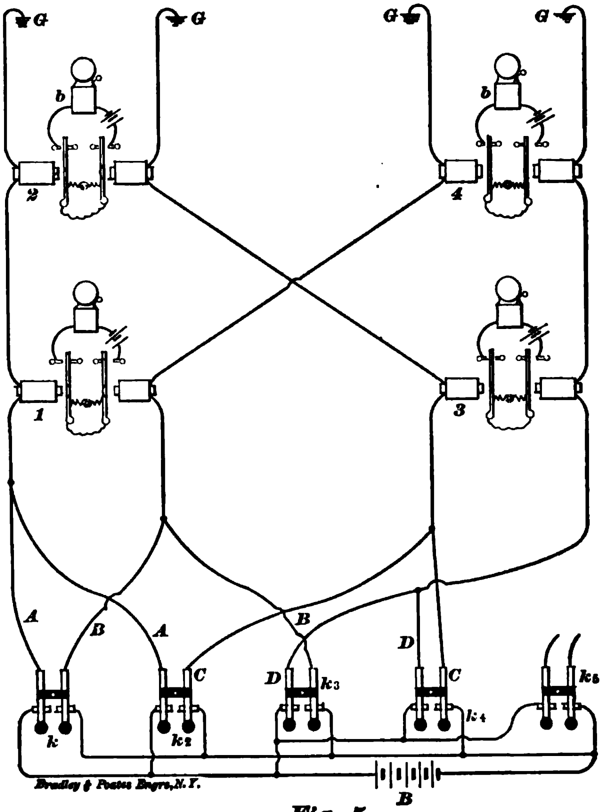


Fig. 5.

At each sub-station two lines both enter and pass respectively through relays, and the concurrent action of the two relays at any station is required to ring the bell, since the bell circuit is led through the armature levers and their front contacts of both.

Taking the conductors in pairs, the number of possible combinations is represented by the expression $\frac{n^2 - n}{2}$ and that number of separate stations can be selectively signaled by the use of n wires. [Patent No. 219,188, Sept. 2, 1879, Vail; Patent No. 224,855, Feb'y 24, 1880, Vail.]

8. *Bells working on the principles of harmonic telegraphy.* At each station the spring, pendulum or reed carrying the bell hammer is tuned to respond to a different note or rate of vibration.

The central station transmitting device is adjustable, and can have its rate made to correspond with that of any sub station bell. When set in operation the coinciding bell only will ring.

Operated always by experts, and carefully constructed and adjusted, these might do well. They are, however, too sensitive; tend to become operative as their proper number of vibrations is approached, and in some degree become irregular with temperature changes.

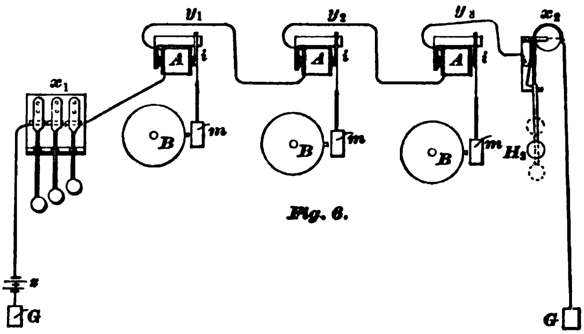


Fig. 6.

Fig. 6 illustrates the idea, and shows a central and three sub-stations.

At the central station is a battery z, and three pendulum circuit breakers formed into a single apparatus x'. Each breaks and makes the circuit at a different rate of speed.

The main circuit passes through the magnets A of the different sub-stations successively, each magnet having a reed armature to which a pendulous bell hammer is attached, the normal rate of vibration thereof corresponding to that of some one of the transmitting circuit-breakers. At the end of the circuit is shown a second transmitter x^2, with which, if desired, the sub-stations may be provided.

It has an adjustable pendulum bob, H^2, which can be moved to correspond with that of any bell which it is desired to ring, and which, then being set in vibration, is responded to by such bell. [Patent No. 251,097, Dec. 20, 1881, Currier.]

9. *Sub-station signals in which galvanometers identically constructed and calibrated, make the same deflection with a given current; to ring the bells different currents are sent, which produce different deflections. Each, of course, has its ringing deflection at a different point, which may by a mercury cup close a local circuit.*

These signals ought to work fairly well, if sufficient care and cost be put into them. [Patent No. 262,252, Aug. 8, 1882; Southworth.] It would not be difficult to add severalother classes to this list, but those which have been mentioned are the most important.

The plans of greatest promise are:

A. Those which by clockwork (as in 5*b*) are brought to a ringing point differing for each, the clockwork being then stopped, and the ringing done by a different kind of current. This is virtually the same plan of operation as is employed in the stock quotation printing telegraphs; and is reliable, but when adapted to do the work well, costly.

B. Those which as in class 7, require the co-action of two circuits.

Either of these when adopted should be worked in connection with a local battery.

Probably in practice it will be found advantageous to have a separate circuit distinct from the telephone circuit, on which a great number of selective signals may be connected.

Many sub-methods and appliances have to be thought of in considering this subject; whether we will be content to ring substations from the central station only, or on the other hand give each sub-station the power of signaling others on the same circuit.

If step-by-step apparatus be employed to successively bring the station appliances to their ringing points, some means is required to prevent the bells of intermediate stations from giving a signal as they are passed. Sometimes the time element may here be utilized. But a better way is to have the call-bell in a local circuit open at two points; to let the advance of the apparatus close one of these, and then send a different kind of current to close the other.

We have to consider also whether the introduction of line-in-use signals, unison apparatus, call sending appliances, and telephone lock-out apparatus, are sufficiently important to be added.

The unison or zero device in some form may be considered as an essential auxiliary in all progressive signals, whether of the clockwork or step-by-step orders. Even the most perfect mechanism slips occasionally, and as in the stock printing systems where instruments "throw out" or get out of step with each other, a suitable zero at which all can periodically be brought to rest, and start even, must be certainly required. A "busy" signal which indicates at each station whether the line is in use at any other is useful, but not essential. And lock-out apparatus, usually provided by closing a shunt circuit round the call sending mechanism and telephones, at all stations on a circuit, except the one

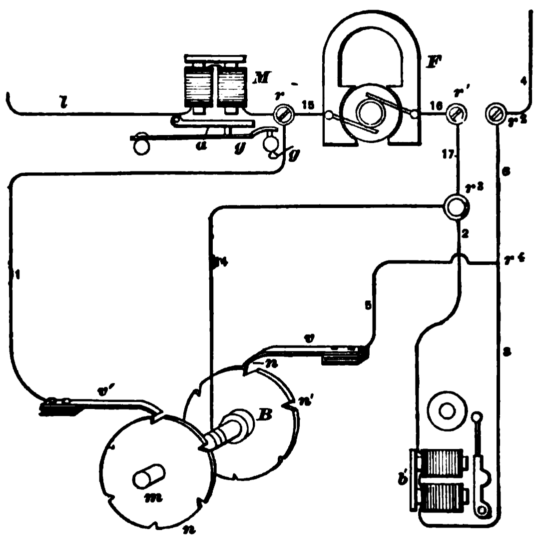


Fig. 7.

or two which are actually communicating, is also highly advisable in order that privacy and freedom from interruption may be maintained.

But, while some of these devices are necessary, and all useful if reliable, the contriver from this time forward, must keep at all times before his eyes, the undoubted fact that selective signals where heretofore tried, have uniformly been handicapped by being too intimately associated with too many such auxiliary devices, and must be correspondingly cautious about the way in whichthey are added.

Some such mode as is depicted in Fig. 7 is best for this purpose.

In the figure, M is a clock tripping magnet; F the magneto generator for sending outgoing calls, *b* the station bell, and *m* and *n* two metallic wheel commutators mounted on, and electrically connected with the same shaft B. Arranged to press on the periphery of *m* is a contact spring *v′* and similarly placed with respect to *n*, is a spring *v*.

When the station mechanism is at rest, it is desirable to have the generators in the line circuit, but the bells out. Accordingly, the bell is short-circuited through the disk *n*, spring *v*, and wires 14 and 5; while a possible shunt circuit round the generator through disk *m*, spring *v′*, and wires 1 and 14 is open, the spring *v′* being over the notch.

The notches of *m* are placed alike at all stations, but those of *n* differ at all stations; and therefore as soon as the shaft B begins to move, when the driving clock-train is tripped, the shunt circuit is established round all the station generators, and no station can interrupt by an attempt to send a call signal.

Such a device is well enough because it can generally be added without at all impeding the operation of the signal proper, and in any case constitutes a perfectly proper adjunct to the equipment of a party line. But when associated with selective signals the greatest care is necessary to provide that the arrangement is such that the auxiliary appliance may not prove a drag on the signaling mechanism.

Selective signals require a fair field and all the favor they can get.

DISCUSSION.

PROFESSOR CROCKER:—Mr. Chairman, Mr. Lockwood asked me to say a word in discussion of his paper, but I fail to see where there is any room for discussion. It is very complete and puts on record in a clear and satisfactory form, a certain branch of the electrical art which has quite an extensive application. As Mr. Lockwood says, it is not confined to the telephone. The ability to call up one particular office or point on a single circuit containing many such offices or points is certainly very useful. I thought so some thirteen years ago, and patented the method referred to byMr. Lockwood. It was my maiden effort in electrical invention and I am pleased to see that it still exists. But I was not aware, until I read Mr. Lockwood's paper, that it had not sunk entirely into oblivion. The perfection of the apparatus is the essential point in this matter. It is not a very difficult thing to think of a method. In fact, there are almost too many possible methods.

If the ability of the inventors and makers of this apparatus had been concentrated on one method, I think the results would have been better. One very interesting point is the fact that in 1881 and 1882 it looked as if such devices were entirely unnecessary, simply because each man wanted his separate circuit. Now, in 1892, we are coming back to the position that we had before that time—that is, where the selective signal is useful again. That cycle of change in electrical engineering is quite interesting. We see the same thing in the case of the alternating current which twenty or thirty years ago was the standard form. Then it disappeared for more than ten years, and then reappeared again.

The necessity or desirability of putting a number of offices on one line is apparent to any one who goes into a telephone station and sees the multiplicity of connections required where there are several thousand subscribers from a single station. That would appear to be an almost essential reason for adopting some form of selective signal system for at least a portion of the subscribers.

MR. LOCKWOOD:—Mr. Chairman, if there are no other gentlemen who wish to say anything on this subject, I would like to add one word which has been called to my mind by what Professor Crocker said. I cordially agree with what he said about the necessity of concentration of attention upon one line, and that the results would no doubt have been greater had that been done. But I should like to add to that, that it largely depended upon which method several inventors concentrated their attention, and I do not think that any amount of concentration of ability devoted to that method in which hammers were brought upward, all at the same time, but prevented from striking by the opportune presentation of a mechanical obstacle, would have produced a good signal system.

THE CHAIRMAN:—The paper on "Series Electric Traction," having already been read by title, if there is any discussion on that we will take it up now.

MR. UPTON:—Mr. Chairman, I believe I am right in saying that it was the intention to have the discussion on the coming papers go together. There are three papers all on electric railways which should be read and the discussion follow at one time.

MR. MARTIN:—That would be a great saving of time, Mr. Chairman, and I move that the three papers on traction be read, and that we have the discussion upon them all at the same time.

[Motion seconded and carried.]

The following papers, by Mr. H. Ward Leonard, of New York, on "A New System of Electric Propulsion," and by Prof. George D. Shepardson and Mr. E. P. Burch, of the University of Minnesota, Minneapolis, Minnesota, on "Electric Railway and Motor Tests," were then read by the author.

The Chairman:—At the time when Mr. Perry's paper was called, as he was not present it was read by title. Being upon the subject of electric traction it is directly in line with the papers which have already been read, and Mr. Perry perhaps would like to summarize in a brief way the particular points in that paper before the discussion takes place.

The paper on "Series Electric Traction," by Mr. Nelson W. Perry, of New York, was then read by the author.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

SERIES ELECTRIC TRACTION.

BY NELSON W. PERRY, E. M.

In telegraphy, that application of electricity where pre-eminently long distances are concerned, the series system is alone adequate to the demands. In telephony, where more than two instruments are concerned, as in the case of several subscribers on the same circuit, or where as in small towns, several of them are connected on a single wire, they are all connected up in series; and again where larger amounts of energy are to be transmitted to considerable distances, as in the case of the arc light, the series arrangement is the only practical one now at hand. Why then should not this system commend itself for long lines of electric railroads? Mr. T. Carpenter Smith, in a series of valuable articles on "Some Views of Central Station Management," now running in one of the weekly electrical journals, lays down as one of his canons in the establishment of a plant, that it should be so planned as to permit of its ready extension as the demands increase; or, in other words, that in laying our plans we should provide for the future rather than for the present. If this be good advice in the case of electric lighting stations, how much more force must it have, if it be applied to electric railway systems, which, as we all know, are being rapidly extended, in many instances to double and treble the distance originally contemplated, only to be increased again as soon as these further limits are reached.

In railway practice, it is the distance rather than the quantity of current that forms the most important factor of increase, though the latter cannot be neglected in planning for the future.

In street railway construction, assuming the distance to remain the same but the traffic to double, the amount of copper required to maintain the same relative economy must also be doubled. This is a minor matter as compared with the case where both distance and traffic are doubled. In this latter case, to maintain the same economy, the weight of copper must not only be doubled but squared. The limit of extension even on these lines is, however, soon reached, and the only recourse, by existing methods, is to erect at or near the further point another generating station, with all that that implies in the way of additional investment in real estate, machinery, etc., and a duplicate set of employés.

In long lines, the bugbear of the multiple arc system of distribution is the drop in potential at the further end. The potential may be amply sufficient near the generating station, but it becomes less and less so as this proximity is departed from, until, at the further end, the lights which burned brightly near the station, dim down to scarcely more than a dull red, and the cars are operated under heavy loads with difficulty or not at all. There are two remedies for this drop in potential at hand—either to increase the amount of copper in the feeders, which within commercial limits is but a partial remedy, or to increase the pressure, using the same amount of copper which, when the multiple arc method of distribution is employed, introduces as many difficulties as it obviates. There is still a third remedy, and that is to employ the constant current method, in which, under all circumstances, the current remains the same and the pressure varies as the work performed.

In the one case the copper must vary as the demands and distances—the pressure remaining the same—and in the other the pressure varies, the copper and current remaining the same.

In an arc light (series) circuit, the wire will be of the same size whether it be erected to supply one lamp or sixty—whether the distance be one mile or five, and if at any future time it be desirable to extend the line to double or treble the distance, the wire already erected is amply sufficient for the part of the line it covers, and merely requires extension to the desired point to meet all the demands. There are in this country numerous arc light circuits in successful operation, twenty miles and more in length, yet I doubt if there is anywhere in the world a direct current constant potential circuit in operation to-day of anywhere near this length.

If energy can be so much more advantageously distributed to long distances by the constant current method for arc lamps, why should this method not commend itself to the ever-increasing distances to which our electric street railroads are reaching? If the steam locomotive is ever to be supplanted by the electric motor, why should not this method of distribution be the one to be adopted?

The answer is that the constant current method, as heretofore developed, has not been sufficiently elastic to meet the requirements, and although the generation of a constant current involved much less complex machinery, and the cost of distribution to distant points necessitated a much smaller initial outlay, still the difficulties introduced by this method largely outweighed all its advantages.

With the arc lamp or other stationary translating device, arrangements were readily devised for automatically shunting the current around in case of disability of the translating device, or the desire to throw it out of service. Not so with a moving object, such as a street car. No means had been found to shunt the current around the latter, or in case it got out of circuit by means of the trolley getting off the wire, of automatically closing up the gap thus made, and the disability of one car became the disability of the whole line and of every car on the line.

Could this and some other difficulties be surmounted, the constant current possesses many advantages over the constant potential that seem to me would bring it into almost universal use for traction purposes, especially on interurban lines and in other cases where long distances are concerned.

It is my purpose to show how all this has been accomplished, and how the constant current system may be made as elastic in every way, at least on paper, as the constant potential, without sacrificing in any way any of the advantages peculiar to the system, and how it is possible to make each unit in such a system nearly if not quite as independent of every other unit as is the case in the system now in vogue.

The most ambitious and painstaking, and withal successful attempt up to the present time, to adapt the series or constant current method to electrical traction, was that made by Prof. S. H. Short, now of Cleveland, Ohio, and he actually constructed and operated for a considerable length of time, and with some success, two roads, one a single track road at Huntington, W. Va., connecting that city with Guyandotte, about three and one-half miles distant, and the other a belt and double track road on South Broadway, St. Louis, which was, I think, about three miles in circuit. Prof. Short employed two wires, divided up into sections of any desired length, but necessarily not less in number than the number of cars to be operated. These sections were connected together by switches operated by a peg on the trolley mast, the peg on one car throwing the switch in one direction, and that on the succeeding car throwing it in the opposite direction. The current coming upon one line of wires, crossed over through the motor to the other line, by which it was carried to the next car motor, through which it passed back again to the original line of wires. Each car as it passed a switch set it so that the current in the section it was entering would come up on the same wire as it had in the section just left, and the succeeding car would set the switches so that the current would come up to it on the opposite wire, and so they alternated.

Since the continuity of the circuit depended upon the presence of a motor between the two lines, if either of the trolleys got off its wire, the circuit was broken and all cars had to stop for lack of current, just as if we had an arc lamp without an automatic cut-out, and the carbons should become broken or the arc blown out, the entire circuit would be disabled, and any irregularities in the resistance of the arc of one lamp would affect all the other lamps on the circuit.

Since the switch must be thrown to opposite wires by each succeeding car, if one car failed to do this, as would be the case if an odd number of cars were added to or removed from the line, it would again become broken by reason of the failure to throw the switch in the proper direction. Cars had, therefore, to be added to or removed from the route in even numbers. This precluded the inter-communication of two or more systems, for the reason that if a car was run off from one line onto another, it would be a case of the removal of an odd number to the other line, and both lines would become broken. So, too, it was impossible to operate a branched road on which part of the cars took one branch and a part the other, for the succeeding car, after it passed the forks, whichever route it took, would either break the circuit itself, by reason of failure to properly turn the switch, or would leave the switches in such a position that they could not be operated by the next car.

On a single track road where the cars passed each other on sidings, it was necessary to wire the whole route as though it were a double track road, the cars going up one pair of wires and returning on the other which followed the siding. This was the case at Huntington, where, although there was but a single siding, perhaps fifty feet long, where the two cars passed each other, the whole three and a-half miles had to be double wired to enable them to pass, else the two cars would be thrown into multiple with each other and neither could run. I succeeded in devising a means by which if there were but two cars and one siding on the road, the only double wiring required was at the siding, but the plan failed where more cars and sidings were involved.

In Short's system the switches were purely mechanical, exposed to the vibration of the trolley wire and to the elements, and had to fit tightly, else they would burn out. If they fitted sufficiently

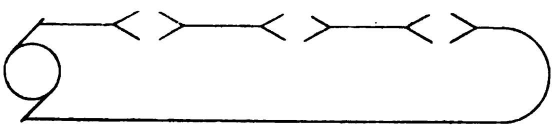


Fig. 1.

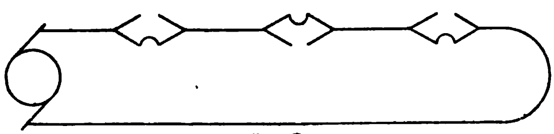


Fig. 2.

tightly to obviate this, they were liable, through corrosion or ice or some other cause, to fit too tightly and fail to operate, in which case the line again became broken.

I speak more freely of the defects of the Short series system from the fact that it has been abandoned by the Short company, and because its failure has been officially announced by its projectors. My object in dwelling upon it at such length is to point out more clearly some of the defects that must be remedied before the series can become a practical working system.

The system which I am about to explain may properly be described as consisting of a circuit interrupted by a series of breaks in multiples of two. Or one consisting of a circuit interrupted by breaks in multiple series with each other—the breaks being in multiples of two. The conception then would be like Fig. 1.

But in order that a current shall pass around this circuit, it is necessary that *one* of the breaks in each multiple shall be normally closed. It matters not which one is closed, so our plan would now look like Fig. 2.

If a translating device should successively occupy each of these

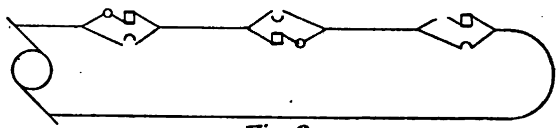


Fig. 3

breaks, it would receive current during the time that its terminals connected the ends of the two broken wires, in proportion to the relative conductivity of the two paths open to the current. But we are not satisfied to have a portion only of the current pass through our motor—it is necessary that *all* the current must so pass. We must, therefore, make the resistance of the other branch infinite during the time in which the motor is bridging, through its terminals, the break, or, in other words, the normally closed branch must be broken.

If, therefore, we place an electro-magnet in *series* with the normally broken branch, so that when vitalized it will open the switch in the normally closed branch, and allow it to close again by gravity or otherwise, when the magnet is devitalized, we have provided in a crude way for operating traveling translating devices in series. Our conception now would be represented somewhat by Fig. 3.

By this arrangment, the moving device only receives a mo-

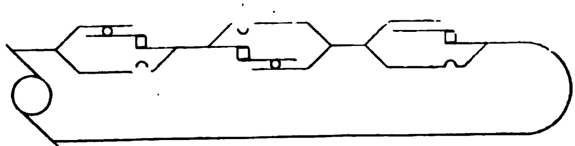


Fig. 4.

mentary impulse as its terminals touch the ends of the break, and would have to rely upon its acquired momentum to carry it to the ends of the next break. It will be apparent, however, that it is immaterial whether the device receives its next impulse by closing the next break in the circuit or whether it skips that one and gets in from any other break, either on that circuit or from one connected with an entirely different dynamo. It is this feature that permits the use in my system of sidings on single track roads, and of forks (the skipping of one or more breaks), and the inter-communication between separate circuits (the jumping from a break on one circuit to a break on another),

It is desirable, however, that the moving device be impelled by as nearly a continuous force as possible, instead of by a succession of momentary impulses. Instead, therefore, of having the ends of the normally opened break face each other as represented heretofore, we may extend these wires from some distance parallel with each other, and our plan assumes the form shown in Fig. 4.

And it is desirable that the interval of time during which the device is without current, viz: that occupied in passing from one break to the next, shall be as small as possible. This naturally suggests having the normally open breaks all on the same side of

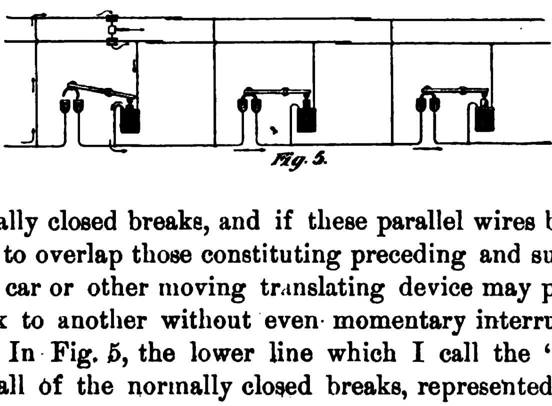


Fig. 5.

the normally closed breaks, and if these parallel wires be continued so as to overlap those constituting preceding and succeeding breaks, a car or other moving translating device may pass from one break to another without even momentary interruption of current. In Fig. 5, the lower line which I call the "feeder," contains all of the normally closed breaks, represented by mercury cups normally connected electrically by a fork taking into them, which constitutes a double pole switch actuated by an electro-magnet in the manner to be described.

The upper pairs of wires, which it will be seen are merely the parallel extensions of the other possible path for the current, are in multiple with the path through the mercury cups. One of each of these pairs of wires, which will hereafter be denominated sections, is connected to the feeder wire on one side of the mercury cups, and the other has a similar connection on the other side. The two wires of each section normally without electrical connection with each other, constitute what has been termed the "series of breaks normally open." If, however, these two wires be connected electrically through the terminals of a motor, the latter will be in multiple with the mercury cups and momentarily receive only the current due to the relative conductivity of the path thus offered. By the arrangement shown in Fig. 5 the electro-magnet which opens the mercury cup switch is in series with the motor circuit, and the latter no sooner receives current than the former is actuated, the switch is opened and the whole of the current which was momentarily divided between the two branches, is diverted to the motor.

If the corresponding wires of the succeeding sections be caused to overlap without making electrical connection with each other, and these laps be staggered as shown, a means is provided where-

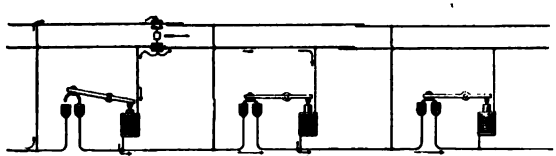


Fig. 6.

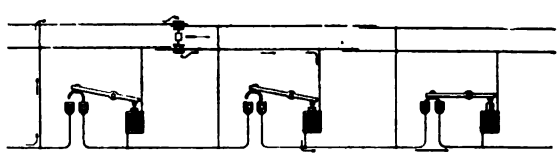


Fig. 7.

by the motor prepares the succeeding section for occupancy before wholly passing out of the one it is about to leave and accomplishes this without interruption to the current. Figs. 6 and 7 show how this is done and the arrows show the paths taken by the current as the transition takes place. When the motor is in the position represented in Fig. 5, there is but one path for the current—viz. around the open switch in the feeder and through the electro-magnet by which it is kept open, back again to the feeder.

As the motor proceeds to the right, one of the terminals first embraces the lower lap, thus offering two paths for the current—one passing through the switching arrangement that controls the section the car is about to leave, and the other through that controlling the section it is about to enter (see Fig. 6). As it progresses still further, this terminal passes beyond this lap at about the same time that the other terminal embraces the other lap. This leaves the first switch without current, and the succeeding switch is automatically opened. There is no break in the circuit, however, even during the short interval occupied by the two switches in acting, for while the further terminal embraces the further lap, both of the switches concerned are short-circuited, as shown in Fig. 7. Before the further terminal has passed beyond the lapping portion of the two succeeding wires, the first switch will have closed and the succeeding switch will have been opened, thus diverting all of the current to the section upon which the motor has now entered.

Fig. 8 shows another arrangement by which a motor is enabled to pass from one section to another without interrupting the cir-

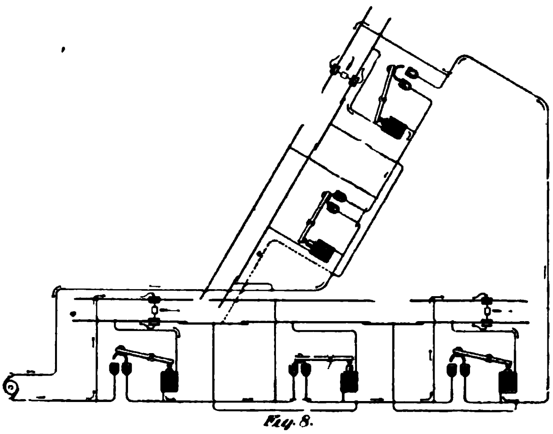


Fig. 8.

cuit. In this arrangement the ends of the sections, while mechanically continuous, are electrically disconnected, but do not lap as before. The break in the wires connected with the switch-actuating device is longer than that between the other two wires. The larger gap, however, is lapped by a subsidiary conductor, which short-circuits the switch actuating the section the motor is about to enter, as shown. As the car proceeds from left to right, before both its trolleys have passed off the section, one of its trolleys has embraced the subsidiary conductor and the electro-magnet controlling that section is cut out of circuit and the switch drops. While the switch is dropping, however, the current continues to flow through the companion wire, through the motor to the subsidiary wire and *around* the switch actuating the section it is entering.

Fig. 8 represents a branched or forked road operated by a single dynamo. In the arrangement shown in Fig. 8, where the branch road is operated by the return circuit, a car turning to the left would really skip from the first section of the road to the very last, if we count them in the order in which they receive current, whereas in going straight ahead it would pass from section 1 to section 2, etc., counting them in the same order. In Fig. 9, however, which represents a similar road operated by the loop system, a car taking the left hand branch would pass from section 1 to sections 2 and 3, whereas if it went straight ahead it would pass from section 1 to sections 4 and 5. It will be apparent from what has preceded that in neither of these cases does the skipping of one or many sections involve an opening of the circuit.

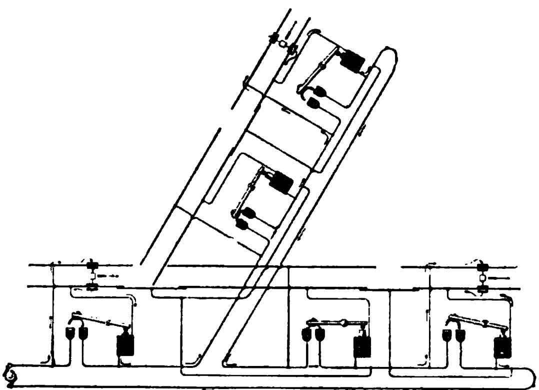


Fig. 9.

But returning to Fig. 8, and following the car still further in its progress from left to right. We left it standing with one trolley on the further wire and the other on the subsidiary or short-circuiting conductor. In this position the current will continue to pass through the motor only so long as the switch actuating that section requires to fall into the mercury cups. Immediately that has occurred, which will be accomplished before the further trolley has passed from its wire, the motor will have been short-circuited and the car will, by its acquired momentum, pass from the system without sparking or other disturbance of the circuit. If the acquired momentum should carry the car to another section of the same system, or to a section connected with an entirely separate system, all that is necessary to enable it to proceed would be some arrangement by which the switch controlling the section upon which it was entering, could be opened by the entrance of the car itself. It will be evident from Fig. 10, which represents two connecting roads operated by separate dynamos, that it matters not as far as the integrity of either circuit is concerned, whether the car goes to the left or to the right; in either case the circuit is closed before it leaves a section, and as it enters a succeeding section it does so before opening the switch which actuates that section, and it is entirely immaterial whether that section belongs to the same system as the one just left, or to one en-

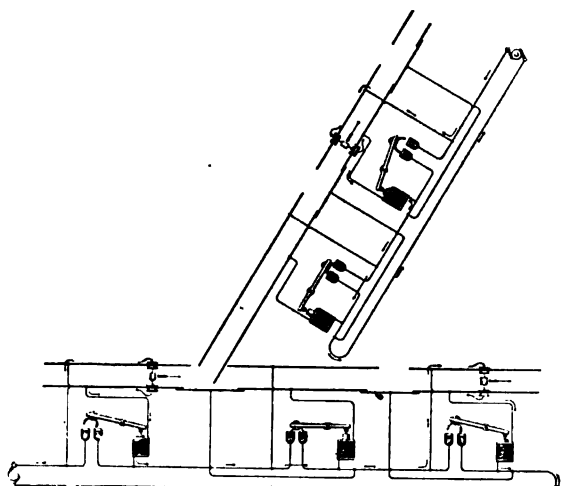


Fig. 10.

tirely foreign to it. If only the proper switch can be opened the car may proceed on its way on either system of roads. In order to accomplish this automatically, each car may be provided with some such an arrangement as is shown in Figs. 11 and 12: M is a solenoid magnet in series with the motor D; L is a lever pivoted at P and playing between two stops, but when not actuated by the plungers of M, kept in contact with the lower stop by the spring S; B is a local battery; W, W[1] are the trolley wires, and C is the mercury switch connecting adjacent sections of the feeder wire. As long as the motor is receiving current from the feeder, as is the case in Fig. 11, the current must pass through M, which, by its pull on the plungers, maintains the lever L against the upper current. As the trolleys pass off from a given section and the motor loses its current as before described, the spring S causes the lever to make the lower contact (Fig. 12), thus throwing the battery B into the circuit W, F, C, F′, W′. The moment the trolleys enter upon a new section this circuit is closed, the local current passes through the feeder switch magnet and opens the switch C, and diverts the current from the feeder to the section just entered. This stronger current actuates the lever L, again

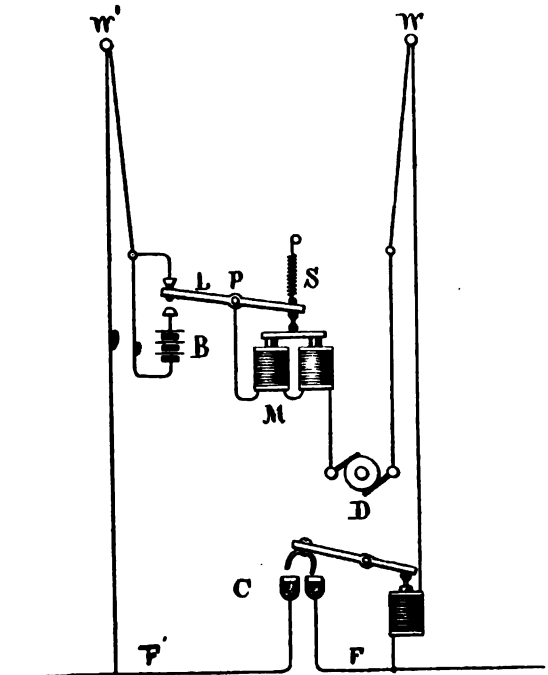


Fig. 11.

bringing it against the upper contact and cutting the battery B again out of circuit. Since the battery B is only momentarily in circuit, the cost of maintenance will be insignificant.

On single track roads where turnouts are required, the turnout constitutes merely an additional section to one side of the main line, which is skipped by the car keeping the main track, and taken by the other car in passing. It, like every other section, has its own individual controlling switch, and when both the main track and siding are occupied by cars, their motors are arranged in series with each other, as represented in Fig. 13. By following the arrows, the course of the current can readily be understood.

But both of the plans thus far discussed possess serious faults. In both we have provided a means by which a car may leave one section on a given road and enter another one on the same or another road without breaking the main circuit, *provided the car is always going in the same direction.* In all of the cuts thus far,

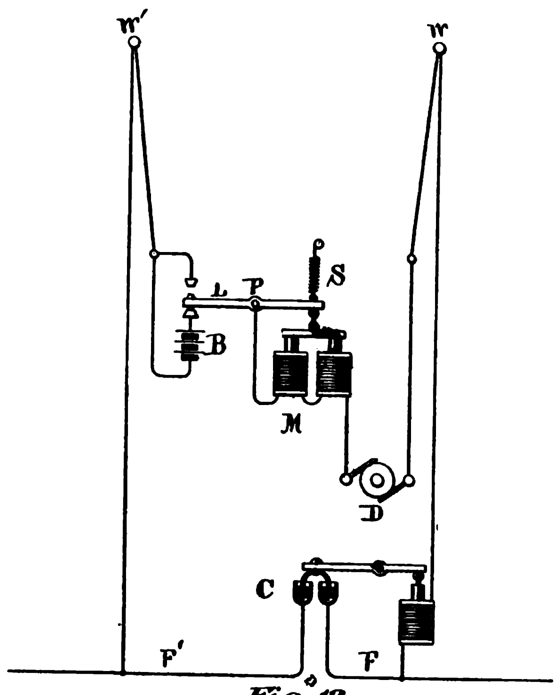


Fig. 12.

the car is supposed to be going from left to right, and the switches are arranged accordingly. But if we examine the drawings again, it will be found that in the plan suggested in Figs. 5, 6 and 7, if the car were going in the opposite direction, the circuit would be momentarily broken as it left one section and would fail to divert the current to the section it was entering. In the second plan, outlined in Figs. 8, 9, 10 and 13, the car is momentarily without current whenever it passes from one section to another.

By combining the two plans, however, all of the difficulties seem to be removed. Figs. 14 and 15 show how this combination is effected, and the courses of the current when the motor terminals are in different positions on the wire. It will be noticed that, as in the first plan described, the trolley wires of adjacent sections

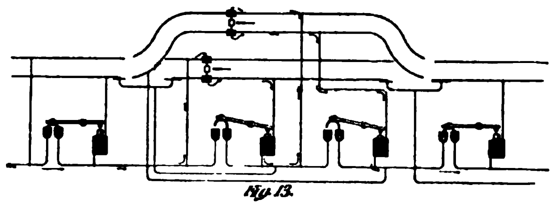


Fig. 13.

are lapped and that these laps are staggered; that parallel to, but insulated from, the nearer laps, is placed the subsidiary wire which short-circuits the switch to the right. The switch-controlling magnet, as is shown, has two coils wound cumulatively, and may be operated either by the current passing through the subsidiary wire, by that passing through the nearer trolley wire, or by both when it takes both paths.

The supplemental conductors and the laps in the trolley wires are so arranged relatively to each other that when a car is traveling in the direction of the main current, as the trolleys approach a lap, the trolley traveling upon the wire connected with the switch will contact with the supplemental conductor before reaching the lapping portion of the trolley wires, and the companion

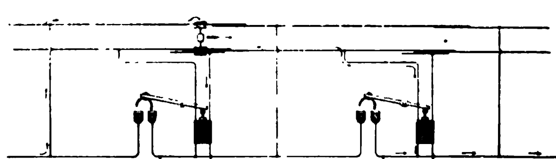


Fig. 14.

trolley will reach its lap after the first trolley has reached its lap and before it has passed beyond the supplemental conductor, while with a car traveling in the opposite direction, the order will be reversed, the trolley upon the wire *not* connected with the switch, first reaching its lap after which its companion trolley reaches first its lap and afterward the supplemental conductor. By this arrangement, in whichever direction the car may be going, in passing from one section to another, it first short-circuits the switch controlling the section it is about to enter; next diverts a portion of that current to that switch, and finally all of it, cutting the switch controlling the section it has

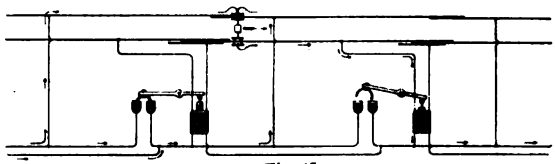


Fig. 15.

left entirely out of the circuit. In this manner the transition is accomplished in either direction from one section to another, either of the same or another connecting road, without spark or interruption of circuit.

Should either one or both trolleys leave the wires, or the circuit through the motor in any other way become broken, the magnet controlling the switch to that section would be left without current and the forks would immediately drop into the mercury cups renewing the circuit through the feeder wire almost instantaneously. There would, however, be an interruption of the current while the fork was dropping. Even this slight interruption may readily be avoided by connecting with the switch any of the devices so successfully employed to obviate the same difficulty in arc light circuits.

Should a second car run upon a section already occupied, the

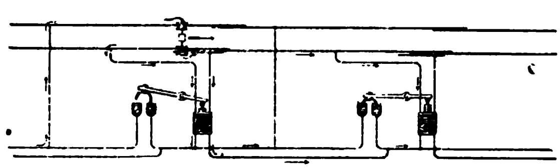


Fig. 16.

two would be thrown in parallel and both would stop. This arrangement therefore constitutes a most perfect automatic block system, not dependent upon frail human nature, but sure and positive in its action. On interurban electric roads, where it is even now proposed to reach greater speeds than are customary or attainable with steam locomotives, the importance of this feature cannot be overestimated. Not only will collisions be rendered practically impossible, but by putting semaphores or other signalling devices in the wires connecting the main feeder with the two trolley wires, each car as it enters a section will automatically set a signal at each end of that section showing that the section is occupied, and when it has left the section set another, indicating that the way is clear. These signals cannot fail to act, for being in series with the motor, they *must* receive current when the motor does, and lose it when the latter has passed out of the block. This seems to be the solution of the block system as it eliminates all the uncertainties inseparable from a dependence upon human intelligence and watchfulness.

This system will no doubt be criticized first, on the score that it is a double trolley system which many are opposed to on general principles, and second, on the score of the high potentials necessarily involved in series distribution to long distances. Anticipating these, I will say in regard to the first, that however valid the objections may be to the double trolley on multiple arc roads, they have but little force as applied to series circuits. In the latter, since both the wires on all sections not occupied by cars are of the same potential, the difficulties of insulation of the one from the other disappear entirely. Then again, I am satisfied, with an intimate knowledge of the electric roads in Cincinnati, where with one exception they are double trolley multiple arc roads, that most of the objections raised against them are greatly magnified. They certainly have the decided advantage over the single trolley—of being in their operation independent of the condition of the track. Their chief objection being the difficulty of insulating the positive and negative wires from each other, (which we have seen does not hold in series roads) and the multiplication of wires, crossings and switches where many lines converge and cross. In suburban districts where these complications do not occur (and this system is particularly adapted to such) the double trolley multiple arc system is in many respects superior to the single trolley. Mr. John Kilgour, President of the Cincinnati Street Railway Company, is justly proud of the Avondale double trolley road (a suburban line), and I doubt if there is a more successful road in the country than this.

In regard to the other objection to the series method, viz., the high potentials, the method outlined in this paper permits the use of any number of feeders, each of which may be used to supply a different portion of the road, thus reducing the potential, which in series distribution is the variable quantity, in the same manner exactly that the "drop" is obviated in parallel systems.

It is perfectly clear to the members of the Institute that this question of potential on series circuits is very much misunderstood by the laity. In the parallel system of distribution, the high potential impressed upon the circuit at the dynamo is carried to every translating device on the circuit, even to that at the extreme end of the line, whereas in a series circuit, the high potential spoken of, exists only at the dynamo terminals and is the sum of the electro-motive forces consumed by all the resistance on the line.

As an illustration in point, supposing we have two circuits—one parallel and the other series, the differences of potential between the terminals of the two generators being exactly the same—let us say 2,000 volts. On the multiple arc circuit, no matter how insignificant the translating device may be or where it is located, one cannot handle its terminals without subjecting himself to a shock due to 2,000 volts. If the motor be generating one H. P. or 100, the danger is exactly the same. On the other hand, in the series system, if we are using a current of say 40 amperes, which is a convenient one for street car purposes, if the motor be generating one H. P., the difference of potential between its terminals will be a little less than 19 volts. If it be generating 100 H. P. it would be but 1865 volts, and before it would be as dangerous to handle as a motor on the multiple arc circuit, it would have to be doing work equivalent to 107 H. P.

Not long since, there was a very animated discussion at a meeting of the Institute as to which was the better method of electric street car control—that of commutating the field, or the other one, of employing a rheostat. Both sides of the question were ably handled, and the discussion resulted as discussions usually do when the subject is either politics or religion, viz., in the making of no converts. Both sides to the controversy admitted, however, that in either case there were disadvantages, and the question practically resolved itself into "which was the lesser evil?" The constant current system simplifies matters at least in this respect, in that neither commutated fields nor external resistances are required in regulation.

As regards economy in transmission of energy to long distances by the constant current method, we have high authority in Silvanus P. Thompson, who, in his "Dynamo Electric Machinery" (edition of 1888), p. 531, says:—"Now, the method of distribution by a constant current is, where power is to be transmitted to long distances, *a much more economical method* than that of distribution with a constant potential, owing to the fact that to the former method thinner, and therefore less expensive conducting wires may be employed."

He might have gone much further than this. As to the cost of installation, the comparison is much in favor of the constant current method on account of the extreme simplicity of the plant required, and the smaller size of both motors and dynamos for the same output. But the economy in plant becomes most obvious where high potentials are used, and these are always necessary where long distances are concerned.

But important as are the economies in installation and in transmission of large energies to long distances, there is another that greatly outweighs them, viz., the economy in operating expenses. In this respect the series method is almost an ideal one. In the parallel or multiple arc method, when a car is going downhill or is being checked, the whole of its $\frac{m\,v^2}{2}$ is absolutely thrown away in the application of the mechanical brake. Not so with the series system. The mechanical brake need never be used except in the case of an emergency. By merely reversing the position of the brushes, the motor becomes, for the time being, a dynamo in series with the one at the power station, driven by gravity or the acquired momentum of the car, and the energy thus absorbed, while checking the car or bringing it to a standstill, is thrown onto the line for use elsewhere. One of the arguments used in favor of the cable road is that a car descending a grade assists another one which is ascending. If this be an argument where at least 75 per cent. of the engine power is consumed in dragging the cable alone, how much more valid should it be if the same thing could be accomplished where there was no cable to drag. Such, in fact, is the case with the series method. A descending car or one being checked assists another car that is ascending a grade or being started from rest, just as truly as it would if the two were connected by cable, and the energy thus thrown onto the line continues to contribute to the economy of the system to the last turn of the wheels. This is not mere theory. Professor Short demonstrated its actuality on the South Broadway line, in St. Louis, by disconnecting the circuit entirely from the dynamo, and causing one car to partly ascend a grade on one part of the line by electrically braking a descending car on another part of the line. It has also been demonstrated in England. Mr. Edward Manville, M. I. E. E., in a paper on "Series Electrical Traction," read before the British Association, in September of 1888, says:

"It may be well to point out in series running, that owing to the employment of current of constant value, it is impossible for the most inexperienced car driver to damage his motor by either too rapid starting or by reversing while running. Indeed, it is a positive advantage, when descending a hill to check the speed of the car by altering the field connections so that the armature tends to revolve in the *opposite* direction to that in which the car is traveling, as the power that would otherwise be lost in braking the car is actually added to that produced by the generator, and thus large systems with many cars and varying gradients would appreciably reduce the total power required to be generated, and the consequent consumption of coal. At Northfleet, they could actually turn the engine back against the steam, when they were going down hill; that is to say, the power developed by the car going down hill, passing through the circuit, is more than at the engine at the moment."

The importance of utilizing electrical brake power, which is impracticable in the parallel system, is emphasized by some experiments on the Third Ave. Elevated R. R., New York, insituted by Mr. Frank J. Sprague, to determine in what manner the power generated was utilized. The result of these was that 83 per cent. of all the power utilized was consumed in overcoming gravity and the inertia of trains, and only 17 per cent. was actually consumed in traction.

I have endeavored in this paper to show both the advantages and disadvantages in the constant current method of distribution compared with the parallel system. I think that many of the disadvantages which have heretofore been regarded as inherent in the series system are not so, and I have ventured to suggest a method by which many of them that were so grave as to preclude the utilization of the constant current in electrical traction, may be remedied. I am glad to have the opportunity of bringing this subject before such an assemblage of practical men—all the more practical because they are theoretical.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

A NEW SYSTEM OF ELECTRIC PROPUSION.

BY H. WARD LEONARD.

In the distribution of electricity from a power station for the operation of electric railways, the only commercial method to-day is by the use of a system of constant E. M. F. operating the motors in multiple arc with each other, and at the present time every consideration of economy and automatic regulation seems to indicate that the constant E. M. F. multiple arc system will always be the best for such distributions.

In the use of electric energy by motors operating under conditions of varying speed and torque, the best results as regards economy and regulation are obtained when the electric energy utilized has a voltage varying directly as the speed, and a current varying directly as the torque, for it is evident that under these conditions the electric energy required will be always proportional to the power developed.

If we could operate, from the constant potential system, a shunt wound motor running at a constant speed, and could interpose between this motor and the axle some device equivalent in its effect to an infinite number of different sets of mechanical gears, so that we could make use of any reduction desired, it would enable us while using a constant power to increase the torque as we decreased the speed and *vice versa*, which is just what is desired in railway practice where the least torque is required when at full speed on the level, and the greatest torque is required at the slow speed in starting and in operating on a grade. Numerous and very ingenious devices have been invented for accomplishing this variable mechanical reduction, but on account of the complication, noise and unreliability they have never proved successful.

The writer has recently devised an electrical method of securing all the results which could be obtained from such a set of gears described, with a freedom from the noise, wear, complication and rigidity which such a set of gears would necessarily involve.

Following is a general description of the arrangement proposed, as indicated by Fig. 1:

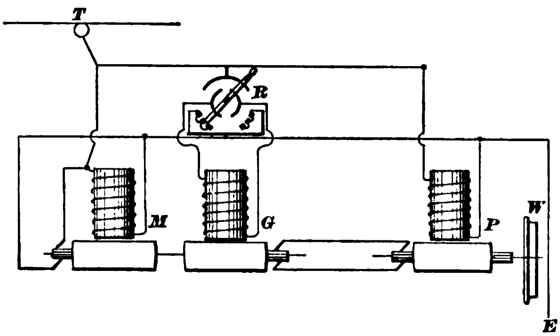


FIG. 1.

T, trolley.
M, motor portion of power converter.
G, generator portion of power converter.
P, the propelling motor for the car.
R, the regulation and reversing rheostat in field of G.
E, the connection to ground.
W, the car wheel.

Each axle is driven by a gearless motor, either directly or by means of a connecting-rod. The fields of these motors are excited directly from the constant E. M. F. of the line and independently of the armature circuit. Beneath the car and between the axles there is suspended a motor-generator, each armature winding being in a seperate field. The motor portion of the motor-generator—which will, for convenience, be called the power converter—is shunt wound and connected just as a shunt motor is for use upon ordinary constant potential circuits. The field of the generator portion of the power converter has its field connected across the line and has inserted in it a regulating and reversing field rheostat. This field circuit is independent of the armature circuit. The generating armature of the power converter is in metallic connection with the armatures of the gearless propelling motors. It will be noticed that this circuit including the armature is a distinct and separate metallic circuit having no connection with the line in any way.

Suppose now that our shunt motor is running at full speed and that our controlling rheostat in the generator field circuit is at its central position, so that the generator field circuit is broken. Although the generator armature is being driven at full speed it is revolving in a field having no magnetism except the residual magnetism, and hence produces practically no volts. Let us now move our controlling switch so as to place the generator field across the line, but with a resistance in series with the field, of ten times the resistance of the field coils. We now give a slight excitation of the field and a development of volts at the brushes of perhaps 40 volts. This voltage will produce a current through the armatures of the driving motors dependent upon the ohmic resistance of this circuit only; and hence, even at this low voltage, a large current will be produced, which being in a field of full strength will cause a torque sufficient to start the armature. The speed of the armature will, of course, be governed by the counter E. M. F. which its revolution produces in its strong field; and hence, just as in the case of a shunt wound motor, its speed will be practically constant so long as the E. M. F. supplied is constant.

If we now gradually increase the magnetic field of the generator by cutting out resistance by moving the controlling switch, we will gradually raise the E. M. F. of the armature circuit, and with it the speed of the driving motors. Since these armatures are revolving in a constant field, the torque they produce will be exactly proportional to the current in them, and the current will automatically flow exactly as is required to produce the necessary torque to maintain a speed such that the counter E. M. F. will approximately equal the E. M. F. supplied by the power converter. Thus it will be seen that the speed of the car will be dependent upon, and proportional to, the E. M. F. supplied by the power converter, and the torque or tractive effort will be dependent upon, and proportional to, the current supplied by the power converter.

Let us suppose that 60 amperes flowing through the armatures in fully excited fields will produce a torque sufficient to move the load when upon a grade. It is evident from what we have seen that 40 volts from the power converter will produce this current. Hence, by an expenditure of 5,400 watts in the secondary circuit, or a total power, including field excitation, etc., of about eight H. P. we can start a fully loaded car upon a grade.

Under the existing systems, we would need the same 60 amperes in the same fully excited field, but would necessarily use the full voltage of 500 volts, and, therefore consume energy represented by 30,000 watts, as against possibly 6,000 in this system. The current from the line in starting the car under ordinary conditions by this system would be about 12 amperes at 500 volts, instead of from 60 to 100 amperes at 500 volts.

In practice, the controlling switch lever can be instantly thrown from its central position to its extreme position for full speed. The field magnetism of the generator is rapidly increased, and consequently also its E. M. F., which in turn causes a gradual acceleration of the car.

The current in the armature circuit, and consequently the torque, is quite large in the beginning; but the E. M. F at this time is quite low, so that the total watts are low. As the inertia is overcome and the counter E. M. F. begins to approximate to the impressed E. M. F., the current falls off and finally becomes constant at an amount necessary to produce the torque required to maintain the speed. The current from the line, and hence the power, gradually increases from zero to the amount required at full speed, but at no time, either at the start or during the acceleration, is the energy from the line greater than that required when we are operating at full speed. It will be noticed that the effect is the same as though we first operated through a set of gear wheels, giving an extremely great reduction of speed and then rapidly changed the ratio of gearing, until finally we operated at full speed, with no reduction.

With our hypothetical gears we could, when running at speed, rapidly increase the ratio of gearing, so that the movement of the car would tend to drive the shunt motor faster and faster This would convert it into a generator, forcing current back into the system, which production of electrical energy would act as a brake and gradually bring the car to rest.

Just so, if, while running at full speed, we suddenly place our switch lever at its central position, the field of the generator will gradually reduce the strength, and the counter E. M. F. of the propelling motors will soon exceed that of the generator. The momentum of the car will now be driving our gearless motors as generators, which will supply current to the former generator, operating it as a motor, causing it to drive the shunt motor coupled to it as a generator, which, in supplying energy to the line, will act as a brake, and smoothly but rapidly bring the car to rest by converting the energy stored up and represented in the movement of the car into electrical energy, which will tend to relieve the work at the central station. Similarly, a car descending a grade and tending to accelerate in speed, can be made to move at any desired speed without the aid of any mechanical brakes, and the energy represented by its falling weight will be converted into electric energy and the car will become a moving feeder supplying energy to assist the generators at the central station in the operation of other cars.

It will be evident from what has preceded, that with this power converter system we can propel a car upon any practicable grade with a consumption of power no greater than is required to operate the car at full speed upon a level, by merely reducing the speed to the required extent.

In street railways of from five to ten cars, this is of great importance, for it means that we can equip a road with about six H. P. per car, as regards the engines and dynamos, and that our conductors can be reduced to about one-third of the amount at present necessary, for we will never require more than 20 amperes at the distant point, where to-day we have to provide for 60 amperes, with the same loss and the same initial E. M. F.

Under the rheostat system, the plant is severely taxed when an unusual crowd must be moved from a certain point. and it is then, when it is of the greatest importance that no break-down should occur, that it usually does occur. With this power converter system we could, upon a five-car road, start up and move with perfect safety 10 or even 20 cars from the most distant point on the road, though of course at a reduced speed, but the crowd would be handled with perfect success and without subjecting any portion of the plant to any unusual strain.

In the large cities it is no unusual sight to see an electric car moving at the slowest possible speed for perhaps several blocks. Perhaps 12 amperes are required to obtain the necessary torque. This, at 500 volts, is 6,000 watts. The power required for this slow motion by the proposed system would not exceed one fifth of this amount

Following is a tabulated statement (Table 1) showing the results we may expect to obtain by this system in operating with fully loaded car under three different conditions :—First, at 12 miles per hour on level ; second, at three miles per hour on five per cent. grade ; and third, at one mile per hour on level.

Leonard System of Electrical Propulsion.

TABLE 1.

DUTY OF CAR. SHOWING VARIOUS LOSSES EXPRESSED IN WATTS.

Various Losses Involved.	8 Tons at 12 Miles per Hour on Level.			8 Tons at 3 Miles (or 5 Tons at 5 Miles) per Hour on 5 per cent. grade.			8 Tons at 1¼ Miles per Hour on Level.		
	Full Speed, 1-6 Full Torque; Armature Current, 10 Amperes.			¼ Full Speed, Full Torque; Armature Current, 60 Amperes.			1-10 Full Speed, 1-6 Full Torque; Armature Current, 10 Amperes.		
	Power Converter.		Driving Motors.	Power Converter.		Driving Motors.	Power Converter.		Driving Motors
	Motor part.	Gen. part.		Motor part.	Gen. part.		Motor part.	Gen. part.	
Field.	250	275	250	250	60	250	250	25	250
$C^2 R$ in armature ...	160	60	60	250	2000	2000	20	60	60
Friction.....	60	60	120	60	60	30	60	30	10
Foucault currents, hysteresis, etc.	200	400	400	200	50	50	200	10	10
Total.	670	705	830	760	2170	2330	530	125	330
Total watts wasted . .		2295			5260			985	
Watts of work done		4000			6000			400	
Total watts absorbed .		6295			11260			1385	
Amperes at 500 v. .		12.6			22.5			2.8	

In arriving at the losses, as indicated, the motor part of the power converter has been assumed as having the following features:

E. M. F. 500 v., current capacity for ten hours' continuous duty, 15 amperes; resistance of shunt field winding, 1,000 ohms, armature resistance, 1.1 ohms.

The generator portion of the power converter and the driving motor are assumed as having the following features:

E. M. F. 500 v.; current capacity for ten hours' continuous duty, 40 amperes; resistance of field, 900 ohms; armature resistance, 0.55 ohms.

The rolling friction with gearless motors on good level track is assumed as 20 lbs. per ton. Car is assumed to be eight tons in weight full loaded and five tons for moderate load.

We find that with 12 tons moving at 12 miles per hour on a level we will require 12.6 amperes which is practically the same as by present series motor systems. With eight tons moving at three miles per hour upon a five per cent. grade 22.5 amperes will be required, which is about one-third of the power required by present systems. With eight tons at one mile per hour on level 2.8 amperes will be required, which is about one-fifth that of present systems. With five tons moving at five miles per hour on five per cent. grade 18.5 amperes will be required, which is about 40 per cent. of the power required by present systems.

Let us examine some of the advantages that this method seems to offer over the existing methods, starting at the car and considering the entire equipment back to the boiler.

In order to place before you the opinions of some of the best authorities on the questions involved, I shall quote freely from "The Electric Railway," (Crosby and Bell); Parshall's "Methods of Electrically Controlling Street Car Motors," "Comparative Test of High and Low Speed Engines in Electric Railway Work," by Charles W. Wason (*Electrical Engineer*, April 27, 1892); "The Practical Operation of the Gearless Motor," by S. H. Short (*Electrical World*, April 16, 1892); "Load Diagrams of Electric Tramways and the Cost of Electric Traction," by A. Reckenzaun (*Electrical Reveiw*, London, March 25, 1892).

The cost of car equipment will be increased by the cost of the motor-generator, but as a partial offset to this we have saved the rheostats, two expensive controlling switches and a complex system of wiring.

Our motors, having constant and fully-excited fields, will operate absolutely without spark under all conditions. The control of the car will be entirely accomplished by a small switch and rheostat, handling never more than one-half of an ampere, and occupying a space of one foot square and one inch deep over all.

As regards efficiency, we will have the advantages of the present system under all conditions. For long runs upon the level we will, by a suitable switch, connect the driving motors directly to the line and secure an efficiency of 90 per cent. for our motor.

As regards depreciation, we will have the advantage of no rheostats or controlling switches to burn out: and with no sparking and no connection with the field circuit we will have the minimum liability of burning out armatures.

Our fields will have no tendency to burn out, since they are not subject to the excessive currents which the present series fields are. The current in our fields will be independent of the load.

As to field windings and rheostats in existing methods, Parshall says:

"With 25 H. P. motors, an external resistance of 10 to 12 ohms is required."

"Lessening the duty of the rheostat is a very important point, since as yet it has been found exceedingly difficult to construct a cheap rheostat that could be placed under the car in the small space available and dissipate so large an amount of energy as is required when the car is to be run for a considerable time at a speed so low as two or three miles an hour. Any method of control that has lessened the energy to be dissipated in the rheostat has in general been considered with favor, since there has been a corresponding diminution of trouble in each case that the energy to be dissipated has been lessened."

"The range of speed without the use of a rheostat is determined by the limit to which it is safe to heat the magnets."

Crosby and Bell say:

"In using this method (commutated fields), the principal difficulty has been met with in disposing of the excessive heat necessarily generated in the compact mass of field windings."

"The practical problem has been to secure a convenient rheostat."

"The principal sources of loss in our present street railway motors are the regulating devices and the gearing."

"With the motors and the gearing generally employed, the average commercial efficiency of the combination is probably not often in excess of 65 per cent., giving a total commercial efficiency for the system, from engine to car wheel, of 39 per cent.; this of course is but an estimate. But taking all the factors into consideration, it is probable that the average of the roads now in operation would fall quite nearly to the point indicated. In very few cases would it fall below 30 per cent.; in still fewer would rise about 40 per cent."

Regarding the power required to start a car on existing methods and to operate it upon level and grades, Crosby and Bell say:

"With the ordinary car equipment of two 15 H. P. motors, and the usual speeds, from eight to twelve miles per hour, experience has shown that five to six electrical H. P. is necessary on nearly level tracks."

"The amount of current ordinarily taken in starting a car, is momentarily more than 50 amperes, which, at the ordinary voltage, corresponds to about 25,000 watts."

Reckenzaun says:

"If we calculate from the accepted coefficients of resistance to traction on common tram-rails, we find that an ordinary tramcar will require but three to four H. P. for its propulsion when once in motion."

He says of Thomson-Houston car:

"The maximum current at any time was 75 amperes."

Of Sprague motors:

"Here, again, we observe a maximum current of 95 amperes."

"Westinghouse motors—maximum current, 75 amperes."

Short finds that 80 to 100 amperes are required to start a car, and says:

"On this road the traffic is very heavy, although grades are light."

Leaving the car, let us now consider the line. It will be evident from what we have seen that we can reduce the amount of copper to one-half the present requirements, as we never will require the enormous currents at present called for in starting and upon heavy grades. Or, to put it in another way, with the existing conductors we could run twice as many cars as at present, with the same loss in the conductors.

Now let us look at the generators and the prime movers, whether steam engines or water wheels.

Under existing systems, for roads of from five to ten cars, it is necessary to install about 20 indicated H. P. (rated at one-fourth cut-off) per car, and about 16 kilowatts per car in generators. Also about 20 H. P. per car in boiler capacity. This large equipment is necessitated by the occasionally very large demands for power and the inefficiency consequent upon this.

Under the proposed system, it is not necessary to provide power in excess of 15 H. P. for any car under any conditions, and since in practice most of the cars will be operating at less power than this, we need only install engine, dynamo and boiler capacity of 8 H. P. per car, instead of 20. Or, to express it in another way, we can operate with existing boilers, engines and dynamos at least double the number of cars they can at present supply.

Crosby and Bell recommend, for a five-car road:

"An equipment consisting of two 40,000 watt dynamos, one 80 H. P. high-speed, simple engine, belted directly to them, and two boilers of about 50 nominal H. P. each."

Now let us look at the economy of the operation of the station. With the extremely fluctuating loads of existing systems, the economy of the entire generating plant is very low. The stations of three roads which have been tested, give for the combined efficiency of engine and dynamo 40 per cent., 54.6 per cent. and 62.8 per cent. respectively. If the load can be kept approximately constant, the combined efficiency of engine and generator should be about 75 per cent., and in the proposed system the load will be sufficiently uniform for us to expect an efficiency equal to this and because of the nearly constant load we can produce a horse power on about 25 lbs. of water, while in present practice for small roads about 50 lbs. of water per horse power is a fair figure; and the best published result thus far obtained, even when the average horse power rose to 750 H. P., is 28 lbs. per H. P., as found by Wason, at Cleveland, in operating a total of 71 motor cars.

With the present systems the average indicated horse power per car is about 12 horse power, which, on account of fluctuating load, requires at least 36 lbs. of water per horse power or about 420 lbs. of water per car per hour.

With the proposed system we will operate with an average of about eight indicated horse power per car, which, on account of the steady load, will be produced with about 25 lbs. of water per horse power, or 200 lbs. of water per car per hour. That is. we require about 50 lbs. of coal per car by present systems, and about 25 lbs. of coal per car per hour by proposed system, or a saving of 50 per cent. in the coal and water required in favor of the pro posed system.

On this subject of fluctuating loads and their effect, Crosby and Bell say:

"A record of ten minutes on a recording ammeter may give some faint idea of the condition of things. It will be seen that at one point the output jumped from zero to 150 H. P. and back inside of a single minute, and during the latter five minutes shown in the diagram there were no less than 25 sudden *variations* of 50 to 100 H. P., each taking place within a few seconds. The road from which this record was obtained is four miles in length, and was operating seven cars at the time of the test."

Reckenzaun says:

"These abrupt changes have the effect of reducing the efficiency of the whole system to a comparatively low figure."

Church says (*Electrical Engineer*, April 27, 1892) that the best compound engines will show an economy of only 28 lbs., and the usual compound engine "an average duty not better than 35 to 40 lbs. The same is true of every form of non-compounded engine, whether high-speed or low speed, both of which show a tremendous falling back of fuel duty under variable load."

Let us now examine the comparative first cost of a railway of moderate size, say, from five to ten cars, equipped by present systems and by the proposed system.

The detailed figures per car are given in Table 2.

TABLE 2.

SHOWING PROBABLE COMPARATIVE FIRST COST PER CAR BY PRESENT AND PROPOSED SYSTEM.

	Present System.	Proposed System.
Steam plant, generators and conductors per car (steam plant 1,000, generators 700, conductors 500	2200	1100
Motors (2 15 H. P. equipments)	1800	1400
Power converter	0	900
Controlling switches, cables, rheostats, etc.	200	30
Total first cost per car	4200.	3430.
Saving in favor of proposed system per car		$770.

Table 3 gives a summary showing the features of the proposed system as compared with the corresponding features of the present system.

TABLE 3.

	Present System.	Proposed System.
First cost of steam plant, generators, conductors and car equipment per car	$4200.	$3430
Amperes at 500 volts required to start full load on level	75	2.8
Amperes at 500 volts for full load at full speed on level	12.5	12.5
Amperes at 500 volts to start full load on 5 per cent. grade	125	10
Amperes at 500 volts for working speed on 5 per cent. grade	60	22.5
Amperes fed back to system in coming down 5 per cent. grade	0	10
Pounds of coal per car per hour	50	25

The features of the proposed system which seem at first sight to be very objectionable are :—The increased cost of the car equipment, and the fact that we are adding an additional machine, having two fields, two armatures and three bearings; but, as we have seen, there is only an apparent increase in the first cost, for the saving in the generators and distributing plant far exceeds the additional cost of the car equipment ; and the use of the motor generator for elevators, traveling cranes, etc., has demonstrated that, as regards the attention it requires and the depreciation it suffers, it has a marked advantage over the rheostat or commutated field used in the present methods of operation.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

ELECTRIC RAILWAY MOTOR TESTS.

BY PROF. GEO. D. SHEPARDSON AND EDWARD P. BURCH.

The experiments here discussed were undertaken for the purpose of obtaining definite information about the performance of electric railway motors under various conditions. There is a diversity of opinion about the relative merits of regulation by rheostat and by commutated fields, the use of one or two motors on a car, value of wetting rails, causes of "bucking" and other points. It is commonly understood that electric roads using rheostat regulation require larger capacity at the generating station than those using the commutating fields. It is also known that one large road has substituted rheostat regulation for commutated fields on all its motors. One large road has reduced the pressure on the lines to a figure considerably below 500 volts, with marked reduction in the repair bill.

Much has been said and written, but the data published are meagre and in some cases misleading. It was therefore thought desirable to obtain data from careful tests under certain conditions in the hope of subtantiating some of the claims made, and of bringing out some new facts. The tests were conducted for the most part by Edward P. Burch, a senior in electrical engineering in the University of Minnesota, in connection with his graduating thesis, and by courtesy of the Minneapolis Street Railway Company, especially the master mechanic, William Cooper. Most of the tests were made upon a No. 6 Sprague double reduction motor of the type described by H. F. Parshall before the Institute May 21, 1890, and April 19, 1892. Some experiments were also made upon a single-reduction motor. Each machine is used at the repair shop for testing armatures, being anchored to a heavy crib sunk eight feet into the ground. Each car axle is replaced by a short shaft carrying a heavy cast-iron wheel with solid web, upon which two oaken blocks are

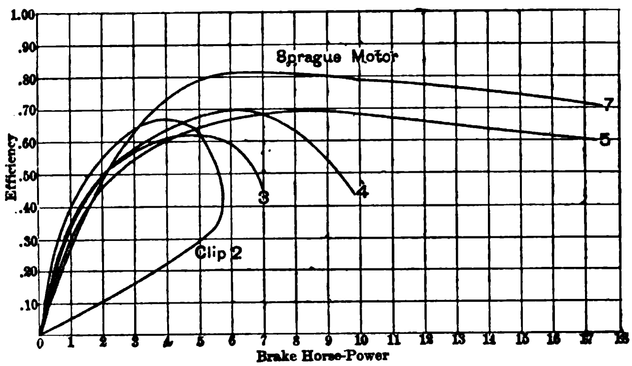


Fig. 1.

bolted for use as a brake. This was made into a Prony brake by removing the angle irons that held it to the floor and bolting on a plank to which an iron plate was fastened, so as to give a knife-edge bearing, at a distance of 63.1 inches from the centre of the

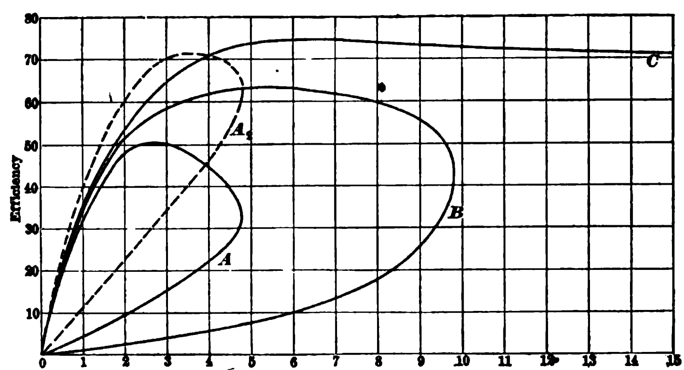


Fig. 2.

shaft. This plate rested upon a knife-edge supported upon a platform scale by which the turning moment could be measured.

The mechanical horse power delivered at the car wheel is

$$\text{H. P.} = \frac{2\,\pi\,R\,P\,N}{33{,}000} = \frac{P\,N}{1{,}000},$$

in which P is the pressure on the scale, N the revolutions of the

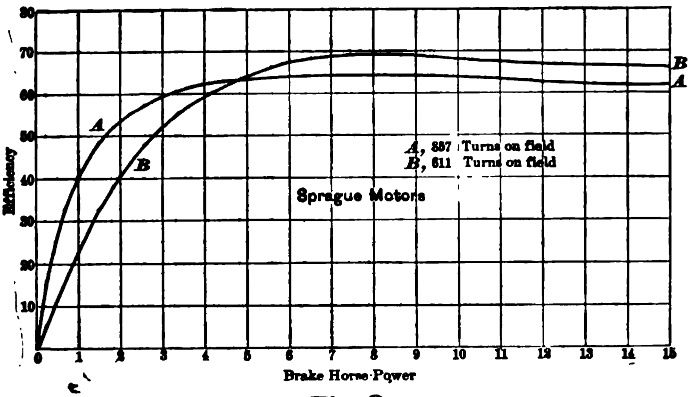


Fig. 3.

car axle per minute. The speed was measured by a common speed indicator with soft rubber tip to prevent slipping. For slow speeds a stop watch was used, the time for five revolutions of the car wheel being noted. Current and potential were meas-

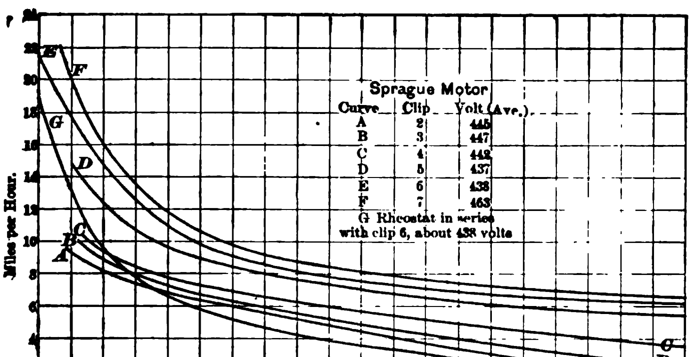


Fig. 4.

ured by new Weston instruments, about 12 feet distant from the motor.

The Sprague motor armature has 56 sections of eight turns each of No. 12 B. & S. G. wires. The speed is reduced 11.765. The field coil as used at first was in three sections—coil A, 700 turns; coil B, 820 turns; and coil C, 620 turns—all being No. 12 B. & S. G. wire. By means of the barrel switch these coils are thrown into the following combinations:

Clip 2. Coils A, B and C in series.

Clip 3. Coils A and B in series.

Clip 4. Coils A and B in parallel, C in series.

Clip 5. Coils A and B in parallel.

Clip 7. Coils A, B and C in parallel.

Several sets of efficiency tests were made with each combination. The three pairs of coils were then replaced by a single pair

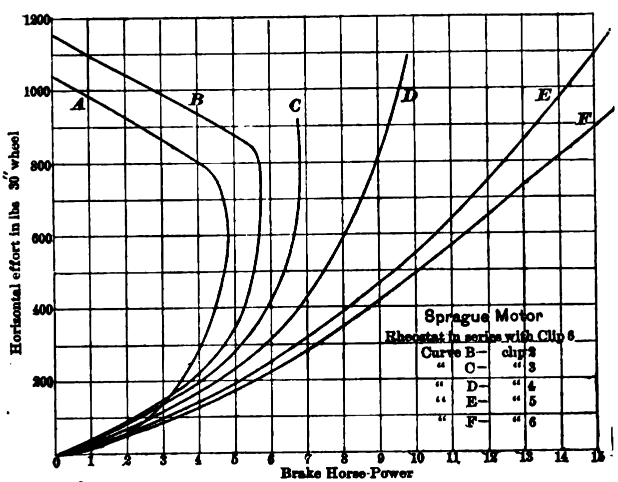


Fig. 5.

of coils connected in series and having several terminals, so that the number of turns used might be altered. This was used in connection with a Thomson-Houston rheostat. Efficiency tests were made with and without the rheostat. Only a few of the tests and curves obtained can be given in this paper. In comparing these curves among themselves and with the result of other experiments, it should be noticed that the voltage was considerably below that for which the motors were designed, and that the power delivered was measured at the car axle. Different armatures were used on different days, and the curves in different places are not strictly comparable; but the curves given in any one place were taken with the same armature and with approximately the same voltage. Each of these armatures had been recently repaired, and although they had been well baked, there may have been some leakage through the green shellac. Foucault currents in the cores were probably greater than in new armatures.

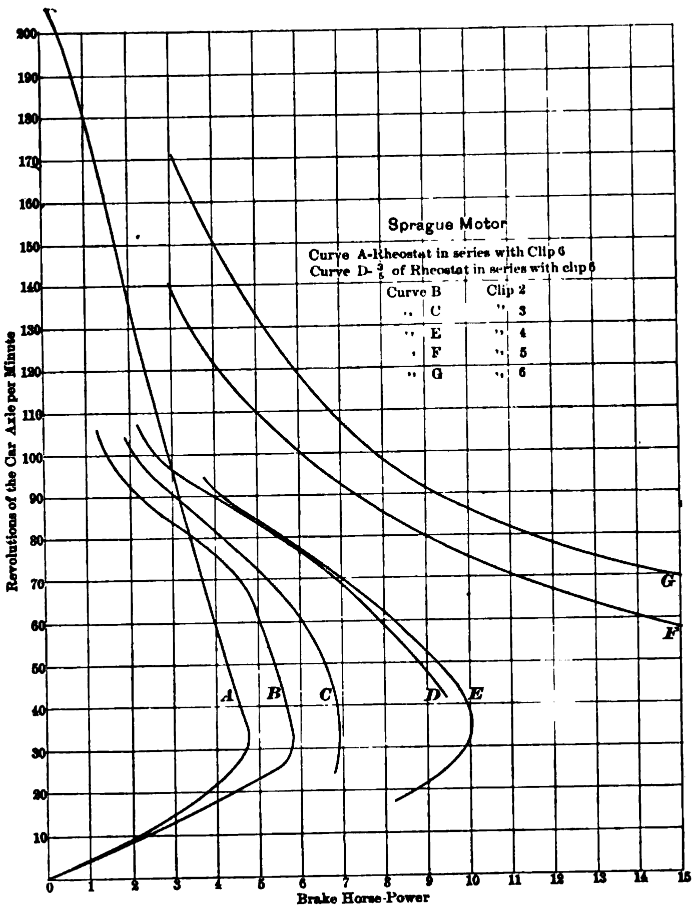


Fig. 6.

tures. With the same armature and fields, the efficiency is a few per cent. higher cold than when hot. It has been the aim to run as nearly as possible at the temperature of ordinary running, so that the fields were comfortably warm but not hot. It is confidently believed that the efficiency of these machines would be considerably above 90 per cent. if taken at armature shaft and with full voltage.

Fig. 1 shows efficiency curves for the motor with different combinations of the field coils.

In Fig. 3 curves A and B show efficiency of the machine with

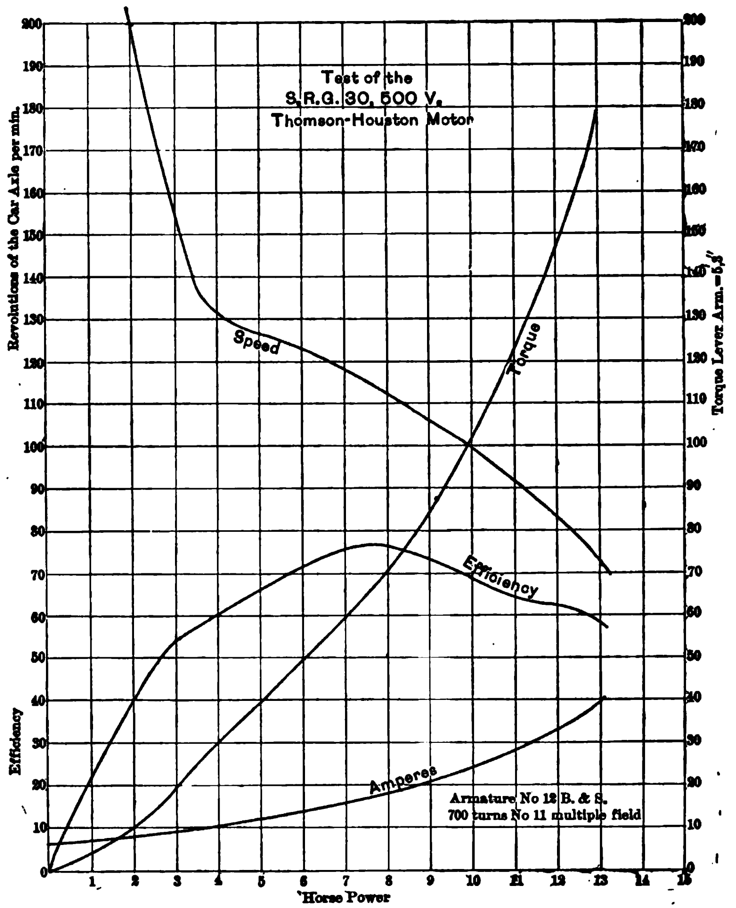


Fig. 7.

857 and 611 turns of No. 7 wire in the field coils. It will be noted in Figs. 1 and 3 that the motor has highest efficiency with the larger number of turns on field coils until the iron is saturated when the better efficiency is given with smaller number of turns and consequent lower resistance in field. This shows the advan-

tage of working on the fifth and seventh clips with barrel regulator, or of cutting out part of the turns on field when the load is heavy. On starting the car, the current is very heavy and the field is saturated with a small number of turns; hence the torque with a given current is nearly the same whatever the windings of the field. The speed and counter-electromotive force are small at starting; hence the potential difference at the armature brushes should be reduced until it passes only enough current to start the car without jerking. The easiest way of reducing the potential difference at the brushes is by interposing resistance, and the heat developed by the $C^2\ R$ can be cared for more easily and cheaply in an open rheostat than in the field coils. Rheostats

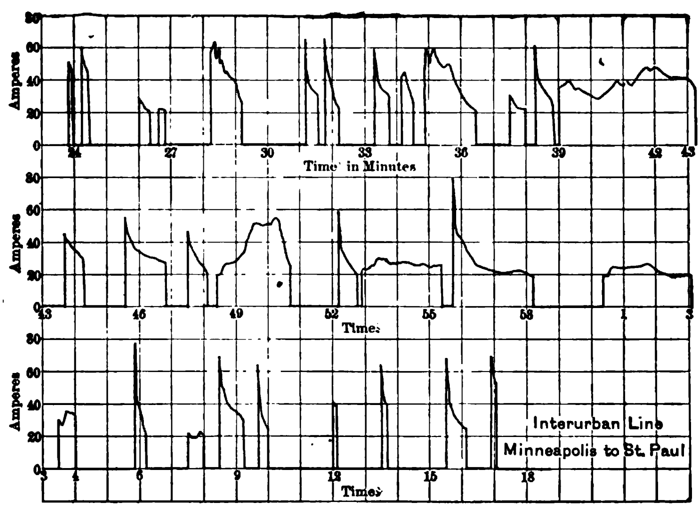


Fig. 8.

of iron and mica are cheaper and more heat-proof than cotton covered wires. This forces the conclusion that for the heavy load due to accelerating the car at starting, the field should have the smaller number of turns, and as the car reaches the normal speed, and the horse power and current becomes less, the efficiency of the motor would be raised by increasing the number of turns in the field. This conclusion is exactly the reverse of the common practice of manufacturers who sacrifice some efficiency for speed at small horse powers. It is also in line with the experience of the road mentioned, that replaced the commutated fields with a single series coil of No. 7 wire, and later with No. 5 wire.

This heat loss could be saved, and the average efficiency raised, by using the two motors in series at the start, and afterwards cutting out one, or putting the two motors in parallel if necessary, as the speed increases and horse power decreases. An average of 12 tests on the road shows that with two motors on a car it requires twenty-seven per cent. less current if only one is working.

In Fig 2, curve A shows the efficiency of the Sprague motor with a single pair of coils, when the whole of a Thomson-Houston rheostat is in circuit; B shows about three-fifths of the rheostat in use; and in C it is all out. The dotted line A^2 gives the efficiency

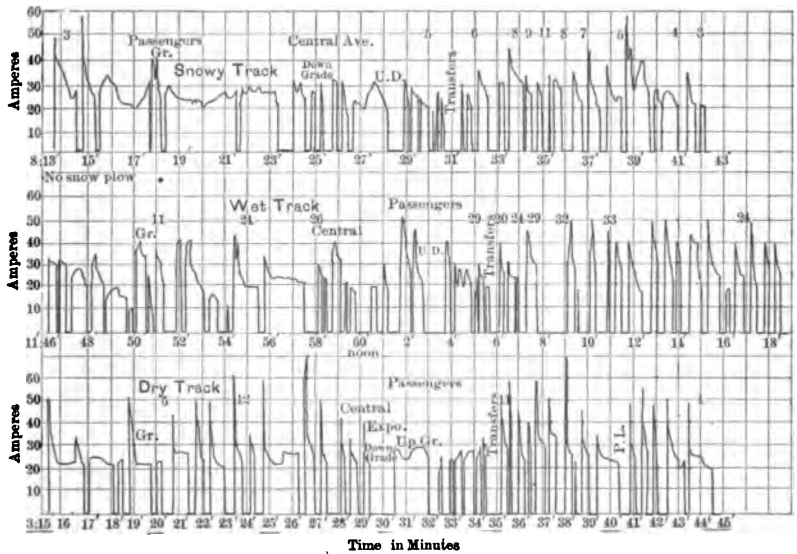


Fig. 9.

as calculated from the difference of potential about the motor alone. Curve A^2 is not strictly comparable with the othors on account of the necessary variations in the voltage at the motor, but it does show the increased efficiency to be obtained by utilizing the superfluous voltage in a second motor in series. In this connection it is interesting to note that the resistance of the rheostat as calculated from current and potential difference, decreases with increase of current. This is as expected, since the larger part of the resistance is due to surface contact between the plates of iron in the rheostat, these being pressed together more closely as the iron heats. A similar effect, but much more marked, has been noticed in earlier experiments by one of us, with alternate plates of carbon and iron.

Figs. 4, 5 and 6 show curves of torque, speed and horse power, referring to the No. 6 Sprague motor. In Fig. 5, A shows horse power and horizontal effort on a 30 inch wheel; B, C, D, E and F

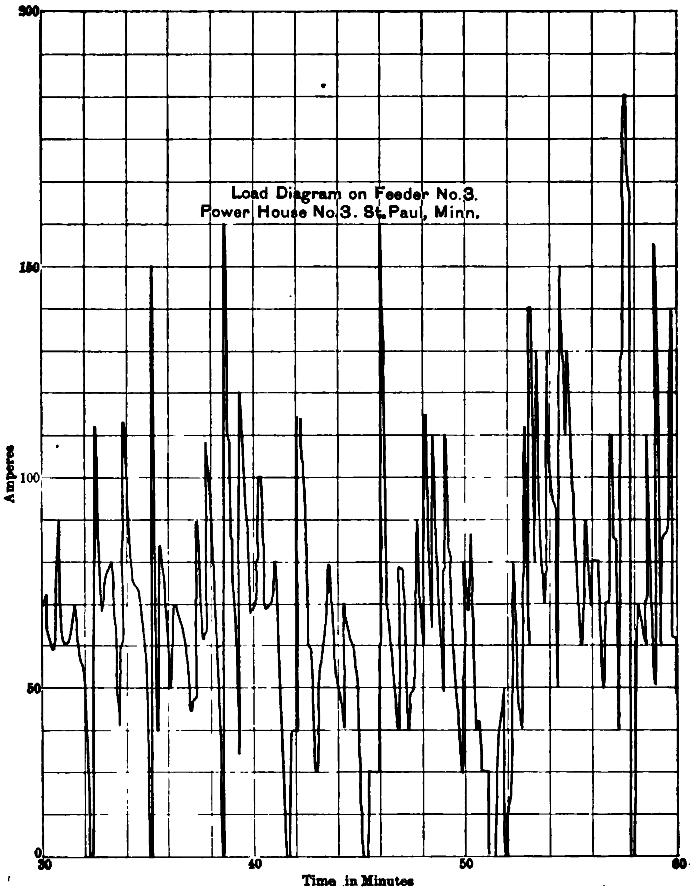
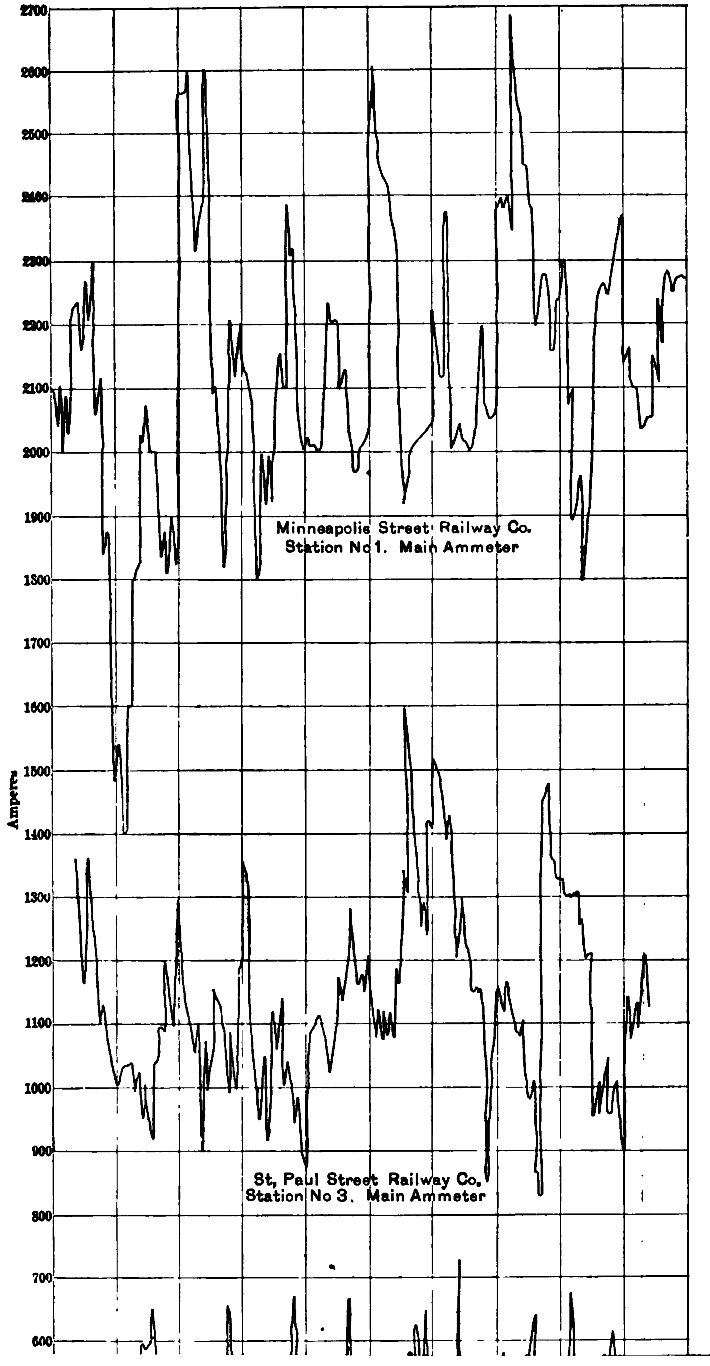


Fig. 10.

clips 2, 3, 4, 5 and 7, respectively. In Fig. 6, A shows speed and horse power, with all of the rheostat in; E with three-fifths of rheostat in; B, C, D, F and G clips 2, 3, 4, 5 and 7, respectively. These may be compared with results presented by Professor S. H. Short before the Chicago Electric Club, March 28, 1892. Fig.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Amperes
Minneapolis Street Railway Co.
Station No 1. Main Ammeter
St, Paul Street Railway Co.
Station No 3. Main Ammeter

7 gives curves of currents, torque, speed and efficiency from a 15 H. P. Thomson-Houston single reduction motor. The reduction ratio is 4.7857.

A large number of running tests were made on cars in regular

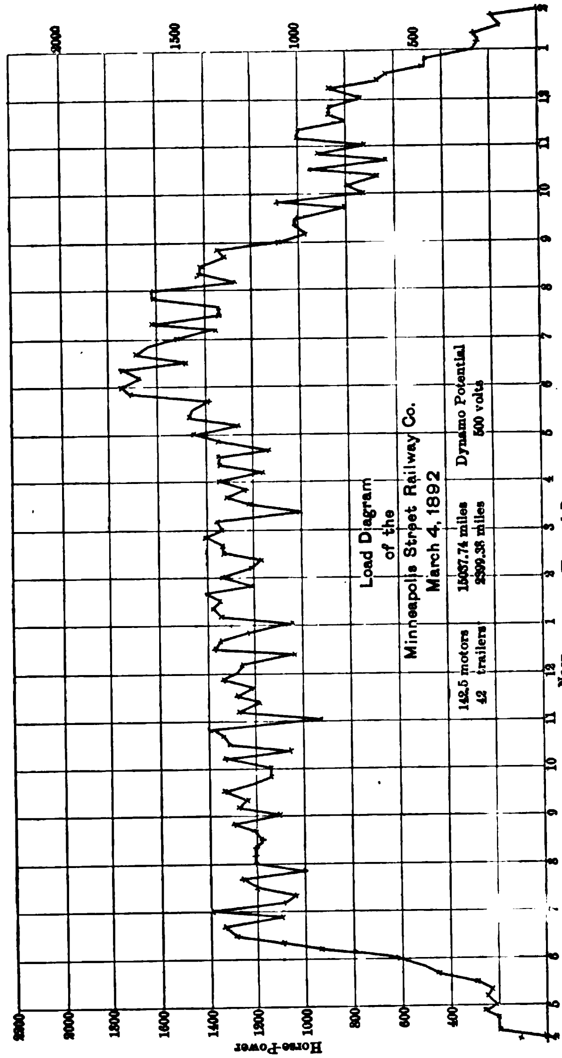


Fig. 12.

service. Fig. 8 shows a run on the interurban line between Minneapolis and St. Paul. The distance is about ten miles, the schedule time 55 minutes, cars equipped with two 25 H. P. single reduction motors. Special trains sometimes make this trip in 30 minutes or less. Fig. 9 shows three runs on the University Line of Minneapolis on successive days, with the same car and same driver. The lower curve was taken when the rails were dry and dusty, middle curve with wet rails and upper curve when the ground was covered with snow eight inches deep on the level. The snow plow had been over a part of the track about an hour before. The curves show variation of time, number of passengers being noted.

	Feb. 5.	Feb. 6.	Feb. 7.
Condition of Track.............	Dry.	Wet.	Snowy.
Number of Stops...............	38	50	36
Average voltage................	445	450	440
Average amperes...............	15.15	14.9	17.5
Average amperes while working.	23.4	20.9	28.1

It will be noted that the current was less with wet rails, although there were more passengers. The load at the station is about the same for a rainy day as for dry, the difference being probably made up by the increased leakage on the lines, and by the larger number of passengers on some cars.

Fig. 9 shows variation of current on a single car. Fig. 10 shows variation of current on a feeder to line with five cars, the average current being about 60 amperes. Fig 10 is plotted from readings taken at intervals of two seconds. The ammeter stops some little time at the high and low points, showing that these are actual values of the current and not due to the inertia of the ammeter.

Fig. 11 gives the results of readings one second apart taken on the main ammeters in Minneapolis and St. Paul and on one feeder in Minneapolis. There were about 190 cars on Minneapolis lines, 100 on St. Paul lines, and 32 on the one feeder.

Fig. 12 gives the daily load of the Minneapolis power house, the curves being plotted from readings of the ammeters taken at ten-minute intervals throughout the day. In this case the power units are unusually large, there being two triple expansion condensing Corliss engines, the constant loss from friction in engines, shafting and dynamos averaging 218 H. P. Indicator cards were taken simultaneously by means of electro-magnetic attachments on each of the twelve indicators, the same current also giving signals to the observers at the ammeters.

A series of 13 tests were made for ascertaining the effect of wetting or greasing the rails on a curve. Two cars were coupled by a spring dynamometer and the pull noted while rounding the curve at ordinary speed, which was kept nearly uniform by means of a brake on the motor car. The average pull on dynamometer is as follows:

	Dry.	Wet.	Greased.
Outer track	500-800 lbs.	500 lbs.	300 lbs.
Inner track	650 "		400 "

The inner rail was wet or greased in each case; but on the inner track the greasing was not so thorough on account of the lateness of the hour. It is noticed that wetting the rail reduces the power required about one-third, and greasing reduces it one-half. Readings of the ammeters on the car correspond in general with the dynamometer readings.

The "bucking" of street car motors is a subject of considerable interest to street railroad men, although it seems never to have been discussed in public. From the silence of the books and papers, and from the ideas current among the railroad employés, the conclusion is reached that little is known about its conditions, causes or remedy. It is therefore thought wise to present the results of observations and tests, with a theory for the cause and remedy. It sometimes happens that an electric car suddenly stops as if by collision. In some cases the car refuses to go further, but usually it goes ahead immediately as if nothing had happened. This is known among railroad men as "bucking." To explain the action it is noted that in common practice the motor fields are connected between the armature and trolley, the armature being grounded at the negative brush. If a second ground occurs on any part of the machine except between the fields and trolley, a heavy current passes to ground, giving an intensely strong field, while the armature is short-circuited by reason of the two ground connections. It therefore acts as a dynamo on short-circuit, and becomes a powerful electric brake that stops the car very suddenly. This agrees with the facts, since a second ground, either from loose connecting wires or broken insulation always causes bucking. Evidently, if the ground occurs entirely outside of the machine, no bucking follows, since the series motor cannot excite its own fields and act as a dynamo unless the armature connections are reversed. It is common practice to connect the two motors together between the fields and armature to equalize the work of the two machines. When a ground occurs in such a case, both armatures act as brakes, and the bucking is more violent than when the "equalizer" connection is not used. A loose reversing switch has been known to reverse the motors accidentally and spasmodically. There are many cases of bucking where no evidence of a second ground can be found. Doubtless some of these may be accounted for by a temporary ground which burns itself out—a common method of removing grounds and crosses. This explanation will not hold in many cases. Extended inquiry was therefore made among railroad men in order to gather as many facts as possible. Some of these reports were incredible at first, but seemed to be honest testimony, and were afterward corroborated by others.

It may be well to state that the term "bucking" is used with some looseness, being sometimes applied to cases where a motor acts badly for a variety of reasons, but as used in this article it is to be taken in the sense above noted. There is a tradition among the car drivers that a motor is very liable to buck if the current is full on while running downhill, but no case of this sort could be substantiated. Cases are reported of motors bucking when the circuit is opened for an instant, as may be caused by the trolley jumping on or off, or by the car passing over a dead rail or over a very dirty track. It is not plain that this is a true case of bucking, but rather of a sudden cessation and re-application of the propelling force.

Sometimes a car will buck at regular intervals. Examination of the motor shows a small bright spot on one brush which rolls to and fro at the contact between brush and commutator. This is intensely bright like a ball of melted metal and grows larger until nearly three-fourths of an inch in diameter, when it suddenly explodes with considerable noise and a blinding flash, and at the same instant the motor "bucks." The car goes on again at once, and the cycle is repeated again in the time required to run from one-half to four city blocks at ordinary speed. In such a case the bucking is stopped by shifting the brushes.

One case is reported where a motor bucked hard, although the brushes were removed so that the armature was entirely disconnected. Here the field was charged by being in parallel with the field of the other motor, and a cross in the armature coils short-circuited it. The foreman of the repair shop where our efficiency tests were made states, that on six or eight occasions he has seen a motor buck because the carbons were not properly placed in the holders. In testing armatures rapidly, the carbons are sometimes placed carelessly, so that the presser foot rests partly on the carbon and partly on the holder. This presses the carbons against the commutator so as to give good contact until the carbon wears off a little, when the presser foot no longer feeds it in. Vigorous flashing occurs, culminating in a buck, the shock of which may jar the presser foot into its proper position, when the motor runs on as if nothing had happened, leaving behind no trace to indicate the cause of the trouble. Cases have been reported where a wire on the track touched the motor as it passed, thereby grounding it and causing it to buck. Similar grounding may be caused by water or mud being thrown upon certain parts of the motor. The motors with Gramme ring armatures are known to buck more frequently than those with drum armatures. These buck worse when run on the "loop," *i. e.* with part of the field coils cut out, some of them bucking regularly every time the loop is cut out. This is one reason why the use of the loop has been abandoned on this road except in a few cases. The machines with commutated fields would buck when the field coils become old, although they showed no signs of being grounded. Bucking became much less frequent when the commutated fields were replaced by a single pair of series coils. It was noticed that bucking was very commonly preceded by flashing at the brushes, though flashing was not always followed by bucking. The explanations offered are various. One is that the iron in the fields varies in magnetic quality so that one motor works harder, and by some means acts upon the other as a dynamo. Another is that one motor becomes reversed while the other does not. Another is that bucking is caused by poor brushes or brush holders. One explanation offered was that a partial break in the circuit, such as may be caused by shaking a loose connection, induces a high electromotive force that causes a flash to span the commutator. In searching for a reasonable explanation for all these cases in which no second ground connection existed, it was noticed in each case that bucking was more liable to occur when the field was comparatively weak; also where the armature reaction was greater. In each case the neutral line is shifted and the coils under the brushes are in an active field. The large current in short-circuited coils further distorts the field, and the sparking at the brush becomes excessive, causing a vigorous flashing. As soon as the counter-electromotive force in the sections leaving the brushes rise above 20 volts, the arc is carried around from one brush to the other, thus grounding the positive brush and short-circuiting the armature, which then acts as a dynamo and causes the motor to buck. Such bucking is usually less vigorous than when caused by a dead ground on account of the resistance of the arc. This explanation covers all the cases noted.

Such being the causes of bucking, the remedies are plain. Armature reaction must be reduced. This militates against the conclusion drawn by Mr. Parshall, in his recent Institute paper, that the strength of field is of little importance, and the windings of the armature should be a maximum. The liability to bucking would be reduced even when there is a large armature reaction, if the armature is divided into a large number of sections.

An obvious remedy for bucking caused by direct grounding would be to connect the fields between armature and ground instead of between armature and trolley. With such an arrangement a ground on the fields would simply cut out a part of the coils and cause the machine to word harder. A ground at the brush between armature and field would cause a sudden forward impulse on account of the field requiring some time to lose its magnetism, and would blow the fuse. A ground on the armature would likewise cause a sudden forward impulse and blow the fuse. With such an arrangement there would be no true bucking except in case of the flashing, as noted. An incidental advantage of this arrangement is that the difference of potential between the field and the frame of the machine is reduced to a few volts caused by a drop through the field; hence there is less danger of grounding the field. The increased difference of potential between armature and core is only a few volts and would not affect the insulation very much.

APPENDIX.

The following tables of data were not accessible to those who took part in the discussion of the paper on "Electric Railway Motor Tests," either at Chicago or New York. They give the data for curves in Fig. 1, and partial data for Figs. 4, 5 and 6, and are now printed in order to make the paper as complete as possible. [Editor.]

Sprague Motor No. 6.

CLIP 2.

C.	E. M. F.	E. H. P.	Revolutions per minute.	Torque in pounds at axle.	H. P.	Efficiency
4.7	452	.85	105	12.5	1.31	.46
7.2	444	4.28	87	30	2.61	.61
11.4	456	6.97	70	66	4.62	.66
15 7	444	9.31	53	100	5.30	569
22.6	434	13.15	37	155	5.74	.436
28.1	440	16.56	28	200	5.6	338
30.3	444	17.88	19	220	4.18	.234
34.	440	20.08	8	250	2.	.10

CLIP 3.

8.2	458	5.03	92	31	2.85	.57
11 9	446	7.14	79	56	4.42	.618
16.5	444	9.81	62	95	5 89	.60
18.7	444	11.13	57	110	6.27	.563
23.6	444	12.26	45	150	6.75	.557
29.2	444	17.37	35	195	6.83	.49

CLIP 4.

7.0	440	4.13	111	20	2.22	.537
7.6	444	4.53	101	25	2.53	.557
10.6	448	6.38	90	45	4.05	.635
15.5	448	9.27	76	85	6.46	.696
23.3	444	13.86	54	155	8.37	.603
30.8	432	17.84	44	210	9.24	.512

CLIP 5.

10.9	444	6.48	122	32	3.9	.602
12.2	434	7.1	116	40	4.64	.654
15.6	444	9.28	97	65	6.3	.678
20.7	448	12.42	86	100	8.6	.693
31.3	432	18.15	69	165	11.38	.628
44.1	420	24.86	58	260	15.08	.607

CLIP 7.

11.0	450	6.63	134	40	5.36	.808
14.2	442	8.43	106	65	6.89	.805
19.0	444	11.31	85	105	8.93	.789
24.1	442	14.26	80	138	11.04	.774
35.3	444	20.96	70	220	15.4	.733
42.3	432	24.57	63	275	17.38	.708

Edw. P. Burch.

Discussion.

The President:—I find, gentlemen, that the time at our disposal is very brief. Three papers on important subjects have been presented to you. Among the references which have been made from time to time in these papers, are some to persons who are not present, and they should take part in the discussion where their figures or statements, selective or otherwise, are brought up for criticism or comment. Furthermore, some of these papers have not been accessible for general perusal or criticism until this morning, and the majority of those present are ignorant of their contents except as they have been generally stated here. That is, there has been no time to digest what has been stated, to enable one to make as clear a criticism as he would care to. I particularly feel that myself, because there are two or three matters which I am anxious to criticise in a more extended manner than it is possible for me to do here to-day. It has been proposed, on account of the fact that there is one more important paper to be read, and which has been prepared with a great deal of care, that we should limit the discussion here on railway matters to a few general statements occupying fifteen or twenty minutes, and that the paper on "Oil vs. Air as an Insulating Medium" be read, and that the complete discussion of the railway papers be postponed to the next meeting of the Institute.

The propositions here are radical, one going back to a system that I for one strongly feel is a system of the past, and the other suggesting for consideration a system that I unhesitatingly condemn. It is apparent that under the present conditions, with the time at our disposal, the discussion would not be fair to those who have spent much time in the preparation of these papers.

Most plans must be judged by their practical results. What interests the street car man or the buyer of securities is, first: What will be the investment per car mile operated by an electric system? And, second: What will be the cost per ton mile or per passenger mile carried? Now, all things must stand or fall upon those decisions. A scheme may be beautiful theoretically; it may accomplish everything as desired from a physical standpoint, but it will be eventually accepted or rejected in the financial world according to whether it produces a return upon invested capital greater than some other method of operation.

Before taking it upon myself to make any criticism upon the statements made in these papers, and I do not know that I shall enter into the discussion on account of the limited time, I will ask those who have criticisms and comments to make, to be as brief and direct to the point as possible. The papers are open for discussion.

Dr. Emery:—Mr. President, it would add very much to the interest of the paper on street railway motors, and give us a better opportunity of studying the effects throughout the range of the experiments, if the current used during all the tests were stated. It is so stated only in relation to one test. The names of the makers of the motors are given, which is not the customary way when the makers do not take part in the tests, and a conclusion is drawn, and impressions given which it is not certain would be warranted if the facts were presented in a little different way. To my mind, the curves which are of the greatest value in the study of the effect of a commuted field are shown in Figs. 4 and 5. Unfortunately, the current is not given for either of these figures. Many of the figures show that when the coils are in series the efficiency falls off rapidly at the higher speeds, where it is expected to use such coils in parallel, but the weight of evidence from the diagrams is that the series arrangement is very valuable at speeds less than six miles per hour, or perhaps would prove so at even higher speeds if the relative currents could be studied.

I repeat the request that a complete record of the current be furnished in connection with the other observations.

MR. BRADLEY :—Mr. President, I would like to call attention to a patent granted to me March 7th, 1889, showing a similar arrangement to Mr. Leonard's, but not so complete a demonstration of the loads, amperes, etc., required. The arrangement of the generator G and of its field and motor is different from my plan. And I would like to call attention to the fact that with this arrangement or with mine, it is possible to use an alternating current on the motor. In my case, the fields of the generator G are charged from its own armature and the motor in series.

PROFESSOR THOMAS :—One of the facts in the presentation of Professor Shepardson's paper that struck me most impressively, was his statement concerning the variation of load with a large number of cars running. I am not familiar with the facts upon other roads, and would like to ask what is the experience of others upon roads using a large number of cars. It has been the general belief that increasing the number of cars operated upon a line, tended to a smooth load diagram ; but this very excessive want of smoothness in the diagram is astonishing. I would like to inquire whether others have observed the same thing or not.

MR. LEONARD :—I have looked after that point as far as I was able to, but Professor Shepardson's paper is the first one that has given positive data as to the matter that was reliable. I have learned from those who are operating several large stations. and I have been present in such stations as Cleveland, Boston, and other places, and it is a fact that an excessive rise of current will occasionally occur, and it has to be provided for at times. It will only occur perhaps once in a day, or once in several hours, but there will be times when many cars will start simultaneously and there will be a tremendous rise of current due to that fact, and the central station must be in a condition to stand that draft.

[President Sprague turned the chair over to Manager Webb.]

MR. SPRAGUE :—Mr. Chairman, in the paper which has been presented by Mr. Leonard, advocating a three-motor system for the operation of street cars, he is of course arguing from the position of the inventor, if invention it may be called. His quotations have been selective, and I do not think fairly represent the facts as they exist on railroads to-day. The experimental field through which railroads have gone in the past five or six years, has been somewhat unnecessarily ignored, and certainly the methods of operation which have been tried by them for railroad propulsion in the earlier railroad days, and which are now being tried and adopted by the larger railroad companies, have been absolutely lost sight of.

I will only point out very briefly a few of the salient points which occur to me. Simplicity of machinery is, of course, a desideratum. The tendency must be towards simple mechanical appliances, towards as simple electrical apparatus as possible. Railroad men are discussing to-day the advantages of the gearless, the single-geared and the double-geared machine. and it is not by any means a settled fact that the abolition of gears will characterize the street car motor of the future. It certainly is not settled in my mind, and I do not think it is settled in the minds of those who are building motors. Prophesies are dangerous. If I may go back some four years ago—there was then published a paper by a gentleman now well-known in electrical fields, in which it was stated that a multiple arc system of distribution for twenty cars, on a ten-mile road, was an impossibility. It was therein mathematically demonstrated that not less than 2500 horse power would be required to operate such a system. It so happened, at the time that paper was published, that exactly that number of cars, on that length of line, and with grades running from one to ten per cent. were operated with 175 horse power. At a later date, not less than forty cars were in operation, carrying fully as many passengers as the average car carries to-day on other railroads, and operating them under difficulties which were greater than those which are met with ordinarily, and with only a 375 horse power steam equipment.

I am a defender, I must confess, of the commutated field arrangement of operating motors even if I did originate it. In connection with this I may state that in my earlier practice I also used motors sometimes in series. Street car practice only requires a reasonable variation in speed. Ordinarily we make the running speed seven or eight miles an hour. To do this it is sometimes necessary in the larger cities to operate a car for a short distance at perhaps three or four miles an hour, precisely as the cable cars in the lower part of Broadway will be operated at a maximum of four miles an hour. Then again it is necessary to run at a mean speed of seven or eight miles an hour, and at other times, with a light load and clear block, on a straight track, fifteen miles an hour. With a view of saving power I some five years ago tried the plan of operating two motors in series when running at slow speed. They operated ordinarily perfectly, and so far as reduction of speed was concerned, this plan brought the machines well within the required limits of speed in street car practice. Where that system failed in its application was when the machines were running on a heavy grade or a slippery track, the wheels not being connected, one motor would get ahead of the other and develop all the necessary counter-electro-motive force, and the other would stand still.

Another object we had at that time in doing this was to reduce the current demand from the central station when on grades, but when we started and had a large number of cars in operation, it was found better to use more current and get up the grade more quickly than to keep several cars on long grades running with less individual current and at slower speeds. You must bear in mind that the demands on street car practice are continually increasing. We have increased the necessary power of the motors and we have increased the running time of the machines. What people are anxious to do is not to get up a five or six or eight per cent. grade at one-fifth or one-eighth the speed on a level, but they want to get up that grade as rapidly as possible, and in this way the returns on investments in railroads will increase in a far greater ratio than the saving of the cost of power, or the saving of depreciation, when running at slower speeds.

Power in a motor is not determined by the necessary effort of getting the car into operation. Any motor which will propel the maximum load at its highest efficiency up a grade at a reasonable speed can be so connected and so arranged without extra apparatus as to start that car on any grade and under any load.

Now this system propose by Mr. Leonard, is somewhat similar to certain suggestions which have been made in regard to storage battery work. One would suppose from the claim made that the laws of motor government were somewhat new. It may be said that they are part of the fundamental laws of electro-dynamics and cannot be changed. Five methods have been proposed of operating a car by storage batteries. The first is where there are four groups of cells; the motors wound with fixed coils and left in a fixed condition in relation to each other; and the electro-motive forces at the terminals of the motor varied in the ratio of one, two, three or four, by variously grouping the sets. Here of course, the field varies with the armature but practically is fully excited all the while. The second method is a grouping of two separate batteries in parallel circuit to form a closed loop. Here the operation of the motor is very much like the operation of the arm of a Wheatstone bridge. The terminals are moved up and down, and there is created a variable difference of potential at the terminals of the machine. Another method had been proposed to excite the field separately. That is where we approach this method of Mr. Leonard. Here the field of the motor is excited by connection at the points of maximum potential and the potential at the terminals of the armature is varied. A fourth method is where the batteries are arranged in various groups, and the field excitation instead of being by the current flowing through the armature is from a coil with the initial potential of one of the groups. The switch arrangement is such that the current flowing through the field is constant. Still a fifth method something similar in idea consists in exciting the field by an independent section of the batteries. These are some of the precedents in storage battery work in that line.

I noticed in one part of Mr. Leonard's paper that it was stated that the total energy required for getting under way or running up a grade is no more than that used on a level. It seems to me that he has forgotten that a motor when starting has to exert energy in two ways. It has to accelerate the load and it must provide traction, and this must necessarily require more energy than when running at a fixed speed.

In the equipment which has been suggested by Mr. Leonard, it is said that we should have for the regular motor equipment two 15 horse power motors, with a power converter having two parts of different capacities. In the method shown, there is a simple movement of one switch to detach the motor from one system and throw it on the line, when wishing to take current from the main line and propel the cars directly instead of through the medium of this power converter. In this case, whatever the capacity required, the capacity of the converter in both parts, in the motor and in the generator, must be sufficient to supply the energy furnished by the line at the time of transfer. In other words, if you are going to pull your car up to a point where you are exerting thirty horse power at the car axles, no matter whether you are on a grade or a level, there must be, when you want to swing over on the line, a demand on the dynamo part equal to that, and a greater demand on the motor part, so that instead of having two parts, one of which is only one-third the capacity of the other, there must be a very decided increase of equipment. Increased weight on a car, is one of the greatest objections to-day to the single-geared machine. It is a greater objection to the gearless machine, but the moment that you add five or six thousand pounds, as it might perhaps be, to a car, in additional apparatus, there will be some very practical objections raised to a system of that kind.

I think it is well to act on the suggestion that has been made, and postpone this discussion until the next general meeting in New York. Still, if any members desire to make brief remarks, I trust we have the time to hear them. I did not intend to take so much of the limited time.

MR. LEONARD:—Mr. Chairman, in answer to some of the points that Mr. Sprague has raised in his discussion, (if discussion it can be called) of my paper, I would say that the principal corrections I wish to make, are some errors on his part in assuming certain points in connection with my article. One of the last of these points, which if fresh in your mind is the assumption on his part that the motor part of the power converter is only one-third in capacity of the propelling motor. He also spoke of the necessity of having power in the converter equal to the maximum power required at the axles in case we are going to swing over from the motor generator to the line, but it is only contemplated that such a switching from the motor generator to the line will be done at a time when we are operating at full speed on a level, which is not the time when the largest amount of power is required on the system.

As to the full speed upon a grade, and the necessity of going at full speed upon a grade, I will call attention to the fact that while the street car motors of to-day go at as full speed as possible upon a grade it is but a fraction of their full speed.

The motor generator, instead of weighing five or six thousand pounds will in reality not exceed three thousand pounds.

Mr. Sprague also incorrectly assumed that I said that no more power would be required in starting upon a grade than running at full speed upon a level. The current in the armature in the motor will necessarily be exceedingly large to accelerate the load. But during the time that we are taking that very large current through the armature of our motor to accelerate the load starting on a grade, it is being produced by the power converter at perhaps thirty or forty or fifty or sixty volts, and therefore a small amount of energy is taken from the line.

Mr. Sprague has said something about other points in the system as regards anticipation by storage batteries and other converters. That is rather foreign to the discussion of the paper and is a matter which, if it ever should be discussed, should be discussed in the courts.

Mr Sprague :—A hurried discussion of a paper of this kind is apt to be misunderstood, motives are liable to be misconstrued and somewhat incorrect conclusions arrived at. Apparently, there is a misunderstanding as to the conclusions of this discussion, and it had better be postponed until there is more time to be devoted to it.

Mr. Martin :—I move, Mr. President, that we adjourn this discussion at this time, and give Dr. Williams an opportunity to read his paper. [Carried.]

The following paper by Dr. J. B. Williams, of New York City, on "Oil vs. Air as an Insulating Medium," was then read by the author:

A paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 8th, 1892, President Sprague in the Chair.

OIL VERSUS AIR AS AN INSULATING MEDIUM.

BY JAMES BOWSTEAD WILLIAMS, M. D.

All who have attempted to enlarge in the smallest degree the bounds of our knowledge, recognize the importance of the faithful collection of facts which, though seeming separately insignificant, may yet when brought together resolve themselves into distinct and important scientific truth. By combining the results of investigations carried on from different standpoints, we obtain a view of the subject more complete than any single mind, however masterly, could give us. Hence every item of information has its importance, as it may prove to some other investigator the exact clue needed to solve some long-pondered problem. Acting upon this principle, the writer now offers an account of some experiments made by himself to determine the comparative insulation resistance of oils and air; and it has appeared to him that the results obtained from these experiments are specially important from the fact that *all* of the apparatus used was absolutely insulated, and that the only leakage that could take place was through or across the various substances experimented upon.

The relative powers of oils and air to resist disruptive discharges and also to insulate alternating currents, will not be considered at this time, as the writer proposes to reserve those subjects for a future paper.

The instruments used in the experiments from which the results about to be set forth in this paper were obtained, were an electrometer, a discharge key, a 6 inch spark coil and a Grenet cell to operate it, and apparatus for holding the oils and other substances while they were being tested.

The electrometer was a special form of quadrant electrometer, designed and made by the writer in San Francisco, in 1886, for the purpose of testing insulating material generally, and particularly for determining the comparative I. R. of very short pieces of insulated electric conductors. Its quadrants and needle system are similar to those of Lord Kelvin's electrometer, but the mounting of the quadrants and the needle suspension are different. No glass is used for insulating the various parts, this insulation being effected entirely by means of the best quality of hard rubber which is well paraffined. The suspension is of the bifilar type, is about six inches in length and is provided with adjustments. The replenisher and gauge are contained in a separate vessel, and when they are electrically connected with the electrometer proper the combination can be used in the same manner and for the same purposes as the "White pattern" quadrant electrometer. The insulation of this instrument is so perfect that its quadrants, when charged to potentials of about 6,000 volts, will retain their charge for several hours without any perceptible leakage.

Before the electrometer is used for comparative testing, it is so adjusted that the quadrants, when fully charged, will be charged to any desired potential of from one to six thousand volts.

The discharge key resembles those in common use, the only difference being in the trigger, which is so constructed as to insulate as highly as any of the pillars of the key.

This instrument was used when time measurements were taken.

All of these instruments were illustrated, and the methods of using the same in making comparative tests of insulated wires explained, in the *Electrical Engineer* of March 30 and April 6, 1892, in a serial by the writer, entitled "Insulated Electric Conductors."

With this apparatus, using the same potential as that used in these experiments, the "dielectric after-working" of Boltzman can be demonstrated, if a few inches of a highly insulated wire are tested. The variation of the capacity of a condenser having a small bare wire for its inner coating can also be shown.

The apparatus in which the oils were first tested consisted of a glass cup to contain the oils and two circular brass disks, parallel to each other, which were immersed in the oil and between which layers of oil could be formed.

These disks were each 2⅛ inches in diameter, one of the disks, the lower, being fixed and the other, the upper, movable. The movable disk was soldered to the end of an adjustable screw passing perpendicularly through the center of the hard rubber cover of the cup, which was 3 inches in diameter. The fixed disk was supported at the middle of a U shaped device formed of hard rubber tubes, both of the arms of which were cemented to the cover of the cup. One of these arms passed through the cover and extended about 6 inches above it, and contained the wire which was soldered to the fixed disk. The disks were absolutely insulated from each other and from the earth, and were separated one-thirty-sixth of an inch by each revolution of the adjustable screw. The apparatus in which the second tests of the oils were made. will be described later.

The method of testing the oils was briefly as follows. The needle of the electrometer, the induction plate, and one pair of quadrants were electrically joined to the frame of the instrument and to earth, and the second pair of quadrants joined to the upper disk.

The lower disk was connected with the binding screw of the upper contact of the discharge key, the lever of the key being depressed and held against the lower contact of the key by the trigger. The lever of the key was joined to earth. Oil was then poured into the cup, sufficient to cover the upper disk when this disk was separated from the lower disk by one-half inch, this being about the effective range of the screw.

The quadrants, and of course the upper disk were then charged by sparks from the coil, to a potential of about 2,300 volts, the illuminating apparatus and scale having previously been adjusted so that when the quadrants were fully charged the image of the cross-wire would settle at the upper end of the scale, at 300, say.

As the quadrants and disks were absolutely insulated at the potential used, there could be no leakage of the charge as long as the lower disk remained insulated from the earth; but as soon as this disk was connected with the earth, either through the medium of the discharge key or by having its electrode touched with a wire fastened to the gas pipe, leakage would take place through the layer of oil, whatever its thickness might be between the disks; and the rate at which this leakage took place was indicated by the rate at which the image of the cross-wire passed down the scale, *i. e.*, by the rate at which the electrometer was discharged.

Before entering into a description of the experiments I wish to refer to a phenomenon which occurs when all good insulating material is tested by means of charges of high potential, if the material forms the dielectric of a condenser.

Take any highly insulated wire and form say four inches of it into a condenser by closely wrapping the dielectric with tinfoil; and then carefully paraffin the ends to prevent surface leakage. The condenser thus formed, is absolutely insulated from earth, and connected with the electrometer and discharge key in the same way as the condenser formed by the two disks and the layer of oil between them, *i. e.*, by connecting the wire with the quadrants, and the tinfoil with the upper contact of the key. The quadrants are then charged to potentials of 2,000 volts or more. This causes the needle of the electrometer, and with it the image of the cross wire to be violently deflected to the right or left, depending upon which pair of quadrants is used. The needle then vibrates, but each succeeding vibration becomes quicker and shorter until the image finally settles at 300, say.

Now, if the trigger of the key be made to release the lever, connection is made between the tinfoil and the earth. A sudden "drop" of the image then occurs, which is due to the rapid absorption of a portion of the charge by the dielectric. The needle again vibrates, but the image soon settles at 250, say, if the wire be *very* highly insulated, and will remain at 250, thus showing that there is practically no leakage. But if the wire be a little less highly insulated, the drop still occurs, but the image simply "hesitates," as it were, at 250, say, and then passes slowly down the scale in proportion to the amount of leakage which is taking place through the dielectric. If the ground circuit be now broken by depressing the lever of the key, the quadrants again charged to the same potential as before, and the ground circuit established, the drop is then very slight, oftentimes nil, and the falling of the image along the scale is now due to the leakage *through* the dielectric and not to absorption *by* it.

No absorption of the charge by the dielectric can be detected as long as the outer coating of the condenser is insulated. If the image *should* move, there is leakage in some portion of the testing apparatus, which *must* be remedied if the tests are to have any value. This drop is observed only when the best kinds of insulating material are tested by the method just described. It cannot be detected when the poorer qualities of insulating material are subjected to the same tests on account of the rapid leakage through them.

The potential of the charge was determined in the following manner:—The length of spark produced by suddenly discharging the quadrants in air was approximately determined by bringing a pointed wire, held in the hand, close up to the electrode of the charged quadrants. Two bright tin disks, each 1½ inches in diameter, were then rigidly cemented upon the ends of two stout hard-rubber tubes which were well paraffined. These tubes were fastened together at the other ends in such manner that by inserting a wedge between them, the disks could be separated or made to approach each other and still remain substantially parallel at the striking distance of the spark. One of the disks was joined to the quadrants and the other to the discharge key. The quadrants were then fully charged and the key closed. If a spark passed between the disks, they were separated a little further apart and the test repeated. If a spark did not pass, the disks were brought a little closer together and the test again repeated. After several trials, the disks were separated at a distance corresponding to the exact length of the spark.

Slips of thin writing paper were then inserted between the disks until they exactly filled the space between them and the thickness of the layer formed by the paper measured with a Brown and Sharp's micrometer gauge.

A suitable spark electrometer provided with parallel plates would have given the spark length by a direct reading, but the writer did not have the time either to make or procure one.

The length of spark was found to be .03 of an inch. From tests made with a Thomson static voltmeter, this length would correspond to a potential of about 2300 volts. (A spark .026″ long = 2,000 v.)

But whatever the potential of the charge may have been—whether it was two, three or five thousand volts—the same potential was used in *all* of the experiments described in this paper.

The oils tested were rosin, paraffin, linseed, cotton-seed and castor. The rosin oil was what is known as London oil. The paraffin oil had a specific gravity of 24° B. All of the samples were procured from wholesale dealers, and were declared to be of the best quality.

The first set of experiments include tests of paraffin and rosin oils, air, and a specimen of a well-known insulated wire. This last test was made to show what took place when the dielectric of insulated wires was tested by means of charges of high potential, and also to make a rough comparison between specific resistance of this dielectric and that of the oils about to be tested.

The temperature during the tests was 82° F., and the humidity, as indicated by a Lambrecht's polymeter, 80.

It was first ascertained, by testing, that the quadrants used and the disks were absolutely insulated. Each separate experiment is designated by a number.

1. Paraffin oil was then poured into the cup and the disks separated one-ninth of an inch. The discharge key was not used in these tests in order to save time, a wire fastened to the gas pipe being used to ground the lower disk. The connections were properly made and the quadrants fully charged. As soon as the image of the cross-wire had become stationary, the electrode of the lower disk was touched with the ground wire. The image immediately flew down the scale, apparently as fast as if the *upper* disk had been touched with the ground wire. That this sudden flight of the image was not due to the "drop"—*i. e.*, to absorption of the charge or the sudden rush of the electricity *into* the oil and not *through* it—was proven by repeatedly charging the quadrants, and then discharging them through the oil. In fact, the amount of leakage was so great that, while the lower disk was kept grounded, the quadrants *could* not be charged.

If leakage through a very thin layer of any good dielectric be not *too* excessive, the quadrants can always be recharged, wholly or in part, even while the leakage is going on; but, in this case, the leakage was too great even when sparks were rapidly poured into the quadrants.

2. The disks were next separated one-fourth of an inch, but no better results were obtained than at first.

It is evident that there must have been less leakage through a layer one-fourth of an inch thick than through one one-ninth of an inch thick. But, in both cases, the movements of the image were too rapid to be timed.

3. The cup was then emptied of the oil and a few drops introduced between the disks, and still no different results were obtained.

4. The oil was then heated to about 280° F., to expel any moisture that might be present. But this made no difference in the tests; there was still great leakage, even after the oil had cooled.

5. Rosin oil was then subjected to the same tests as the paraffin oil, but no better results were obtained from it than from the paraffin oil.

6. All oil was removed from the disks and a layer of air one-eighteenth of an inch thick tested. The drop was about five divisions, but after that the image remained stationary, thus showing that the insulation resistance of the air, at the potential used, was absolute.

7. A piece of the insulated wire before referred to, about five inches long, was connected with the quadrants and the quadrants charged. The edge of a pocket knife blade was then held transversely upon the dielectric, when the image passed rapidly down the scale. This experiment was repeated and the same result obtained. The ends were then paraffined and the specimen again tested. Result almost the same as before paraffining, thus showing that there had been some surface leakage at first.

Many of the insulated wires now in use yield the same results when tested exactly as this present sample was tested. But there are also many which give excellent results when thus tested, and there are a few in which there is very little leakage even when several feet are formed into a condenser and tested at this same potential.

It is important to remark that tests of different sections of the same wire, having a vulcanized dielectric, may not always give the same results. For example, a three inch piece of a certain wire may have a very high I. R., while the next three inches may have an I. R. much lower than that of the first. Where this is the case, it will almost always be found that the dielectric of the second sample contains some flaw, or else has particles of wood, metal, etc., embedded in the mass.

By using this method of testing, the superiority of one insulated wire over another, whenever samples a few inches long can be obtained, can easily be demonstrated. It will readily be seen that this fact may become of great importance in legal or other cases in which the comparative insulation resistance of wires is involved. Decisive results can be obtained in many cases from lengths of two or three inches only.

The second set of experiments included tests of all five oils, paraffin, wax, ordinary air, and steam. The temperature was 80° F., and the humidity 75.

In the second set, the layers of oil were formed between an upper disk nine-sixteenths of an inch in diameter, and a lower disk 1¼ inches in diameter. This lower disk was the flat bottom of a tin box. Its sides were covered with a thick layer of paraffin wax, so that no leakage could take place except through the layers of oil. The disks were mounted the same as the larger disks, and were absolutely insulated from each other and from earth.

1. Paraffin oil was first tested in a layer $\frac{1}{4}$ of an inch thick, but the falling of the image was too rapid to be accurately noted. A layer $\frac{1}{2}$ inch thick was then tested and gave a fall of 207 divisions in one minute.

2. Rosin oil tested in a layer $\frac{1}{4}$ of an inch thick, gave a little better results than the paraffin oil; but when a layer $\frac{1}{2}$ inch thick was tested, the fall was 177 divisions in one minute.

In these two tests of the two oils all effects due to the drop were eliminated by repeated chargings, so that the fall due to leakage alone was noted.

3. Linseed, cotton-seed and castor oils were each tested in $\frac{1}{2}$ inch layers, but as the fall of potential was so much greater than that of the other two oils no further tests were made of them.

Of the three, castor oil had the lowest specific resistance; and there was but little difference between the linseed and the cotton-seed oils, what little difference there was, being in favor of the linseed oil.

4. A layer of paraffin one-sixteenth of an inch thick and free from air bubbles, was next formed between two tin disks, each $1\frac{5}{8}$ inches in diameter, and tested like the layers of oils. When the ground circuit was closed the drop was just 5 divisions. The quadrants were again fully charged, and the falling of the image noted. This fall was one division in two minutes, or 30 divisions in one hour.

5. A brass tube 10 inches long and five-sixteenths of an inch in diameter was next used for a receptacle for oil. In the center of this tube was a straight copper wire one-sixteenth of an inch in diameter, the wire being kept concentric with the tube by means of two hard rubber plugs with holes through their centers. The tube contained rosin oil. The wire was connected with the quadrants, and the tube absolutely insulated from the earth and neighboring objects.

The quadrants were then charged and the tube grounded. The image passed down the scale too rapidly to have its rate of falling timed. The hard rubber plugs were carefully paraffined so that all of the leakage took place inside the tube.

A torrent of sparks was poured into the electrometer, but it could not be charged on account of the rapid leakage through the oil.

6. Three plates of glass each 3 by 4 inches and one-eighth of an inch thick, were carefully cleaned and then dried over a lamp. Before they had cooled, one was covered with a film of rosin oil, one with a film of paraffin oil, each film having an area of about two square inches, and the third had a film of paraffin wax about one inch square formed on it. A No. 20 copper wire was fastened to the quadrant electrode, and its free end placed in contact with the center of the film on the glass. The glass was insulated and the quadrants charged. The image remained stationary as long as the glass was insulated, but as soon as any conducting body, the hand for instance, came in contact with *any* portion of the glass plate, leakage over the film of material on the glass occurred. In each case there was a slight drop, but the quadrants were immediately recharged. The rate of falling of the image with the glass plates covered with the oils was practically the same, the fall being about 5 divisions to the second; but with the paraffin wax the image remained stationary.

Repeated chargings failed to alter the rates of falling of the image.

7. The last tests were made with air and steam, and in both tests the layers were formed with the device used to ascertain the potential of the fully charged quadrants. In the first of these tests, the disks were separated a trifle more than .03 of an inch.

The drop in this test was just two divisions, but after that the image did not move in 20 minutes. The writer has made this same kind of test in former years, and has allowed the instruments to stand for hours, and yet there would be no leakage through the layer of air.

The last test was made with a layer of steam of the same thickness as the layer of air in the test just described.

The quadrants were fully charged and the ground circuit closed. Steam was then generated in a test tube and the mouth of the tube held directly beneath the disks. This enveloped the disks in steam and also formed a layer of steam between them. As soon as the layer of steam was formed, leakage took place through it, and the leakage increased as moisture was deposited upon the disks (thereby reducing the distance between them) until a bridge of water was formed, when, of course, the quadrants were immediately discharged. From many tests, the writer found that, as nearly as he could determine, the rate of fall, when the layer was composed entirely of steam, was about 20 divisions in one second.

He would state, however, that as he was entirely alone during these experiments upon steam, and as his attention was necessarily divided between several parts of the apparatus, each of which required continual watching, he cannot vouch for the accuracy of these figures; but he has every reason to believe that they are approximately correct.

Several times during the tests, oil was accidentally smeared upon the surface of the paraffined hard rubber, and in every case the hard rubber would have to be recleaned and reparaffined before its surface insulation was restored. From a careful consideration of the foregoing tests, the results thereof appear to the writer to prove, when continuous high tension currents *alone* are concerned :

1. That air, even when it has a humidity of 80 per cent., is infinitely superior to oil for insulating conductors carrying such currents.

2. That pure paraffin is far superior to oil, both for insulating conductors and for preventing the escape of the current across the surface of glass

3. That air having a humidity of 80 per cent. is superior to paraffin as an insulating medium.

4. That oil will not prevent leakage of the current across the surfaces of glass.

5. That whenever oil covers the surface of hard rubber, even when the latter is paraffined, it destroys the high surface insulation of the paraffined hard rubber, that is, the low surface insulation of the oil has been substituted for the higher surface insulation of the hard rubber, when used bare and clean, or when covered with paraffin.

The writer would state that the results of the present tests, which were made in New York City, correspond substantially with results obtained by himself and his brother, Mr. R. W. Welty, while they were making the investigation of insulating material and its applications, which is now being described in the serial before referred to.

A few words relative to the use of the oils in practice, may not be amiss here. To use oil for insulating conductors, there must be an enclosing vessel of iron, or its equivalent, for the oil and conductors. If long tubes are employed for this purpose, two things are indispensable—plugs in the ends of the tubes and means for keeping the wire or cable concentric with the tube, and the individual wires of a cable separated from each other. For the latter purpose, fibrous material is probably the most convenient means. Jute, when pure and dry, is an excellent fibre, both for the oils when used alone and when thickened with rosins, etc., for by reason of the peculiar nature of the fibre, a larger amount of insulating material can be placed within a given space than if a closely-lying vegetable fibre is used; and there will also be fewer points of contact of fibre between the wires and the inside of the tubes. Experiments made by the writer show that there is but little difference in the specific resistance of different kinds of vegetable fibre when the fibre is clean and absolutely dry. The resistance of such fibre is high as long as it remains in this condition. But it is almost impossible to keep it so. It may be a matter of surprise to many to learn that cotton which has been dried, and which therefore possesses good insulating properties, loses these properties in less than ten minutes if exposed to a damp atmosphere.

Whatever means are used for the purpose last above stated, they should have a high specific resistance and allow the use of as much oil as possible.

The plugs must be formed of insulating material which is not injuriously affected by the oils. The best hard rubber, or some special vulcanized rubber or gutta percha compound, appears to be the best for this purpose. Paraffined wood is very apt to be of little use in a short time, for no matter what kind of soft porous material is paraffined by allowing it to absorb the melted wax, the wax rarely hardens in a solid form, but usually contains numerous small spaces and these spaces absorb moisture by capillary attraction. It is for this very reason that a dielectric which is formed of fibre saturated with paraffin soon loses its high insulation when exposed to the air. The microscope will demonstrate the presence of these minute air spaces.

All oil should be carefully heated, sufficient to expel all moisture and air, before it is used. If paraffin oil is used, it is better to subject the oil to a comparatively low temperature and exhaust the air by means of a vacuum than to heat the oil to a high temperature. After the moisture has been removed, the oil must be kept excluded from the air or it will again absorb moisture.

If oil is used as a covering for insulators made of inferior glass or porcelain, to be of value it must contain no moisture or dirt; and if used in damp and dusty localities, means must be provided for the self-renewal of the oil, so that fresh surfaces of oil may constantly be exposed. But if insulators had surfaces formed of glass which contained a large proportion of pure silica, better insulation would be effected, if these surfaces were not covered with oil. The writer once found a molded glass vessel, having about the same dimensions and area as the "pony" insulators, which had a surface insulation vastly superior to that of the "pony" insulators. If insulators were made wholly or in part of *such* material a covering of oil would be worse than useless, for experiments have shown that when glass or other material does prevent surface leakage, covering it with oil at once ruins the high surface insulation.

Experiments made upon the expansion of paraffin and rosin oils show that when paraffin oil is heated to 280° F., a column of it 3½ inches long and thee-fourths of an inch in diameter, expands one-half of an inch; and that if a column of rosin oil of the same dimensions is heated to the same temperature, it expands three-eighths of an inch. These facts should be taken into consideration when using these oils in pipes, for if the pipes are full and the oil gets heated, it will expand and probably either expel the plugs or exude at the ends. If it exudes, dust and moisture will collect upon the film of oil and cause surface leakage. This leakage at the ends of pipes containing telephone or telegraph wires, might not be detrimental to the working of the lines, but if the pipes contained wires carrying high tension currents, serious trouble might arise.

The efficiency of oil to fill holes in dielectrics depends greatly upon circumstances. If the holes or gaps should be formed in the dielectrics of wires conveying weak currents, the oil, if not too sluggish, would have plenty of time to move into and fill such spaces; but if in the dielectrics of wires conveying strong currents; the oil must move very quickly or a disastrous burn-out is the result. And not only this, but the oil, becoming hot expands, and the pipes, if of lead, are apt to be strained or broken by the increased pressure from within, outwards. If the burn-out occurs near the ends of the pipes, the plugs may be expelled. If the filling of spaces were the *only* thing required of the oils, the lighter ones would accomplish this purpose better than the denser ones.

But the heavier oils—*e. g.*, heavy and light paraffin oils—are much better for insulating purposes than the lighter.

In conclusion, the writer would state that he feels warranted in believing, unless the contrary can be demonstrated, that dry air, if employed to form a portion of the dielectrics of insulated conductors and if the conditions upon which its highest efficiency depends are fulfilled, is an insulating material superior to oil and even paraffin. In making this statement, he takes it for granted that his method of testing—a method which he does not remember ever to have seen published before his use thereof over five years ago—yields results, the accuracy of which can be relied upon. This belief has been established after several years of experimental work upon insulating materials and the manufacture of different kinds of insulated conductors. Certainly air is cheaper than any other insulating material, and it is not destroyed or injured by intense currents. Burn-outs do not affect it, and if it can be kept dry, which is the great difficulty attending its use, the conductors which it insulates will have a high insulation resistance, and a low electrostatic capacity—two things which are of the greatest importance in electrical engineering.

THE PRESIDENT:—It is unfortunate that this paper was not presented at a time when there could have been a full discussion upon the questions that arise. I am sure that some of the conclusions which have been arrived at by Dr. Williams are entirely contrary to the generally accepted belief, and there are a number of members of the Institute who have made experiments on high potentials and oil insulators. Since, however, Dr. Williams intends to repeat his experiments in New York, and inasmuch as the discussion can take place at that time, when it will be more instructive than the very brief discussion which could be had now, I will not call for remarks on the paper, but ask that members of the Institute, appreciating the importance of it, will be prepared at the next meeting. [Adjourned.]

The following paper by Professor Carhart, was read on June 6th. Owing to the absence of the author in Europe, the revised copy was not received in time to be printed in regular sequence.

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 6, 1892, Vice-President Lockwood in the Chair.

RELATION BETWEEN THE ELECTROMOTIVE FORCE OF A CLARK CELL AND THE DENSITY OF THE ZINC SULPHATE SOLUTION.

BY PROFESSOR H. S. CARHART.

It is now well known that there is an inverse relation between the E. M. F. of a Clark cell and the density of the solution of zinc sulphate; that is, an increase in the density of the solution is accompanied by a decrease in the E. M. F. of the cell. This relation for the Daniell cell I investigated ten years ago.[1] A similar investigation for the Clark cell was recently undertaken at my suggestion by two students in my laboratory, Mr. T. E. Barnum and Mr. E. A. Cheney. They have also undertaken to determine whether the temperature coefficient changes with a change in the density of the solution, provided there are no crystals of zinc sulphate present.

The importance of this investigation is connected with the fact that the temperature coefficient of the Clark cell containing zinc sulphate crystals is almost exactly double the value exhibited by cells containing no crystals. Lord Rayleigh's value is 0.00077 at 15° C.;[2] Dr. Fleming found 0.00082 for cells with crystals. My own cells, containing no crystals, have a coefficient of 0.000386 per degree C. at 15°.[3] Dr. Kahle in Berlin has obtained a value almost identical with that of Lord Rayleigh for cells containing zinc sulphate crystals. Half of this so-called temperature coefficient is due to the dissolving of the crystals with rise of temperature, or conversely to recrystallization when the temperature falls. A large change in the E. M. F. of a standard cell with change of tem-

1. *American Journal of Science*, Vol. xxviii., Nov., 1884.
2. *Phil. Trans. Royal Soc.*, Part ii., 1885.
3. *American Journal of Science*, Vol. xxxviii., Nov., 1889.

perature is clearly a disadvantage, especially because of the difficulty of ascertaining the temperature with exactness. Another incidental but important disadvantage, due to the presence of the crystals, is the slowness with which the cells reach their equilibrium after change of temperature. Time for diffusion must be allowed before the cell assumes a value corresponding to its new temperature. Hence such cells exhibit a time lag, sometimes amounting to several days, and differing for different cells. Such considerations as these led me to make a cell without zinc sulphate crystals. It is then important to know what variations in E. M. F. will follow any departures from the density of the zinc sulphate solution adopted as the "normal" solution; in other words, what decrements in the E. M. F. of the cell correspond to given increments in the density of the zinc sulphate solution.

A series of twenty-four cells, two for each density of solution, were made, and their E. M. F. at one temperature was determined by comparison with a Clark cell containing crystals and kept very near 15° C. The E. M. F. of this comparison cell was assumed to be 1.435 volts at 15°.

Table I shows the results of such a comparison.

TABLE I.

Per cent. of $ZnSO_4$ in solution.	Density of solution at 20° C.	Resistance to balance.	Electromotive force.	Comparison Cell. Resistance.	Comparison Cell. Temperature.
5	1.036	9728	1.4850	9400	15°
10	1.062	9683	1.4777	9404	14.7
15	1.096	9645	1.4724	9400	15
20	1.131	9621	1.4686	9400	15
25	1.164	9595	1.4647	9400	15
30	1.206	9566	1.4605	9400	15
35	1.249	9543	1.4567	9400	15
40	1.293	9525	1.4540	9400	15
45	1.343	9506	1.4488	9415	15
50	1.383	9459	1.4444	9400	15
Saturated at 15° C.	1.417	9453	1.4398	9423	14.5
Saturated at 20° C.	1.429	9420	1.4380	9400	15

The comparisons were all made by the potentiometer method, and the "resistance to balance" in each case was the resistance between the points of derivation of the derived circuit, the main circuit having a constant resistance of 10,000 ohms.

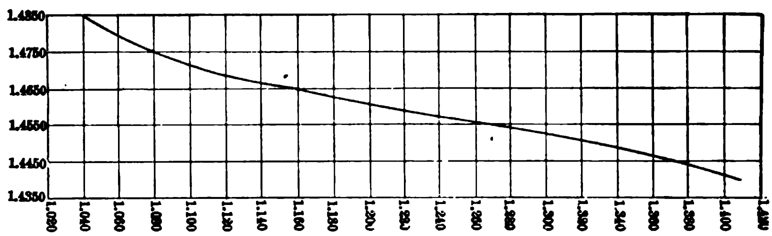
Plotting the electromotive forces of the table as ordinates and the corresponding densities as abscissæ, the curve of the diagram was obtained. The minimum rate of change of E. M. F. occurs with a density of about 1.265.

The further question of temperature coefficient was investigated by determining it for each cell. For this purpose the cells were placed in large test-tubes which were in turn immersed in a water-bath kept at the desired temperature.

Table II. gives the data for the five per cent. cell.

TABLE II.

Comparison Cell.		Five per cent. Cell.		
Temperature.	Resistance.	Temperature.	Resistance.	E. M. F.
14.5°	9414	15.1°	9740	1.4850
15.5	9413	16.6	9737	1.4840
.....	.....	17.3	9730	1.4837
14.7	9411	18.4	9726	1.4831
......	......	20.0	9720	1.4822
14.7	9412	21.2	9716	1.4815
.....	......	22.0	9713	1.4810
14.7	9412	23.0	9711	1.4806
......	.....	24.0	9706	1.4800
14.7	9412	26 0	9697	1.4787
.....	.....	29.0	9687	1.4771



RELATION BETWEEN E. M. F. AND DENSITY.

If these temperatures and electromotive forces are plotted as coördinates the resulting curve, exhibiting the relation between them, does not differ sensibly from a straight line. We may therefore write

$$E_t = E_{15} [1 - a (t - 15)]$$

as the formula connecting E. M. F. and temperature. The value for a which satisfies the observations of the table is 0.00039.

Table III. contains the data for the coefficient of the 10 per cent. cell.

TABLE III.

Comparison Cell.		Ten per cent. Cell.		
Temperature	Resistance.	Temperature.	Resistance.	E. M. F.
14.7°	9404	15.0°	9683	1.4777
14.5	9405	16.0	9680	1.4772
15.5	9406	17.8	9677	1.4760
15.3	9404	19.4	9672	1.4756
14.9	9405	20.6	9665	1.4747
15.0	9406	21.6	9663	1.4742
14.8	9406	23.2	9657	1.4734
14.9	9408	24.2	9655	1.4727
14.9	9408	26.1	9647	1.4715
15.0	9407	27.5	9643	1.4710
15.0	9407	29.6	9637	1.4700

These observations give a slightly smaller value of a than those on the 5 per cent. cell.

Each cell was tested in a similar manner, and the variation from a temperature coefficient of 0.00039 was small and probably within the errors of observation of the experimenters. It appears probable then, that the temperature coefficient of Clark cells not containing crystals is independent of the density of the zinc sulphate solution, and is only half that belonging to cells with zinc sulphate crystals in excess.

DISCUSSION.

THE CHAIRMAN [Vice-President Lockwood]:—Each one of us who has performed electrical measurements must have been considerably chagrined to note the discrepancies resulting where no discrepancy should exist, in operating Standard Cells and apparatus worked by them; and any information which we and the world at large can get which will tend to make the Standard Cell anything less of a *Standard Sell* than it often is, must unquestionably be of great value.

MR. WILLYOUNG:—Mr. Chairman, I think Professor Carhart has not stated the case with entire fairness to himself. A great many very thorough tests have been made on those cells, and I think the maximum inaccuracy obtained for some time past has been only about four parts in ten thousand, while a number of cells that have recently been tested at Johns Hopkins', show an actual variation of only two parts in ten thousand; so that the cell is really, I think, much more accurate than Professor Carhart has claimed it to be.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York City, September 27th, 1892.

The sixty-ninth meeting of the Institute was held this date. The meeting was called to order by President Sprague.

THE PRESIDENT:—We meet to-night for the first time after the summer vacation. The paper that is going to be presented to you is one of great interest. It embodies the results of investigations which have been made by one of the ablest mathematicians of this Institute, carried on for months both day and night with resources which were practically unlimited in their experimental character, and they have been embodied in a paper which I think may fairly be said to be one of the most important ever presented here.

Owing to the pressure of private duties which has borne heavily on me for some time, I shall not be able to preside at this meeting and I will request Mr. Hammer to take my place. If there is any new business to present, the Secretary will do that in connection with the announcement of the election of new members.

THE SECRETARY:—At the meeting of the Council held this afternoon, the following associate members were elected:

Name.	Address.	Endorsed by
ALBRIGHT, H. FLEETWOOD,	Electrical Engineer, Western Electric Co., 227 So. Clinton St., Chicago, Ill.	G. M. Phelps. E. M. Barton. Chas. A. Brown.
ARMSTRONG, CHAS. G.	Electrical Expert and Electrical Architect, 1301 Auditorium Tower, Chicago, Ill.	F. J. Sprague. C. T. Hutchinson. Louis Duncan.
CALLENDER, ROMAINE	Electrician, Brantford Electrical Laboratory, Brantford, Canada.	T. J. Smith. F. Jarvis Patten. Ralph W. Pope.
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 227 South Clinton St., Chicago, Ill.	E. M. Barton. Geo. M. Phelps. Chas. A. Brown.
FISHER, GEORGE E.	General Manager, Commercial Electric Co., 55-57 Gratiot Ave., Detroit, Mich.	Elias E. Ries. Ralph W. Pope. Fred'k Reckenzaun.

FLESCH, CHARLES	Electrical Engineer, Melbourne, Australia.	Jos. Wetzler. T. C. Martin. Geo. W. Davenport.
JACKSON, J. P.	Assistant Professor of Electrical Engineering, Penn. State College, State College, Pa.	D. C Jackson. Gilbert Wilkes. W. G. Whitmore.
KINSMAN, FRANK E.	Electrical Engineer, Plainfield, N. J.	Geo. A. Hamilton. Ralph W. Pope. H. C. Townsend.
MAGENIS, JAMES P.	Editor the *Adams Freeman*, Adams, Mass.	Frank J. Sprague. P. B. Delany. C. E. Dressler.
MACFADDEN, CARL K.	Chief Electric Light Inspector, Chicago & Northwestern Ry. Co., 22 Fifth Ave., Chicago, Ill.	R. W. Pope. Fred DeLand. A. H. Bauer.
MCBRIDE, JAMES	Superintendent, N. Y. & Boston Dye Wood Co., 146 Kent St., Brooklyn, N. Y.	W. A. Rosenbaum. J. A. Seely. Ralph W. Pope.
NOLL, AUGUSTUS	New York Insulated Wire Co., 15 Cortlandt St., New York City.	Jos. Wetzler. T. C. Martin. F. J. Sprague.
RAY, WILLIAM D.	Electrician of Local Line of Northern Pacific R. R. Co, at Chicago, 308 Home Ave., Oak Park, Ill.	D. C. Jackson. Fred. DeLand. Ralph W. Pope.
RODGERS, HOWARD S.	Electrical Engineer, Thomson-Houston Electric Co., 624 Western Ave., Lynn, Mass.	Franklin Sheble. Caryl D. Haskins. H. G. Reist.
ROSS, ROBERT A.	Engineer in charge of Engineering Dept., Edison General Electric Co., Petersborough, Ont.	John Langton. Wm. S. Andrews. Samuel Insull.
SMITH, FRANK STUART	Supt. of Carbon Dept., Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	Chas. A. Terry. O. B. Shallenberger. Chas. F. Scott.

Total, 16.

Probably at one of the following meetings the Committee on Units and Standards, which has been pursuing its work for the last year or two will bring up a report for consideration by the Institute at large, in accordance with the action of the Council. We have a few proof copies of this report which I will be glad to have any of the members who are interested in this subject take with them in view of discussion at some future date.

THE PRESIDENT:—It is good for the Institute that we have at each returning meeting such a list of new members. I am glad to notice that the number of members, who either under the pressure of personal business or for other reasons, have found it necessary to drop out of the Institute are few.

The paper this evening will be by Mr. Charles P. Steinmetz. It is the second paper "On the Law of Hysteresis, and other Phenomena of the Magnetic Circuit." His work in the past has been most important in its character and this paper will fully support the reputation he has already earned.

The following paper was then read by the author.

A paper read at the sixty-ninth meeting of the American Institute of Electrical Engineers, New York, September 27th, 1892, Vice-President Hammer in the Chair.

ON THE LAW OF HYSTERESIS (PART II.)

AND OTHER PHENOMENA OF THE MAGNETIC CIRCUIT.

BY CHARLES PROTEUS STEINMETZ.

At the sixty-third meeting of this Institute, on January 19th, 1892, in a paper, "On the Law of Hysteresis,"[1] I have shown that the energy converted into heat during a complete cycle of magnetization can be expressed by the empirical formula

$$H = \eta\, B^{1.6},$$

where $\pm B$ is the maximum magnetic induction reached during the cyclic process, and η a "coefficient of hysteresis."

I have given the numerical values of this coefficient, η, for different materials, varying for

Wrought-iron, between	.002	and	.0045	
Cast-iron	.016			
Annealed steel	.008	to	.012	and up to
Hardened steel	.025	to	.082	in manganese steel
Magnetite	.020			

I have shown that this "coefficient of hysteresis," η, is apparently independent of the speed of reversals in practical limits, being the same for slow reversals as for rapid alternations up to somewhat over 200 complete periods per second. The tests published there, covered the whole range, from very low magnetization, $B = \pm\ 85$ lines of magnetic force per cm.^{2} up to saturations as high as $B = \pm\ 19{,}000$ lines of magnetic force per cm.^{2} giving fair agreement with the law of the 1.6th power.

Under conditions where eddy or Foucault currents were induced

1. TRANSACTIONS, vol. ix, p. 1,

in the iron, the loss of energy followed the more general formula,

$$H = \eta\, B^{1.6} + \varepsilon\, N\, B^2,$$

where N is the frequency, H the whole loss per cycle and cm.^{3} in ergs or absolute units, and

$H_1 = \eta\, B^{1.6}$ represents the loss by molecular hysteresis,
$H_2 = \varepsilon\, N\, B^2$ represents the loss by eddy-currents.

In an appendix I have shown that when the hysteretic loss H is represented as function of the M. M. F. F,

$$H = f(F),$$

we derive a curve of that shape which we would expect on the hand of the theory of molecular magnets, as formulated by Ewing.

The next question which offered itself was, to determine the conversion of energy into heat during a magnetic cycle completed between any two limits, either of opposite or of equal sign; for instance during a cyclic variation of B between $B_1 = +\ 10{,}000$ and $B_2 = -\ 2000$, or between $B_1 = +\ 18{,}000$ and $B_2 = +\ 6000$.

In the latter case Ewing, I believe on the hand of theoretical reasoning rather, contended the hysteretic loss to be very small or, in the limits of saturation, even nil.

To determine the loss of energy in a magnetic cycle between any two limits, B_1 and B_2, I have made a number of tests:

1. By the electro-dynamometer method, by employing *pulsating* currents for the excitation of the magnetizing helices; that is, currents which were derived by the superposition of an alternating and a continuous E. M. F.

2. By means of the Eickemeyer differential magnetometer, described in the former paper.

CHAPTER I. ELECTRO-DYNAMOMETER TESTS.

In the same manner as described in the former paper, a magnetic circuit of rectangular form was built up of 41 layers of sheet-iron, each layer consisting of two pieces of 20 cm. length and 2.62 cm. width, and two pieces of 7.5 cm. length and 2.62 cm. width, of the thickness $\delta = .042$ cm. (calculated from weight, specific gravity = 7.7).

Length of magnetic circuit, 41 cm.
Cross-section . . . . 4.512 cm.^{2}

Between the different layers, two sheets of thin paper were laid to give thorough insulation against eddy-currents. On the long sides of the rectangle forming the magnetic circuit, two magnetizing coils were wound, and connected in series, each consisting of 50 turns of three wires, No. 10 B. and S. gauge, wound simultaneously. Connecting the three wires, No. 10, in parallel gave 100 exciting turns of a resistance of .048 ω.

The instruments employed were the same as used in the former experiments, of which the constants are there given. The alternating E. M. F. was derived from the same Westinghouse 1 H. P. dynamo, varied in frequency and E. M. F., and driven in the same manner as before. In the same circuit with the Westinghouse dynamo and exciting helices, were connected in series three cells of an Eickemeyer storage battery and a rheostat.

To determine whether the superposition of the alternating E. M. F. affected the E. M. F. of the storage battery, the fixed coil of an electro-dynamometer was excited from a separate source, and the current of the storage battery sent through the movable coil, the armature of the Westinghouse dynamo and the rheostat. Then the Westinghouse dynamo was started, and it was found that the deflection of the electro-dynamometer was not changed perceptibly, thereby showing the absence of any perceptible interference between the alternating and the continuous E. M. F.'s.

The method of determination had to be changed somewhat to make it applicable to tests with pulsating current.

If the fine wire coil of the wattmeter is connected in shunt to the magnetizing helices, across the main circuit, the wattmeter measures the whole energy expended in the magnetizing helices, which consists of the energy consumed by the iron, and the energy consumed by the electric resistance of the magnetizing helices. For low and medium magnetization, the magnetizing current, and therefore the energy consumed in the electric resistance, constitutes only a small percentage of the whole wattmeter reading, and correction, therefore, can be easily made. But if a higher rate of saturation is reached, the magnetizing current becomes very large and the energy consumed by the electric resistance becomes a great or even the greater part of the whole expenditure of energy. At the same time, the temperature of the magnetizing helices rises somewhat, and consequently, the electric temperature coefficient of copper being very large, its electric resistance increases and the energy expended thereby can not be determined exactly. This impairs the exactness of the readings at higher saturation considerably.

Now, if upon the alternating E. M. F. a continuous E. M. F. is superposed, the current increases greatly, while the magnetic fluctuation and consequently the energy consumed by the iron decreases, because now the magnetic cycle is performed entirely or greatly within the limits of saturation.

For instance, while an *alternating* E. M. F. of 15.8 volts effective, at the frequency 170, sends only 1.6 amperes through the magnetic circuit described above, a *pulsating* E. M. F. of 15.8 volts effective, produced by the superposition of six volts storage battery upon an alternating E. M. F., sends not less than 14.5 amperes

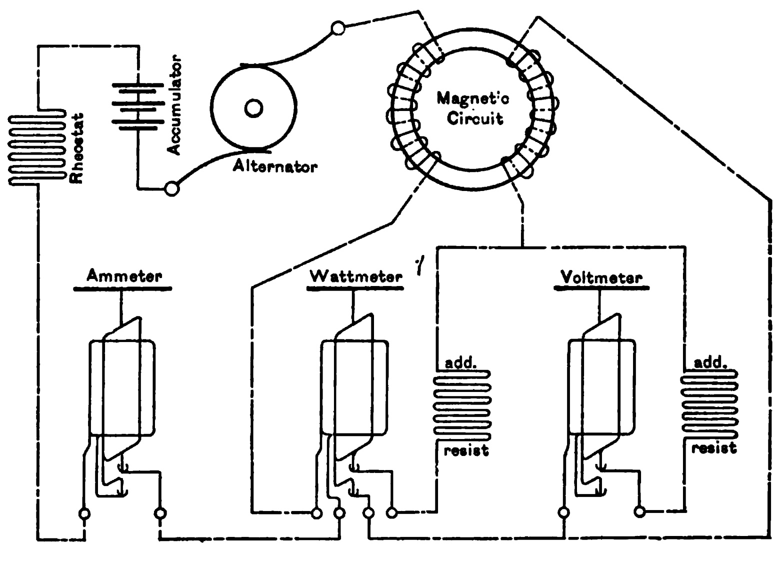


FIG. 1.—Diagram of Connections.

effective through the same magnetic circuit at the same frequency. Hence I devised another method whereby I was enabled entirely to eliminate the loss of energy caused by the electric resistance of the magnetizing helices (and of ammeter, etc.) and directly to measure the energy given off to the iron.

Of the three wires, No. 10, which were wound simultaneously on the magnetizing helices, only two were joined in parallel and connected into the main circuit, in series to ammeter, coarse wire coil of wattmeter, alternator, storage battery and rheostat. Voltmeter and fine wire coil of wattmeter, with their additional resistances, were connected into the third wire of the magnetizing helix in a separate secondary circuit, as shown in the diagram Fig. 1.

As seen, in this connection the voltmeter directly measures the E. M. F. induced by the fluctuation of the magnetism, that is, measures these fluctuations, while the wattmeter measures the time integral of the product of instantaneous values of main current into variation of magnetism,

$$\frac{1}{T}\int_0^T c\, d\, M,$$

that is, the energy given off to the iron. It was necessary to correct only for the small amount of energy transferred from the iron to the secondary circuit, and possible thereby to measure exactly even small magnetic fluctuations taking place at high values of saturation. The precautions taken, the method of determination and calculation of the readings, etc., were essentially the same as in the former tests, so that I need not dwell upon them.

The magnetic characteristic $B = f(F)$ derived from these tests, was checked by means of the differential magnetometer.

Tests were made at the frequencies of

170 complete periods per second,
110 " " "
67 " " "

first with alternating current, using only the alternator, then with pulsating current, having three cells of storage battery in series to the alternator, and then with pulsating currents with three cells of storage battery and rheostat in series to alternator.

The *magnetic characteristic* is given in Table I. in the usual manner, that

F = M. M. F. in ampere-turns per cm. length of magnetic circuit,
B = magnetic induction in thousands of lines of magnetic force per cm.^{2},
ρ = metallic reluctivity in thousandths, that is:

If we subtract from the magnetic induction B the magnetic field intensity $H = \frac{4\pi}{10} \sim \frac{5}{4} F$, and thereby derive the "metallic induction,"[1] $L = B - H$, this metallic induction is

1. Kennelly on Magnetic Inductance, TRANSACTIONS, vol. viii, p. 485, October, 1891.

TABLE I.

MAGNETIC CHARACTERISTIC OF SHEET-IRON IN KILOLINES.

$$\rho = 3.16\, e^{-.72\, F} + .275 + .058\, F, \text{ in mils.}$$

F.	B.	ρ. obs.	$\rho - \rho$ calc. obs.	F.	B.	ρ.
1.	.54	1.85	+.02	16	13.32	
1.5	1.00	1.50	—.06	18	13.67	
2	1.70	1.18	—.04	20	13.95	
2.5	2.60	.952	—.018	25	14.52	
3	3.65	.822	—.009	30	14.94	
3.5	4.74	.738	—.006	35	15.23	= .275 + .058 F.
4	5.86	.683	+.001	40	15.47	
4.5	6.85	.658	+.002	45	15.65	
5	7.77	.644	+.007	50	15.80	
5.5	8.55	.644	+.010	60	16.06	
6	9.27	.648	+.016	70	16.24	
6.5	9.85	.661	+.020	80	16.38	
7	10.28	.682	+.018	90	16.49	
8	10.83	.739	+.010	100	16.57	
9	11.30	.797		[120	16.71	
10	11.71	.855		150	16.86	
12	12.37	.971		200	17.09	
14	12.90	1.087		1000	18.41]	

Absolute saturation, $(B - H)_\infty = 17.24$.

$$L = \frac{F}{\rho},$$

where ρ is the "metallic reluctivity" (referred to *ampere-turns* as unit); indeed, referring to *magnetic field intensity* H as unit, we get

$$L = \frac{H}{\rho_0},$$

where

$$\rho_0 = \frac{4\pi}{10}\rho \sim \frac{5}{4}\rho.$$

Or, in the usual manner of writing, calling the "permeability" μ and the "susceptibility" $\varkappa$, we have

$$B = \mu H = (4\pi\varkappa + 1) H,$$

and I being the "intensity of magnetization," or "magnetic moment,"

$$I = \varkappa H, \text{ and}$$
$$B = 4\pi I + H,$$

so that the "metallic induction" is

$$L = 4\pi I,$$

and the "metallic reluctivity"

$$\rho_0 = \frac{1}{4\varkappa\pi} \sim \frac{2}{25\varkappa}.$$

In the following I shall, as in my former communication, exclusively use as unit of M. M. F., F, the "ampere-turn per cm.," since this is the unit directly derived by the tests and, at the same time, the value needed in electrical design, so that by this the factor $\frac{4\pi}{10}$ is avoided. The absolute units H and ρ_0 can easily be derived herefrom by the equations given above, $H = \frac{4\pi}{10} F$, and $\rho_0 = \frac{4\pi}{10} \rho$.

In Table I. this "metallic reluctivity" in thousandths can, over the whole range of magnetization, be expressed with fair approximation by the equation

$$\rho = 3.16\, e^{-.72\, F} + .275 + .058\, F,$$

About at $F = 7$ the first term, $3.16\, e^{-.72\, F}$, vanishes and the reluctivity assumes the simpler form

$$\rho = .275 + .058\, F,$$

given by Kennelly, in his paper already cited.

The "metallic induction" is, then,

$$L = \frac{F}{\rho},$$

and the whole induction

$$B = \frac{F}{\rho} + \frac{4\pi}{10} F;$$

where, in the range used in dynamo building, etc., the last term can usually be neglected, and instead of B using L.

This iron reaches "absolute saturation" at the "metallic induction" $L_{\infty} = 17.24$ kilolines.

TABLE II.

Frequeney, $N = 170$ complete periods per second.

ALTERNATING MAGNETISM.

± *B.*	*H.* obs.	*H.* calc.	*H.* − *H* = obs. calc.	%
2.74	1.17	1.11	−.06	−5
3.59	1.62	1.70	+.08	+5
3.89	1.97	1.94	−.03	−2
5.50	3.41	3.38	−.03	−1
7.52	5.61	5.57	−.04	−1
		Av.	±.05	±3
		Av. dev......	−.02	−1

TABLE III.

Frequency, $N = 110$ complete periods per second.

ALTERNATING MAGNETISM.

± *B.*	*H.* obs.	*H.* calc.	*H.* — *H.* = calc. obs.	%
1.91	.68	.62	—.06	—10
2.54	.93	.98	+.05	+ 5
2.80	1.14	1.15	+.01	+ 1
3.185	1.50	1.41	—.09	— 6
4.12	2.19	2.13	—.06	— 3
4.77	2.56	2.68	+.12	+ 4
5.82	3.75	3.69	—.06	— 2
6.48	4.25	4.39	+.14	+ 3
7.12	4.72	5.10	+.38	+ 7
7.72	5.46	5.80	+.34	+ 6
8.48	6.98	6.75	—.23	— 4
9.74	8.50	8.43	—.07	— 1
11.70	11.65	11.29	—.36	— 3
14.65	16.30	16.19	—.11	— 1
16.64	19.83	19.85	+.02	+ 0
		Av........	±.14	±4
		Av. dev.. ...	+0	—0

TABLE IV.

Frequency, $N = 67$ complete periods per second.

ALTERNATING MAGNETISM.

± *B.*	*H.* obs.	*H.* calc.	*H.* — *H.* = calc. obs.	%
2.50	.93	.95	+.03	+2
7.22	5.40	5.22	—.18	—3
8.18	6.07	6.37	+.30	+5
		Av. ...	±.17	±3
		Av. dev	+.02	+1

In Tables II. III. and IV. are given the tests made with *alternating currents.*

$\pm B =$ maximum value of magnetic induction in kilolines of magnetic force per cm.^{2} The corresponding M. M. F. $\pm F$ can be taken from Table I.

$H_{\text{obs.}} =$ the observed value of the energy consumed by hysteresis during one complete cycle of magnetization, in kilo-ergs or thousands of ergs per cm.^{3} iron.

$H_{\text{calc.}} =$ the value of the energy consumed by hysteresis, calculated by means of the "coefficient of hysteresis" $\eta = .003497$.

$\underset{\text{calc.}}{H} - \underset{\text{obs.}}{H}$ gives the difference between these two values in ergs and in percentages of $\underset{\text{calc.}}{H}$.

The tests cover the range of magnetization from $B = 1910$ up to $B = 16{,}640$, for frequencies of 170, 110 and 67 complete periods per second.

As seen, at these speeds the "coefficient of hysteresis" is *constant*, and therefore the consumption of energy by hysteresis is still independent of the frequency.

As average of these 23 values, as coefficient of hysteresis, is derived the value

$$\eta = .003497,$$
$$\sim .0035 \qquad (^1)$$

TABLE V.

Frequency, $N = 178$ complete periods per second.

PULSATING MAGNETISM.

Constant E. M. F., $V_c = 6$ volts.
Constant M. M. F., $F_c = 22.93$ ampere turns per cm.
Magnetism induced thereby, $B_c = 14.3$ kilolines per cm.²

$\underset{\text{obs.}}{B} = \frac{B_1 - B_2}{2}$	H. obs.	H. calc.	$H - H$. calc.obs	$=\%$	V. Volts effective.	F. Amp. turns effective.	B_1	B_2	$\frac{B_1+B_2}{2}$
2.41	.93	.90	−.03	−3	8.4	30	+15.4	+10.6	13.0
3.12	1.35	1.36	+.01	+1	11.1	34	+15.5	+ 9.2	12.4
4.08	2.07	2.09	+.02	+1	14.6	37	+15.5	+ 7.4	11.4
7.00	5.03	4.96	−.07	−2	25.1	44	+15.6	+ 1.6	8.6
7.70	5.46	5.78	+.32	+6	26.3	47	+15.7	+ .3	8.0
		Av...	±.09	2.6					
		Av.dv	+.05	+.6					

1. In the appendix to the paper of January 19th, 1892, a curve of hysteresis is already given, constructed by means of a part of these tests, giving

$$\eta = .003507,$$
$$\sim .0035.$$

TABLE VI.

Frequency, $N = 115$ complete periods per second.

PULSATING MAGNETISM.

Constant E. M. F., $V_c = 6$ volts and less.
Constant M. M. F., $F_c = 22.2$ to 17.8 ampere turns per cm.
Magnetism induced thereby, $B_c = 14.15$ to 13.70 kilolines per cm.^{2}

$B =$ obs. $\frac{B_1 - B_2}{2}$	H. obs.	H. calc.	$H-H$. calc obs	$=\%$	V. Volts effective.	F. Amp. turns effective.	B_1	B_2	$\frac{B_1+B_2}{2}$
1.63	.50	.48	−.02	−5	3.7	22	+15.0	+11.8	13.4
2.80	1.14	1.15	+ 01	+1	6.5	26	+15.2	+ 9.6	12.4
5.40	3.30	3.28	−.02	−1	12.1	33	+15.3	+ 4.5	9.9
5.75	3.68	3.63	−.05	−1	13.1	38	+15.3	+ 3.7	9.5
11.35	10.55	10.76	+.21	+2	25.8	42	+15.5	− 7.2	4.15
		Av ..	±.06	±2					
		Av.dv	+.03	−1					

TABLE VII.

Frequency, $N = 175$ complete periods per second.

PULSATING MAGNETISM.

Constant E. M. F., $V_c = 6$ volts.
Constant M. M. F., $F = 3.415$ ampere turns per cm.
Magnetism induced thereby, $B_c = 4.6$ kilolines per cm.^{2}

$B =$ obs. $\frac{B_1 - B_2}{2}$	H. obs.	H. calc.	$H-H$. calc.obs	$=\%$	V. Volts effective.	F. Amp. turns effective.	B_1	B_2	$\frac{B_1+B_2}{2}$
1.51	.44	.43	−.01	−2	5.3	5.1	+ 6.1	+3.1	4.6
1.75	.59	.54	−.05	−9	6.0	5.3	+ 6.4	+2.9	4.6
3.31	1.54	1.50	−.04	−3	11.5	6.1	+ 8.1	+1 5	4.8
3.88	1.92	1.93	+.01	+1	13.6	7.1	+ 8.7	+ .9	4.8
5.24	3.18	3.12	−.06	−2	18.4	9.1	+10.3	− .2	5.1
		Av...	±.034	±3.4					
		Av.dv	−.03	−3					

TABLE VIII.

Frequency, $N = 111$ complete periods per second.

PULSATING MAGNETISM.

Constant E. M. F., $V_c = 6$ volts.
Constant M. M. F., $F_c = 3.49$ ampere turns per cm.
Magnetism induced thereby, $B_c = 4.7$ kilolines per cm.^{2}

$B =$ obs. $\frac{B_1 - B_2}{2}$	$H.$ obs.	$H.$ calc.	$H-H.$ calc.obs	$=\%$	$V.$ Volts effective.	$F.$ Amp. turns effective.	B_1	B_2	$\frac{B_1+B_2}{2}$
.92	.193	.193	−0	−0	2.1	3.8	+5.6	+3.8	4.7
1.86	.62	.60	−.02	−3	4.1	5.7	+6.0	+2.8	4.7
1.96	.64	.65	+.01	+2	4.3	5.7	+6.7	+2.7	4.7
2.52	1.00	.97	−.03	−3	5.5	6.7	+7.3	+2.3	4.8
		Av...	±.015	±2					
		Av.dv	−.01	−1					

In tables V., VI., VII. and VIII. are given tests made with pulsating currents at the frequencies 178 and 115, and 175 and 111.

B_1 and B_2 are the two limiting values of magnetic induction between which the cycle was performed.

Since in the alternating current tests $B =$ the amplitude of magnetic fluctuation, here as B is given half the difference between B_1 and B_2, that is, again the amplitude of magnetic variation.

$$B = \frac{B_1 - B_2}{2}.$$

The continuous E. M. F. consisted of three cells of storage battery, giving approximately $V_c = 6$ volts.

The M. M. F. of the continuous part of the current is given as F_c, and amounted to 22.93, 22.2 to 17.8, 3.415 and 3.488 ampere-turns per cm. respectively. The magnetic induction excited by this M. M F., F_c, if no alternating M. M. F. is superposed, is given by B_c, and amounted to 14.30, 14.15 $\sim$ 13.70, 4.60 and 4.70 kilolines of magnetic force per cm.^{2} respectively.

In the second set of tests the E. M. F. of the storage battery fell off somewhat.

V gives the E. M. F. of the *alternator*, which was superposed upon the $V_c = 6$ volts, in volts *effective.*

F gives the M. M. F. of the *alternating* part of the current, in *effective* ampere-turns per cm. (so that the maximum alternating M. M. F. is = $\sqrt{2} \times F$).

B_1 and B_2 give *approximate* values of the two limiting values of magnetization, and $\frac{B_1 + B_2}{2}$ their mean, calculated by means of the observed values $B = \frac{B_1 - B_2}{2}$.

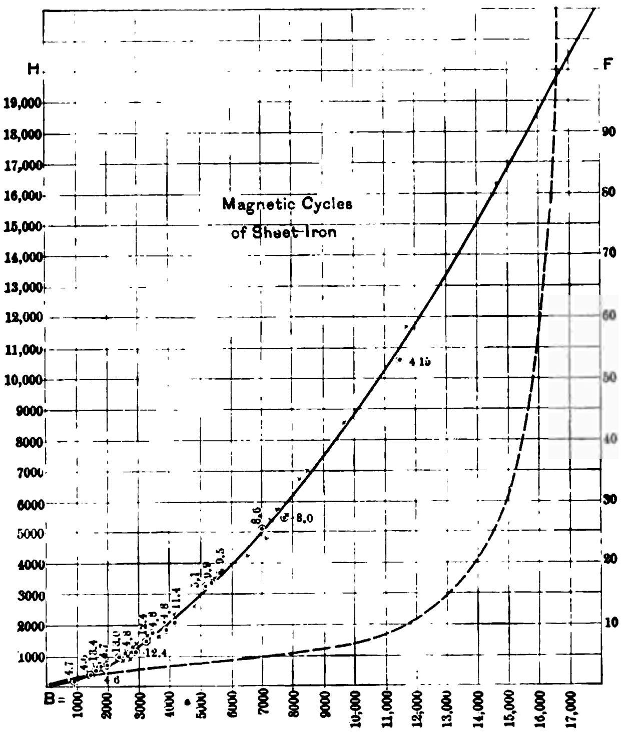


FIG. 2.—Sheet-Iron. Curve of Hysteresis.

$H_{obs.}$ = the observed value of energy consumed by hysteresis during the magnetic pulsation with the amplitude 2 B, that is, between the values B_1 and B_2, in kilo-ergs per cycle and cm.^{3}

$H_{calc.}$ = the energy calculated by the formula

$$H = \eta \, B^{1.6}$$

where $B = \frac{B^1 - B^2}{2}$, and η = .003497 is the coefficient of hysteresis, found by tests with alternating currents.

$H_{calc.} - H_{obs.}$ gives again the difference in ergs and in per cents.

Fig 2 gives the curve of hysteresis, with the values observed by means of alternating currents marked by crosses +, the values observed by pulsating currents marked by circles ⊙. The average value of magnetization, $\frac{B_1 + B_2}{2}$, is written in the figure in kilolines. The dotted curve is the magnetic characteristic.

These tests prove that *the energy dissipated by hysteresis depends only upon the difference of the limiting values of magnetic induction, between which the magnetic cycle is performed, but not upon their absolute values, so that the energy dissipated by hysteresis is the same as long as the amplitude of the magnetic cycle is the same, no matter whether the cycle is performed for instance between the values of magnetization,*

$$\begin{aligned} & B_1 = + \; 4000 \text{ and } B_2 = - \; 4000, \\ \text{or } & B_1 = + \; 6000 \text{ and } B_2 = - \; 2000, \\ \text{or } & B_1 = + \; 8000 \text{ and } B_2 = \; 0, \\ \text{or } & B_1 = + \; 14000 \text{ and } B_2 = + \; 6000. \end{aligned}$$

In either case the hysteretic loss is the same, since the magnetic variation is the same, $B_1 - B_2 = 8000$.

Hence the general form of this empirical law of hysteresis is

$$H = \eta \left(\frac{B_1 - B_2}{2} \right)^{1.6},$$

where B_1 and B_2 are the values between which the magnetism varies, η a constant of the material, in our case $= .0035$.

Including the energy dissipated by eddy-currents, we derive

$$H = \eta \left(\frac{B_1 + B_2}{2} \right)^{1.6} + \varepsilon N \left(\frac{B_1 - B_2}{2} \right)^2,$$

where N is the frequency, ε a coefficient of eddy-currents.

Herewith I conclude the first part, the results of the tests made by means of the electro-dynamometer method with alternating and with pulsating current. A large number of further tests made by the same method proved these results, but cannot be given here, since I have had no time to reduce them to absolute units.

For further tests made with alternating currents by means of the electro-dynamometer method, see Chapter IV.

CHAPTER II.—MAGNETOMETER TESTS.

A large number of tests have been made by means of the Eickemeyer differential magnetometer, of which description and illustration is found in the former paper.

To increase the sensitivity of the instrument and reach down to lower values of magnetization where the directing force of the magnetizing coil is weak enough to allow a perceptible influence of outside magnetism, the terrestrial magnetism was balanced by means of two permanent steel bar magnets of 10″ length and $\frac{3}{4}$″ cross-section.

In the tests, the direct method was used exclusively, and the tested piece balanced against standard iron of known magnetic characteristic, because the method of overbalancing the test piece by an integer number of cm.^{2} of Norway iron and then adding to the test piece as much standard iron as will restore equilibrium, is for low magnetization and test pieces of high coercitive force liable to an error introduced by the fact that the test piece is the seat of an independent M. M. F., that of the remanent magnetism, as will best be understood by comparing it with the differential galvanometer.

In determining the magnetic characteristic, before each test the magnetizing current, and therefore the magnetism, was reversed repeatedly to destroy the remanent magnetism left from former readings, and always *first readings with lower, than with higher magnetization, were taken to make sure that the remanent magnetism of the former test could be destroyed by the reversal of magnetism in the following test.*

The hysteretic curves were taken by varying the magnetizing current cyclic and taking readings at every step. Usually two or three complete cycles were taken, plotted on cross-section paper, and the values of the magnetization from 5 to 5 taken from the plotted curve, or from 10 to 10 ampere turns per cm., and these values added together, which gave the value of H. Before the readings a larger number of cycles were performed to make sure that during the readings the cyclic process had become stationary already.

In some cases a differential method was used, by balancing the test piece against another piece of similar magnetic characteristic, which had been tested before, and was in this way used as an auxiliary standard.

TABLE IX.

MAGNETIC CHARACTERISTIC OF THIN TIN-PLATE.

30 pieces = 2.05 cm.²

$C.$	$s+a$	$F.$	$S.$	$A.$	$M. = Ss+Aa$	$L. = \frac{M.}{2.05}$	$\rho._{obs.} = \frac{F.}{L.}$	$\rho._{calc.} = .192 + .05464\,F.$	$\frac{\rho._{calc} - \rho._{obs.}}{}$	= %	$H.$	$B.$
.45	1+16	8	13.30	540	21.94	10.70	.748	(.629)	.. .. ..	....	.01	10.71
.55	2—2¼	10.5	14.20	595	27.06	13.19	.798	(.766)	.. ....	....	.01	13.20
.80	2—7/16	14	15.10	645	29.92	14.59	.960	.957	—.003	—.3	.02	14.61
1.15	2—1/16	20	16.00	695	31.96	15.58	1.284	1.285	+.001	+.1	.03	15.61
1.40	2+⅛	26	16.47	730	33.02	16.10	1.616	1.613	—.003	—.2	.03	16.13
1.70	2+7/16	34	16.90	758	34.16	16.65	2.04	2.05	+.01	+.5	.04	16.69
2.20	2+½	47	17.30	781	34.98	17.05	2.76	2.76	0	0	.06	17.11
2.90	2+½	62	17.57	802	35.54	17.33	3.58	3.58	0	0	.08	17.41
4.4	2+⅝	85	17.78	818	36.08	17.59	4.84	4.84	0	0	.11	17.70
5.6	2+11/16	97	17.83	821	36.22	17.66	5.49	5.49	0	0	.12	17.78
7.5	2+¾	110	17.89	825	36.40	17.74	6.20	6.20	0	0	.14	17.88
10.5	2+¾	124	17.94	829	36.50	17.79	6.97	6.97	0	0	.16	17.95
18	2+¾	143	18.02	832	36.66	17.87	8.00	8.01	+.01	+.1	.18	18.05
								Av. =	±.0025	= ±.1		

$$F \geq 14. \qquad \rho = .192 + .05464\,F.$$

As an example, I give in Table IX. a set of tests made for determining the magnetic characteristic of a sample of thin tin-plate, of which 30 pieces were used, of 2.55 cm. width and .0268 cm. thickness, giving 2.05 cm.² cross-section.

C = current in the magnetizing coil of the magnetometer.

$s + a$ = number of cm.² Norway iron (s) and of pieces of soft sheet-iron (a), of $\frac{1}{20}$ cm.² cross-section, necessary to balance the test piece.

F = M. M. F. in ampere turns per cm., corresponding to current C and reluctance $s + a$, taken from the characteristic curves of the instrument.

S and A are the number of lines of magnetic force which a cm.² Norway iron (s) or $\frac{1}{20}$ cm.² sheet-iron (a) carry respectively at the M. M. F., F.

$M = s\,S + a\,A$ is consequently the number of lines of magnetic force carried by $s + a$ and therefore by the test piece. Hence

$L = \frac{M}{2.05} = \frac{s\,S + a\,A}{2.05}$ is the (metallic) magnetic induction in the test piece.

$\rho_{obs.} = \frac{F}{L}$ is the metallic reluctivity of the test piece which, for

$$F \geqq 14,$$

can be expressed by the equation, derived from these tests,

$$\rho = .192 + .05464\ F.$$

$\rho_{calc.}$ is the value of metallic reluctivity calculated from this equation, and

$\rho_{calc.} - \rho_{obs.}$ the difference in absolute values and in percentage of $\rho_{calc.}$

$H = \frac{4\pi}{10} F$ is the field intensity, corresponding to M. M. F., F, and thus

$$B = L + H,$$

the whole magnetic induction in the test piece.

It must be understood that the differential magnetometer measures *not* the whole induction B, but the *metallic induction*

$$L = B - H = 4\pi x H.$$

In all the following tests, NOT *the whole induction* B, *but the metallic induction* L *is given. To determine, therefore, the whole induction* B, *the field intensity* $H = \frac{4\pi F}{10}$ *has to be added.*

For the value of hysteresis, the addition of H makes no difference, since space has no hysteresis.

Where the dimensions of the test piece are not given, they are cylindrical pieces of 4 cm.² cross-section and 20 cm. length, fitting into the pole-blocks of the magnetometer.

TESTS.

I. Cast-Iron.

1. *Ordinary Cast-Iron.*

Table X. gives the magnetic characteristic in the first column.

TABLE X.

MAGNETIC CHARACTERISTICS OF GRAY CAST-IRON.

	No. 1.		No. 4.		No 7. $\frac{1}{8}$% Al.		No. 8. $\frac{1}{4}$% Al.	
F.	ρ.	*L.*	. ρ.	*L.*	ρ.	*L.*	ρ.	*L.*
7.5	6.20	1.21	3.98	1.92	6.80	1.10	8.20	.92
10	5.00	2.00	3.70	2.70	5.45	1.84	6.55	1.53
12.5	4.20	2.98	3.58	3.49	4.50	2.78	5.40	2.31
15	3.94	3.81	3.59	4.17	4.13	3.63	4.80	3.12
17.5	4.05	4.33	3.72	4.73	4.16	4.21	4.70	3.73
20	$\rho = 2.40 + .0940\ F.$	4.68	$\rho = 2.05 + .09725\ F.$	5.00	$\rho = 2.37 + .0976\ F.$	4.63	$\rho = 2.92 + .0948\ F.$	4.15
30		5.74		6.04		5.67		5.20
40		6.50		6.72		6.37		5.96
50		7.05		7.23		6.90		6.52
60		7.46		7.60		7.30		6.97
80		8.06		8.13		7.87		7.61
100		8.47		8.50		8.25		8.07
150		9.10		9.00		8.81		8.74
[200		9.42		9.31		9.14		9.14
300		9.81		9.60		9.48		9.57
400		10.00		9.77		9.66		9.80
500		10.12		9.89		9.78		9.93]
Absolute saturation		10.66	....	10.28	....	10.25	....	10.55

F = M. M. F. in ampere turns per cm.
L = metallic induction in thousands of lines of force per cm.²
ρ = metallic reluctivity $\frac{F}{L}$ in thousandths (10^{-3}).

The values inclosed in brackets are extrapolated by means of the law

$$\rho = a + \sigma F \quad \text{[Kennelly, paper before cited].}$$

Tables XI. and XII. give 11 magnetic cycles of this cast-iron and Table XIII. the results of these cycles.

TABLE XI.

HYSTERESIS OF ORDINARY GRAY CAST-IRON, No. 1.

F.	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r	(4) L_d	(4) L_r	(5) L_d	(5) L_r
+44			± 6.68		+ 6.70		+ 6.70		+ 6.70	
40			6.58	6.44	6.60	6.52	6.60	6.54	6.60	6.56
35			6 42	6.10	6.46	6.22	6.46	6.25	6.46	6.32
30			6 20	5.70	6.28	5.91	6.28	5.93	6.28	6.03
25			5.93	5.10	6.01	5 45	6.01	5.51	6.01	5.66
20			5.60	4.35	5.70	5.00	5.70	5.26	5.70	5.50
15	± 3.40		5.17	3.00	5.30	4.35	5.30	5.13	+ 5.33	
10	2.92	1.60	4.58	.70	4.80	3.40	+ 4.66		[F_2 = + 16.]	
+ 5	2.35	— .55	3.80	— 1.40	4.20	1.00	[F_2 = + 11.]			
0	± 1.60		± 2.80		3.10	0				
— 5					1.60	— .25				
— 9					— .32					
H =	5.82		17.08		6.13		.86		.48	
L =	3.40		6.68		3.51		1.02		.685	
η =	.01302		.01297		.01303		.01320		.01393	

TABLE XII.

HYSTERESIS OF ORDINARY GRAY CAST-IRON, No. 1.

F.	(6) L_d	(6) L_r	(7) L_d	(7) L_r	(8) L_d	(8) L_r	(9) L_d	(9) L_r	(10) L_d	(10) L_r	(11) L_d	(11) L_r
140					± 9.01		+ 9 06		+ 9.06		+ 9.06	
130					8.92	8.88	8.97	8.94	8.97	8.96	8.97	8.96
120					8.81	8.72	8.86	8.79	8.86	8.84	8.86	8.84
110			± 8.71		8.70	8.56	8.75	8.65	8.75	8.72	8.75	8.72
100			8.54	8.50	8.59	8.39	8.64	8.50	8.64	8.57	8.64	8.60
90			8.37	8.28	8.50	8.24	8.55	8.35	8.55	8.44	8.56	8.49
80	[*F* = ± 74.]		8.20	8.05	8.34	8.04	8.39	8.11	8.39	8.23	8.42	8.30
70	± 7.92		8.05	7.76	8.16	7.74	8.21	7.83	8.21	8.01	8.26	8.11
60	7.62	7.44	7.80	7.40	7.96	7.36	8.01	7.51	8.02	7.78	8.08	7.92
50	7.38	6.93	7.55	6.90	7.68	6.80	7.73	7.08	7.74	7.48	7.80	7.70
40	7.06	6.37	7.20	6.35	7.34	6.36	7.39	6.61	7.41	7.16	+ 7.26	
30	6.60	5.68	6.75	5.65	6.86	5.70	6.96	6.01	7.00	6.84	[F_2 = + 40.]	
20	5.95	4.32	6.10	4.25	6.16	4.51	6.31	5.21	+ 6.09			
10	4.90	.60	5.00	.40	4.95	1.20	5.17	3.50	[F_2 = + 17.]			
0	± 3.03		± 3.15		± 3.30		3.40	.80				
— 9							0					
H =	22.46		26.34		27.54		9.19		1.53		.72	
L =	7.92		8.71		9.01		4.53		1.485		.90	
η =	.01298		.01308		.01295		.01299		.01288		.01350	

TABLE XIII.

HYSTERESIS OF ORDINARY GRAY CAST-IRON, No. 1—RESULTS.

No.		F_1	F_2	$F = \frac{F_1 - F_2}{2}$	L_1	L_2	$L = \frac{L_1 - L_2}{2}$	H	η	$10^5 \times \triangle\eta$	$= \%$
(1)	α	+15	−15	15	+3.40	−3.40	3.40	5.82	.01302	−2	−.2
(2)	α	+44	−44	44	+6.68	−6.68	6.68	17.08	.01297	+3	+.2
(3)	β	+44	−9	26.5	+6.70	−.32	3.51	6.13	.01303	−3	−.2†
(4)	β	+44	+11	16.5	+6.70	+4.66	1.02	.86	.01320	−20	−1.5†
(5)	β	+44	+16	14	+6.70	+5.33	.685	.48	.01393	−93	−7.1†
(6)	α	+74	−74	74	+7.92	−7.92	7.92	22.46	.01298	+2	+.1
(7)	α	+110	−110	110	+8.71	−8.71	8.71	26.34	.01308	−8	−.6
(8)	α	+140	−140	140	+9.01	−9.01	9.01	27.54	.01295	+5	+.4
(9)	β	+140	−9	74.5	+9.06	0	4.53	9.19	.01299	+1	+.1†
(10)	β	+140	+17	61.5	+9.06	+6.09	1.485	1.53	.01288	+12	+.9†
(11)	β	+140	+40	50	+9.06	+7.26	.90	.72	.01350	−50	−3.8†
								Av.	.01300		

Here are

F_1 and F_2, the maximum and the minimum value of M. M. F. in ampere turns per cm.

L_1 and L_2, the maximum and the minimum value of magnetic induction in kilolines of magnetic force per cm.[2]

$F = \frac{F_1 - F_2}{2}$, the amplitude of variation of M. M. F.

$L = \frac{L_1 - L_2}{2}$, the amplitude of variation of magnetic induction.

H, the observed value of hysteretic dissipation of energy in kilo-ergs per cycle and cm.[3]

η, the coefficient of hysteresis calculated therefrom.

$\triangle$, the difference between this observed value of η and the average of η taken from the five largest cycles (since in small cycles the exactness is necessarily considerably smaller, the result being based upon a lesser number of readings, I deemed it advisable to use only the largest cycles for the calculation of the mean value of η).

The conclusion derived from these tests is the same as that derived from the electro-dynamometer tests, namely, that the loss of energy by hysteresis can be expressed by the equation

$$H = \eta \left(\frac{L_1 - L_2}{2} \right)^{1.6}.$$

Hence the magnetic properties of this cast-iron can be expressed by means of the equations

$$\rho = \alpha + \sigma F,$$
$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6},$$

by three constants,

α, the "*coefficient of magnetic hardness,*"
σ, the "*coefficient of magnetic saturation,*"
η, the "*coefficient of magnetic hysteresis.*"

Only for values of $F \leqq 20$ the value of ρ, if determined by *reversals* of magnetism, is larger and may necessitate the introduction of a term, $c\ e^{-\delta F}$, or of similar shape.

The term α I call the "coefficient of magnetic hardness," since the value of α determines what is called "magnetically hard." I shall still show in the following that α is smallest in soft Norway iron, increases by hardening and reaches very large values in glass-hard steel.

The term σ I call the "coefficient of magnetic saturation," because $L_\infty = \frac{1}{\sigma}$ is the value of absolute saturation of the metallic induction, that is, the value which the metallic induction reaches for infinitely large M. M. F's that is, for values larger than $F = 1000$ to 20,000 (according to the value of magnetic hardness α).

2. *Cast-Iron with ⅛ %, viz., ½ % Aluminium.*[1]

(Here the tests were made by comparing the two test pieces with the cast-iron given in 1.)

Table X. gives the magnetic characteristic in the third column; Table XIV. gives two magnetic cycles of the sample containing ⅛ per cent. aluminium.

Table X. gives the magnetic characteristic in the fourth column; Table XV. gives two magnetic cycles of the sample containing ½ per cent. aluminium.

1. Derived from Cornell University; a sample containing no aluminium could not be tested, because it was too hard to be turned off to standard size.

TABLE XIV.

HYSTERESIS OF CAST-IRON CONTAINING $\frac{1}{8}$ % ALUMINIUM.

F	(1) L_d	L_r	F	(2) L_d	L_r
44	± 6.49		110	± 8.48	
40	6.40	6.26	100	8.32	8.27
35	6.25	5.93	90	8.16	8.06
30	6.03	5.54	80	8.00	7.84
25	5.78	4.95	70	7.86	7.56
20	5.46	4.18	60	7.63	7.22
15	5.04	2.80	50	7.40	6.76
10	4.48	.55	40	7.08	6.23
5	3.68	− 1.50	30	6.65	5.51
0	± 2.67		20	6.01	4.04
			10	4.91	.18
			0	± 2.90	
H =	17.07			26.50	
L =	6.49			8.48	
η =	.01358			.01373	

Av. $\eta = .01365$.

TABLE XV.

HYSTERESIS OF CAST-IRON CONTAINING $\frac{1}{2}$ % ALUMINIUM.

F	(1) L_d	L_r	F	(2) L_d	L_r
44	± 6.15		110	± 8.33	
40	6.05	5.90	100	8.16	8.11
35	5.89	5.55	90	7.98	7.88
30	5.67	5.14	80	7.80	7.64
25	5.41	4.53	70	7.65	7.34
20	5.09	3.77	60	7.39	6.97
15	4.68	2.43	50	7.13	6.44
10	4.14	.28	40	6.78	5.84
5	3.45	− 1.52	30	6.32	5.07
0	± 2.60		20	5.67	3.59
			10	4.61	− .03
			0	± 3.00	
H =	16.89			27.28	
L =	6.15			8.33	
η =	.01463			.01455	

Av. $\eta = .01459$.

The denotations are the same as in the former set of tests (1).

3. *Different Samples of Cast-Iron.*

In like manner, five other samples of common cast-iron, obtained from different foundries, were tested. They are marked with 2, 3, 4, 5, 6, while the two samples of aluminium cast-iron were marked with 7 and 8. Only one cycle of each of these five samples was taken and the magnetic characteristic determined.

Of sample No. 4 the magnetic characteristic is given in the second column of Table X. Of the four other samples, Nos. 2, 3, 5 and 6, the magnetic reluctivity ρ is given in Table XVI.

TABLE XVI.

MAGNETIC RELUCTIVITY OF GRAY CAST-IRON.

F	No. 2. ρ	No. 3. ρ	No. 5. ρ	No. 6. ρ
7.5			5.50	4.95
10.	5.15	5.40	4.60	4.10
12.5	4.35	4.65	4.10	3.68
15.	4.08	4.32	4.00	3.57
17.5	4.12	4.44	4.04	3.76
20.				
	$\rho = 2.76 + .0954\ F$	$\rho = 2.43 + .0943\ F$	$\rho = 2.34 + .0950\ F$	$\rho = 2.07 + .0972\ F$

The results of the cyclic tests of all the eight cast-iron samples are combined in Table XVII.

TABLE XVII.

MAGNETIC HYSTERESIS OF CAST-IRON—RESULTS.

	$\pm F$	$\pm L$	H	η
No. 1........ ...	Graded Cycles			.01300
No. 2	58	7.35	20.22	.01317
No. 3............	58	7.00	22.39	.01577
No. 4....	110	8.63	22.47	.01132
No. 5	110	8.60	25.01	.01267
No. 6............	110	8.62	24.17	.01222
No. 7, ⅛ per c. Al.	44	6.49	17.07	.01365
" "	110	8.48	26.50	
No. 8, ½ per c. Al.	44	6.15	16.89	.01459
" "	110	8.33	27.28	

These tests prove conclusively that beyond a certain minimum value of M. M. F., $F = 18$ to 20 ampere turns per cm., the metallic magnetic reluctivity ρ (inverse value of $\frac{16\ \pi^2}{10} x$, where x is the magnetic susceptibility) rigidly follows a straight line, $\rho = a + \sigma F$, showing that the metallic induction, $L = B - H$, approaches, for infinitely high M. M. F's., as limit of absolute magnetic saturation,

$$L_\infty = \frac{1}{\sigma} .$$

Hence, beyond a minimum value of M. M. F., all the magnetic properties of cast-iron can be expressed by three constants, the

Coefficient of magnetic hardness, a;
Coefficient of magnetic saturation, σ;
Coefficient of magnetic hysteresis, η.

These three coefficients are given for the eight tested samples of cast-iron in Table XVIII., together with the absolute saturation $L_\infty = \frac{1}{\sigma}$ and the minimum value F, where ρ coincides with the straight line.

TABLE XVIII.

MAGNETIC CONSTANTS OF CAST-IRON.

	$F \geq$	Coefficient of Magnetic Hardness a	Coefficient of Magnetic Saturation σ	Coefficient of Magnetic Hysteresis η	Absolute Saturation $L_\infty = \frac{1}{\sigma}$
No. 1............	20	2.40	.0940	.01300	10.66
No. 2............	20	2.43	.0943	.01317	10.60
No. 3.....	20	2.76	.0954	.01577	10.48
No. 4......	18	2.05	.09725	.01132	10.28
No. 5............	18	2.34	.0950	.01267	10.55
No. 6	18	2.07	.0972	.01220	10.29
No. 7, ⅛ per ct. Al.	20	2.37	.0976	.01365	10.25
No. 8, ½ per ct. Al.	20	2.92	.0948	.01459	10.55
Average.......		2.4	.096	.013	10.50

Furthermore, these tests prove that for cast-iron the dissipation of energy during a complete magnetic cycle between the limits L_1 and L_2 is expressed by the equation

$$H = \eta \left(\frac{L_1 - L_2}{2} \right)^{1.6}.$$

The cycles 1, 2. 6 and 7 of Table XI., made between opposite and equal limits of M. M. F. on cast-iron No. 1., are shown in Fig. 3.

Fig. 4 gives the cycles 2, 3, 4 and 5 of Table XI., referring also to cast-iron No. 1.

The results of all the 11 magnetic cycles of cast-iron No. 1 are shown in Fig. 5. The drawn line is the curve of hysteresis, $H = .013 \left(\frac{L_1 - L_2}{2}\right)^{1.6}$.

The observed values are marked by crosses +, when taken between opposite and equal limits, $L_1 = - L_2$; by circles ⊙, when taken between unequal limits of M. M. F. In the latter case the average magnetization, $\frac{L_1 + L_2}{2}$, is written in Fig. 5. The dotted line represents the magnetic characteristic.

Further cast-iron characteristics are shown in Fig. 17.

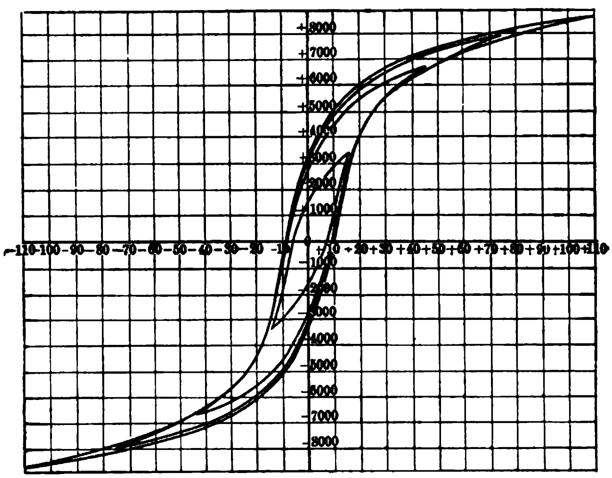


FIG. 8.—Cast-Iron. Hysteretic Cycles.

II. Tool Steel of Different Degrees of Hardness.

To determine the influence of hardening upon the magnetic constants, three pieces were cut from the same rod of tool steel, turned off cylindrical to 15 cm. length and 1 cm.^{2} cross-section, and then the one piece was annealed, the second piece was heated and hardened in oil, the third piece hardened in cold water and thereby made glass-hard. To reach higher M. M. F. than possible with test pieces of 4 cm.^{2} cross-section and the instrument at my disposition, the pole-faces of the magnetometer were brought closer together, to 6.35 cm. distance, and only 1 cm.^{2} of test piece used, whereby M. M. F.'s. up to $F = 350$ ampere turns, that is, field intensities up to $H > 400$, were available.

The test pieces were laid in holes in the pole-faces of the magnetometer, of 1 cm.² cross-section, and after a *preliminary* determination of their magnetic characteristic, a number of magnetic cycles were completed with each of them between different limiting values of *F*.

Then all the three samples were found permanently and strongly magnetized. Hence, I demagnetized them by means of a powerful alternating current in the following manner:—A wire spool was slipped over each piece, and solid Norway iron blocks laid against its ends to concentrate the alternating magnetism through the whole length of the piece and to afford low transient reluctance from piece to air. Then, with a frequency of about 170

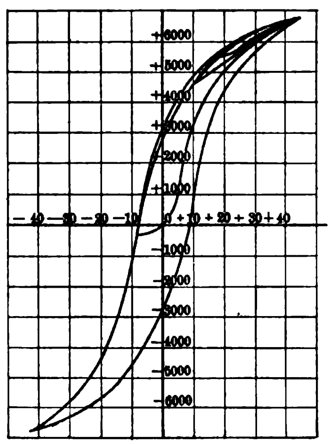


FIG. 4.—Cast-Iron. Hysteretic Cycles.

complete periods per second, an alternating current was sent through the wire spool, representing about 5000 to 6000 ampere-turns. The test piece got rather hot after some minutes' application of the alternating current, but, nevertheless, in the glass-hard piece the permanent magnetism was not fully destroyed even yet by this alternating magnetic strain, but the cycles taken with it were afterwards found unsymmetrical.[1]

1. This sample of glass-hard steel was the only one which I was not able to demagnetize by a rapidly alternating M. M. F. Otherwise an alternating M. M. F. of 3000 to 4000 ampere-turns I found always able to destroy remanent and permanent magnetism within a few minutes so completely that not the least trace could be discovered.

Nevertheless, the magnetic constants of all the three pieces were found considerably changed in the way a partial annealing would do it.

Then the magnetic characteristic of each piece was determined by the method of reversals, that is, by reversing the magnetism repeatedly before each reading, since this seems to be the only method which gives *constant* and therefore *reliable* results, while the determination of the curve of rising magnetism becomes, especially for small M. M. F.'s., unreliable because of not giving always the same value for the same M. M. F.; and then again a number of cycles completed with either of the pieces.

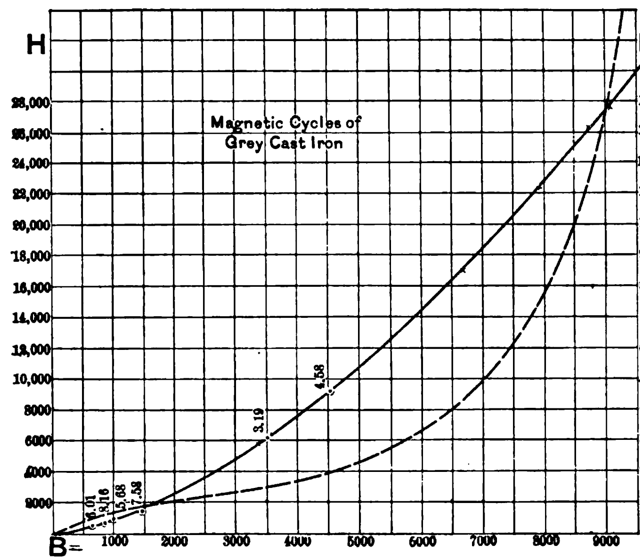


FIG. 5.—Cast-Iron. Curve of Hysteresis.

The three pieces are marked with *H*—glass-hard,
O—oil-hardened,
S—annealed,

and the values derived before the application of the alternating current marked with an *h*: *Hh*, *Oh*, *Sh*.

Unfortunately, before the application of the alternating current the magnetic characteristics had been determined only preliminarily, so that the values given therefor can be considered only as approximations, but sufficiently near to allow perceiving the influence fo the application of the alternating current.

Table XIX. gives the magnetic characteristics of the three samples in their two states.

TABLE XIX.

MAGNETIC CHARACTERISTICS OF TOOL-STEEL.

	Hh		*H*		*Oh*		*O*		*Sh*		*S*	
F	ρ	*L*	ρ	*L*	ρ	*L*	ρ	*L*	ρ	*L*	ρ	*L*
20							9.0	2.22			3.0	6.67
30			27.0	1.11	5.8	5.18	4.9	6.12	3.8	7.90	3.2	9.37
40			23.0	1.74	5.4	7.40	4.7	8.50	4.0	10.00	3.6	11.10
50	23.0	2.17	20.0	2.50	5.6	8.94	5.0	10.00	4.45	11.24	$\rho = 1.22 + .0575\ F$	12.20
60	21.0	2.86	18.0	3.33	6.05	9.92	5.3	11.34	5.0	12.00		12.87
70	19.5	3.58	17.3	4.04	6.6	10.60	$\rho = 1.54 + .060\ F$	12.20	$\rho = 1.33 + .060\ F$	12.68		13.34
80	18.5	4.25	17.2	4.65	$\rho = 1.9 + .066\ F$	11 10		12.60		13.05		13.75
90	19.0	4.74	17.5	5.15		11.54		13.00		13.37		14.08
100	$\rho = 8.0 + .121\ F$	5.00	$\rho = 7.8 + .105\ F$	5.47		11.76		13.25		13.67		14.37
150		5.75		6.40		12.70		14.25		14.50		15;16
200		6.22		6.95		13.25		14.78		15.04		15.75
250		6.54		7.35		13.60		15.13		15.33		16.05
300		6.78		7.64		13.80		15.40		15.55		16.25
[400		7.08		8.02		14.15		15.68		15.80		16.52]
[500		7.30		8.30		14.34		15.90		16.00		16.72]
Absolute saturation ...		8.28		9.53		15.16		16.70		16.70		17.40

F = M. M. F. in ampere-turns per cm.

L = metallic induction in thousands of lines of magnetic force per cm.^{2}

ρ = metallic reluctivity $= \frac{F}{L}$ in thousandths.

The samples are denoted by *Hh*, *H*, *Oh*, *O*, *Sh*, *S*.

The tables XX. to XXVII. give magnetic cycles performed with the pieces, and Table XXVIII. the results of these cycles.

TABLE XX.

HYSTERESIS OF TOOL-STEEL Hh.

F	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r	(4) L_d	(4) L_r
+275	± 5.93		+ 5.94		+ 5.95		+ 5.97	
260	5.92	5.91	5.93	5.92	5.94	5.93	5.96	5.95
240	5.91	5.83	5.92	5.85	5.93	5.86	5.95	5.93
220	5.90	5.78	5.91	5.80	5.92	5.80	5.94	5.91
200	5.89	5.70	5.90	5.72	5.91	5.74	5.93	5.88
180	5.88	5.60	5.89	5.64	5.90	5.68	5.92	5.85
160	5.87	5.45	5 88	5.52	5.88	5.58	5.90	5.80
140	5.82	5.28	5.84	5.40	5.84	5.46	5.87	5.74
120	5.73	5.10	5.79	5.21	5.78	5.29	5.82	5.68
100	5.61	4.70	5.70	4.98	5.68	5.09	5.75	5.60
80	5.43	4.10	5.57	4.47	5.55	4.75	5.60	5.43
60	5.20	2.90	5.28	3.53	5.33	4.22	5.38	5.18
40	4.80	.40	4.90	1.75	4.97	3.35	5.00	4.82
+ 20	4.10	−1.90	4.36	− .70	4.47	2.15	+ 4.66	
0	± 3.30		3.60	−1.86	3.80	1.00	[F_2 = + 30]	
− 20			2.37	−2.63	2.50	.45		
− 40			.30	−3.12	.40	.07		
− 60			−1.75	−3.51	0			
− 83			− 3.76		[F_2 = − 45]			
H =	82.04		59.04		26.52		2.42	
L =	5.93		4.85		2.975		.655	
η =	.07533		.07480		.07342		.07546	

TABLE XXI.

HYSTERESIS OF TOOL-STEEL Hh.

F	(5) L_d	(5) L_r	(6) L_d	(6) L_r	(7) L_d	(7) L_r
+124	± 5.12		+ 5.13		+ 5.17	
110	5.09	4.90	5.12	4.95	5.13	5.04
100	5.06	4.64	5.10	4.77	5.11	4.92
90	5.00	4.35	5.06	4.56	5.07	4.80
80	4.90	4.00	5.00	4.30	5.01	4.68
70	4.79	3.40	4.90	4.05	4.91	4.56
60	4.65	2.60	4.75	3.75	4.76	4.44
50	4.50	1.60	4.60	3.33	4.61	4.32
40	4.30	.40	4.43	2.90	4.44	4.16
30	4.05	−1.00	4.22	2.33	4.23	4.03
20	3.80	−1.90	4.00	1.73	+ 3.88	
+10	3.45	−2.55	3.75	1.20	[F_2 = + 15.]	
0	± 3.10		3.40	.75		
−10			3.00	.45		
−20			2.30	.25		
−30			1.20	.10		
−41			0			
H =	64.50		21.46		2.36	
L =	5.12		2.565		.645	
η =	.07493		.07533		.07560	

TABLE XXII.

HYSTERESIS OF TOOL-STEEL *H*.

	(1)		(2)		(3)		(4)		(5)		(6)	
F	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r
+120	+ 6.25		+6.25		+6.25				+6.25			
110	6.15	6.00	6.16	6.00	6.23	6.13			6.23	6.13		
100	6.03	5.65	6.04	5.73	6.18	6.00			6.18	6.00		
90	5.90	5.15	5.90	5.42	6.11	5.86			6.11	5.87		
80	5.72	4.50	5.75	5.08	6.02	5.71			6.02	5.72		
70	5.53	3.50	5.58	4.70	5.89	5.57			5.89	5.59		
60	5.32	2.50	5.42	4.30	5.73	5.42			5.61	5.45		
50	5.06	1.24	5.22	3.80	5.56	5.27			+5.25			
40	4.80	0	5.00	3.20	5.30	5.11			[F_2 = + 47.]			
30	4.50	−1.15	4.75	2.50	+4.95							
20	4.15	−1.95	4.45	1.80	[F_2 = + 28.]							
+ 10	3.72	−2.60	4.12	1.25								
0	3.30	−3.05	3.70	.77								
− 10	2.62	−3.50	3.20	.42								
− 20	1.84	−3.85	2.55	.20			[F_1 = − 28]					
− 30	.75	−4.16	1.55	.03			−4.57					
− 40	− .55	−4.43	.50	− .08			5.01	4.68			[F_1=−47.]	
− 50	−1.75	−4.68	−.12				5.22	4.84			−4.93	
− 60	−2.90	−4.90	[F_2 = − 47]				5.37	5.00			5.32	5.08
− 70	−3.84	−5.10					5.50	5.19			5.52	5.23
− 80	−4.60	−5.29					5.60	5.36			5.63	5.38
− 90	−5.08	−5.45					5.70	5.52			5.73	5.53
−100	−5.40	−5.60					5.80	5.67			5.82	5.67
−110	−5.64	−5.72					5.86	5.80			5.87	5.82
−120	−5.80						−5.90				−5.90	
H =	68.52		24.68		1.96		2.03		1.29		1.21	
L =	6.025		3.185		.65		.665		.50		.485	
η =	.06136		.06124		.06188		.06178		.06197		.06103	

TABLE XXIII.

HYSTERESIS OF TOOL-STEEL *Oh*.

	(1)		(2)		(3)	
F	L_d	L_r	L_d	L_r	L_d	L_r
+260	± 13.25		+ 13.25		+ 13.25	
240	13.22	13.19	13.22	13.19	13.22	13.21
220	13.19	13,10	13.19	13.10	13.19	13.17
200	13.15	13.00	13.15	13.01	13.15	13.12
180	13.10	12.88	13.10	12.90	13.10	13.06
160	13.05	12.77	13.05	12.80	13.05	12.99
140	12.99	12.66	13.00	12.70	13.00	12.92
120	12.85	12.40	12.87	12.46	12.88	12.76
100	12.66	12.03	12.68	12.12	12.69	12.50
80	12.42	11.50	12.45	11.62	12.47	12.15
60	11.95	10.30	12.00	10.50	12.02	11.65
40	11.00	7.00	11.20	8.60	11.22	11.04
+ 20	9.40	− 1.70	9.80	4.60	+ 10.60	
0	± 6.70		7.20	− .30	[F_2 = + 30.]	
− 20			1.80	− 1.90		
− 30			+ 2 24			
H =	106.20		44.78		2.75	
L =	13.25		7.745		1.325	
η =	.02695		.02683		.02778	

TABLE XXIV.

HYSTERESIS OF TOOL-STEEL *Oh*.

F	(4) L_d	(4) L_r	(5) L_d	(5) L_r	(6) L_d	(6) L_r
+80	± 11.30		+11.30		+11.30	
70	11.10	10.70	11.10	10.75	11.10	10.82
60	10.85	9.85	10.85	10.10	10.90	10.50
50	10.55	8.75	10.55	9.30	10.68	10.22
40	10.10	6.60	10.10	8.20	10.26	9.95
30	9.50	2.70	9.55	6.70	9.48	
20	8.60	− 1.20	8.70	4.30	[F_2 = +27]	
+10	7.50	− 4.30	7.60	2.00		
0	± 6.00		6.20	.60		
−10			4.30	− .20		
−20			1.60	− .60		
−26			−.70			
H =	82.20		28.96		1.48	
L =	11.30		6.00		.91	
η =	.02692		.02611		.02727	

TABLE XXV.

HYSTERESIS OF TOOL-STEEL *O*.

F	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r
112	±13.65		+13.65		+13.64	
100	13.54	13.32	13.54	13.35	13.54	13.40
90	13.40	12.88	13.40	13.05	13.40	13.16
80	13.22	12.32	13.22	12.74	13.22	12.93
70	13.00	11.72	13.00	12.42	13.00	12.71
60	12.70	10.90	12.70	12.08	12.70	12.46
50	12.30	9.50	12.30	11.70	12.30	12.16
40	11.75	7.00	11.75	11.28	+11.95	
30	11.00	2.50	11.09	10.80	[F_2 = + 43]	
20	10.10	− 2.90	+10.48			
10	9.00	− 5.55	[F_2 = + 24]			
0	±7.50					
H =	111.64		3.52		1.32	
L =	13.65		1.585		.85	
η =	.02700		.02669		.02713	

TABLE XXVI.

HYSTERESIS OF TOOL-STEEL *Sh.*

F	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r
+240	±16.60		+16.60		+16.60	
220	16.58	16.52	16.58	16.53	16.58	16.57
200	16.52	16.40	16.52	16.42	16.52	16.50
180	16.45	16.27	16.45	16.30	16.45	16.41
160	16.38	16.10	16.38	16.13	16.38	16.32
140	16.28	15.90	16.28	15.95	16.28	16.20
120	16.17	15.60	16.17	15.68	16.17	16.06
100	15.95	15.20	15.95	15.30	15.95	15.78
80	15.66	14.70	15.66	14.90	15.68	15.35
60	15.20	13.30	15.20	13.60	15.25	14.80
40	14.20	9.60	14.25	10.80	14.35	14.00
20	12.00	2.00	12.40	4.50	+13.00	
0	±7.20		8.20	−3.20	[$F_2 = +26$]	
−20			1.50	−7.50		
−26			−8.00			
$H =$	108.00		66.00		3.16	
$L =$	16.60		12.30		1.80	
$\eta =$	.01911		.01887		.01955	

TABLE XXVII.

HYSTERESIS OF TOOL-STEEL *S.*

F	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r	(4) L_d	(4) L_r
112	±14.55		+14.55		+14.55		+14.55	
100	14.45	14.31	14.45	14.32	14.48	14.42	14.51	14.49
90	14.35	14.09	14.35	14.10	14.40	14.28	14.43	14.38
80	14.25	13.74	14.25	13.76	14.29	14.12	14.34	14.25
70	14.09	13.28	14.09	13.31	14.12	13.88	14.20	14.07
60	13.87	12.74	13.87	12.77	13.83	13.58	13.97	13.85
50	13.57	11.94	13.57	11.99	13.46	13.20	13.63	13.55
40	13.08	10.70	13.08	10.89	13.02	12.78	+13.28	
30	12.32	8.60	12.35	9.55	12.41	12.30	[$F_2 = +43$]	
20	11.10	5.06	11.30	7.20	+11.90			
10	9.55	−.80	9.90	3.60	[$F_2 = +24$]			
0	±6.40		7.70	−.90				
−10			4.60	−3.80				
−20			−1.70	−6.20				
−30			−7.20					
$H =$	66.74		41.22		1.43		.48	
$L =$	14.55		10.875		1.325		.635	
$\eta =$	.01457		.01434		.01444		.01434	

TABLE XXVIII.

HYSTERESIS OF TOOL-STEEL—RESULTS.

No.		F_1	F_2	$F = \frac{F_1 - F_2}{2}$	L_1	L_2	$L = \frac{L_1 - L_2}{2}$	H	η obs.	$10^5 \Delta\eta$	= %
Hh, Glass-hard. . . . . Av. η = .07476 ∼.075											
(1)	*a*	+275	−275	275	+ 5.93	− 5.93	5.93	82.04	.07533	− 57	− .8
(2)	*p*	+275	− 83	179	+ 5.94	− 3.76	4.85	59.04	.07480	− 4	− .1
(3)	*p*	+275	− 45	160	+ 5.95	= 0	2.975	26.52	.07342	+134	+1.8
(4)	*p*	+275	+ 30	122.5	+ 5.97	+ 4.66	.655	2.42	.07546	− 70	− .9+
(5)	*a*	+124	−124	124	+ 5.12	− 5.12	5.12	64.50	.07493	− 17	− .2
(6)	*p*	+124	− 41	82.5	+ 5.13	= 0	2.565	21.46	.07533	− 57	− .8
(7)	*p*	+124	+ 15	54.5	+ 5.17	+ 3.88	.645	2.36	.07560	+ 16	+ .2+
H, Glass-hard, {after application of alternate current.} Av. η = .06130 ∼.061											
(1)	*a*	+120	−120	120	+ 6.25	− 5.80	6.025	68.52	.06136	− 6	− .1
(2)	*p*	+120	− 47	83.5	+ 6.25	− .12	3.185	24.98	.06124	+ 6	+ .1
(3)	*p*	+120	+ 28	46	+ 6.25	+ 4.95	.65	1.96	.06188	− 58	− .9+
(4)	*p*	− 28	−120	46	− 4.57	− 5.90	.665	2.03	.06178	− 48	− .8+
(5)	*p*	+120	+ 47	36.5	+ 6.25	+ 5.25	.50	1.29	.06197	− 67	−1.1+
(6)	*p*	− 47	−120	36.5	− 4.93	− 5.90	.485	1.21	.06103	+ 27	+ .4+
Oh, Oil-hardened. . . . . Av. η = .02670 ∼.027											
(1)	*a*	+260	− 20	260	+13.25	−13.25	13.25	106.20	.02695	+ 25	+ .9
(2)	*p*	+260	− 30	145	+13.25	− 2.24	7.745	44.78	.02683	− 13	− .5
(3)	*p*	+260	+ 30	115	+13.25	+10.60	1.325	2.75	.02778	−108	−4.0+
(4)	*a*	+ 80	− 80	80	+11.30	−11.30	11.30	82.20	.02692	− 22	− .8
(5)	*p*	+ 80	− 26	53	+11.30	− .70	6.00	28.96	.02611	+ 59	+2.2
(6)	*p*	+ 80	+ 27	26.5	+11.30	+ 9.48	.91	1.48	.02727	− 57	−2.0+
O, Oil-hardened, {after application of alternate current.} Av. η = .02700 ∼.027											
(1)	*a*	+112	−112	112	+13.65	−13.65	13.65	111.64	.02700	0	
(2)	*p*	+112	+ 24	44	+13.65	+10.48	1.585	3.52	.02669	+ 31	+1.2+
(3)	*p*	+112	+ 43	34.5	+13.65	+11.95	.85	1.32	.02713	− 13	− .5+
Sh, Annealed. . . . . Av. η .01899 ∼.019											
(1)	*a*	+240	−240	240	+16.60	−16.60	16.60	108.00	.01911	− 12	− .6
(2)	*p*	+240	− 26	133	+16.60	− 8.00	12.30	66.00	.01887	+ 12	+ .6
(3)	*p*	+240	+ 26	107	+16.60	+13.00	1.80	3.16	.01955	+ 56	−3.0+
S, Annealed, {after application of alternate current.} Av. η = .014455 ∼.0145											
(1)	*a*	+112	−112	112	+14.55	−14.55	14.55	66.74	.01457	−11.5	− .8
(2)	*p*	+112	− 30	71	+14.55	− 7.20	10.875	41.22	.01434	+11.5	+ .8
(3)	*p*	+112	+ 24	44	+14.55	+11.90	1.325	1.43	.01444	+ 1.5	+ .1+
(4)	*p*	+112	+ 43	34.5	+14.55	+13.28	.635	.48	.01434	+11.5	+ .8+

F_1 and F_2 = maximum values of M. M. F. in ampere-turns per cm.

L_1 and L_2 = maximum values of metallic induction in kilolines per cm.[2]

$F = \frac{F_1 - F_2}{2}$ and $L = \frac{L_1 - L_2}{2}$ are the amplitudes of the variation of M. M. F. and induction.

H = observed value of the dissipation of energy in kilo-ergs per cycle and cm.[3]

η = coefficient of hysteresis calculated therefrom, and

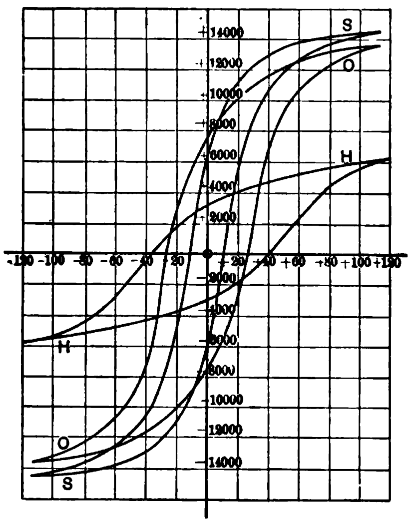


FIG. 6.—Welded Steel. Hysteretic Cycles.

$\Delta \eta$, the difference between the individual values and the average value of η, where again the cycles of small amplitude and therefore of lesser exactness are excluded in calculating the average of η. (The values *not* used for calculating av. η are marked by crosses $+$, as in the former tests.)

Again, we find the hysteretic loss dependent only upon the amplitude of the magnetic variation, but not upon their absolute values, and derive as constants of the six samples,

$$\rho = \alpha + \sigma F,$$

$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6},$$

the values given in Table XXIX.

TABLE XXIX.

MAGNETIC CONSTANTS OF TOOL-STEEL.

	$F \geq$	Coefficient of Magnetic Hardness a	Coefficient of Magnetic Saturation σ	Coefficient of Magnetic Hysteresis η	Absolute Saturation $L_{\infty} = \frac{1}{\sigma}$
Hh............	90	8.0	.121	.0748	8.28
H..............	90	7.8	.105	.0613	9.53
Oh..........	70	1.9	.066	.0267	15.16
O...............	60	1.54	.060	.0270	16.70
Sh.............	60	1.33	.060	.0190	16.70
S...............	40	1.22	.0575	.0145	17.40

Fig. 6 gives a cycle of either of the three samples after the application of the alternating current *H*, *O*, *S* between the opposite and equal M. M. F's. $F = \pm\ 112$ [Table XXII., (1); Table XXV., (1); Table XXVII., (1)].

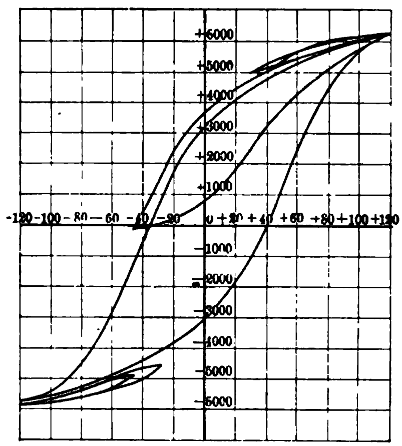


FIG. 7.—Glass-hard Steel. Hysteretic Cycles.

Fig. 7 gives the six magnetic cycles of *H* represented in Table XXII.

III. CAST-STEEL.

In the same manner as in Test II., two pieces of annealed cast-steel were treated.

Two pieces of annealed cast-steel were obtained from the same manufacturer, of the same casting, turned off to standard size, 20 cm. long and 4 cm.[2] cross-section, and by comparing them on the magnetometer, found to be exactly alike. Then one was left annealed, the other heated and hardened in cold water. Although cast-steel, it was after this found mechanically very much harder. In Table XXX. are given the magnetic characteristics of both samples, annealed and hardened.

TABLE XXX.

MAGNETIC CHARACTERISTICS OF CAST-STEEL.

F	Annealed.		Hardened.	
	ρ	L	ρ	L
10	2.80	3.57		
15	2.23	6.70		
20	2.16	9.30	5.20	3.85
25	2.29	10.90	4.60	5.43
30	$\rho = .88 + .054\,F$	12.00	4.50	6.67
40		13.15	$\rho = 2.7 + .054\,F$	8.24
60		14.60		10.20
80		15.40		11.40
100		15.90		12.35
150		16.73		13.90
[200		17.10		14.82
300		17.55		15.88
400		17.84		16.50
500		17.95		16.88]
Absolute saturation		18.50		18.50

As seen, for low M. M. F's. the two samples are magnetically very different, but approach each other for higher M. M. F's. and reach the same value of saturation.

TABLE XXXI.

HYSTERESIS OF HARDENED CAST-STEEL.

F	(1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r	(4) L_d	(4) L_r	(5) L_d	(5) L_r
+82	±11.58		+11.58		+11.58		+11.58		+11.58	
70	11.35	10.94	11.32	10.87	11.28	10.98	11.29	11.14	11.35	11.21
60	11.00	10.20	11.02	10.12	10.92	10 34	10.96	10.62	11.04	10.75
50	10.57	9.12	10.63	9 18	10.50	9 60	10.53	9.89	10.60	10.23
40	10.06	7.05	10.13	7.72	10.00	8.70	10.08	9.37	10.33	10.06
30	9.51	3.40	9.62	5.05	9.47	7.65	9.69	9.00	10.13	10.05
20	8.90	− 1.80	9.03	− .10	8.92	5.80	9.32	8.72	+10.05	
10	8.20	− 5.70	8.32	−4.35	8.28	.80	8.93	8.49	[F_2 = + 27.5]	
0	±7.33		7.40	−5.93	7.60	− .30	+8.42			
−10			5.70	−6.80	6.30	− .70	[F_2 = 0]			
−20			1.50	−7.52	1.25	− .82				
−30			−3.65	−8.06	−.81					
−40			−6.90	−8.53	[F_2 = − 26.5]					
−53			−9.07							
H =	87.63		72.905		32.51		3.645		1.14	
L =	11.58		10.325		6.195		1.58		.765	
η =	.02760		.02758		.02784		.02779		.02770	

TABLE XXXII.

HYSTERESIS OF HARDENED CAST-STEEL.

	(6)		(7)		(8)		(9)		(10)		(11)	
F	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r
+45.6	±8.70		+8.75		+8.96		+8.96		+8.96		+8.96	
40	8.50	7.77	8.57	8.07	8.76	8.30	8.76	8.30	8.76	8.34	8.76	8.41
35	8.28	6.35	8.38	7.31	8.51	7.70	8.51	7.70	8.53	8.02	8.53	8.22
30	8.03	4.51	8.16	6.35	8.25	7.00	8.25	7.10	8.27	7.78	8.33	8.20
25	7.77	2.42	7.92	5.03	7.97	6.11	7.96	6.27	8.02	7.59	+8.20	
20	7.46	− .33	7.63	2.70	7.63	4.86	7.66	5.28	7.73	7.48	[$F_2 = +27$]	
15	7.07	−2.53	7.29	− .55	7.31	2.75	7.33	4.18	7.57	7.42		
10	6.63	−3.88	6.85	−2.12	6.87	.66	6.93	3.19	+7.42			
+5	6.12	−4.82	6.38	−2.90	6.43	.22	6.50	2.31	[$F_2 = +13.5$]			
0	±5.54		5.83	−3.44	5.90	. 0	6.05	1.65				
−5			5.26	−3.90	5.28	−.17	5.44	1.25				
−10			4.54	−4.28	4.51	−.33	4.73	1.00				
−15			3.19	−4.61	3.30	−.48	3.63	.92				
−20			−1.00	−4.90	.30	−.62	+.92					
−25			−3.90	−5.10	−.70		[$F_2 = -18.5$]					
−31 6			−5.31		[$F_2 = -22$]							
$H =$	56.11		38.72		22.42		16.10		1.10		.38	
$L =$	8.70		7.03		4.83		4.02		.77		.38	
$\eta =$	.02792		.02836		.02859		.02754		.02649		.02832	

TABLE XXXIII.

HYSTERESIS OF CAST-STEEL—RESULTS.

No.		F_1	F_2	$F = \frac{F_1 - F_2}{2}$	L_1	L_2	$L = \frac{L_1 - L_2}{2}$	H	η obs.	$10^5 \Delta\eta$	= %
Hardened .... Av. η = .02792											~.028
(1)	*a*	+82	−82	82	+11.58	−11.58	11.58	87.63	.02760	+ 32	+1.1
(2)	*p*	+82	−53	67.5	+11.58	− 9.07	10.325	72.905	.02758	+ 34	+1.2
(3)	*p*	+82	−26.5	54.2	+11.58	− .81	6.105	32.51	.02784	+ 8	+ .3
(4)	*p*	+82	= 0	41	+11.58	+ 8.42	1.58	3.645	.02779	+ 13	+ .5+
(5)	*p*	+82	+27.5	27.2	+11.58	+10.05	.765	1.14	.02770	+ 22	+ .7+
(6)	*a*	+45.4	−45.4	45.4	+ 8.70	− 8.70	8.70	56.11	.02792	0	0
(7)	*p*	+45.4	−31.6	38.5	+ 8.75	− 5.31	7.03	38.72	.02836	− 44	−1.6
(8)	*p*	+45.8	−22	33.9	+ 8.96	− .70	4.83	22.42	.02859	− 67	−2.4
(9)	*p*	+45.8	−18.5	32.1	+ 8.96	+ .92	4.02	16.10	.02754	+ 38	+1.4
(10)	*p*	+45.8	+13.5	16.1	+ 8.96	+ 7.42	.77	1.10	.02649	+143	+5.1+
(11)	*p*	+45.8	+27	9.4	+ 8.96	+ 8.20	.38	.38	.02832	− 40	−1.4+
Annealed .... Av. η = .008481											~.0085
(1)	*a*	+100	−100	100	+15.85	−15.85	15.85	35.00	.008502	−2.1	− .4
(2)	*a*	+ 44	− 44	44	+13.62	−13.62	13.62	44.40	.008460	+2.1	+ .4

Tables XXXI. and XXXII. give a number of cycles made with the hardened piece *h*, and Table XXXIII. the results of these cycles and of two cycles made with the annealed piece, the denotation being the same as before.

Herefrom we derive the results for this cast-steel,

$$\rho = a + \sigma F,$$

$$H = \eta \left(\frac{L_1 - L_2}{2} \right)^{1.6},$$

		Coefficient of		
		Magnetic Hardness.	Magnetic Saturation.	Magnetic Hysteresis.
	$F \geqq$	a	σ	η
Soft cast-steel *s*,	30	.88	.054	.00848
Hardened cast-steel *h*,	40	2.7	.054	.02792

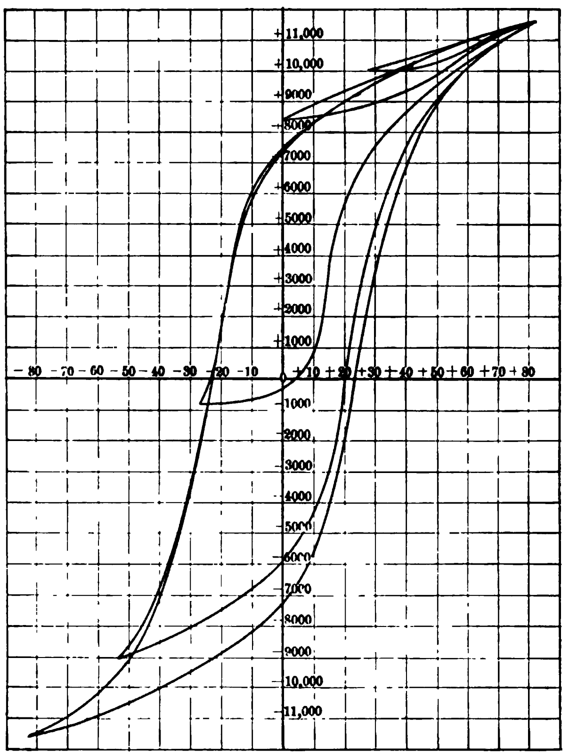


FIG. 8.—Hard Cast-Steel. Hysteretic Cycles.

The magnetic characteristics of these two samples of cast-steel, together with many other characteristics, are represented in Figs. 17 and 21. Fig. 8 gives the five cycles of hardened cast-steel from Table XXXI.

Numerous data on the magnetic constants of different kinds of cast-steel are given in Chapter III. and collected in tables XLVII. and LI, represented in Figs. 16, 17 and 21.

IV. Different Kinds of Iron and Steel.

A number of tests were made with different kinds of iron and soft steel, to determine the magnetic constants α, σ, η.

Here the differential method was used for the determination of the coefficient of magnetic hysteresis η, that is the test piece was balanced step by step against a sample of known magnetic hysteresis, usually Norway iron or the sheet iron of Chapter I. and so the difference in the dissipation of energy by hysteresis in both samples read. Since in the former tests I believe to have proved the coincidence of the observed values with the general formula,

$$H = \eta\left(\frac{L_1 - L_2}{2}\right)^{1.6},$$

here usually only one cycle, between opposite and equal values of M. M. F. F was determined, and η calculated therefrom.

Tests were made on Norway iron, by comparing it with the sheet-iron tested by alternating currents in Chapter I., which gave $\eta = .0035$.

Wrought-iron, a solid bar of 4 cm.^{2} cross-section (standard size).

Mitis metal, cylindrical piece of standard size.

A sample of very soft annealed cast-steel, marked No. 6.

A sample of soft annealed cast-steel, from another manufacturer, marked No. 5.

Very thin sheet-iron, known as "ferrotype."

This "ferrotype" was found magnetically rather hard, and of a high value of the coefficient of hysteresis. Therefore it was annealed by an electric current and tested again, whereby it was found improved.

Tin plate, 2 samples, thin and of medium thickness.

Galvanized wire, apparently of soft steel.

The magnetic characteristics of these materials are given in Table XXXIV., and to a great part shown as curves in Fig. 17.

TABLE XXXIV.

Different Kinds of Iron and Steel.

	Norway Iron, Standard.		Wrought-Iron, in Bars.		Very Soft Annealed Cast-Steel No. 6.		Soft Annealed Cast-Steel No. 5.		Mitis Metal.		Ferrotype, Commercial.		Ferrotype, Annealed.		Tin Plate, Thin.		Tin Plate, Medium Thickness.		Soft Galvanized Steel Wire.	
F	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L	ρ	L
5.5	$\rho = .166 + .05435\ F$	11.83	.54	10.20	$\rho = .232 + .05577\ F$		$\rho = .260 + .05511\ F$		.77	7.15	1.10	5.00								
7.5		13.08	.64	10.96		11.50			.79	8.88	1.01	7.44	1.05	7.15	.75	10.00	.98	7.65	1.79	4.20
8.5		13.56	.70	12.11					.81	10.54										
10		14.10	.77	13.06		12.66		12.33	.88	11.43	1.04	9.63	.97	10.32	.78	12.85	.98	10.20	1.71	5.85
11.5		14.56	.85	13.57					.92	12.50										
12.5		14.80	$\rho = .20 + .05547\ F$	13.98		13.45		13.12	$\rho = .30 + .05444\ F$	12.75	1.10	11.38	1.03	12.15	$\rho = .192 + .05464\ F$	14.28	1.01	12.38	1.70	7.37
15		15.30		14.55		14.03		13.80		13.44	1.20	12.50	1.12	13.40		14.80	$\rho = .321 + .05315\ F$	13.44	1.75	8.60
20		16.00		15.30		14.84		14.68		14.40	$\rho = .450 + .04975F$	13.75	$\rho = .337 + .04905F$	14.93		15.60		14.45	$\rho = .67 + .066\ F$	10.05
25		16.42		15.80		15.40		15.30		15.07		14.80		15.85		16.08		15.15		10.80
30		16.72		16.10		15.75		15.68		15.55		15.45		16.40		16.40		15.68		11.30
40		17.10		16.60		16.28		16.28		16.18		16.40		17.23		16.85		16.30		12.10
60		17.53		17.03		16.78		16.85		16.85		17.48		18.03		17.30		17.12		12.94
80		17.74		17.30		17.08		17.10		17.20		18.00		18.55		17.55		17.50		13.44
100		17.83		17.42		17.25		17.55		17.45		18.40		18.80		17.68		17.75		13.80
200		18.15		17.72		17.60		17.73		17.90		19.30		19.45		18.00		18.30		14.50
Absolute Saturation		18.40		18.03		17.95		18.15		18.37		20.10		20.10		18.30		18.81		15.15
Coefficient of hysteresis η =		.002275		.003260		.003181		.004573		.004281		.00548		.00458		.002863		.004255		.00349

The results of the tests, without exception proved the law of metallic magnetic reluctively,

$$\rho = a + \sigma F.$$

The results are,

(1.) *Norway Iron.*

This is the softest metal magnetically and has the lowest coefficient of hysteresis I ever observed, little larger than the "soft iron wire" of Ewing. It is the piece used as Standard in the Differential Magnetometer. The whole instrument is built of this material.

The dissipation of energy by hysteresis, and the other magnetic constants were found,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
75	17.70	14.25	.002275	.166	.05435	18.40
				for $F \geqq 5$		

(2.) *Ordinary Good Wrought-Iron in Bars.*

The hysteresis and the other magnetic constants are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
75	17.20	19.50	.003260	.20	.05547	18.03
				for $F \geqq 12$		

(3.) *Mitis Metal.*

The hysteresis and the other magnetic constants are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
75	17.11	25.40	.004281	.30	.05444	18.37
				for $F \geqq 12$		

As seen, magnetically this mitis metal behaves almost exactly like wrought-iron and sheet-iron. Its coefficient of magnetic hardness is $a = .30$, while for different kinds of sheet-iron and wrought-iron I found values varying between .166 (Norway iron) and .35 (thick sheet-iron), and in unannealed ferrotype even .45. The coefficient of magnetic saturation $\sigma = .05444$ is about the average found for different samples of wrought-iron, which vary between .058 (the sample of sheet-iron, given in Chapter I.) and .04975 (ferrotype), while Norway iron has $\sigma = .05435$, that is almost the same as mitis metal.

The coefficient of hysteresis $\eta = .00428$ is somewhat larger, but still within the limits of sheet-iron, which reaches .0045 in a sample described on p. 26 in my former paper and was found still higher in ferrotype. Hence, the conclusion to be derived herefrom is, "*For all practical purposes mitis metal is to be considered magnetically as identical with ordinary good wrought-iron.*"

(4.) *Very Soft Annealed Cast-Steel*, No. 6.

The hysteresis and the other magnetic constants are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
75	17.00	18.67	.003181	.232	.05567	17.95
				for $F \geq 6$		

As seen, this annealed cast-steel is *far superior to ordinary good wrought-iron*, and almost approaches Norway iron.

The magnetic hardness $a = .232$ is about midway between that of Norway iron, and the lowest value found in ordinary good sheet-iron.

The coefficient of magnetic saturation is about the same as that of wrought-iron and sheet-iron.

The coefficient of magnetic hysteresis is lower than for average wrought-iron.

(5.) *Soft Annealed Steel*, No. 5.

The hysteresis, and the magnetic constants are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
75	17.00	26.84	.004573	.260	.05511	18.15
				for $F \geq 10$		

Even this annealed cast-steel is in its magnetic hardness $a = .260$ still superior to average wrought-iron, in magnetic saturation equal, and with its coefficient of hysteresis, still in the range of wrought-iron. Both the materials, Nos. 5 and 6, are used for the magnetic field in the Eickemeyer-Field street car motors.

(6.) *Ferrotype.*

Twenty-three strips of 20 cm. length, 1.27 cm. width and .015 cm. thickness (calculated from weight, by specific gravity 7.7), that is of .019 cm.^{2} cross-section, were used, giving a joint cross-section of .438 cm.^{2} This material is remarkable in so far as it reaches a very high value of magnetic saturation, over 20,000 lines of magnetic force per cm.^{2} But with regard to magnetic hardness and hysteresis it was found poor; perhaps it was rolled rather cold, and thereby hardened. Hence, after testing it once, I annealed it. Each strip was fastened with its ends between two clamps, and a (continuous) current of about 50 $\sim$ 60 amperes sent through, which heated it to bright red. The current was applied repeatedly. About 10 per cent were burnt off, leaving a joint cross-section of .396 cm.^{2}

The hysteresis and the magnetic constants are,

	± F	± L	H	η	α	σ	L_∞
not annealed:	65	17.6	34.04	.00548	.45	.04975	20.10
annealed:	65	18.2	30.00	.00458	.337		

$F \geqq 15 \sim 20$.

As already stated, this material is remarkable for its high magnetic saturation.

(7.) *Tin-Plate.*

Two samples of ordinary commercial tin-plate were tested, of the thickness .0268 cm. and .0378 cm. (calculated from weight and including the tin.) The length of the test pieces was 20 cm., the width 2.55 cm.

Of the thicker sample 22 pieces were used, of a joint cross-section of 2.12 cm.^{2}, of the thinner sample 30 pieces were used, of 2.05 cm.^{2} joint cross-section. Considerable difference was found between the two samples, while the thicker sample equalled ordinary and even rather poor sheet-iron, the thinner sample was superior to any sheet-iron, and came very near to Norway iron.

The hysteresis and the magnetic constants are,

Thicker sample .0378 cm. thick.

± F	± L	H	η	α	σ	L_∞	$F \geqq$
26	15.31	21.0	.004229				
62	17.15	25.5	.004282				
		av.	.004255	.321	.05315	18.81	14

Thinner sample .0268 cm. thick.

± F	± L	H	η	α	σ	L_∞	$F \geqq$
26	16.13	15.4	.002853				
62	17.33	17.4	.002873				
		av.	.002863	.192	.05464	18.30	12

In these values no reduction has been made for the tin-covering of the sheet-iron, but these figures refer to the whole cross-section of the tin-plate, including the tin. Therefore, especially in the thinner sample, in the iron proper L_∞ will be a little higher than given.

(8.) *Galvanized Iron (Steel?) Wire.*

One hundred and forty-three pieces of wire, of 20 cm, length and .0193 cm.^{2} cross-section (calculated from weight, specific gravity 7.7), that is of .157 cm. diameter, were used, giving a joint cross-section of 2.76 cm.^{2}

The hysteresis and the magnetic constants are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞.
80	13.35	13.78	.003455			
32	11.50	10.85	.003454			
18	9.70	8.50	.003550			
		av. $\eta =$	.00349	.67	.066	15.15
			$\sim$ .0035	for $F \geqq 20$		

As seen, the constants σ and a have values found in soft cast-steel, but η is remarkably low, in the range of average wrought-iron.

V. Amalgam of Iron.

In the amalgams of iron we have a very interesting class of alloys in-so-far as they bridge over the wide gap existing between the paramagnetic materials, as iron, nickel, cobalt, etc., and the non-magnetic materials, as air, etc. It is not easy to get amalgam of iron, since iron does not dissolve in mercury, and is not even wetted thereby. But when separated in molecular form, iron dissolves readily. So by electrolyzing a solution of ferro-sulphate $S\ O_4\ Fe$ with mercury as cathode by a dense electric current, the iron, deposited in molecular form, dissolved in quicksilver; and by pressing the quicksilver through a piece of linen, a solid, crystalline amalgam was separated from a liquid one. This liquid amalgam still contained a certain amount of iron in solution, as its attraction by the magnetic-pole showed; but was not sufficiently magnetizable to make tests with it.

With great current density and small supply of mercury, sometimes a crystallized amalgam of dark steel color was separated, in needle-formed crystallization. This amalgam evidently contained still more iron, but was not tested.

The crystalline amalgam, which was still pliable enough to be pressed into a solid body, contained 11 per cent. of iron, and small traces of foreign matter, as a chemical analysis showed. Since it evidently still contained traces of the liquid amalgam, it may about correspond to the formula,

$$Fe\ Hg_2$$

All these amalgams were liable to slow decomposition, and separated in a few weeks a part of the iron as fine black powder. Hence they had to be tested soon after preparation. It was placed in a fibre tube and compressed by two wrought-iron pieces which from either side screwed into the tube, thereby affording a path for the magnetism. These Norway iron cylinders were balanced by an equal pair of cylinders at the other side of the instrument, and the amalgam tested then.

The dimensions of the tested piece of amalgam were,

Length, 4 cm.

Cross-section, 4.45 cm.^{2}, cylinder.

Although showing strong attraction against a magnet-pole, the amalgam had only about twice the permeability of air.

Table XXXV. gives the magnetic characteristic of the amalgam containing 11 per cent. of iron, with the usual denotation, $L =$ metallic induction, $\rho =$ metallic reluctivity.

TABLE XXXV.

MAGNETIC CHARACTERISTIC OF AMALGAM OF IRON, 11 %.

F	L	ρ obs.	ρ calc.
20	22	909	Approximately, $\rho = 500 + 1.12 F$ for $F \geq 240$
40	49	816	
60	76	790	
80	103	775	
100	130	769	
120	157	764	
140	184	761	
160	211	759	
180	238	756	
200	265	755	
220	290	759	
240	310	774	
260	328	792	
280	345	811	
300	360	833	
320	374	856	
340	387	879	
360	399	902	
[Absolute Saturation	900]		

For higher values of M. M. F., $F \geq 240$, the metallic reluctivity can *approximately* be expressed by the equation,

$$\rho = 500 + 1.12\, F$$

though the bend in the curve is so small, that the constants α and σ are rather uncertain.

Table XXXVI. gives a cycle of hysteresis,

TABLE XXXVI.

HYSTERESIS OF AMALGAM OF IRON, 11 %.

F	L_d		L_r
320		± .375	
250	.326		.308
200	.285		.252
150	.238		.185
100	.182		.112
50	.118		.033
0		± .045	
$H =$		3.04	
$L =$		.375	
$\eta =$		.2314	

The results are,

	$\pm F$	$\pm L$	H	η	a	σ	L_∞	Coercitive Force.
Amalgams of iron,	320	.375	3.04	.2314	500	1.12	.900	$F = 28.$
Common air,	320	.400	0	0	800	0	∞	

All the three coefficients, η, a, σ, are unusually high in this material, the "absolute saturation" amounting to only,

$$L_\infty = 900.$$

Fig. 9 gives the magnetic characteristic and one cycle of hysteresis of this amalgam of iron. The dotted straight line denotes the magnetic characteristic of air, H which has to be added to get the whole induction, $B = L + H$.

Since 11 per cent. of weight corresponds to about 17.5 volume per cent., the magnetic constants referred to the volume of iron contained in the amalgam are,

η	a	σ	L_∞
.0815	87.5	.196	5.10

η is still higher than the highest values found for glass-hard steel. (*cf.* Chapter V.)

In the same manner as amalgam of iron, *amalgam of nickel* was prepared by electrolysis, and gave the three amalgams:

1. A liquid amalgam, consisting of quicksilver with traces of nickel, but showing no perceptible influence upon the magnet-needle.

2. A silver-colored, pliable amalgam, containing apparently about 10 per cent. of nickel. This amalgam seems to be entirely non-magnetic, since I could get no deflection of the compass-

needle by it. It dissociates very rapidly, even when dry. By heating in boiling paraffin, or at ordinary temperature within a day, it was always found dissociated into quicksilver (or the first

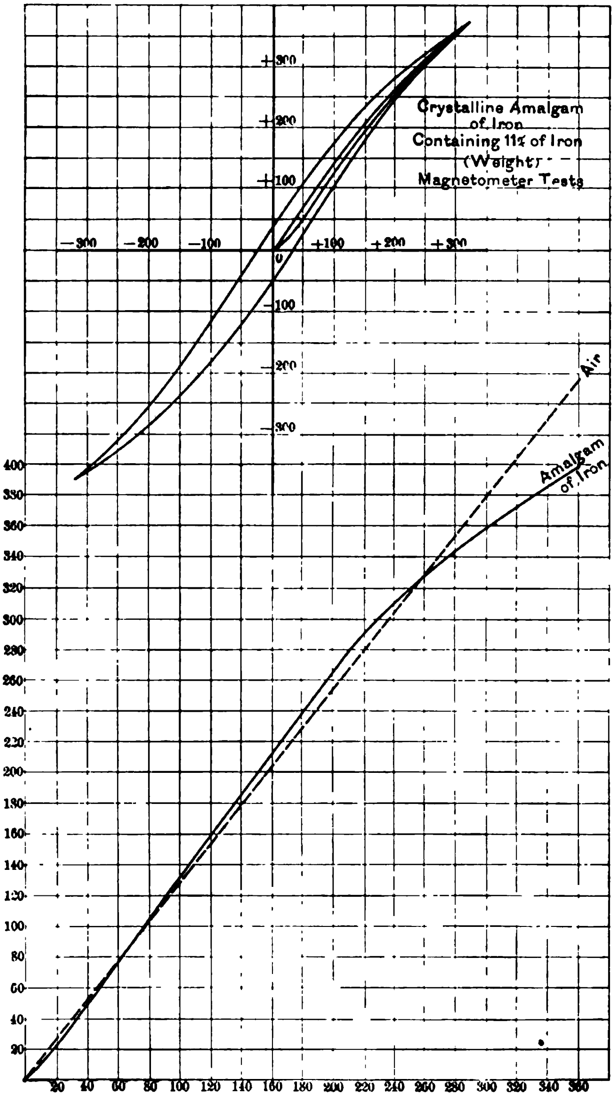


FIG. 9.—Amalgam of Iron.

amalgam) and the third amalgam.

3. A gray-colored amalgam, hard, or when freshly prepared by heating the second amalgam, still pliable, deflects the compass-

needle strongly, and becomes permanently (and relatively strongly) magnetized in the magnetic field. Though an allotropic modification of this amalgam seems to exist, which is *unmagnetic.* No exact tests have yet been made with these amalgams.

VI. Porous Iron.

By heating this amalgam of iron to dull red heat, the mercury evaporated, and a very porous mass of iron, containing some percentage of oxides, remained. The material contracted considerably hereby, from 14.75 cm.^{3} to 8.055 cm.^{3}, but was, nevertheless, full of smaller and larger pores, containing very nearly 30 volume percentage of iron.

TABLE XXXVII.

MAGNETIC CHARACTERISTICS OF POROUS IRON, 30 VOLUME PER CENT.

F	(1) L	(1) ρ	(2) L	(2) ρ
20	.53	$\rho = 25.4 + .604\, F$	.22	$\rho = 76 + .71\, F$
40	.81		.38	
60	.97		.50	
80	1.08		.60	
100	1.16		.68	
120	1.23		.75	
150	1.30		.82	
200	1.37		.92	
300	1.45		1.04	
[500	1.53		1.16	]
Absolute saturation........	1.66		1.41	

TABLE XXXVIII.

HYSTERESIS OF POROUS IRON, 30 VOLUME PER CENT.

F	L_d		L_r
140		± 1.28	
130	1.26		1.26
120	1.23		1.23
110	1.20		1.19
100	1.17		1.15
90	1.13		1.11
80	1.09		1.06
70	1.04		1.00
60	.98		.93
50	.92		.84
40	.86		.73
30	.78		.59
20	.69		.35
10	.59		− .06
0		± .43	
H =		3.98	
L =		1.28	
η_1 =		.0425	

The test piece had the following dimensions,

Length, 4.45 cm.

Cross-section, 1.81 cm.^{2}, almost square.

Volume, 8.055 cm.^{3}.

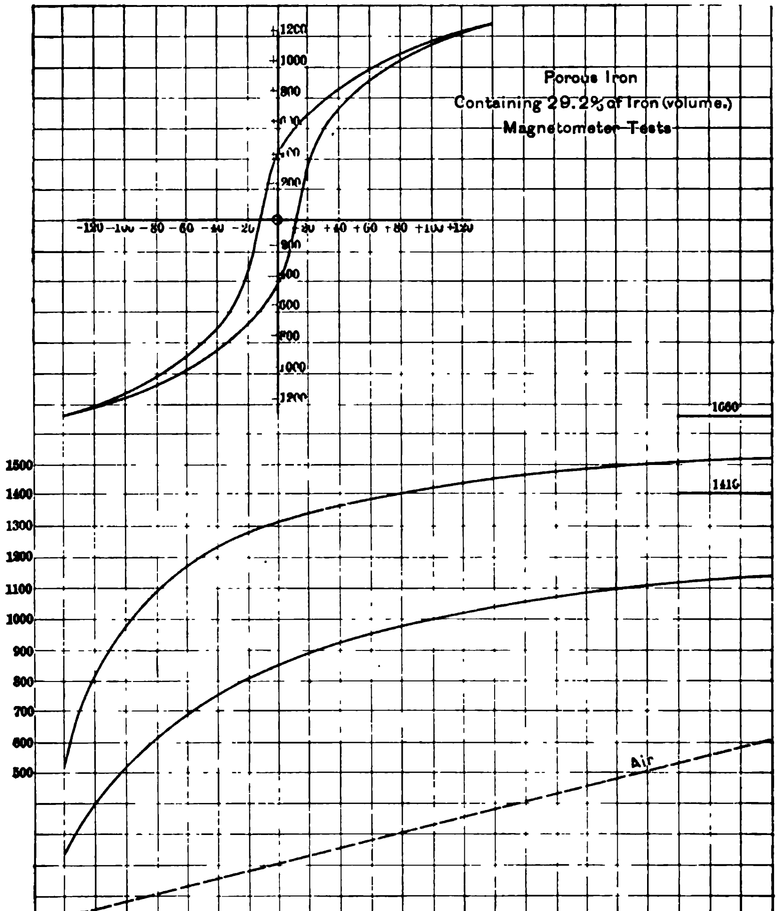


FIG. 10.—Porous Iron.

Its magnetic characteristic is given in Table XXXVII., in column 1, a cycle of hysteresis in Table XXXVIII.

The results are,

$\pm F$	$\pm L$	H	η	a	σ	L_∞
140	1.28	3.98	.0425	25.4	.604	1.66

$F \geqq 90.$

Another piece of such porous iron, of the dimensions.

Length, 6.03 cm.; cross-section, .53 cm.^{2}; volume, 3.2 cm.^{3}; containing 31 volume per cent. of solid matter, but much impurer, gave the characteristic in Table XXXVII., Column 2, expressed by the equation,

$$\rho = .76 + .71\ F$$
$$\text{for } F \geqq 90.$$

Here again are noteworthy the high values of magnetic hardness and hysteresis, and the low value of magnetic saturation, $L_\infty = \frac{1}{\sigma}$, which lies at 1660 viz. 1410.

Fig. 10 gives the magnetic characteristics of both samples with the air-characteristic as dotted lines for comparison, and one cycle of hysteresis. It is noteworthy, that the hysteretic cycle is entirely unlike that of the iron-amalgam, where the porous iron was derived from, and resembles much more a cast-iron cycle, but of one-eighth the height of ordinates. The first sample was heated to dull red heat, for evaporating the mercury, the second one heated over the alcohol lamp, had not become as hot. This may account for its far greater magnetic hardness.

Referred to the volume of the iron contained in the test pieces, 3) and 31 per cent. respectively, their magnetic constants are,

	η	a	σ	L_∞
(1)	.0206	7.6	.181	5 52
(2)		23.6	.22	4.55

The value $\eta = .0206$ corresponds to that of medium hard steel, and so the test pieces behaved, getting strongly and permanently magnetized.

VII. Magnetite.

With a piece of magnetite (Magnetic Iron Ore) of 6 cm.^{2} cross-section (square) and 6.5 cm. length, a very pure sample, derived from the Tilly Foster Mines, Brewsters, Putnam County, State of New York, a large number of tests were made.

The magnetic characteristic is given in Table XXXIX.

TABLE XXXIX.

MAGNETIC CHARACTERISTIC OF MAGNETITE (MAGNETIC IRON ORE).

F	L	ρ
15	.71	21.0
20	1.09	18.4
25	1.47	17.0
30	1.80	16.7
35	2.07	16.9
40	2.28	17.5
45	2.43	
50	2.56	$\rho = 8.9 + .2132\,F$
60	2.77	
80	3.08	
100	3.31	
120	3.48	
140	3.62	
160	3.72	
180	3.81	
200	3.89	
[300	4.12	
500	4.33]	
Absolute Saturation......	4.69	

TABLE XL.

HYSTERESIS OF MAGNETITE (MAGNETIC IRON ORE),

	(1)		(2)		(3)		(4)		(5)		(6)	
F	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r	L_d	L_r
0	±.60		+.80		±.89		+.94					
5	.92	−.20	1.16	−.36	1.24	−.46	1.28	−.55				
10	1.17	+.30	1.43	+.14	1.50	+.06	1.54	−.05	[+16]			
15	1.39	.80	1.68	.67	1.73	.58	1.76	+.44	+1.82			
20	1.55	1.20	1.87	1.10	1.90	1.02	1.96	.90	1.97	1.85		
25	1.68	1.52	2.04	1.46	2.10	1.39	2.14	1.30	2.15	1.99	[+30]	
30	±1.77		2.19	1.75	2.27	1.70	2.30	1.64	2.30	2.13	+2.32	
35	[±29]		2.32	2.00	2.40	1.95	2 43	1.89	2.43	2.24	2.44	2.34
40			2.43	2.20	2.53	2.16	2.55	2.10	2.55	2.36	2.56	2.45
45			2.53	2.37	2.64	2.34	2.66	2.29	2.65	2.48	2.65	2.54
50			2 61	2.52	2.72	2.47	2.75	2.43	2.74	2.58	2.74	2.64
55			2.68	2.66	2.81	2.59	2.84	2.55	2.82	2.69	2.82	2.72
60			±2.69		2.88	2.70	2.91	2.66	2.90	2.78	2.90	2.82
65			[±57]		2.94	2.80	2.98	2.77	2.96	2.87	2.96	2.89
70					3.00	2.90	3.04	2.87	3.01	2.95	3.01	2.96
75					3.06	3.00	3.10	2.97	3.06	3.02	3.06	3.03
80					3.11	3.08	3.15	3.05	3.11	3.09	3.11	3.10
85					3.15	3.14	3.20	3 12	3.15	3.14	3.15	3 15
90					±3.18		3.24	3.18	±3.18		+3.18	
95					[+88]		3.29	3.23	[+88]		[+88]	
100							3.33	3.28				
105							3.37	3.32				
110							3.41	3.37				
115							3.44	3.41				
120							3.48	3.45				
125							3.51	3.49				
130							3.55	3.53				
135							3.58	3.57				
140							±3.61					
$H =$	3.69		7.23		9.45		11.52		.81		.38	
$L =$	1.77		2.69		3.18		3.61		.68		.43	
$\eta =$	.02345		.02352		.02353		.02342		.02379		.02324	

Av. $\eta = .02348$.

Beyond the M. M. F. $F = 40$ the magnetic reluctivity strictly follows the linear law,

$$\rho = 8.9 + .2132\,F,$$

giving a characteristic similar to that of cast-iron, only that absolute saturation is already reached at the metallic induction,

$$L_{\infty} = 4.69.$$

To determine whether the law of the 1.6th power holds for the hysteretic loss of energy in magnetite also, a number of magnetic cycles were taken, which are given in Table XL., first between opposite and equal limits, $\pm F = 29, 57, 88, 140$ then between high values of induction of the same sign, between $F_1 = +88$ and $F_2 = 30$ and 16 respectively.

The results of these cycles are given in Table XLI.

TABLE XLI.

HYSTERESIS OF MAGNETITE (MAGNETIC IRON ORE)—RESULTS.

No.		F_1	F_2	$F = \frac{F_1 - F_2}{2}$	L_1	L_2	$L = \frac{L_1 - L_2}{2}$	H	η obs.	$10^5 \Delta \eta$	$= \%$
(6)	*p*	+ 88	+ 30	29	+3.18	+2.32	.43	.38	.02324	+24	+1.0
(5)	*p*	+ 88	+ 16	36	+3.18	+1.82	.68	.81	.02379	−31	−1.3
(1)	*a*	+ 29	− 29	29	+1.77	−1.77	1.77	3.69	.02345	+ 3	+ .1
(2)	*a*	+ 57	− 57	57	+2.69	−2.69	2.69	7.23	.02352	− 4	− .2
(3)	*a*	+ 88	− 88	88	+3.18	−3.18	3.18	9.45	.02353	− 5	− .2
(4)	*a*	+140	−140	140	+3.61	−3.61	3.61	11.52	.02342	+ 6	+ .3
							Av. η =		.02348		

They prove conclusively, that the same law of hysteresis holds for magnetite.

$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6}$$

and give as magnetic constants of *magnetite*,

η	a	σ	L_{∞}	$F \geqq$
.02348	8.9	.2132	4.69	40

Fig. 11 gives the cycles of Table XL., 1, 2, 3 and 4, made between oppositely equal limits.

The two tests made on another sample and published in the paper of January 19th, 1892 give, $\eta = .020$, that is nearly the same

VIII. Ewing's Tests.

Before leaving the consideration of the phenomenon of hysteresis in *iron* and its alloys and compounds, I may be allowed to dwell upon some determinations of the loss of energy by hysteresis, made by Ewing, and given in his book on "Magnetic Induction in Iron and other Metals."

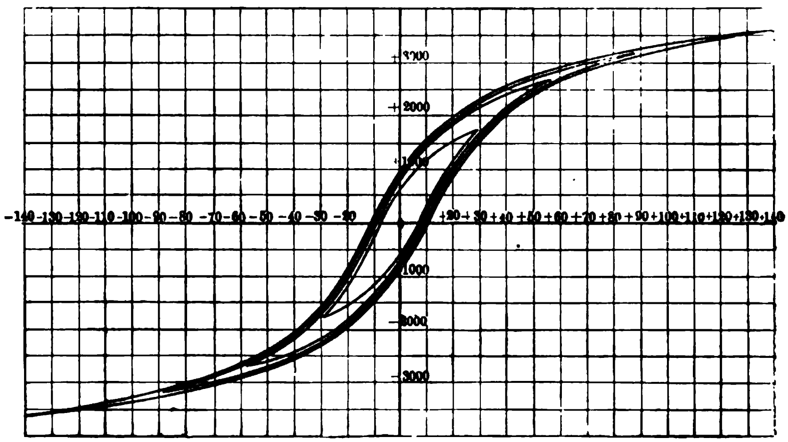


Fig. 11.—Magnetite. Hysteretic Cycles.

TABLE XLII.

MAGNETIC CYCLES OF SOFT IRON WIRE.

(Ewing, p. 106.)

F	*L*	*H* obs.	*H* calc.	*H* — *H* calc. obs.	= %
1 20	1.974	.41	.375	+.035	+8 5
1.56	3.83	1.16	1.082	+.058	+5.0
2.05	5.95	2.19	2.190	——	——
2.41	7.18	2.94	2.956	—.016	— .5
3.01	8.79	3.99	4.08	—.090	—2.3
3.97	10.59	5.56	5.51	+.050	+ .9
5.30	11.47	6.16	6.26	—.100	—1.7
5.63	11.95	6.59	6.69	—.100	—1.5
21.2	13.69	8.69	8.31	+.380	+4.4
60 2	15.48	10.04	10.11	—.070	— .7
Av. η = .002				±.090	±2.5

TABLE XLIII.

MAGNETIC CYCLES OF ANNEALED PIANOFORTE STEEL WIRE.

(Ewing, p. 109.)

F_1	F_2	$F = \frac{F_1 - F_2}{2}$	L_1	L_2	$L = \frac{L_1 - L_2}{2}$	H obs.	H calc.	$H - H$ calc. obs.	= %
+8	−8	8	+1.51	−.94	1.225	1.20	1.52	+.32	+21
+12	−10.4	11.2	+3.64	−2.32	2.98	5.50	6.32	+.82	+13
+15.2	−15.2	15.2	+5.66	−4.90	5.28	15.90	15.80	−.10	−.6
+18.4	−19.2	18.8	+7.53	−7.43	7.48	27.30	27.50	+.20	+.8
+24	−24	24	+9.45	−9.55	9.50	41.90	40.20	−1.70	−4.2
+65	−65	65 (?)	+13.80	−13.80	13.80	71.80	73.50	+1.70	+2.2

Av. $\eta = .01742$.

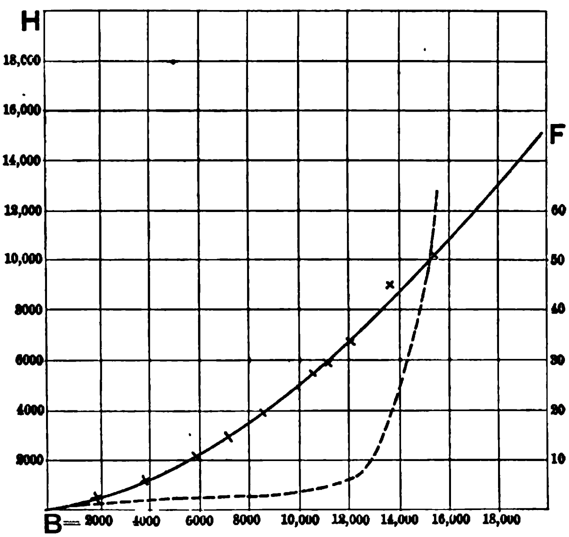


FIG. 12.—Soft Iron. Curve of Hysteresis. [Ewing.]

In Table XLII. and Fig. 12 are given the results of the graded cycles of hysteresis of very soft iron wire (pages 106–7 Ewing).

In Table XIII. and Fig. 5 are given the results of the graded cycles of hysteresis of medium good cast-iron, (No. 1).

In Table XLIII. and Fig. 13 are given the results of the graded cycles of annealed pianoforte steel wire (page 109 Ewing). These latter are taken from the plotted curve published by Ewing; hence only a considerable lesser exactness can be expected since the numerical data are not published by Ewing, as far as I know, and printed curves are never very exact, and not improved by measuring.

The data in Table XLII. are of interest in so far as they are the lowest values of hysteretic loss ever observed on iron. so far as I know. From these figures I found the law of the 1.6th power, two years ago, when trying to find a misprint which got into the table of the hysteretic loss, given in Kapp's "Alternate-Current Machinery" and calculated from these tests.

The denotations are the same as before,

F_1 and F_2 = the highest and the lowest values of E. M. F., in ampere turns per cm.

B_1 and B_2 = the highest and the lowest value of magnetic induction, in kilolines per cm.².

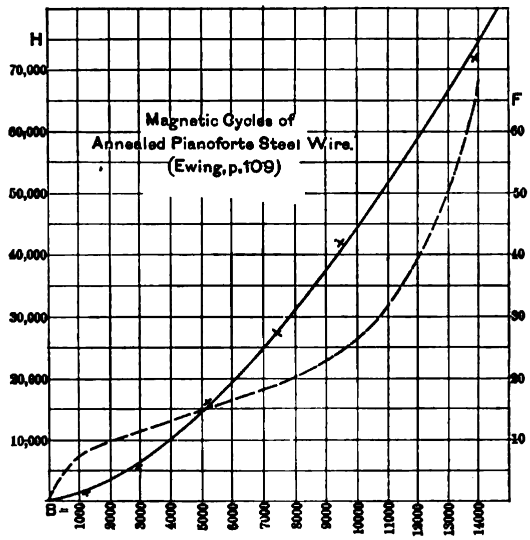


FIG. 18.—Pianoforte Steel Wire. Curve of Hysteresis. [Ewing.]

$F = \frac{F_1 - F_2}{2}$ and $B = \frac{B_1 - B_2}{2}$ = their amplitudes, or half their variations.

H = the energy consumed by hysteresis, during one complete cycle, in kiloergs per cm.³.

η = coefficient of hysteresis, calculated therefrom.

Two further cycles, with annealed and with glass-hard pianoforte steel wire (Ewing page 84) give the results,

	F_1	F_2	$\frac{F_1 - F_2}{2}$	B_1	B_2	$\frac{B_1 - B_2}{2}$	H	η
Annealed pianoforte wire.	+75	−74	74.5	+14.2	−14.4	14.3	95.46	.022
Glass hard pianoforte wire.	+79	−78	78.5	+12.9	−13.0	12.9	147.2	.039

TABLE XLIV.

MAGNETIC CHARACTERISTIC OF SOFT NICKELWIRE.

F	L	ρ	F	L	ρ
7.5	2.03	3.7	40	5.13	$\rho = 1.00 + .17 F$
8	2.36	3.4	50	5.26	
9	2.73	3.3	60	5.36	
10	3.03	3.3	80	5.48	
12	3.58	3.35	100	5.56	
14	3.95	3.55	120	5.61	
16	4.21	3.8	140	5.65	
18	4.43	$\rho = 1.00 + .17 F$	160	5.68	
20	4.55		180	5.70	
25	4.76		200	5.72	
30	4.92		[300	5.77	
35	5.04		500	5.81]	
Absolute Saturation				5.88	

TABLE XLV.

HYSTERESIS OF NICKEL.

	Soft Nickelwire.		Ewing. Soft Nickelwire.		Ewing. Hard Nickelwire.	
F	L_d	L_r	L_d	L_r	L_d	L_r
135	±5.64					
120	5.61					
110	5.59					
100	5.56					
90	5.53		[$F_1 = \pm 83$]			
80	5.49	5.48	±4.95		±4.15	
75			4.94	4.92	4.13	4.10
70	5.43	5.40	4.92	4.89	4.11	4.06
65			4.90	4.85	4.09	4.00
60	5.37	5.30	4.88	4.80	4.07	3.94
55	5.32	5.21	4.84	4.75	4.04	3.87
50	5.26	5.10	4.80	4.70	4.00	3.78
45	5.20	4.99	4.76	4.63	3.95	3.68
40	5.14	4.88	4.71	4.55	3.90	3.53
35	5.06	4.75	4.65	4.47	3.84	3.34
30	4.96	4.56	4.58	4.37	3.78	2.97
25	4.80	4.30	4.49	4.25	3.72	2.47
20	4.60	3.88	4.40	4.08	3.64	1.65
15	4.30	3.12	4.28	3.80	3.56	0
10	3.90	1.90	4.14	3.00	3.47	—1.70
5	3.33	—.40	3.95	—2.00	3.32	—2.63
0	±2.50		±3.56		±3.11	
$H =$	12.26		12.74		23.67	
$L =$	5.64		4.95		4.15	
$\eta =$	.01220		.01562		.03849	

IX. Nickel.

Some tests were made on commercial soft nickel wire.

The cross-section of the wire was = .0156 cm.^{2}.

The diameter, = .141 cm.

For the determination of the magnetic characteristic 45 wires, of 20 cm. length, were used, giving a joint cross-section of .7 cm.^{2}.

For the determination of the hysteresis 83 wires, of 1.23 cm.^{2} joint cross-section were used.

The wire was found magnetically softer than that of Ewing.

The magnetic characteristic is given in Table XLIV., one cycle of hysteresis in Table XLV., first column.

The denotations are the usual.

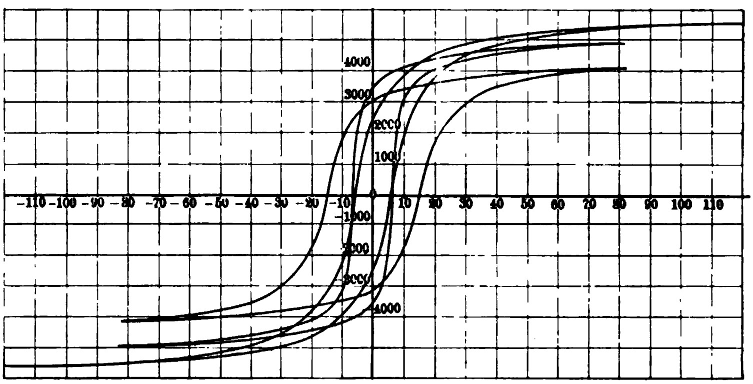


Fig. 14.—Nickel. Hysteretic Cycles.

As magnetic constants were found,

Coefficient of magnetic hardness.	Of magnetic saturation.	Of magnetic hysteresis.	Absolute saturation.
$\alpha = 1.00$	$\sigma = .17$	$\eta = .0122$	$L_\infty = 5.88$

for $F \geqq 18$.

Hence,

$$\rho = 1.00 + .17\,F \qquad F \geqq 18$$

$$H = .0122 \left(\frac{L_1 - L_2}{2}\right)^{1.6}$$

The existence of the law of 1.6th power for the hysterésis of nickel has been proved by Kennelly, by two sets of tests communicated in the "*Electrical Engineer*," April 6th, 1892.

Ewing (page 87) gives two cycles, for soft and for hardened nickel wire. From these curves are taken the values given in Table XLV., second and third column.

The two cycles are not quite symmetrical, as given by Ewing. The figures given in Table XLV. are the mean values of the positive and of the negative part of the curve.

The results are,

		$\pm F$	$\pm L$	H	η	a	σ	L_∞
Soft nickel wire	Ewing	83	4.95	12.74	.0156			
Hardened " "	Ewing	83	4.15	23.67	.0385			
Very soft " "		135	5.64	12 26	.0122	1.00	.17	5.88

These tests give for soft nickel about the same coefficient of hysteresis as for cast-iron, but a greater magnetic softness, while

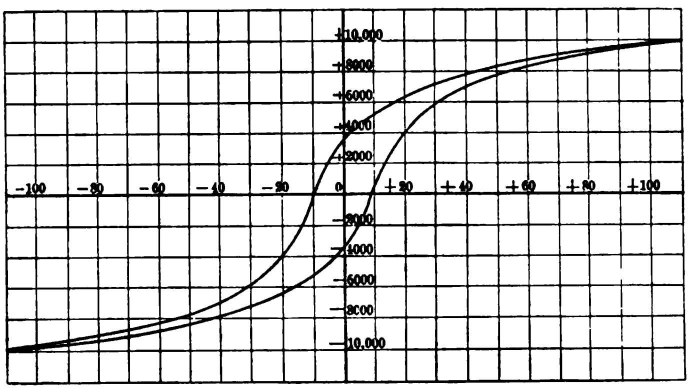


Fig. 15.—Cast Cobalt. Hysteretic Cycle. [Ewing.]

the value of absolute magnetic saturation, $L_\infty = \frac{1}{\sigma}$, is a little more than half that of cast-iron.

The magnetic characteristic is shown in Fig. 17, the three cycles of hysteresis in Fig. 14.

X. *Cobalt.*

Table XLVI. and Fig. 15 give an hysteretic cycle of cast-cobalt, from Ewing, page 89, which gives the results,

$\pm F$	$\pm L$	H	η
112	10.00	30.00	.0120

That means, cast-cobalt behaves magnetically very much like cast-iron, gives the same coefficient of hysteresis, and about the same value of magnetic saturation. Though it would be interesting to repeat these tests with different kinds of cobalt, of different degrees of softness.

TABLE XLVI.

HYSTERESIS OF CAST-COBALT (EWING).

F	L_d	L_r
112	±10.00	
100	9.8	9.75
90	9.6	9.45
80	9.4	9.1
70	9.1	8.7
60	8.8	8.3
50	8.35	7.75
40	7.8	6.95
30	7.2	5.8
20	6.4	4.0
10	5.2	.5
5	4.5	—2.0
0	±3.6	
$H =$	30.00	
$L =$	10.00	
$\eta =$	.01194 ∼.012	

CHAPTER III.—RESULTS.

Combining now the results of the foregoing tests, we arrive at the conclusions:

1. *The dissipation of energy into heat by molecular hysteresis, during a complete cycle of magnetization, performed between the limiting values of magnetic induction L_1 and L_2, is expressed by the formula.*

$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6},$$

where L_1 and L_2 very likely have to represent the metallic magnetic induction,

$$L = B - H = 4 \pi I,$$

while, when eddy—or Foucault—currents are induced by the cyclic variation of magnetization, the dissipation of energy is given by,

$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6} + \varepsilon N \left(\frac{B_1 - B_2}{2}\right)^2$$

where the first term is the loss by molecular hysteresis, the second term the loss by eddy-currents, N denotes the frequency.

2. *Beyond a certain minimum value of* M. M. F. *F_m, the metallic magnetic reluctivity, ρ (and consequently the inverse*

value of susceptibility, x, which is, $\frac{1}{x} = \frac{16\,\pi^2}{10}\,\rho$) *follows the linear law,*

$$\rho = \sigma + a\,F$$

Below this minimum value of M. M. F. F_m *first the curve of alternating, then that of rising magnetism drops below, while the curve of decreasing magnetism rises above the curve derived from the linear law,* $\rho = a + \sigma\,F$.

3 *Beyond a certain minimum value* F_m, *that is for medium and high* M. M. F's. *all the main features of the magnetic properties of materials can be expressed by three constants,* a, σ, η,

a, *the coefficient of Magnetic Hardness,*

σ, " " " " *Saturation,*

η, " " " " *Hysteresis.*

Instead of a, σ *and* η *the three constants may be used,*

$L_\infty = \frac{1}{\sigma}$ *the value of absolute magnetic saturation.*

$F_0 = \frac{a}{\sigma}$ *that* M. M. F., *where half-saturation* $\frac{L_\infty}{2}$ *would be reached if the linear law of reluctivity holds already for* F_0.

$H_\infty = \eta\,L_\infty^{1.6}$ *the maximum value of hysteretic dissipation of energy, for absolute saturation.*

Then we have the equations:

RELUCTIVITY,

$$\rho = a + \sigma\,F = \frac{F_0 + F}{L_\infty}$$

HYSTERESIS,

$$H = \eta\left(\frac{L_1 - L_2}{2}\right)^{1.6} = H_\infty\left(\frac{L_1 - L_2}{2\,L_\infty}\right)^{1.6}$$

In the latter case the exponent 1.6 only covers an absolute number, while the coefficient of hysteresis H_∞ is of the dimension "work" or "energy," = (cm.$^2\,g$ sec^{-2}).

4. *These formulas hold for all kinds of wrought and cast-iron and steel, for nickel, and magnetite, and most likely for amalgam of iron,* hence apparently for all magnetizable materials.

For air simply σ and $\eta = O$, $a = 800$.

In Table XLVII. are given in the first six columns the three magnetic constants of all materials tested,

a, σ, η viz. L_∞, F_0, H_∞ ..

TABLE XLVII.

Magnetic Constants.

MATERIAL.	Centimetre Measure.						Inch Measure.						Centimetre Measure.	Inch Measure.
	a	σ	η	L_∞	F_0	H_∞	a^1	σ^1	η^1	L_∞^1	F_0^1	H_∞^1	$\gamma \times 10^6$	$\gamma^1 \times 10^6$
Wrought-Iron, Norway Iron	.166	.05435	.002275	18.40	3.05	15.17	.065	.0084	.00189	119	7.8	248	14.4	12.0
" Ordinary Wrought-Iron	.20	.05547	.003260	18.03	3.61	21.09	.079	.0086	.00271	116	9.2	345	20.6	17.1
Sheet-Iron ; thickness, δ = .042 cm.	.275	.058	.00350	17.24	4.74	21.01	.109	.0090	.00290	111	12.1	345	22.1	18.4
" " .026 "	.275	.0507		19.7	5.42		.109	.0079		127	13.8			
" " .038 "	.290	.0561		17.8	5.17		.114	.0087		115	13.1			
" " .071 "	.30	.0522		19.2	5.75		.118	.0082		122	14.6			
" " .071 "	.35	.0542		18.5	6.46		.138	.0084		119	16.4			
" " .015 " Ferrotype, Commercial	.450	.04975	.00548	20.10	9.05	42.07	.177	.0077	.00455	130	23.0	690	34.6	28.7
" " .014 " " Annealed	.337	.04975	.004[illegible]8	20.10	6.77	35.16	.133	.0077	.00380	130	17.2	574	28.9	24.0
" " .027 " Tin-Plate	.192	.05464	.02863	18.30	3.51	18.92	.076	.0085	.00237	118	8.9	310	18.1	15.0
" " .038 " "	.321	.05315	.004255	18.81	6.04	29.37	.127	.0082	.00353	122	15.4	480	26.8	22.3
Very Soft Iron-Wire (Ewing)	.20	.0635	.002	15.75	3.15	10.61	.079	.0096	.00166	104	8.0	174	12.6	10.5
Cast-Iron No. 1	2.40	.0940	.01300	10.66	25.5	36.18	.95	.0145	.0108	69	65	592	82.0	68.
" 2	2.43	.0943	.01317	10.60	25.8	36.26	.96	.0146	.0109	69	66	594	83.0	69
" 3	2.76	.0954	.01577	10.48	29.0	42.70	1.09	.0148	.0131	68	74	700	99.5	82
" 4	2.05	.09725	.01132	10.28	21.1	29.72	.81	.0151	.0[illegible]94	66	54	486	71.4	59
" 5	2.34	.0950	.01267	10.52	24.7	34.56	.93	.0147	.0105	68	63	566	79.9	66
" 6	2.07	.0972	.01220	10.29	21.3	32.08	.82	.0150	.0102	67	54	526	77.0	64
" 7 (⅛ per cent. Aluminium)	2.37	.0976	.01365	10.25	24.3	35.77	.94	.0151	.0114	66	62	584	86.1	71
" 8 (½ " ")	2.92	.0948	.01459	10.55	30.8	39.94	1.15	.0147	.0121	68	78	655	92.1	76
Cast-Steel, Hardened	2.7	.054	.02792	18.5	50.0	187.7	1.07	.0084	.0232	119	127	3070	176.0	146
" Annealed	.88	.054	.00848	18.5	16.30	57.00	.347	.0084	.0070	119	41.4	935	53 5	44
"	2.00	.0913	.012	11.0	21.9	35.11	.79	.0141	.010	71	55.7	573	75.7	63
"	.82	.0521		19.2	15.74		.323	.0081		124	40.0			
"	.74	.0509		19.6	14.54		.292	.0079		127	37.0			
"	.76	.0534		18.7	14.23		.299	.0082		122	36.2			
"	1.26	.0931		10.7	13.64		.495	.0144		69	34.7			
" (Average of 5 Samples)	.736	.0568	.009	17.6	12.96	55.85	.290	.0088	.0075	114	33.0	912	56.8	47
"	.68	.0587		17.0	11.58		.268	.0091		110	29.5			
"	.545	.0575		17.4	9.48		.215	.0089		112	23.0			
"	.44	.0553		18.1	7.96		.173	.0086		116	20.2			

TABLE XLVII.—Continued.

Magnetic Constants.

MATERIAL.	Centimetre Measure.						Inch Measure.						Centimetre Measure.	Inch Measure.
	a	σ	η	L_∞	F_o	H_∞	a^1	σ^1	η^1	L_∞^1	F_o^1	H_∞^1	$\gamma \times 10^6$	$\gamma^1 \times 10^6$
Cast-Steel (Average of 5 Samples)	.35	.0535	.005	18.7	6.54	34.19	.138	.0083	.0041	121	16.6	560	31.6	26
"	.344	.0543		18.4	6.34		.136	.0084		119	16.1			
"	.430	.0700		14.3	6.14		.170	.0108		93	15.6			
"	.300	.0521		19.2	5.76		.118	.0070		127	14.6			
"	.300	.0543		18.4	5.52		.118	.0084		119	14.0			
"	.308	.0565		17.7	5.45		.121	.0087		115	13.8			
" No. 5	.260	.05511	.004573	18.15	4.72	29.82	.103	.0085	.00380	118	12.0	480	28.9	24.0
" No. 6	.232	.05577	.003181	17.95	4.16	20.38	.092	.0086	.00264	116	10.6	334	20.1	16.7
Mitis Metal	.300	.05444	.004281	18.37	5.51	28.46	.118	.0084	.00355	119	14.0	466	27.0	22.4
Galvanized Wire	.67	.066	.00349	15.15	10.15	17.03	.264	.0102	.00290	98	25.7	280	22.0	18.3
Welded Steel, Tool-Steel *Hk*	8.0	.121	.0748	8.28	66.1	138.9	3.15	.0187	.0620	54	168	2280	472	392
" " *H*	7.8	.105	.0613	9.53	74 3	142.6	3.08	.0162	.0508	62	188	2340	387	322
" " *Ok*	1.9	.066	.0267	15.16	28.8	130.5	.75	.0102	.0222	98	73	2140	168	140
" " *O*	1.54	.060	.0270	16.70	25.7	154.1	.61	.0093	.0224	108	65	2530	170	141
" " *Sk*	1.33	.060	.0190	16.70	22.2	108.4	.53	.0093	.0158	108	57	1780	120	100
" " *S*	1.22	.0575	.0145	17.40	21.2	88.3	.48	.0089	.0121	112	54	1440	91.5	76
Annealed Pianoforte Steel Wire (Ewing)			.0174						.0144					
Porous Iron	25.4	.604	.0425	1.66	42	6.03	10	.094	.0353	10.6	107	99	268	223
"	76	.71		1.41	107		30	.110		9.1	270			
Amalgam of Iron	500	1.12	.2314	.90	447	12.33	197	.173	.192	5.8	1140	203	1460	1220
Magnetite	8 9	.2132	.02348	4.69	41.7	17.56	3.5	.0330	.0195	30	10.6	287	148	123
Soft Nickel-Wire	1.00	.17	.01220	5 88	5.88	13.10	.394	.0263	.01015	38	14.9	215	77	64
Nickel-Wire, Soft (Ewing)			.0156						.0130					
" Hardened (Ewing)			.0385						.0320					
Cobalt, Cast			.01194						.0099					
Coiled Iron-Wire, Crossways	86.3	0	.0403				34		.0334				254	211
Laminated Iron, Crossways	31.6	0	00721				12.4		.0060				45.5	37.8
Iron Filings, 30 per cent. { Electro-Dynamometer Tests	62.5	.209	.0465	4.80	300	38.4	24.6	.0324	.0410	31.0	763	627	312	259
Iron Filings, 30 per cent. } Magnetometer Tests	77.5	.375	.0656	2.67	207	20.0	30.5	.0581	.0543	17.2	525	327	413	342

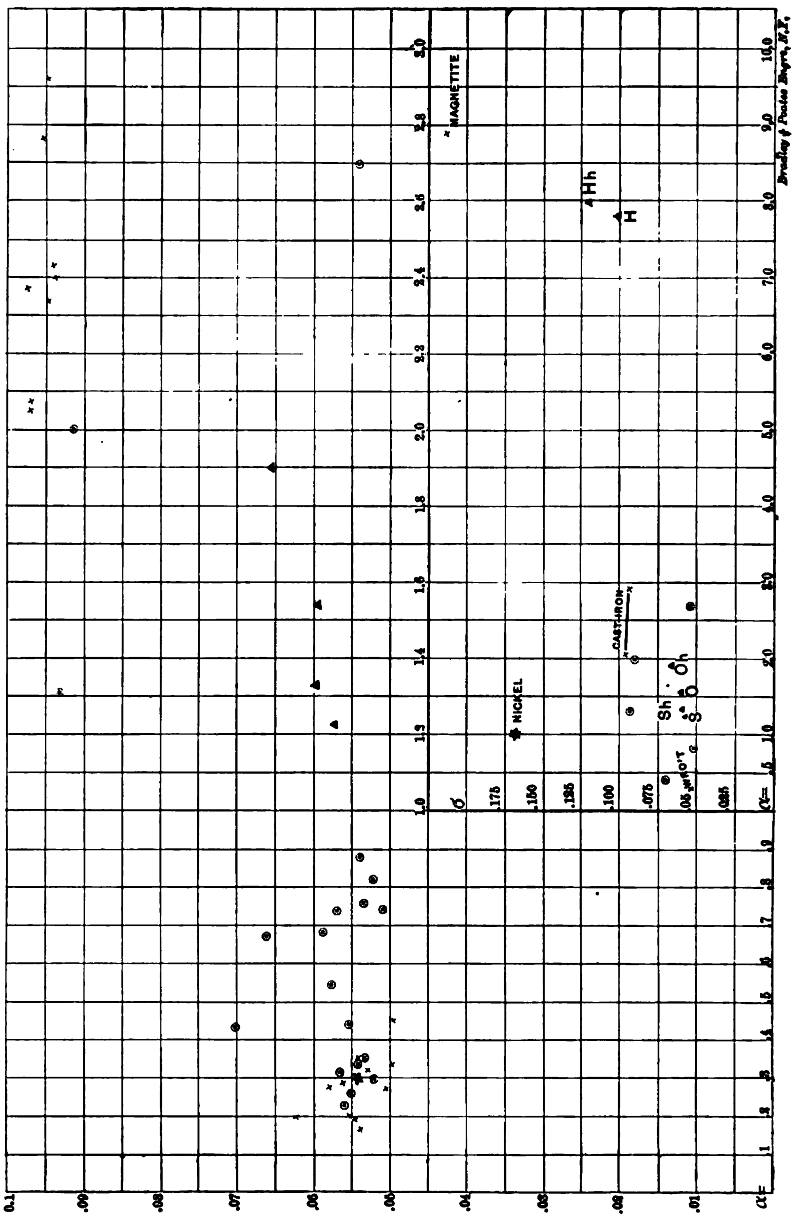


FIG. 16.—Magnetic Constants.

In Fig. 16 are given the values of α as abscissæ with the corresponding values of σ as ordinates.

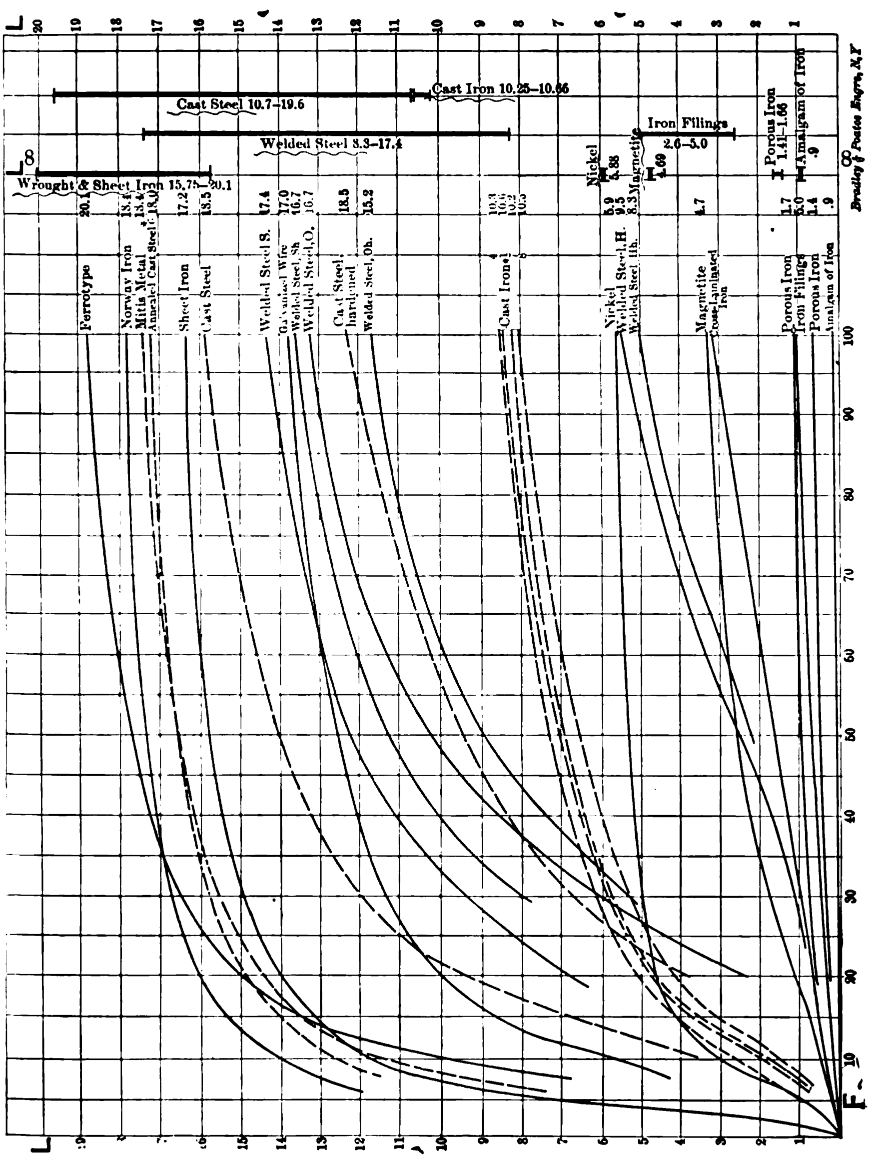


FIG. 17.—Magnetic Characteristics.

Wrought and sheet-iron, cast-iron and magnetite are marked by crosses × (since these two can not possibly be mistaken.)

Cast-steel is marked by circles ⊙, and welded steel by three-cornered dots, •

Mitis metal and Nickel are marked by six-cornered stars.

In Fig. 17 are shown the magnetic characteristics of the most interesting of these materials.

5. Referring now to inch measure, and denoting all the quantities referring to inches, by indices, we have

M. M. F., ampere-turns per inch, $F^1 = 2.54\ F$

Magnetic induction, lines per square inch, $B^1 = 2.54^2\ B = 6.451\ B$

Magnetic Hysteresis, ergs per cubic inch, $H^1 = 2.54^3\ H = 16.386\ H$

Consequently, the magnetic constants are for inch measure,

Coefficient of Magnetic Hardness, $a^1 = \frac{1}{2.54}\ a = .394\ a$

" " " Saturation, $\sigma^1 = \frac{1}{6.451}\ \sigma = .155\ \sigma$

" " " Hysteresis, $\eta^1 = 2.54^3 \times \frac{1}{2.54^{3.2}}\ \eta = \frac{1}{2.54^{.2}}\ \eta = .83\ \eta.$

$$L^1_\infty = 6.451\ L_\infty$$
$$F^1_0 = 2.54\ F_0$$
$$H^1_\infty = 16.386\ H_\infty$$

Consequently,
Reluctivity,

$$\rho^1 = a^1 + \sigma^1\ F^1 = \frac{F^1_0 + F^1}{L^1_\infty}$$
$$= .394\ a + .155\ \sigma\ F^1 = \frac{2.54\ F_0 + F^1}{6.451\ L_\infty}$$

Hysteresis,

$$H^1 = \eta^1 \left(\frac{L_1^1 - L_2^1}{2}\right)^{1.6} = H^1_\infty \left(\frac{L_1^1 - L_2^1}{2\ L^1_\infty}\right)^{1.6}$$
$$= .83\ \eta \left(\frac{L_1^1 - L_2^1}{2}\right)^{1.6} = 16.386\ H_\infty \left(\frac{L_1^1 - L_2^1}{12.902\ L_\infty}\right)^{1.6}$$

For the materials tested, these values of the magnetic constants in inch measure are given in column (7) to (12) of Table XLVII., as,

$$a^1,\ \sigma^1,\ \eta^1,\ L^1_\infty,\ F^1_0,\ H^1_\infty.$$

6. From the Coefficient of Magnetic Hysteresis, the *loss of power* by molecular hysteresis in the iron under the influence of

an alternating current of N complete periods per second, that is the heating effect of this current, can easily be calculated. It is,

In centimetre measure,

$$W = N\,10^{-7}\,H = \eta\,N\,10^{-7}\left(\frac{L_1 - L_2}{2}\right)^{1.6}\text{ watts.}$$

In inch measure,

$$W^1 = N\,10^{-7}\,H^1 = \eta^1\,N\,10^{-7}\left(\frac{L_1^1 - L_2^1}{2}\right)^{1.6}$$

$$= .83\,\eta\,N\,10^{-7}\left(\frac{L_1^1 - L_2^1}{2}\right)^{1.6}\text{ watts.}$$

Or, if we express the magnetization in kilolines, or thousands of lines of magnetic force, we get,

Centimetre measure,

$$W = \eta\,N 10^{-7} \times 1000^{1.6}\left(\frac{L_1 - L_2}{2}\right)^{1.6} = N\,\gamma\left(\frac{L_1 - L_2}{2}\right)^{1.6}\text{ watts.}$$

where $\gamma = 10^{-2.2}\,\eta = .00631\,\eta$

Inch measure,

$$W^1 = \eta^1\,N\,10^{-7} \times 1000^{1.6}\left(\frac{L_1 - L_2}{2}\right)^{1.6} = N\gamma^1\left(\frac{L_1 - L_2}{2}\right)^{1.6}\text{ watts.}$$

where $\gamma^1 = .00524\,\eta$

These coefficients γ and γ^1 are given in column (13) and (14) of Table XLVII.

Hence, making use of this Table XLVII., to find the Magnetic Induction, or Magnetization, and the Hysteresis, given the M. M. F. F, in ampere-turns per centimetre length of magnetic circuit [$F = .8\,H$ if H is the "field intensity"], we get from columns 1 and 2, α and σ and have the reluctivity,

$$\rho = \alpha + \sigma\,F$$

Hence the metallic induction, in kilolines per cm.^{2}.

$$L = \frac{F}{\rho}$$

and the whole induction,

$$B = L + H = L + .8\,F$$

Usually the H can be neglected, and $L = B$.

Taking now γ from the 13th column of Table XLVII., we get the dissipation of energy under the influence of an alternating current of N complete periods per second, in watts per cubic centimeter.

$$W = \gamma\, N\, L^{1.6}$$

where L is to be taken in kilolines.

To get B and W in inch measure, the M. M. F. F^1 being given in ampere turns per inch length of the magnetic circuit [consequently the field intensity $H = \frac{.8\, F^1}{2.54} = .245\, F^1$] we proceed in the same way, but take the values a^1, σ^1, γ^1 from columns 7, 8 and 14 of Table XLVII., and derive,

$$L^1 = \frac{F^1}{a^1 + \sigma^1\, F^1}$$

$$W^1 = \gamma^1\, N\, L^{1.6}$$

7. As M. M. F. here ampere-turns per unit length of the magnetic circuit are always used. To reduce to absolute measure, we have,

Field intensity, $H = \frac{4\,\pi}{10}\, F = \frac{4\,\pi}{25.4}\, F^1$

Susceptibility, $\varkappa = \frac{10}{16\,\pi^2\,\rho}$

Permeability, $\mu = 4\,\pi\,\varkappa + 1 = \frac{10}{4\,\pi\,\rho} + 1$

Intensity of Magnetization, or

Magnetic Moment, $I = \varkappa\, H = \frac{L}{4\,\pi} = \frac{F}{4\,\pi\,\rho}$

Magnetic Induction,
$$\begin{aligned} B &= L + H \\ &= 4\,\pi\, I + H \\ &= (4\,\pi\,\varkappa + 1)\, H = \mu\, H \\ &= \frac{F}{\rho} + \frac{4\,\pi}{10}\, F \end{aligned}$$

8. If now on the hand of the data collected in Table XLVII. and the curves represented in Fig. 17, we look over the numerical values of the magnetic constants of different materials, we see, that in

Wrought-Iron and Sheet-Iron.

The Coefficient of				
Magnetic Hardness, a,	varies from	.166	to	.450
Magnetic Saturation, σ,	"	.04975	"	.058
Magnetic Hysteresis, η,	"	.002275	"	.00548
Consequently the value				
of absolute saturation, L_∞,	"	17.24	"	20.10

The variations are considerable enough to make it advisable everywhere, where a somewhat greater accuracy of calculation is required, especially to determine the individual constants of the material employed, which can be done easily, since only three observations are required hereto, two of L, or ρ, and one of H.

As a fair average of good wrought or sheet-iron we can consider an iron of the constants,

$$\alpha = .30 \qquad \sigma = .055 \qquad \eta = .0030$$
$$L_\infty = 18.0$$

In Tables XLVIII., XLIX., L. and Figs. 18, 19, 20 the magnetic curves of this average wrought-iron are given.

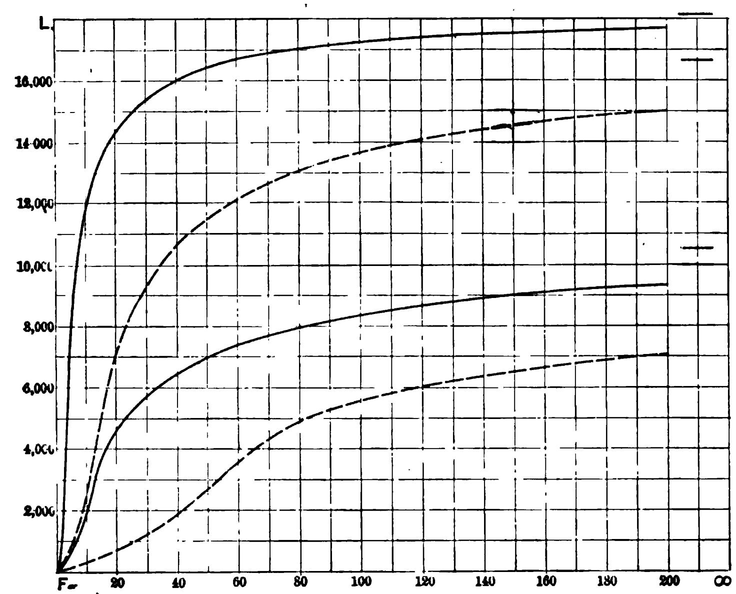


FIG. 18.—Average Materials. Magnetic Characteristics.

Cast-Iron.

Although cast-iron, as the raw-material, should be expected to vary considerably, nevertheless the difference between the eight samples tested—though derived from different sources—are remarkably small, the

Coefficient of			
Magnetic Hardness, α, varying from	2.05	to	2.92
Magnetic Saturation, σ, "	.0940	"	.0976
Magnetic Hysteresis, η, "	.0113	"	.0158
Consequently the value of absolute saturation, L_∞, "	10.25	"	10.66

Hence of *cast-iron* it is much oftener permissible to take an average set of magnetic constants,

$$\alpha = 2.40 \qquad \sigma = .095 \qquad \eta = .013$$
$$L_\infty = 10.5$$

In Tables XLVIII., XLIX., L. and Figs. 18, 19, 20, the magnetic curves of this cast-iron are given.

Welded Steel.

That is, that kind of steel which can be hardened, evidently varies in its constants enormously with its degree of hardness.

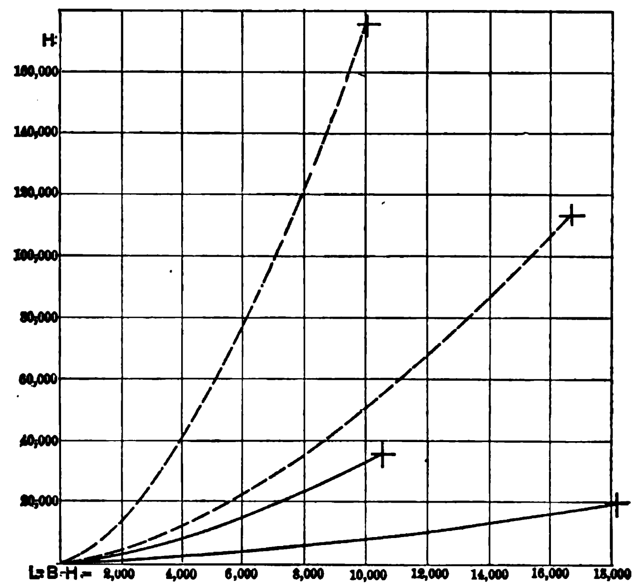


FIG. 19.—Average Materials. Curves of Hysteresis.

For instance the tests referring to one and the same material of different degrees of hardness, give the variations in

Magnetic Hardness, α, from 1.22 to 8.0
Magnetic Saturation, σ, " .0575 " .1 1
Magnetic Hysteresis, η, " .0145 " .0748
Absolute Saturation, L_∞ " 8.28 " 17.40

In comparison with cast material the relatively high coefficient of hysteresis is remarkable, as even for the softest annealed condition it is higher than the average of cast-iron.

Tables XLVIII., XLIX., L. and Figs 18, 19, 20, give two sets of curves, in dotted lines, of soft material,

$$a = 1.33 \qquad \sigma = .060 \qquad \eta = .020$$
$$L_{\infty} = 16.67$$

and glass-hard material,

$$a = 8.0 \qquad \sigma = .10 \qquad \eta = .070$$
$$L_{\infty} = 10.00$$

Coming now to

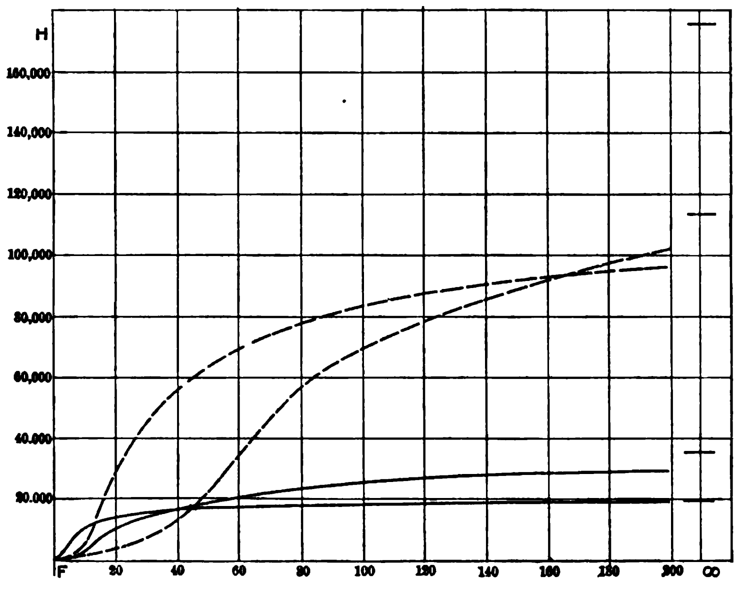


FIG. 20.—Average Materials. Curves of Hysteresis.

Cast-Steel.

We see that no averaging is possible at all, but cast-steel comprises and includes the whole range of materials, giving a continuous and unbroken range from the softest kind of sheet-iron down to and beyond cast-iron and to medium hard welded steel, as a glance on Tables XLVII., LI. shows and especially on Fig. 16 (where the cast-steel is marked by circles), and Fig. 21, where some cast-steel characteristics are shown as drawn lines together with the Norway-iron curve (*N*), the average wrought iron curve (*W*), the soft welded steel curve (*s*) and the cast-iron curve (*C*) as dotted lines.

Magnetic Hardness, α,	from	.232	to	2.7
Magnetic Saturation, σ,	"	.0509	"	.0931
Magnetic Hysteresis, η,	"	.00318	"	.0279
Absolute Saturation, L_{∞}	"	10.7	"	19.6

Consequently, for good annealed cast-steel of high permeability—as it can be got now very easily—the average wrought-

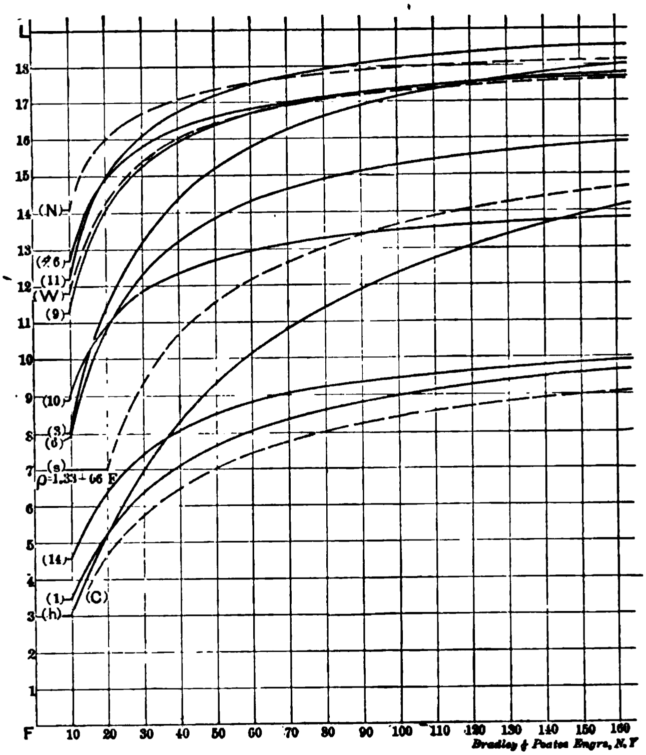


FIG. 21.—Cast-Steel. Magnetic Characteristics.

iron curves can be used, since they represent also a fair average of soft annealed cast-steel and of mitis metal.

Poorly annealed cast-steel of high permeability will give a curve similar to that of soft welded-steel, and cast-steel of low permeability is as good as identical with cast-iron, as will be best seen on Fig. 21.

In Table XLVIII. are given magnetic constants of average materials, in Tables XLIX. and L. the magnetic characteristics and curves of hysteresis calculated therefrom. In Figs. 18, 19, 20, these curves are shown, the two welded-steel curves dotted, the cast-iron and wrought-iron curves drawn.

TABLE XLVIII.

MAGNETIC CONSTANTS OF AVERAGE MATERIALS.

MATERIAL.	Coefficient of Magnetic Hardness α	Coefficient of Magnetic Saturation σ	Coefficient of Magnetic Hysteresis η	Absolute Saturation L_∞	$F \geqq$
Average *Wrought* and *Sheet-Iron*, *Soft Annealed Cast-Steel* and *Mitis Metal*	.3	.055	.003	18.2	7
Average *Cast-Iron*, *Cast-Steel* of *Low Permeability*	2.4	.095	.013	10.5	18
Average *Soft Steel*, *Hard Cast-Steel* of *High Permeability*	1.33	.06	.02	16.7	40
Average *Glass-Hard Steel*........	8	.1	.07	10.0	90

TABLE XLIX.

MAGNETIC PROPERTIES OF AVERAGE MATERIALS.

	Average Wrought and Sheet-Iron.		Average Cast-Iron.		Average Soft Steel.		Average Glass-Hard Steel.	
L	F	H	F	H	F	H	F	H
1	2	.2	7	.8	6	1.3	26	4.4
2	2	.6	10	2.5	9	3.8	42	13.4
3	3	1.1	13	4.8	11	7.3	54	25.6
4	3	1.7	16	7.5	13	11.6	66	40.6
5	4	2.5	23	10.8	15	16.6	83	58.0
6	4	3.3	33	14.4	17	22.2	120	77.8
7	5	4.3	50	18.5	20	28.4	188	99.4
8	5	5.3	81	22.9	23	35.2	320	123.1
9	6	6.4	148	27.6	28	42.4	720	148.5
10	7	7.5	500	32.6	35	50.2	∞	175.8
11	8	8.8	∞	35.5	44	58.5	[L_∞ = 10.0]	
12	11	10.1	[L_∞ = 10.5]		58	67.3		
13	14	11.5			79	76.4		
14	18	12.9			117	86.1		
15	26	14.4			200	96.1		
16	30	16.0			500	106.6		
17	67	17.6			∞	113.7		
18	600	19.3			[L_∞ = 16.7]			
	∞	19.6						
	[L_∞ = 18.2]							

TABLE L.

MAGNETIC PROPERTIES OF AVERAGE MATERIALS.

	Average Wrought and Sheet-Iron.		Average Cast-Iron.		Average Soft Steel.		Average Glass-Hard Steel	
F	L	H	L	H	L	H	L	H
1	.4	.1						
2	1.7	.4			.2			
3	3.8	1.6						
4	5.6	3.0			.6			
5	7.5	4.8	.7	1	.8	1	.1	
6	9 9	6.4			1.0			
7	10.1	7 6						
8	10.8	8.5			1.7			
9	11.4	9.3						
10	11.8	9.0	1.9	2	2.5	5	.3	1
12	12.5	10.8			3.5			
15	13.4	12.1	3.7	7	5.0	17	.5	2
20	14.3	13.5	4.6	10	7.0	29	.7	4
25	14.9		5.2	12	8.3	38	.9	5
30	15.4	15.1	5.7	14	9.3	44	1.2	7
35	15.7		6.1	15	10.1	50	1.5	9
40	16.0	16.0	6.5	17	10.7	55	1.9	13
45	16.2		6.8	18	11.2	59	2.3	17
50	16.4	17.0	7.0	19	11.5	63	2.7	22
60	16.7		7.4	20	12.1	69	3.5	33
70	16.9		7.7	22	12.6	73	4.3	46
80	17.0		8.0	23	13.0	77	4.9	55
90	17.1		8.2	24	13.4	80	5.2	63
100	17.3	18.0	8.4	25	13.6	83	5.5	69
120	17.4		8.7	26	14.1	87	6.0	78
140	17.5		8.9	27	14.4	90	6.4	85
160	17.6		9.1	28	14.6	93	6.7	91
180	17.6		9.2	29	14.8	95	6.9	97
200	17.7	19.0	9.3	29	15.0	96	7.1	102
Absolute Saturation	18.2	19.6	10.5	36	16.7	114	10.0	176

TABLE LI.

MAGNETIC CHARACTERISTICS OF CAST-STEEL.

(1)			(2)			(3)			(4)			(5)			(6)			(7)		
F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.
11	3.00	3.00	17.5	1 71	1.73	12	1.32	1.35	12	1.41	1.40	8	1.72		21	1.89	1.91	10	1.51	
27	4.47	4.47	25	2.15	2.13	18	1.66	1.66	14.5	1.56	1.54	10	1.70		28.5	2.36	2.35	18	1.62	1.58
76	9.00	8.94	32.5	2.52	2.51	25	2 02	2.01	25	2.08	2.09	15	1.76		37.5	2.88	2.88	34	2.46	2.48
92	10.34	10.40	63	4.10	4.10	34	2.46	2.47	41	2.95	2.95	20	1.95		45	3.32	3.32	76	4.92	4.92
			73	4.61	4 62	61	2.86	2.85	79	4.98	4.98	25	2.17		50	3.63	3.62	92	5.83	5.83
			85	5.28	5.26	69	4.26	4.25	97	5.95	5.94	Average of 5 Samples.			62	4.32	4.33			

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\alpha =$	2.00	.82	.74	.76	.736	.68	.545
$\sigma =$	.0913	.0521	.0509	.0534	.0568	.0587	.0575
$\eta =$	.012				.009		
$L_\infty =$	11.0	19.2	19.6	18.7	17.6	17.0	17.4
$\frac{\alpha}{\sigma} = F_0 =$	21.9	15.74	14.54	14.23	12.96	11.58	9.48

TABLE LI.—Continued.

MAGNETIC CHARACTERISTICS OF CAST-STEEL.

	(8)			(9)			(10)			(11)		
	F	ρ obs.	ρ calc.	F	ρ obs	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.
	11	1.04	1.05	12	.99	.99	8	1.04		15	1.08	1.08
	16	1.33	1.33	13.5	1.08	1.08	13	1.31	1.32	22	1.45	1.45
	21	1.60	1.60	21	1.48	1.48	34	2.83	2 81	34	2.16	2.17
	28	1.99	1.99	24.5	1.67	1.67	76	5.73	5.75	54	3.12	3.11
	40	2.64	2.65	30	1.98	1.97	92	6.90	6.87	70	3.95	3.95
	51	3.22	3.26	35	2.24	2.25				95	5.25	5.25
	76	4.67	4.64	41	2.60	2.57						
	95	5.71	5.69	56	3.39	3.39						
				65	3.87	3.87						
				73	4.31	4.31						
$a =$			.44			.344			.43			.300
$\sigma =$			.0553			.0543			.070			.0521
$\eta =$												
$L_\infty =$			18.1			18.4			14.3			19.2
$\frac{a}{\sigma} = F_0 =$			7.96			6.34			6.14			5.76

	(12)			(13)			(14)			(15) Average of 5 Samples.
	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	F	ρ obs.	ρ calc.	
	10	.84	.84	10	.85	.87	44	5.34	5.35	
	19	1.34	1.33	12	.97	.98	61	6.95	6.94	
	32	2.04	2.04	15	1.14	1.15	78	8.52	8.52	
	76	4.43	4.43	19	1.42	1.38	95	10.10	10.10	
	95	5.45	5.46	23	1.62	1.62				
				36	2.36	2.34				
				46	2.88	2.91				
				61	3.79	3.76				
				73.5	4.45	4.46				
				94	5.63	5.62				
$a =$			.300			.308			1.26	.35
$\sigma =$			.0543			.0565			.0931	.0535
$\eta =$										.005
$L_\infty =$			18.4			17.7			10.7	18.7
$\frac{a}{\sigma} = F_0 =$			5.52			5.45			13.64	6.54

With regard to cast-iron, I must remark, however, that some tests of Ewing and others show magnetizations as high as $L = 16{,}000$, while I was never able to reach much beyond $L = 10{,}000$.

It must be assumed, therefore, that either the linear law of magnetic reluctivity, $\rho = a + \sigma F$ ceases to hold for higher magnetizations than I was able to reach—which is not likely, however,—or we must assume that there exist kinds of cast-iron far superior to all the samples I ever came across, and if so, then very great improvements are possible in the manufacture of cast-iron for magnetic purposes.

CHAPTER IV.—HETEROGENEOUS MATERIALS.

I. Coiled Wire.

Since armatures of dynamo electric machines have quite extensively been wound of iron wire, I thought it interesting to determine the magnetic reluctance of wire against a magnetic flux passing crosswire through it.

Therefore I wound on a brass wire of $\frac{1}{8}$ in. diameter 6 layers of the galvanized wire, tested in Chapter II., iv., 8, the adjacent turns closely touching each other (with only the thin film of zinc between, which the wire is covered with). The consequent layers were wound always in the same direction into the interstices between the turns of the layer underneath, starting each layer separately. The outside diameter was $\frac{7}{8}$ in., so that the spiral just fitted into the holes in the pole faces of the magnetometer, which have a cross-section of 4 cm^2. The projection of the 6 layers of wire upon a plane vertical to the axis was very nearly 3.9 cm^2. The magnetism passed in the direction of the axis of the spirals, thereby crossing from turn to turn. The magnetic induction L and the magnetic reluctivity ρ were calculated with regard to the whole space taken up by the spirals, 4 cm.^{2}, no allowance being made for the hole in the middle, since it only amounted to 2 per cent. of the cross-section.

The magnetic reluctivity of this heterogeneous body was found remarkably high, about one-ninth that of common air; no decided trace of saturation was perceptible, which indeed is not astonishing, since the highest value of induction reached in the tests was only 1,900 lines per cm^2.

The magnetic characteristic is given in Table LII.

The metallic magnetic reluctivity was found $\rho = 86.3$.

The different readings indeed varied considerable, an average of 4 per cent., but these variations were entirely irregular and to be expected, since the magnetic reluctivity was very small, and the smallest fractional standard to balance with is $\frac{1}{40}$ cm.^{2} sheet-iron, of which quarters can be estimated, so that, when taking the average of two readings, a sensitivity of about 10 to 15 lines of magnetic force per cm.^{2} can be reached by the instrument.

Two magnetic cycles of this coiled wire are given in Table LIII.

Their results and the constants of the magnetic characteristics are,

$\pm F$	$\pm L$	H	η	a	σ
35	.37	.505	.0393		
140	1.61	5.60	.0414		
		av. η =	.0403	86.3	~ 0
			$\sim .04$		

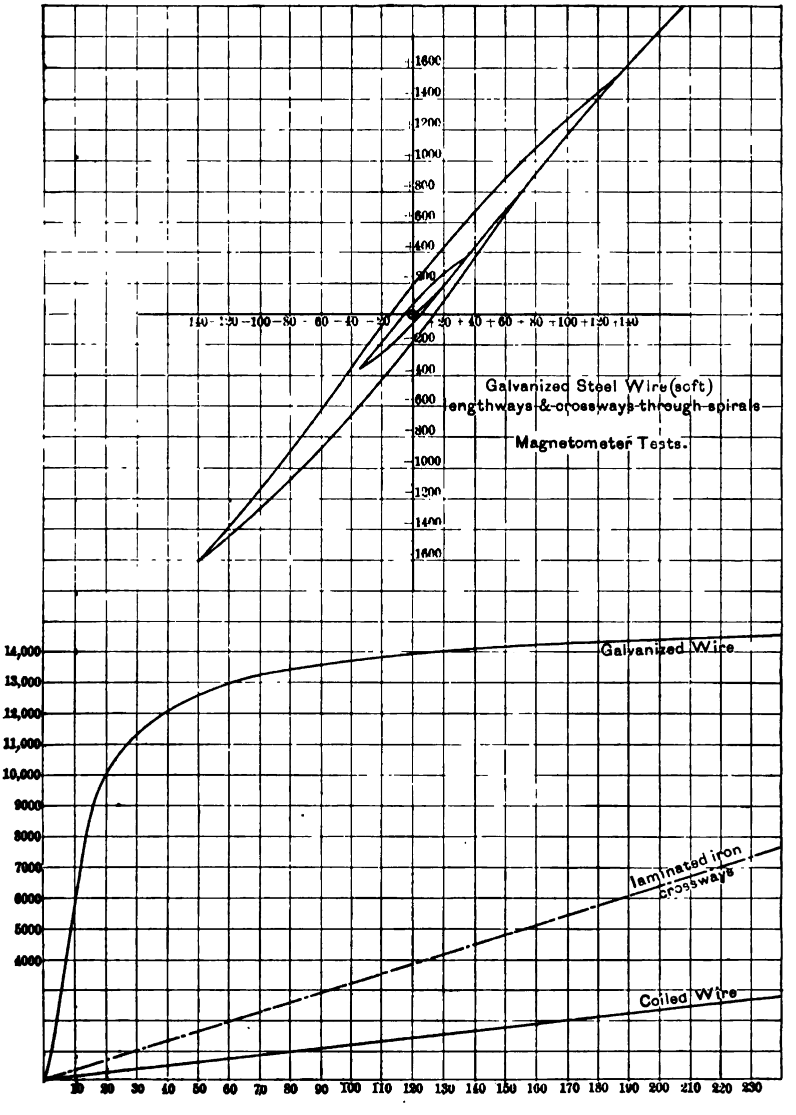


Fig. 22.—Coiled wire and cross laminated iron.

Fig. 22 gives the magnetic characteristic of this coiled wire, and of the wire magnetized lengthwise, and the two cycles of hysteresis.

TABLE LII.

MAGNETIC CHARACTERISTIC OF COILED WIRE.

F	L	ρ	$\Delta\ \rho$	= %
8.5	104	82.0	+4.3	+5
11.5	144	80.0	+6.3	+7
26	297	87.5	−1.2	−1
31	364	85.0	+1.3	+1
52	575	90.5	−4.2	−5
66	730	90.4	−4.1	−4
100	1228	81.5	+4.8	+5
116	1395	83.0	+3.3	+4
140	1555	90.0	−3.7	−4
155	1670	92.8	−6.5	−8
Av. ρ =		86.3	±4.0	±4.4

TABLE LIII.

HYSTERESIS OF COILED WIRE.

F	(1) L_d	(1) L_r	F	(2) L_d	(2) L_r
±140	±1.61		35	±.370	
130	1.52	1.50	30	.335	.315
120	1.43	1.38	25	.295	.255
110	1.35	1.27	20	.255	.195
100	1.25	1.15	15	.215	.130
90	1.17	1.04	10	.170	.060
80	1.08	.91	5	.115	−.010
70	.99	.77	0	±.065	
60	.88	.64			
50	.77	.50			
40	.66	.36			
30	.55	.22			
20	.43	.08			
10	.30	−.06			
0	±.18				
H =	5.60			.505	
L =	1.61			.37	
η =	.0414			.0393	

$$\text{Av. } \eta = .04035 \sim .04.$$

Since the reluctivity was found constant, it was interesting to determine, how far the reluctance of the spirals can be replaced by an air gap. Therefore the coiled iron wire was laid into the holes in the pole-faces at the one side of the magnetometer, and in the holes in the pole-faces at the other side of the instrument two Norway iron cylinders, of 4 cm.^{2} cross-section and 8 cm. length, were laid, with plane faces against each other, and their distance adjusted until equilibrium was restored. The distance from pole face to pole face was 10.9 cm., and it was found, that for M. M. F. of $F > 80$ the spirals can be perfectly balanced by an air gap of 1.852 cm. length, between circular faces of 4 cm.^{2}

For M. M. F's. lower than $F \leqq 80$ more lines of magnetic force passed through the air-gap than through the spirals; but the difference was small.

It was found, that the difference between the number of lines of force passing through the spirals, per cm.^{2}, and the lines of force passing through the air gap (divided by 4, to reduce to 1 cm.^{2})

at $F =$	20	40	60	80	100	ampere turns per cm.
was $\delta L =$	40	30	20	10	0	lines of force per cm.^{2}
while $L =$	230	460	680	910	1140	

was the number of lines of force per cm.^{2}, calculated by the formula,

$$L = \frac{F}{86.3 \times 10^{-3}}.$$

These values, and especially the differences δL, are indeed too small to decide whether for low magnetization the reluctivity of the air-gap has increased or that of the coiled wire decreased, or both taken place.

In so far as for higher values of L the Norway iron at the sharp edges of the circular end faces, which form the gap, may approach saturation, an apparent increase of reluctivity of the air gap is possible, while a closer contact between the spirals of the coiled wire, caused by the magnetic pull at higher values of F, may account for the decrease of their apparent reluctivity.

Comparing the reluctivity of this coiled wire with that of the wire when magnetized lengthwise, in Table XXXIV. we see, that for the low magnetizations reached in the spirals their magnetic reluctance per 1 cm. length can be replaced by that of the same iron, including an air gap of the same cross section and of .106 cm., $\sim \frac{1}{9}$ cm. length. That is, the reluctivity of coiled wire is equal to that of solid iron including about one-ninth of its length air reluctance. Indeed, these numerical values are conclusive only for the conditions of this particular test, and will differ, when different sizes of wire are used, when the wire is wound on under strain, to make a closer contact, or when insulated wire is used, and thereby adjacent turns are separated further, and will differ with the magnetization reached.

But what these tests prove is, that the magnetic reluctivity of coiled wire against a magnetic flux passing crosswise through the wire, is enormously higher than that of solid iron, is under circumstances equivalent to one-ninth of its length in air resistance.

As before stated, the reluctivity of the coiled wire is equivalent to that of solid iron including 10.6 per cent. of its length in air reluctance. The distance between the pole faces of the magnetometer being 10.9 cm., the spirals were equivalent to solid iron plus an air reluctance of $10.9 \times .106 = 1.15$ cm. length and 4 cm.^{2} cross section. But they were directly balanced by an air gap of 1.852 cm. length between circular faces of 4 cm^2. Hence, to calculate the reluctance of air gaps by the reluctance of air of the length of the air gap and the cross section of its faces,

$$\rho = \frac{\text{length}}{\text{crosswise}}$$

as is even done in the new edition of Silvanus Thompson's "Dynamo Electric Machinery," introduces a very serious error when the length of the gap is considerable compared with its cross section, caused by the spreading out of the lines of magnetic force. For instance, in the case mentioned here, the cross section of the faces being circular and 4 cm.^{2}, the length of the gap 1.852 cm., the usual manner of calculation, without taking into consideration the spreading out of the lines, will bring out the reluctance 61 per cent. too large. The reluctance of this air gap of $l = 1.85$ cm. between circular pole faces of 4 cm.^{2} = 2.26 cm. diameter, is equal to the reluctance of an air cylinder of $l = 1.85$ cm. and 6.44 cm.^{2} cross section, that is 2.86 cm. diameter, or the diameter has to be increased approximately by $\frac{l}{3}$, one-third the length of the gap. Hence,

The reluctance of an airgap of the length l between cylindrical pole faces of the diameter d is approximately equal to the reluctance of an air cylinder of the same length l but of the diameter $d + \frac{l}{3}$, hence it is,

$$\rho^{\circ} = \frac{l}{(d + \frac{l}{3})^2 \frac{\pi}{4}}$$

or, if the same is true for rectangular air gaps, as will be in rough approximation, if a and b are the sides of the rectangle, the reluctance is:

$$\rho^{\circ} = \frac{l}{(a + \frac{l}{3})(b + \frac{l}{3})}$$

as long indeed only as the length l of the gap is not greater than its diameter.

I have dwelled upon this point somewhat longer, not that I consider the results as conclusive, but because I consider it as a good topic for further investigation.

One more point is remarkable with these wire spirals:

The cofficient of hysteresis is for cross magnetization:

$$\eta = .04$$

more than ten times larger than for length magnetization:

$$\eta = .0035.$$

This is astonishing, the more, as under cross magnetization the conditions resemble those of an open magnetic circuit.

In my former paper I have already pointed out that in an open magnetic circuit the coefficient of hysteresis must be apparently larger than in a closed circuit, since in the closed circuit the magnetization is more homogenous than in an open circuit where the density decreases near the air gaps.

Since the average of the 1.6th powers of different quantities is larger than the 1.6th power of the average of the different quantities, the coefficient of hysteresis, if the magnetization is not homogenous, must come out larger by the ratio of $\frac{\text{average of 1.6th power}}{\text{1.6th power of the average}}$ of different magnetic densities. In my former paper I proved this on the instance of a magnetic circuit with two air gaps.

Here in the case of the coiled wire the magnetization must be enormously heterogenous. While the greatest part of the iron is magnetized very low, at those linear places where the turns touch each other, high saturation may be already reached. Besides, obviously a large amount of magnetism does not cross from turn to turn, but passes along the wire in spirals from pole to pole, so that really the iron is magnetized much higher than the readings give, which represent only the axial component of the magnetism. For, at the M. M. F. $F = 100$, between adjacent wire turns, is a difference of magnetic potential: $F \times d$, where d is the diameter of the wire; that is: 15.7 ampere-turns.

Now the average length of a turn is 4 cm., and therefore act spirally upon the wire $F = 4$ ampere-turns per cm., giving an induction $L = 2000$, of which only an imperceptibly small portion counts in axial direction. That is, in other words, the axis of maximum magnetization in the iron does not coincide with the direction of M. M. F. in which the readings are taken but a circular magnetization is superposed upon the length magnetization.

Furthermore, it is not impossible that in such a heterogenous body as drawn wire the magnetic constants are different axially and radially. But a still better explanation of the high coefficient of hysteresis of these spirals will be pointed out in the next chapter.

II. Laminated Iron.

The test pieces of thick tin plate of $\delta = .0378$ cm. thickness described in Chapter II., IV. *f*, Table XXXIV. were cut into pieces of 1 in. $\times$ $\frac{3}{4}$ in., built into a pile, clamped together and soldered, forming a solid block of iron with intervening layers of tin, that is: laminated crosswise; or in the direction perpendicular to the direction of the M. M. F., of 16 cm. in length and 2.53 cm. $\times$ 1.90 cm. = 4.8 cm.^{2} cross section.

The block contained 26 sheets per cm., and consequently 26 gaps filled with tin per cm. length. Each gap was equivalent to an airgap of about $\frac{1}{700}$ cm., as will be seen hereafter.

TABLE LIV.

MAGNETIC CHARACTERISTIC OF LAMINATED IRON, ACROSS THE LAMINATION.

F	L	ρ	$\triangle\ \rho$	= %
7	.22	31.5	+ .1	+ .3
11	.33	32.3	− .7	−2.2
16	.50	32.0	− .4	−1.2
29	.97	30.0	+1.6	+5.3
39	1.24	31.5	+ .1	+ .3
50	1.63	30.7	+ .9	+2.8
53	1.62	32.7	−1.1	−3.5
65	2.09	31.2	+ .4	+1.2
66	2.04	32.3	− .7	−2.2
82	2.56	32.0	− .4	−1.2
102	3.29	31.0	+ .6	+1.9
120	3.82	31.2	+ .4	+1.2
165	5.12	32.2	− .6	−1.9
	Av...	31.6	± .6	±2

TABLE LV.

HYSTERESIS AND MAGNETIC CONSTANTS OF LAMINATED IRON, ACROSS THE LAMINATION.

	F	L	H	η	a	σ
Laminated with 26 plates per cm., each gap about $\frac{1}{700}$ cm.	70	2.20	1.63	.00732		
	40	1.26	.65	.00712		
	Average			.00722	31.6	~0
Material proper				.00426	.321	.05315

Magnetometer tests gave for the reluctivity the values given in Table LIV. The magnetic characteristic is shown as dotted line in Fig. 22. As seen, up to the highest magnetization reached, of $L = 5.12$, the reluctivity is constant, $\rho = 31.6$, and the differences between the observed values and the average value are entirely irregular, and not larger than the errors of observation account for, which in such a case are necessarily larger than with homogenous materials of high permeability. The results of two magnetic cycles of this cross-laminated iron are given in Table LV, showing a coefficient of hysteresis $\eta = .00722$, while the material proper had the coefficient of hysteresis $\eta = .00426$, that is somewhat more than half the former value.

Since the magnetic reluctivity of the material proper is known, from the observed reluctivity of the laminated block and the number of sheets per cm. = 26, we can compute the approximate width of air space equivalent to each layer of tin or gap between adjacent plates and find it equal to about $\frac{1}{700}$ cm. Probably the gap is less in reality. In the average, the reluctivity of laminated sheet-iron with the laminæ very close together as in this case, is about 30 times higher than that of the sheet-iron in the direction of lamination. But even across the lamination, laminated sheet-iron is still superior to coiled wire. The coefficient of hysteresis across the lamination is still about 70 per cent. higher than along the lamination, .0722 against .0426, though not by far as much higher as in the case of the coiled wire.

This higher value of hysteresis may be partly due to a higher coefficient of hysteresis perpendicular to rather than in the plane of the sheet-iron. But mainly I believe it is caused by the unequal magnetic density at the different points of the cross-section.

The separate laminæ are evidently not absolute planes, and consequently the interstices between them not of a constant width, but the plates at some places almost in molecular contact, at other points farther apart. That means that each gap between adjacent laminæ is not of constant width, but of a width varying from almost nothing to say .01 cm. But, since the reluctance of each gap is about 30 times that of each lamina, the greatest part of the M. M. F. is consumed in the gap, and the magnetic lines of force will crowd together at those points where the adjacent laminæ come nearest together. In the iron consequently the magnetism will not flow perpendicularly across, but will largely spread sideways from the point nearest to the preceding lamina to the point nearest to the next lamina, and in consequence of this irregular cross-magnetization the magnetic density in the iron must be larger than the magnetic density in the direction of the M. M. F., and consequently η comes out larger. Numerical figuring shows that this fact fully accounts for the higher value of η without any further assumption. This effect must become less when the gaps between the laminæ are larger, for instance, sheets of paper are placed therein. Though I must leave this question also for future research.

III. Iron Filings.

Remarkable results were obtained by testing the magnetic behavior of iron filings. The iron filings were produced by clamping a large number of sheets of the iron tested in Chapter I. together, and cutting notches therein by means of a rotary cutter of $\frac{5}{16}$ in. = .79 cm. width, thereby producing fine needle-like iron chips. Tests were made by the electro-dynamometer method and by the magnetometer method. In the dynamometer method the same magnetizing spools were used as in Chapter I., and by means of these spools and two U-shaped end-pieces a box-like receptacle formed. This was filled with the iron filings, and by vigorously beating it against the table the filings were made to settle down.

In the magnetometer method a brass tube of 4 cm.^{2} cross-section and 8 cm. length was filled with these iron filings, which were enclosed between two cylindrical Norway iron pieces, and thereafter tested. The magnetic constants were found very much higher than in the electro-dynamometer tests.

Since in the electro-dynamometer tests the iron filings by beating to make them settle closer together had evidently assumed a kind of horizontal stratification, that is, stratification in the direction of the magnetic flux, while in the magnetometer tests the tube containing the filings had been filled from the end, and consequently the filings had assumed a stratification perpendicular to the direction of the magnetic flux, a higher magnetic hardness was to be expected.

Therefore a larger tube of 17.8 cm.^{2} cross section was secured, a slot cut in the tube lengthwise, the tube fastened between the cylindrical pole blocks, and then filled with iron filings from the top through the slot, and by vigorously beating the filings were made to settle down in a stratification in the direction of the magnetic flux, the same as in the electro-dynamometer tests. In all these tests approximately 30 per cent. of the volume filled by the filings consisted of iron.

One more test was made by wetting the iron filings with turpentine and stamping them tight into the brass tube of 4 cm.^{2} cross section.

1. *Electro-dynamometer Tests.*

Length of magnetic circuit, 30 cm.
Cross-section " " 13.7 cm.^{2}

Tests were made with the frequencies of 180 and 114 complete periods per second, and a few readings with still lower frequency.

The results are given in Table LVI., in the usual denotation.

TABLE LVI.

ELECTRO-DYNAMOMETER TESTS OF IRON FILINGS.

F	B	L	H obs.	ρ	μ	η_B	H calc.	Δ	$=$ %	η_L	H calc.	Δ	$=$ %
(1) 180 Complete Periods per Second, $N = 180$.													
24	323	293	400	82.0	10.8	[.0387]	470	+ 70	[+15]	[.0455]	470	+ 70	[+15]
27.7	420	385	700	72.0	12.2	.0445	720	+ 20	+3	.0511	730	+ 30	+4
36.6	523	477	1000	77.0	11.4	.0447	1010	+ 10	+1	.0518	1030	+ 30	+3
41.3	597	545	1220	76.0	11.6	.0441	1260	+ 40	+3	.0511	1270	+ 50	+4
51	738	674	1900	$\rho = 64 + .218\ F$	11.5	.0489	1780	−120	−7	.0566	1790	−110	−6
	750	690	1750			.0439	1820	+ 70	+4	.0502	1860	+110	+6
	826	740	2200			.0473	2120	− 80	−4	.0557	2100	−100	−5
70	980	892	2750		11.2	.0450	2790	+ 40	+2	.0523	2800	+ 50	+2
85	1130	1024	3480		10.7	.0454	3500	+ 20	+1	.0531	3490	+ 10	+0
98	1270	1147	4280		10.4	.0463	4230	− 50	−1	.0557	4190	− 90	−2
112	1410	1270	5120		10.1	.0468	4990	−130	−3	.0554	4930	−190	−4
Absolute Saturation..... $L_\infty = 4590$. Av η =						.0457		± 60	±2.9	.0533		± 80	±3.3
(2) 114 Complete Periods per Second, $N = 114$													
49.4	580	531	1070	74.0	11.8	.0405	1050	− 20	−2	.0467	1050	− 20	−2
47	724	665	1420	$\rho = 61 + .200\ F$	12.3	.0378	1490	+ 70	+5	.0432	1500	+ 80	+5
68	1000	915	2460		11.8	.0390	2500	+ 40	+2	.0450	2510	+ 50	+2
76	1100	1005	2980		11.6	.0405	2910	− 70	−2	.0468	2910	− 70	−2
96	1310	1190	3930		10.9	.0404	3850	− 80	−2	.0472	3820	−110	−3
Absolute Saturation..... $L_\infty = 5000$. Av. η =						.0396		± 56	±2.6	.0458		± 66	±2.8
(3) 79 and 91 Complete Periods per Second, $N =$													
79 86	1260	1152	3380	74.5	11.7	.0370	3410	+ 30	+1	.0418	3450	+ 70	+2
91 109	1510	1372	4580	79.3	11.1	.0375	4550	− 30	−1	.0436	4480	−100	−2
$\rho \sim 56 + .21\ F$. Av. η =						.0373		± 30	±1	.0427		± 85	±2

F = M. M. F., in ampere-turns per cm.

B = whole magnetic induction, in lines of magnetic force per cm.²

L = metallic magnetic induction, $= B - H$, where $H = \frac{4\pi}{10} F$ is the field-intensity.

H_{obs} = observed value of hysteretic loss, in ergs per cycle and cm.³

ρ = metallic magnetic reluctivity, in thousandths $= \frac{1000\ F}{L}$

μ = magnetic permeability, $= \frac{B}{H} = \frac{10\ B}{4\pi F}$

η_B and η_L respectively = the coefficient of hysteresis, referring to B and L respectively, that is calculated by means of the formulæ:

$$H = \eta_B \left(\frac{B_1 - B_2}{2}\right)^{1.6} \text{ and } H\, \eta_L \left(\frac{L_1 - L_2}{2}\right)^{1.6}$$

H_{calc} = calculated loss by hysteresis, and Δ = difference between H_{obs} and H_{calc}.

As seen, the magnetic reluctivity varies in the range of tests from $\rho = 72$ to $\rho = 88$.

For M. M. F.'s. of $F \geq 45$ the observations agree with the law,

$$\rho = \alpha + \sigma F.$$

But the coefficients α and σ are decidedly dependent upon the frequency, increasing with increasing frequency, while the value of absolute magnetic saturation L_∞ decreases with increasing frequency.

The coefficient of hysteresis η is — with the only exception of the one, lowest, reading — constant within the errors of observation, and proves thereby the law of 1.6th power.

But it can not be decided whether H varies with the 1.6th power of B, or of L, since either agrees with the law of 1.6th power, B and L being near enough proportional to bring the differences within the limit of the errors of observation.

Therefore for either value, B and L, the coefficient of hysteresis is calculated and given, η_B and η_L. The coefficient of hysteresis depends decidedly upon the frequency, increasing with increasing frequency. The coefficients of hysteresis are very large, giving hard-steel values.

2. *Magnetometer Tests.*

Table LVII. gives the magnetic characteristic derived from magnetometer tests.

The first two columns give the values found along the stratification, that is in the same condition as the electro-dynamometer tests, with a cross-section of 17.8 cm.^{2}; the first column found by the usual method of reversals, that is by reversing the current repeatedly before each reading; the second column gives the maximum values of magnetization taken from the slow magnetometer cycles in Table LVIII.

TABLE LVII.

MAGNETOMETER TESTS OF IRON FILINGS, MAGNETIC CHARACTERISTICS.

(1) 17.8 cm.² Cross-Section. Along Stratification.						(2) 4 cm.² Cross-Section.			(3) 4 cm.² Cross-Section.		
By Reversals.			By Slow Cycles.			Across Stratification.			Compressed.		
F	L	ρ	F	L	ρ	F	L	ρ	F	L	ρ
12	99	121	32	342	93.7	9	64	140	10	68	147
16	167	96	55	530	103.5	12	91	132	14	112	125
24	262	91.6	90	787	114.5	17	140	114	18	162	111
34	384	$\rho = 77.5 + .375\,F$	180	1250	144.0	24	222	$\rho = 106.3 + .384\,F$	27	266	$\rho = 97 + .244\,F$
44	468					30	260		34	320	
58	574					42	330		45	405	
72	690					54	400		59	512	
95	840					68	532		77	660	
130	1092					105	765		115	932	
145	1150					150	880		160	1165	
170	1220					180	985				
186	1260					210	1150				
200	1310										
225	1370										
Absolute Saturation	$L_\infty = 2670$					Absolute Saturation ..	$L_\infty = 2600$		Absolute Saturation	$L_\infty = 4100$	

The third column gives the values found across the stratification, with 4 cm.² cross-section. The fourth column gives the tests of iron filings wetted with turpentine and compressed.

Remarkable in all these tests is the considerably higher value of reluctivity, coefficient of hardness and especially coefficient of saturation, and consequently the much lower value of absolute magnetic saturation than that derived from electro-dynamometer tests.

The straight line law,

$$\rho = a + \sigma F.$$

holds for

$$F \geq 25.$$

The absolute magnetic saturation is very nearly the same across and along the stratification, a little more than half as high as found by the electro-dynamometer method. The magnetic hardness is considerably larger across than along the stratification, 106.3 against 77.5. The compressed iron filings reach a higher value of saturation, but contain more than 30 per cent. of iron.

Table LVIII. gives a number of cycles of these iron filings, and their results, the coefficient of hysteresis η being given for B as well as for L.

TABLE LVIII.

MAGNETOMETER TESTS OF IRON FILINGS, HYSTERETIC CYCLES.

F	(I.) 17.8 cm.² Cross-Section. (1) L_d	(1) L_r	(2) L_d	(2) L_r	(3) L_d	(3) L_r	(4) L_d	(4) L_r	(II.) 4 cm.² Cross-Section. (1) L_d	(1) L_r	(2) L_d	(2) L_r	(III.) Compressed. 4 cm.² Cross-Section. (1) L_d	(1) L_r
180	±1250													
170	1220	1210												
160	1190	1168												
150	1162	1123												
140	1127	1073												
130	1090	1020												
120	1050	960												
110	1010	900												
100	964	837												
90	917	770	±787						±660				[±75]	
80	868	700	750	716					620	600			±650	
70	812	620	704	640					580	530			628	607
60	757	540	650	554	[±55]				540	460			590	538
50	695	460	596	472	±530				490	390	±390		548	460
40	630	370	540	388	462	400	[±32]		450	320	360	330	493	375
30	560	280	480	296	408	305	±342		400	230	320	260	427	280
20	476	145	406	170	340	180	280	190	340	130	280	160	350	165
10	370	—55	310	—20	260	10	200	30	250	0	210	40	255	0
0	±240		±190		±150		±100		±140		±100		±150	
$H=$	6034		2820		1480		738		2300		960		2.022	
$L=$	1250		787		530		324		660		390		650	
$\eta_L=$	.0669		.0656		.0648		.0651		.0709		.0686		.0639	
	Av. η_L = .0656								.0698				.0639	
$B=$	1475		900		600		382		770		450		744	
$\eta_B=$	.0514		.0541		.0531		.0545		.0554		.0546		.0514	
	Av. η_B = .0533								.0550				.0514	

These coefficients η are larger than the values found by electro-dynamometer tests.

Table LIX. gives a collection of the different values of the magnetic constants of these iron filings, a, σ, L_∞, η_L, and η_B, as found for the material proper (Chapter I.), for the filings by electro-dynamometer tests along stratification, for the frequencies of 180, 114, and about 85 complete periods per second; by magnetometer tests along and across stratification, and compressed.

Fig. 23 gives the different magnetic characteristics, with the air line as dotted line. Fig. 24 gives the different curves of hys-

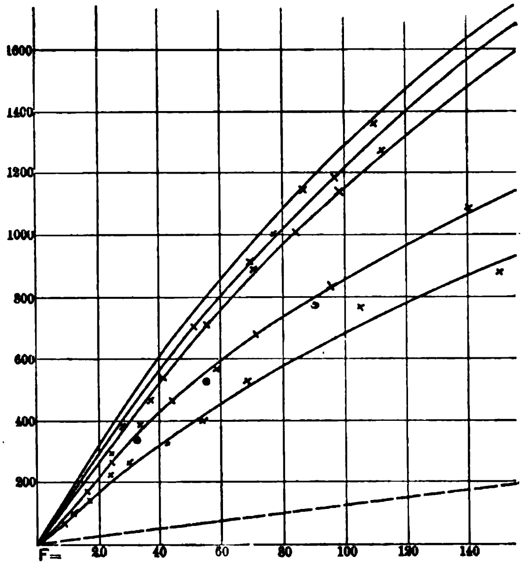


FIG. 23.—Iron Filings. Magnetic Characteristics.

teresis, the observed values being marked by crosses, and Fig. 25 gives the four magnetometer cycles of hysteresis, from Table LVIII., 1.

TABLE LIX.

MAGNETIC CONSTANTS OF IRON FILINGS, 30 VOLUME PER CENT.

	Number of Complete Cycles per Second	Coefficient of Magnetic Hardness	Coefficient of Magnetic Saturation	Absolute Saturation	For	Coefficient of Magnetic Hysteresis	
	N	α	σ	L_∞	$F \gtrsim$	η_L	η_B
The Sheet-Iron proper ..	67 ~ 170	.275	.058	17.24	~ 8	.0035	.0035
Filings, 13.7 cm.[2] cross-sec.	180	64	.218	4.59	~45	.0533	.0457
" " "	114	61	.200	5.00	~45	.0458	.0396
" " "	~85	56	.21	4.76		.0427	.0373
" 17.8cm.[2] Magnetom'r.	Very Slow.	77.5	.375	2.67	~30	.0656	.0533
" 4cm.[2], across stratifi'n	"	106.3	.384	2.60	~20	.0698	.0550
" 4 cm.[2], compressed..	"	97	.244	4.10	~25	.0639	.0514

Herefrom it seems, that α, σ and η are largest for very slow magnetic cycles, as in the magnetometer tests, *decrease* for *increasing* frequency, reach a *minimum* for a moderate frequency,

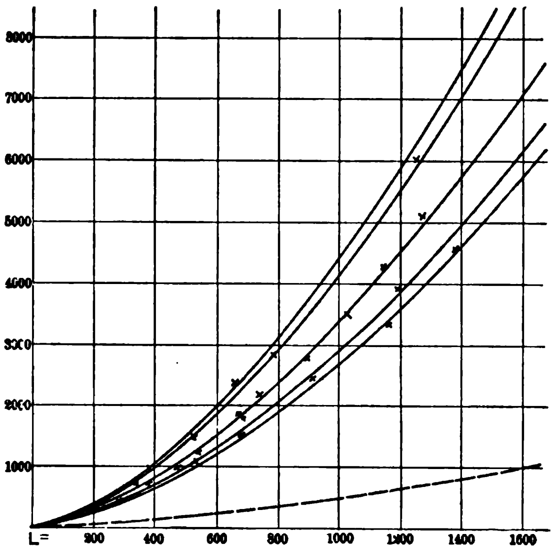


FIG. 24.—Iron Filings. Curves of Hysteresis.

and *increase* again for *increasing* frequency, though being at the frequency 180, still far lower than for slow cycles.

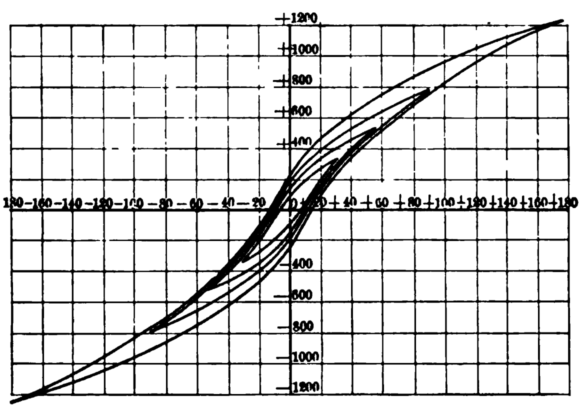


FIG. 25.—Iron Filings. Hysteretic Cycles.

For the electro-dynamometer tests, η_L can be expressed by the formula,

$$\eta_L = .0330 + .000113\,N$$

The conclusions derived herefrom are,

"*Even for such heterogeneous materials as iron filing the linear law of reluctivity,*

$$\rho = a + \sigma F$$

and the law of hysteresis,

$$H = \eta \left(\frac{L_1 - L_2}{2}\right)^{1.6}$$

hold true,

But the coefficients a, σ, η depend upon the speed of magnetic variations, reaching a minimum for moderately slow frequencies."

That the reluctivity is very high was to be expected from the introduction of air resistance in the interstices between the iron filings. But the high coefficients of hysteresis η need still an explanation, for it can not be seen how molecular friction could be larger in iron filings than in solid iron, since even the smallest iron chip is still infinitely large compared with the sizes of molecules.

The iron filings containing 30 per cent. = .3 volumes of iron, in Table LX. the magnetic constants are reduced to the iron proper by multiplying a and σ, and dividing L, L_∞ and H by .3, consequently multiplying $\eta = \frac{H}{L^{1.6}}$ by $.3^{.6} = .486$.

TABLE LX.

MAGNETIC CONSTANTS OF THE IRON CONTAINED IN IRON FILINGS, 30 VOLUME PER CENT.

	Number of Complete Cycles per Second	Coefficient of Magnetic			Absolute Saturation
		Hardness	Saturation	Hysteresis	
	N	a	σ	η_L	L_∞
The Sheet-Iron proper	67~170	.275	.0558	.0035	17.24
Filings, 13.7 cm.² cross-section.	180	19.2	.0654	.0259	15.30
" " "	114	18.3	.0600	.0222	16.67
" " "	~85	16.8	.0630	.0207	15.87
" 17.8 cm.², magnetom'r tests	Very Slow.	23.2	.1125	.0318	8.90
" 4 cm.², across stratification.	"	31.9	.1152	.0339	8.67

As seen from this table, the highest values of absolute saturation L_∞ = 16.67, come pretty near the value of the iron proper, 17.24; but the values derived from magnetometer tests remain far below that.

But even the lowest values of the coefficient of hysteresis η are still hard-steel values.

The values of η are 4 to 6 times as high as the highest values ever found for sheet-iron (commercial ferrotype) 7 to 11 times as high as average wrought-iron, and 10 to 17 times as high as the lowest wrought-iron values.

It is to be expected that the mechanical treatment in cutting the iron filings has increased their magnetic hardness and hysteresis somewhat. But it is entirely out of question that mechanical treatment can have increased η 7 to 11-fold, the more as the value of absolute saturation $L_{\infty} = 16.67$ is in contradiction thereto.

The only conclusion left is, therefore, *that the looped curve of hysteresis does not represent the energy consumed in the iron by molecular friction.*

CHAPTER. V.—CONCLUSIONS AND FALLACIES.

The tests communicated in the former chapters seem to prove that molecular friction in magnetizable materials under variations of magnetization is much more constant a phenomenon than has been usually supposed. The connection between loss by molecular friction H and amplitude of induction L seems to be absolutely rigid, while the connection between induction L and M. M. F. F is decidedly flexible, especially with lower M. M. F.'s, because L does not only depend upon the present, but also upon the former conditions of F and L and even upon the time by a kind of viscous hysteresis or better called sluggishness as observed by Ewing, and also noticed by me under certain circumstances on the magnetometer, so that for a given L the corresponding F can have a large range of different values, while H is univalent.

In concordance herewith is that for the correspondence between L and F no simple law could be found which holds over the whole range, while the law of interdependence of L and H evidently does so.

Consequently I believe that the best chance to arrive at a fuller understanding of the phenomenon of magnetism we shall have when starting in the research from the correspondence $H—L$. However, this law of 1.6th power I believe is not a *differential* law, like for instance the quadratic law of gravitation, but in an *intregal* law like the law of *probability* with which it seems to be connected in some way.

In the former chapters we have for the determination of the *molecular friction* made use largely of the cyclic curve of hysteresis, that is the correspondence between the magnetic induction and the M M. F. when the latters performs a complete cycle.

If the magnetization is given as magnetic intensity or moment,

$$I = \frac{L}{4\pi} = x\,H,$$

and the M. M. F. as field intensity H, the area of this loop directly represents the energy expended by the variation of the M. M. F., in ergs per cm.^{3} and cycle.

If the magnetization is given as magnetic induction, L or B, the M. M. F. as field intensity, H, the area has to be divided by 4π, to give the energy. But if the M. M. F. is given in current-turns per cm., the area is equal again to the consumption of energy, in ergs, or, if the M. M. F. is given in ampere turns per cm., F, since 1 ampere $= 10^{-1}$ absolute units, the area is 10 times the energy in ergs. This is another reason why I preferred the use of ampere turns per cm., F, as M. M. F., to make this area directly equal to the hysteretic energy, with a power of ten as factor, as usual in our system of practical units.

Giving L in volt lines, F in ampere turns, the area is directly equal to H in volt seconds or joules.

As said before, this looped curve of hysteresis measures the energy expended by the M. M. F. during a complete cycle.

It has been assumed then, that the area of this loop represents the energy consumed by molecular friction in the iron. This is a *fallacy*. The area of this looped curve is not the energy dissipated by molecular friction in the iron. Warburg and Ewing have shown—the former by supposing the cycle of M. M. F. performed by changes in the position of steel magnets, and determining the energy expended in performing these changes in position; Ewing by supposing the magnetic cycle produced by a cyclic variation of the exciting current in a magnetizing helix and calculating the energy consumed by the E. M. F.'s induced in the magnetizing helix by the cyclic variation of magnetic induction, that the energy expended by the M. M. F. during a complete cycle is equal to the area of this looped curve.

Hence, it has been concluded that the area of this loop represents the energy expended by molecular friction in the iron.

Here is the mistake in the conclusion. For

"*The area of the looped curve of hysteresis represents the energy dissipated by molecular magnetic friction then, and only then, when during the magnetic cycle neither energy is exerted upon the magnetic circuit by another source of energy, nor work done by or in the magnetic circuit.*"

Instances of the first case have been observed—and misinterpreted—numerously.

For instance, on pages 114–115, and on pages 319–320 in Ewing's book is shown, that under the influence of vigorous vibration, or of an alternating current passing lengthwise, that is in the direction of the magnetic flux, through the magnetized wire, the looped curve of hysteresis more or less collapses, ***hysteresis disappears.*** But *not so molecular friction.* The energy dissipated by molecular friction is simply derived not from the cyclic varying M. M. F., but from the *force vibrating the wire*, viz: from the *alternating current.* For when violently vibrating a magnetized body molecular motions are produced by the mechanical force, which consume a part of its mechanical energy. But the best proof is, that under circumstances, by the action of such a mechanical force, the magnetic loop made by the correspondence of L to F can be overturned, so that the rising curve of magnetization is higher than the decreasing, that is the cycle represents, not expenditure, but production of energy. Since obviously molecular friction can not produce energy, here the action of mechanical force is plain.

In rotating the keeper before the poles of an electromagnet, magnetism and magnetizing current are made fluctuating, and in plotting the magnetism as a function of the M. M. F., we derive such an overturned loop.

To such overturned loops, based on actual tests made on an alternating dynamo of the "humming bird" type, are shown in Fig. 26.

Here simple mechanical energy has delivered not only the energy dissipated by molecular friction in the iron, but also the energy exerted by the varying magnetion upon the M. M. F., and while the M. M. F. does not expend, but receives energy, the mechanical force of rotation expends energy. Consequently, if the magnet is not an electro-magnet, but a steel-magnet, it will be strengthened, as is well known. Another instance is, if we alternately tear the keeper off a permanent magnet and put it on again. After a number of cycles the permanent magnet will come into a stationary condition, neither lose nor gain in magnetic potential. Nevertheless, by molecular friction in these parts of the steel magnet, and in the keeper, where the magnetism varies in strength and direction, energy is dissipated. This is derived. consequently, from the source of mechanical energy. The case may be similar in dynamo-armatures. The opposite phenomenon, that the hysteretic loop represents more energy than expended by molecular friction, is still more frequent.

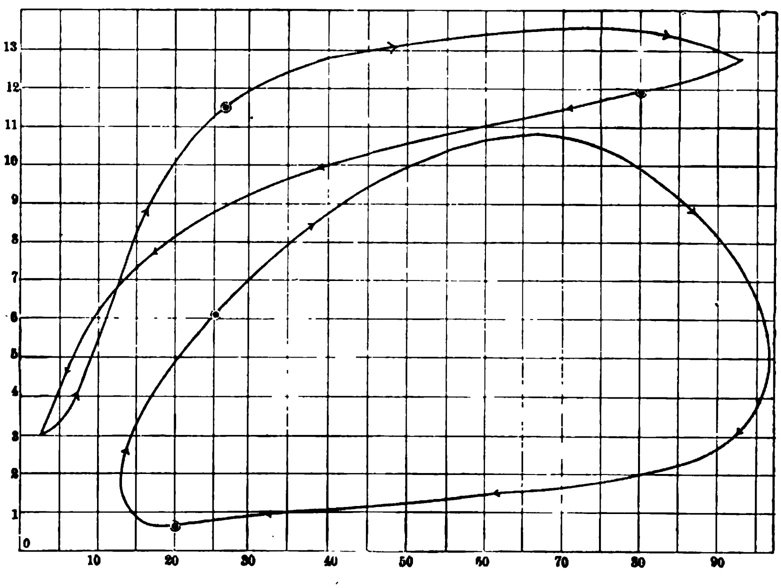


FIG. 26.—Overturned Hysteresis Loops of "Humming Bird."

For instance, if eddy, or Foucault-currents are induced in the iron, the hysteretic loop is considerably widened, and represents now not only the energy expended by molecular friction, but also the energy spent by the eddies.

But since the eddy currents are electric currents also, and represent a certain M. M. F., in this case the difficulty is overcome by stating that not the impressed M. M. F., but the M. M. F. resulting from the impressed M. M. F. and the M. M. F. of eddy currents has to be considered in determining the energy spent by molecular friction. This is still more plain in the case of the transformer, where it evidently would be incorrect to represent the induction L only as a function of the impressed M. M. F. of primary current, instead of the resultant M. M. F. of primary and secondary current.

But in the magnetic circuit built up of iron filings, as treated in Chapter IV., III., we have a case where without the existence of secondary currents the hysteresis loop represents more energy than spent by molecular friction.

In this case evidently mechanical motions take place in the iron filings, which consume energy, derived from the M. M. F.

The mechanism of action may be about the following:—When the M. M. F. increases, more and more iron filings fall in alignment, by setting up chains of filings as soon as the M. M. F. is large enough to cause the motions required hereto. When the M. M. F. decreases, these chains of filings will be maintained down to a much lower M. M. F. than was required to produce them. The consequence hereof is that—independent of molecular hysteresis —for the M. M. F. on the decreasing branch the apparent magnetic reluctivity will be considerably smaller, hence the induction larger, than for the same M. M. F. on the increasing branch—that means, the hysteric loop will be widened, and widened by that amount of energy expended by the mechanical motions of the iron filings.

The same is seen in the case of the loose wire spirals, in Chapter IV., I., where the increasing M. M. F. brings the spirals in closer contact, while in the case of the crosswise laminated iron, Chapter IV., II, no such expenditure of energy is possible, and, indeed, experiment gives a much closer agreement between the hysteretic loss of the cross laminated iron and that of the material proper, the difference being small enough to be explained by the unequalities of magnetic distribution.

To test the correctness of this reasoning, I dipped the tube containing the iron filings in melted paraffin. After having cooled down, I made another set of tests, of the hysteretic cycles of these iron filings (magnetometer tests, along stratification) and got the values:

$\pm F$:	$\pm L$	H:	η:
87	892	2606	.04959
50	616	1122	.03860
31	424	520	.03252

while the tests of these iron filings without paraffin had given: $\eta = .0656$.

The tests show a considerable decrease of the value of η, when the filings were hindered in their motion by filling the interstices with paraffin, especially for lower M. M. F's, and thereby prove the assumption.

These tests were made on a hot summer day, and the still comparatively large values of η seem to indicate, that motions of the filings still took place, especially under larger magnetic strains, that is, that with a M. M. F. $F = 87$ the paraffin partly gave way before the push of the iron filings, at the same time these tests prove conclusively, that the value η decreases, if motions of the iron filings are impeded, as was to be expected.

The simplest case of this phenomenon is that of an electromagnet with keeper excited by a slowly alternating current, at a certain M. M. F. the keeper will be attached, and then held down to a far lower M. M. F. since a much larger M. M. F. is required to attract the keeper over a distance, than is required to keep it in contact. Consequently the loop performed by such an electromagnet will not represent the molecular friction only, but this molecular friction plus the mechanical work done by the magnet.

In the alternating current synchronous motor with wireless shuttle armature the whole mechanical energy is derived by an enlargement of the cyclic curve of magnetization of the field magnet.

Very likely in the amalgam of iron we have such a case also.

An interesting fact is then, that the law of the 1.6th power holds for iron filings also, and consequently the expenditure of mechanical energy in the motions of the iron filings must follow the same law, and nevertheless these iron filings do not resemble at all the conditions claimed for the molecules of paramagnetic substances. For these iron filings are neither permanent magnets, nor are their distances infinitely large compared with their dimensions, as must be assumed for molecules.

This explains also, why the coefficient η is largest for very slow cycles, decreases, and after reaching a minimum for a moderate frequency, increases again. This explains also the corresponding variation of absolute saturation.

That, nevertheless, the law of the 1.6th power holds, proves, that this law does not depend upon a particular constitution of the material, but is of more general meaning.

Another consequence is. if, as we have seen, by mechanical vibrations the hysteretic loop is made to collapse, this does not mean, that by shaping the magnetic circuit so that the alternating magnetism produces vibration, the loss of energy by molecular friction would be avoided or overcome, as has been thought by misinterpretation of the tests referred to above, but in the contrary such an arrangement would have just the opposite effect, to add to the unavoidable loss by molecular friction the loss by mechanical vibration. It is not yet proved, indeed, that under the influence of mechanical vibration, or of an alternating longitudinal current the molecular friction is still the same, although this is made very likely by all that we know about the constancy of this molecular friction. Further tests will give more light upon this matter.

It is highly probable, that the initial inward bend of the magnetic characteristic, and the deviation of the metallic reluctivity from the linear law, caused thereby, is merely due to the expenditure of energy by the M. M. F. for molecular friction, and that consequently, if the energy of molecular friction is derived from another source, for instance mechanical vibration, the magnetic reluctivity follows the linear law from the beginning, as observed by Ewing, and the inward bend of the magnetic characteristic dissapears.

This explains the enormous increase of permeability for low M. M. F.'s., caused by vibration. In the absence of an external source of energy the rise of magnetic induction following the linear law of reluctivity is for low M. M. F.'s. made impossible by the fact, that in this case more energy must be expended by molecular friction, than would be derived from the M. M. F. by the E. M. F. induced in the exciting circuit.

THEORY OF MOLECULAR MAGNETS.

Relatively the best explanation of the phenomena of magnettic induction and of magnetic hysteresis is afforded by the assumption, that the molecules of the paramagnetic materials are permanent magnets, which, as long as no outside directing force H acts, have no definite direction and consequently no resulting magnetic moment, but, following their mutual attraction, are grouped in pairs and chains.

By the application of an outside force H, the molecules are turned into alignment with H, against the opposing forces of mutual attraction, and hereby deflected by a certain angle. Now for certain positions of molecules exists an angle of deflection, which makes H a maximum, so that for a further increase of the angle of deflection a smaller value of H is required, and consequently the H necessary to reach this critical angle of deflection overthrows the molecule—an irreversible process, which represents the loss of energy by what is called molecular friction.

This theory can not, indeed, be considered an explanation of the phenomenon of *magnetism*, since it refers it back to permanent molecular *magnetism* again; it is merely an explanation of the particular shape of the magnetic characteristic and of the loss by molecular friction.

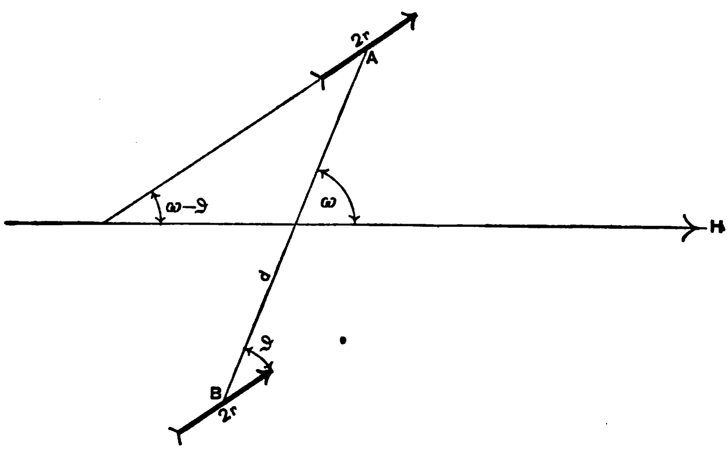


FIG. 27.—Theory of Molecular Magnets.

This theory of molecular magnets, and the unstable equilibrium reached by them for a certain H, has been worked out especially by Ewing. But in determining the fundamental equation of this theory, the equation of equilibrium of a pair of molecules acted upon by an outside force H, Ewing makes an assumption which is in contradiction to all our present knowledge of molecular physics.

All the facts of the kinetic theory of gases, of thermodynamics, etc., carry to the conclusion, that the *dimensions* of molecules are *infinitely* small compared with their *distances*.

But Ewing supposes the distance of the centres of molecular magnets is not much greater than their length, to be able to make the assumption, that the attracting force between the magnet poles pointing away from each other is negligibly small compared with the attraction of the poles pointing towards each other- while both forces become nearly *equal* by assuming the distance of the molecules very large compared with their dimensions. Ewing's assumption introduces a quadratic term into the equa, tions, where we must get a cubic term, and essentially changes the conditions of unstable equilibrium.

It would carry me too far for the scope of this paper, to give a complete essay on the theory of molecular magnets, and so I must leave this for a future paper and give only the general way of conclusions.

Let, in Fig. 27, represent

H = the direction and intensity of the M. M. F. (field intensity);
A and B, two molecules, being permanent magnets;
d = the distance of the centres of the two molecular magnets;
$2r$ = the distance of the poles of each of the two molecular magnets;
m = the pole-strength of the molecular magnets;
ω = the angle between the distance d of the centres of molecules and the M. M. F. H;
ϑ = the angle of deflection of the molecular magnets. (1)

We have, then—

Deflecting couple,

$$M = -2\, r\, m\, H \sin(\omega - \vartheta).$$

Restoring couple,

$$N = \frac{8\, r^2\, m^2 \sin\vartheta \cos\vartheta}{d^3}.$$

Consequently,

Conditions of equilibrium,

$$M + N = 0, \qquad \text{or}$$

$$\frac{4\, r\, m}{d^3} \sin\vartheta \cos\vartheta = H \sin(\omega - \vartheta). \tag{2}$$

The fundamental equation of a pair of molecular magnets. Denoting

$$\frac{4\, r m}{d^3} = \lambda, \tag{3}$$

we derive

$$\frac{\sin \omega}{\sin \vartheta} - \frac{\cos \omega}{\cos \vartheta} = \frac{\lambda}{H} . \qquad (4)$$

As condition of *unstable equilibrium*, we get from

$$\frac{d\, H}{d\, \vartheta} = 0 \qquad \text{the equation}$$

$$\left.\begin{aligned} &\tan \omega + \tan^3 \vartheta_0 = 0, \qquad \text{or} \\ &\tan \vartheta_0 = - \sqrt[3]{\tan \omega}, \end{aligned}\right\} \quad (5)$$

and, herefrom

$$H_0 = \frac{\vartheta}{\left\{ \sqrt[3]{\sin^2 \omega} + \sqrt[3]{\cos^2 \omega} \right\}^{\frac{3}{2}}} .$$

As *minimum value of* H_0, which causes unstable equilibrium, we get

$$\left.\begin{aligned} &H_0 = \frac{\lambda}{2} \qquad \text{for} \qquad \omega = 135^\circ \\ &\text{As } \textit{maximum value of } H_0 \text{, we get} \\ &H_0 = \lambda \qquad \text{for} \qquad \omega = 90^\circ, 180. \end{aligned}\right\} \quad (7)$$

Equation (5) gives the condition of unstable equilibrium,

$$\omega > 90^\circ. \qquad (8)$$

From these equations, we see now

"These pairs of molecules, which in their initial position make a sharp angle, $\omega < 90^\circ$, with the M. M. F. H, never reach unstable equilibrium; these pairs of molecules, which in their initial position make an obtuse angle, $\omega > 90^\circ$, with the M. M. F. H, reach unstable equilibrium between the values of M. M. F. $H_0 = \frac{\lambda}{2}$ and $H_0 = \lambda$, and the instability is reached first for the angle $\omega = 135^\circ$, last for $\omega = 90^\circ$ and $\omega = 180^\circ$. At this point of instability the molecules are overturned and pass by an irreversible motion—which causes the dissipation of energy into heat—in the position corresponding to the angle $\omega' = 180 - \omega$."

A complete view of these phenomena can be had best geometrically.

Considering, in a system of polar co-ordinates,

$$\left.\begin{aligned} &H \text{ as radius vector,} \\ &\omega \text{ as amplitude,} \end{aligned}\right\} \quad (9)$$

the equation (6) represents the *sextic hypocycloide*, with λ as half-axis, a curve enveloped by a straight line of constant length λ sliding within a right angle.

This curve, in rectangular co-ordinatesof the equation.

$$\sqrt[3]{x^2} + \sqrt[3]{y^2} = \sqrt[3]{\lambda^2} \qquad (10)$$

is given in Fig. 28.

It is at the same time the "Evolute of the Circle."

Only the arc in the second quadrant is of interest to us, and drawn in Fig. 29, while the arc in the first quadrant is dotted.

Set, in Fig. 29, $O\ A$ = the direction of the two molecules A and B in their initial position.

Draw the M. M. F. $\overline{O\ H} = H$ under its angle $\omega = H\ O\ A$ and lay from H the tangent $\overline{H\ T}$ on to the hypocycloide, than $\overline{T\ H}$

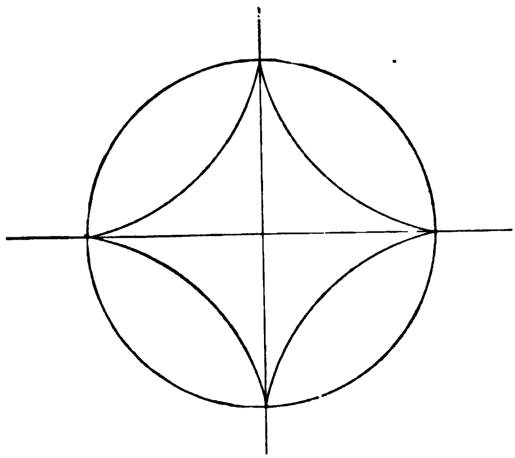


FIG. 28.—Sextic Hypocycloide.

is the direction of the molecules when deflected by M. M. F. H., and angle $H\ C\ O = \vartheta$.

In the first quadrant, $\omega < 90°$, we see that when H increases from zero to infinite, angle ϑ steadily increases from 0 to ω, also the direction of the molecules varies steadily from $\overline{O\ A}$ to $\overline{O\ H}$.

In the second quadrant, $\omega > 90°$, if H increases from zero to infinite the angle ϑ increases from 0 to a maximum value ϑ_0, which is reached at the point of intersection H_0 of the M. M. F. H with the hypocycloide.

In this point H_0 the tangent $\overline{H\,T}$ ceases to exist, instability is reached, and the angle ϑ abruptly varies from the value ϑ_0 to the value $\vartheta_0{}^1$, the molecules are overthrown from the direction $\overline{C_0\,H_0}$ to the direction $\overline{C_0^1\,H_0}$, by the angle of hysteresis,

$$C_0\,H_0\,C_0^1 = \varphi_0.$$

For a farther increase of H the angle ϑ increases again by the variation of the tangent laid on to the dotted curve.

Withdrawing the M. M. F. H again, it no longer intersects the

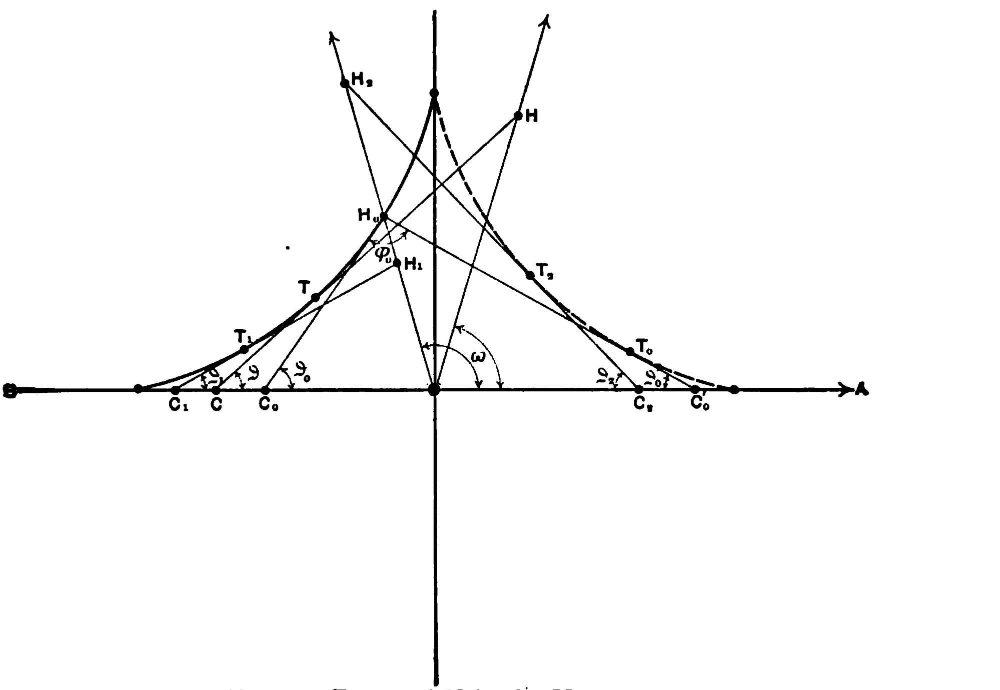


FIG. 29.—Theory of Molecular Magnets.

hypocycloide, since now, after the overthrow, the dotted curve is in use, and consequently no instability is reached.

Considering now the phenomena taking place by the action of a M. M. F. H of given direction, we see first, that the number of pairs of molecules with a given ω is proportional to sin ω, so that very few pairs of molecules exist with angles of nearly $= 0$ or $180°$, the number of pair increases first rapidly, last very slowly for increasing ω, and reaches a maximum for $\omega = 90°$.

For increasing H we see that first no irreversible motions take place, and the magnetic moment—the projection of the molecular moments upon the direction of M. M. F.—increases slowly, until $H = \frac{\lambda}{2}$ is reached. Between $H = \frac{\lambda}{2}$ and $H = \lambda$ all the irreversible action take place, and the magnetism increases rapidly, and very slowly again, after $H = \lambda$ is passed.

But since at $H = \frac{\lambda}{2}$ the circle drawn with H as radius, touches the hypocycloide, at $\omega = 135°$, a small increase of H causes a great number of pairs of molecules to be overthrown, and the magnetic moment and the hysteretic loss to increase very rapidly. But very soon, for increasing H, the circle drawn with H as radius intersects the hypocycloide under a steeper and steeper angle, the increase of the range of overthrow of ω decreases, and the rapidity of increase of magnetization and hysteresis decreases still quicker, since at the side approaching $\omega = 180°$ the number of pairs of molecules decrease fast, at the side approaching $\omega = 90°$ the number of pairs of molecules still slowly increases, but the angle of throw φ_0 decreases rapidly, so that almost all the irreversible actions, or overthrows of molecules, take place in a very short range beyond $H = \frac{\lambda}{2}$, and very few afterwards, up to $H = \lambda$.

Consequently all the irreversible actions can approximately be said to take place at a point beyond, but near $H = \frac{\lambda}{2}$.

Now is an amorphous body we must assume the molecules scattered at random so that, if D is their average distance, this is the distance of molecules existing most frequently, but all the other distances between pairs of molecules exist, in a frequency determined by a *law of probability*, and consequently, if

$$A = \frac{4\,rm}{D^3} \text{ is the value of } \lambda = \frac{4\,rm}{d^3}$$

corresponding to the average distance D of molecules, this $\lambda = A$ is the most frequent value, but all the values of λ exist, though rapidly becoming less frequent, the more they differ from $\lambda = A$.

For a given λ, the greatest part of the magnetic induction and the hysteretic loss takes place at or near a point $H = \frac{\lambda}{2}$.

Consequently, in a body as a whole the greatest part of the magnetic induction and the loss by molecular friction simply depend upon that *law of probability* which determines the distances of molecules.

This conclusion is, indeed, derived under the assumption that the molecules act upon each other only in pairs. To consider the more general case of mutual action of more than two molecules, would carry me too far here, the more as the assumption of an arrangement in pairs can not be so far from giving an approximately true picture of the phenomenon, since the mutual action depends upon the third power of distance, and consequently only the next molecule will have a greater influence.

As conclusion, we derive, then,

"*In first approximation, the magnetic induction and the molecular friction depend upon the* M. M. F. *by the law of probability of molecular distances.*"

The point of maximum increase of induction is not the same as the point of maximum increase of molecular friction, since different factors enter into the function of probability.

The *law of hysteresis*, of the 1.6th power, is the interdependence of two functions depending upon the same law of probability, hence can be of simpler form than either function.

A more complete research on these theoretical questions, I must postpone for a later occasion.

Eickemeyer Laboratory, Yonkers, N. Y., July, 1892.

APPENDIX.

1. As *Methods of Determination*, I have generally used the Electro-dynamometer method and the Eickemeyer Differential Magnetometer; using the ballistic method but a few times for controlling observations, generally employing in this case an electro-dynamometer with separately excited fixed coil as ballistic galvanometer.

The electro-dynamometer-method has the advantage of great sensitiveness and large range of readings (by varying the additional resistance), and is the only method which determines the Foucault —or eddy—currents also, in using alternating currents, its results being specially applicable for alternate-current practice. But it is limited in so far as it can be used with laminated materials only, and has the serious disadvantage of giving too small values of M. M. F. for higher saturations, so that for the determination of the magnetic characteristic it can be used only for low and medium magnetizations, while at higher saturations the wave of the current is more and more changed in shape, and becomes pointed, so that the maximum value of current is occasionally very many times higher than $\sqrt{2} \times$ the effective value. and consequently can not be calculated therefrom. Because of this feature of the method, in Fig. 2 and 3 of my former paper on hysteresis, the values of M. M. F. beyond $B = 17,000$ are given to small, being calculated from the "effective" electro-dynamometer readings as explained there. Therefore for reluctance determinations at higher saturations I abandoned the electro-dynamometer-method altogether, and used the magnetometer or ballistic method.

The ballistic method has the largest range of readings, and is applicable for any shape of test-pieces. But it has the disagreeable feature of instantaneous readings, and, in cyclic tests, the readings depend upon the exactness of former readings, so that the errors of observation are summed up. But the greatest objection to the ballistic method is, that it records only the instantaneous changes of magnetization, but fails to take account of the so-called "magnetic creeping," wrongfully called "time hysteresis," the phenomenon that on the unstable branch of the magnetic characteristic the magnetism does not increase suddenly with the increase of M. M. F., but after a smaller increase simultaneously with the increase of M. M. F., the magnetism continues to rise still for seconds and minutes. This slow rise is not recorded, and in consequence thereof the ballistic tests by the step-by-step method usually yield too low values of induction, while the method of reversals gives correct results at least for the higher values of induction.

In consequence of this creeping, with cast iron under certain conditions, the ballistic galvanometer may give a larger throw than with soft wrought iron.

The usual magnetometer method takes account of this magnetic creeping—in fact, this phenomenon has been observed by the magnetometer method (Ewing, p. 121 *et seq*); but the magnetometer is not applicable to closed magnetic circuits.

The Differential Magnetometer has the great advantage of being a zero method, yet I could not make it applicable for very low magnetizations.

2. *Demagnetizing by alternating currents, and screening effect of eddies:* It has been asserted repeatedly, that the best means of destroying remanent and permanent magnetism is the application of a rapidly alternating M. M. F., while again other experimenters failed to succeed in demagnetizing by alternating currents.

It is beyond doubt that a rapidly alternating magnetic induction leaves under normal circumstances not only no trace of remanent magnetism, but after being exposed to such an alternating magnetic induction, remanent or permanent magnetism, which before existed in the iron, are found destroyed.

But to do this, the alternating magnetic field must be powerful enough to magnetize the iron through. For the eddy-currents induced in the iron by the alternating magnetism represent a true M. M. F. also, which combines with the impressed M. M. F. so that the resulting M. M. F. in the interior of the sample may be very small or almost nil, in spite of a large impressed M. M. F. To calculate this "screening effect" of eddy-currents, we cannot assume the permeability of the iron as constant, as usually done in this case. But in another way we can determine the maximum possible M. M. F. of eddy-currents, and therefrom derive the minimum impressed M. M. F., which is sure to demagnetize the sample.

By assuming the sample magnetized by the impressed M. M. F. up to absolute saturation L_∞, we can calculate therefrom the E. M. F. and thence the eddies set up thereby, and their M. M. F.

Let us suppose the sample to be a rod or ring of circular cross-section, with radius R.

Let L_∞ be the absolute saturation attainable by the material of the sample, $\varkappa$ its specific electric conductivity, N the frequency of the alternating impressed M. M. F.

A cylindrical zone of thickness dr and radius r (and unit width) then incloses the magnetic flux,

$$m = r^2 \pi L_\infty ,$$

as maximum and, consequently, in this zone is induced an E. M. F.,

$$\begin{aligned} e &= 2 \pi M N 10^{-8} , \\ &= 2 \pi^2 r^2 L_\infty N 10^{-8} , \end{aligned}$$

and, since the electric conductivity of this cylindrical zone is

$$k = \frac{\varkappa \, d r}{2 \pi r} ,$$

the electric current induced in this zone is

$$d\,c = e\,k$$
$$= x\,\pi\,r\,L_{\infty}\,N\,10^{-8}\,d\,r,$$

and consequently the current induced in the rod per unit length, that is, the induced M. M. F., or M. M. F. of eddy-currents, is, in maximo,

$$f = \int_0^R d\,c,$$

$$= x\,\pi\,L_{\infty}\,N\,10^{-8}\int_0^R r\,d\,r,$$

$$f = \frac{x\,\pi\,R^2\,L_{\infty}\,N\,10^{-8}}{2} \text{ ampere-turns per cm.}$$

Now, suppose the sample to have 1 cm.[2] cross-section, that is,

$$R = .57, \quad \text{and let}$$
$$x = 30{,}000,$$
$$L_{\infty} = 16{,}000,$$
$$N = 100,$$

then we derive

$$f = 240 \text{ ampere-turns per cm.,}$$

as maximum value of induced M. M. F., which it would reach if the whole sample were magnetized up to absolute saturation, and no difference of phase exists between the different zones.

Hence, if the maximum impressed M. M. F. is

$$F = 250,$$

which combines with the induced M. M. F. f 240 to the resulting M. M. F. F_0; this resulting M. M. F. is

$$F_0 = \sqrt{F^2 - f^2} = 70 \text{ ampere-turns per cm.,}$$

since f lags behind F_0 by one-quarter period. Consequently, $F = 250$ may not be sufficient to quickly destroy the permanent magnetism. It will destroy it, however, after a short time, since the sample gets heated by the eddy-current and its electric conductivity x thereby decreases. So an increase of temperature up to 200° C. will decrease the conductivity by about 33 per cent., to $x = 20{,}000$, and then we get

$$f = 160\,;$$

$$\text{consequently,} \quad F_0 = 190 \text{ ampere-turns per cm.,}$$

sufficient to destroy any permanent magnetism, except, perhaps, in glass-hard materials.

With regard to these induced or eddy-currents, which circulate in laminated materials also, though in a lesser degree, upon the magnetic characteristic, when determined by the electro-dynamometer method, they will generally have no perceptible influence, since they lag one-quarter of a period behind and consequently change the resulting M. M. F. very little. Only at very high frequencies with thicker sheet-iron, the magnetic reluctance becomes apparently increased somewhat for lower and medium magnetizations, by the demagnetizing effect of the eddies, while at higher saturations the influence of eddies upon the characteristic entirely disappears even in thick sheets and for high frequencies.

3. *Denotations*:—In the foregoing, I have used the terms "cast-iron," "steel," "wrought-iron," though these terms have, nowadays, scarcely any individual meaning, either mechanically or magnetically. Mechanically, since large varieties of cast-steel are rolled, drawn into wire, etc., and thereby have assumed fibrous textures, while wrought-iron is cast in the mitis-iron, and thereby formed into an homeogeneous material, and the different kinds of cast-steel completely overbridge the gap between cast-iron and soft, tough material.

Magnetically, some kinds of cast-steel are identical with soft wrought-iron; others approach cast-iron, so that the difference between wrought-iron, steel and cast-iron does not exist, and, if we intended to classify the materials—so far as they are contained in the tests given in the paper, we would distinguish about four classes.

1. Soft material, α low, below 1, σ low, below .06.
2. Medium hard material, α medium, from 1 to 3, σ low, below .07.
3. Low permeability, α medium, from 1 to 3, σ high, beyond .09.
4. Hard material, α high, beyond 3.

In the first class range Norway-iron, sheet-iron, soft wire, annealed cast-steel, mitis metal.

In the second class cast-steel, welded-steel, etc.

In the third class some cast-steel and cast-iron.

In the fourth class glass-hard steel, magnet-steel.

4. *Chemical Analysis*:—It may be considered as of some interest to give the chemical analysis of the tested samples, and I originally intended to analyze them, but had to give up this idea because of the enormous time necessary for an exact analysis and more especially as I came to the conclusion that a chemical analysis would be of a very doubtful, if of any value For, as I have shown in the fore going, the magnetic constants of materials depend much more upon their physical than upon their chemical constitution, so that a chemical analysis can be of value only if the *physical* and *mechanical* properties of the material, and its *history* is given also, the latter in so far, as chemical constituents influence the material considerably even if they do not exist any more in the finished material, by the changes brought about by their entering and leaving the material, as it seems to be the case with aluminium, and sometimes with manganese.

This brings us to the question of the alloys of iron, of which, with regard to magnetism, very little is yet known. A research of them, comprising their history, their chemical constitution and their physical and mechanical properties, would undoubtedly lead to very interesting results. We should find alloys, which have no characteristic feature of their own, but simply show the magnetic properties of the iron, rapidly decreasing with increasing percentage of alloying material, as it seems to be the case with the iron alloys of quicksilver, aluminium, etc. Perhaps cast-iron, as carbon alloy, ranges here.

Other alloys are characteristic bodies, magnetically different from either of their constituents, as the nickel and manganese alloys. In other alloys, again, a very small percentage of alloying material has a great influence upon the magnetic constants, not directly, but indirectly, by the chemical and physical changes brought about by the addition of the alloying material to the fused iron, though this material may no longer exist in the finished iron, but have passed into the slag. So a very small percentage of aluminium and even of manganese or titanium may improve the mechanical and magnetic qualities of the iron by reducing the oxide of iron dissolved in the fused metal and causing the separation of carbon as graphite, becoming oxidized thereby itself. In this case, with increasing percentage of alloying material, the action reverses, and while a small percentage of manganese added to the fused iron increases its permeability, a larger percentage rapidly decreases it. This is the case where the *history* of the iron is of main importance, since chemical analysis does not record the added aluminium or manganese which has passed out by oxidation. But all these problems are still unsolved, offering a large and promising field for further investigation.

Yonkers, N. Y., Sept. 10th, 1892.

NOTE.—In part I. of the paper "On the Law of Hysteresis," of Jan. 19th, 1892, on page 51, in the second column of Table XIV. it should read:

$B = 14.500$	$B^{1.6} = 4.552$
16,000	5.329

C. P. S.

Discussion.

The Chairman [Vice-President Hammer]:—It may be desirable at this hour to postpone the general discussion of a paper of such magnitude and importance until a future meeting. But there are among our members to-night some gentlemen who have given this class of work their particular attention and it would be interesting to hear from them. Most of them, I believe, have received advance copies of the paper. We should be very glad to have Mr. Kennelly open the discussion.

Mr. A. E. Kennelly:—I think it will be unnecessary for me to express the general and very high opinion in which we hold the paper we have just listened to. It is a classic to us and I think it will be a classic to a great many more than ourselves. The Institute may well congratulate itself upon this paper having been read before it.

Let us, in a few words, try to outline some of the facts which we learn here for the first time. About two years ago Mr. Steinmetz first drew attention to the fact, then unnoticed, that when you magnetize a piece of iron between a certain terminal negative value and a corresponding terminal positive value—say, 5,000 C.G.S. lines per sq. cm. in one direction, and 5,000 in the other direction—the area of the enclosed Ewing loop or the hysteretic energy which had been given to the iron was a certain definite function of the maximum magnetization, namely, it varied as $B^{\frac{8}{5}}$ where B was the maximum value. That in itself was a discovery, but it was found to agree with results which had already been obtained. Ewing's own curve supplied that law. But no one would have supposed, at first sight, that if you took a piece of iron and magnetized it from 5,000 lines positive to zero and back, or from 5,000 lines positive to 2,000 lines positive and back, that you would still have the same law within that limited range. Mr. Steinmetz has shown us that it does follow even in that case. The loop itself is not the same. But the new loop, under those conditions, still retains between these values the law of the $\frac{8}{5}$th power, and I heartily congratulate him upon that discovery.

Besides that, which would be enough to immortalize one paper, we have a very interesting method of measurement given to us, upon which, perhaps, the attainment of these results depend; for it may be that without that means of measurement, Mr. Steinmetz would have had much greater difficulty in arriving at the numerous results there given to us than he actually has had. The method consists in putting, as he has described, a second coil upon the tested iron and connecting this independent coil to the wattmeter. As shown in the paper, I take it, the diagram in Fig. 1 is diagrammatical only, because there would be under the conditions of winding there indicated, a considerable magnetic leakage, and I presume, from the paper, that the three coils were wound on together. It is well to point that out, because any one trying to repeat that measurement might, by following the diagram, be led into difficulty.

With respect to the units that Mr. Steinmetz employs. I am sorry that I have the honor to differ from him. I think we should discuss this matter freely, because when a paper of this importance is generally circulated it is very desirable that we should know just in what units the results are expressed. There is nothing more convenient, one must acknowledge, than taking the total number of ampere-turns on a magnetic circuit as the magneto-motive force. There is a simplicity about it that recommends itself. But, unfortunately, it is very doubtful if you can confine that simplicity to the case which it is intended for. For example, the reluctivity that Mr. Steinmetz employs is $\frac{1}{1.257}$ times the reluctivity in the ordinary units, and the magneto-motive force is reduced to suit. The notion is very plausible that reluctivity could be kept as a thing apart in the electro-magnetic units, and that so reserved, it would not alter the general system of absolute units by a deviation from the ordinary rule. But there is this danger with magneto-motive force, particularly in the sense in which Mr. Steinmetz employs it, namely, that magneto-motive force per centimetre of circuit is really of the nature of a flux density, that is to say, so many lines of force per sq. cm. When you divide the total magneto-motive force in a circuit by the total length of that circuit you get a quantity of the nature of intensity or lines of force to the unit of area, and there will always be the danger of persons confusing the entire electro-magnetic system by using this unit. For example, in describing the intensity of the earth's field, you might get drawn into using a value for the earth's intensity of field which would be 20 per cent. too small, and which would conflict with all our existing notions. The existing system of electro-magnetic units may perhaps be likened to a card-house. It contains defects, but if you try to pick out the defects by taking out one card, you may destroy the whole construction. So that while one cannot but admire the simplicity of this device, there is a danger in it. However, all that we have to do in this case is to add 25 per cent. to the stated reluctivities and to the magneto-motive forces in order to convert them into the ordinary values.

Mention is made in the paper about iron being improved by aluminium up to a certain point, and afterwards the reverse action taking place. I think the fact of the improvement consists in the absence of the aluminium. That is to say, up to a certain point you put aluminium into the material that is going to be cast, and in the process of casting that aluminium disappears in combination with other impurities gaseously. The resulting iron is left more nearly pure. But if you put too much aluminium in, a certain excess will remain which is a new impurity and so affects the curve.

MR. WM. STANLEY, JR.:—It seems to me that Mr. Steinmetz has done for the magnetic circuit very much what Ohm did for the electric circuit. He has defined the law relating loss of energy to flux. I feel utterly unable to discuss the paper in the same terms Mr. Steinmetz has given it to us, because few of us have been equipped with the knowledge and the facilities necessary to investigate the problem as he has. But to the constructing engineer working with the alternating current appliances of to-day, the paper of Mr. Steinmetz affords more assistance than anything we have ever had the pleasure of listening to.

One of the most remarkable things about the paper is the agreement of the results. We are accustomed to look upon decimal figures of the third place as rather uninteresting and are skeptical as to their value, but Mr. Steinmetz's results seem to show the most remarkable agreement.

Can Mr. Steinmetz give us any physical picture that will allow us to realize in any way how it is that this wonderful discovery that he has made is true—how it is that when the induction is varied between any two limits, the loss of energy is the same? If we consider that we have 2,000 lines passing through a centimetre of iron, and add 10,000 more to it, we seem to use up the capacity of that centimetre, and it seems natural that the energy spent must be greater than if we reverse the magnetization between equal limits through the zero point of magnetization. Can Mr. Steinmetz give us any picture of how it is that the hysteretic loss due to the changing magnetization is constant when the included limits of induction are the same?

Mr. Steinmetz has spoken of the change of the magnetic hardness of the steel that he has experimented with, and the effect of the alternating current upon that property. I am not prepared to say now that we have discovered that iron, subject to alternating magnetization, ages, but we are very suspicious of it. We have found that transformers whose hysteretic loss was well known at the time they were manufactured, after being in continuous service for over a year had an increased hysteresis in some cases amounting to 40 per cent., and we found, after pulling out the cores of the transformers and rebuilding them (placing them in other coils and rebuilding them), that we were unable to change the hysteretic loss unless we *re-annealed the iron.* When the transformers were first made, the iron was very carefully annealed and it was extremely soft. The iron which we employ, when up to its standard value, has a hysteretic coefficient which corresponds, as nearly as one can reckon, with the coefficient given by Ewing. It is American iron, made especially for our purposes, almost free from carbon and is extremely uniform. But the slightest alteration of the annealing condition produces enormous differences in the quality of the metal. For example, the metal is obtained in sheets which are approximately 4 feet long and 2 feet wide. The iron at the edges of the sheet is well annealed—blued, extremely soft, and its hysteretic coefficient is very low. The iron taken from the centre is often very different—much harder, and may have a hysteretic coefficient 20 or 30 or, possibly, 40 per cent. higher, and, furthermore, the entire sheet may be made uniform by having it cut up and properly annealed; so that it is very necessary to carefully anneal iron in all cases where it is used in a magnetic core.

Mr. Steinmetz speaks of ferrotype iron. I have found it to vary greatly, and I have found it was the most difficult metal I have ever attempted to get into uniform and standard shape. But if the iron be very carefully annealed and if the process be continued for a week; if the iron be heated up to a red temperature and then be allowed to cool very slowly for a week, it possesses a very low hysteretic coefficient, with extremely high permeability. I was greatly interested in the description Mr. Steinmetz gave of the loss of energy, in the case of the iron filing experiment, being much greater than could possibly be due to hysteretic loss, and it occurred to me to ask him how the iron filings were placed in the field—whether it was possible that the field shifted. If one takes a test tube partly filled with filings and places it in a moving or Tesla field, the filings will be seen to jump around and, if the field be made strong enough and its direction shift enough, the filings may be pulled in various directions inside the tube.

I cannot pass by the opportunity of asking some of the members here to criticise an experiment we have made. The experiment is this [making a sketch on the blackboard] and it is probably misleading, but it has not been explained. If a coil of wire be wound around an iron core, and especially a core which has an air-gap which does not form a closed magnetic circuit, the magnetizing power required to magnetize the core will be dependent primarily on the potential which is employed and upon the reluctance of the circuit. An alternating E. M. F. being applied, a certain amount of current will flow dependent upon the reluctance. Now, that component of the current which does flow and which lags 90 degrees behind the energy current can be supplied by a condenser located in parallel with the coil. Such a condenser is supposed to be represented here. So that if the coil required 10 amperes of current to magnetize it, and the energy wasted is represented by one ampere, then, theoretically, we ought to be able to supply the one ampere from the source of supply, while the lagging current would come from the condenser and would be equal to the $\sqrt{10^2 - 1^2}$. These conditions, however, are practically impossible, because of the fact that the hysteretic loss in the iron distorts the shape of the wave of current and it is no longer a sine-shaped wave. We therefore, instead of being able to supply one ampere of current from the source of supply, have to furnish a current of about three amperes, or one-third of the total value. Now, if, instead of using a frequency of 130 periods a second, in this experiment we decrease the frequency to one-half, keeping the magnetization the same, and if we again place a suitable condenser in parallel, we will be able to furnish more of the current from the condenser than in the first place. Now, why is it that we cannot furnish the entire current from the condenser? Obviously because, in the first place, of the shape of the wave, and secondly, I think, because the whole wave lags in time. With a sufficiently low frequency we are able to almost entirely supply the necessary current from the condenser, the source of supply giving only the energy current.

Now, I am aware that this is rather away from the subject in question, but if the theory that I hold of it is correct, the wave of magnetism in the coil, does not lag at low frequencies as much as it does at the higher frequency, while the loss of energy is less at the lower frequency; it is so small in all cases as to be inconsiderable. The experiment has never been tried with sufficient accuracy to warrant my giving any more than this suggestion of it, and I would like it to be pulled to pieces by Mr. Steinmetz and some of the other gentlemen, if they can do it.

MR. MAILLOUX:—I would like to ask Mr. Steinmetz about the formula on page 679 ($H_\infty = \eta L_\infty^{1.6}$). I do not quite see how one can get infinity to a higher power.

DR. CHAS. E. EMERY:—This paper of Mr. Steinmetz has evidently required an enormous amount of earnest work. The results in general are novel and some of the experiments so exhaustive, that further investigation in the same direction seems unnecessary. While we expect to criticize some of his generalizations, his demonstration that what he terms "loss by hysteresis" is proportional to the "amplitude of magnetic fluctuation" independent of absolute values, is a very notable example of successful experimental investigation, for which, as well as the clear and complete manner in which the subject has been examined and presented, he is to be commended and congratulated.

Years ago when making original investigations in an entirely different field, I found it desirable at times to stop and *think*, and especially to compare the bearing of the recent work upon that previously accomplished, and endeavor to make some practical application of the digested results. If we adopt this policy in relation to this paper, and calculate the so called loss by hysteresis in the core of an armature making only 1,000 revolutions per minute, with the magnetization alternating between minus and plus 16,000 lines per square centimetre, we find that according to the formula of Steinmetz on page 685 of his paper such loss will be something over 13 per cent. We all know that such a loss is impossible. Dynamos and motors show mechanical efficiencies of over 90 per cent., and they as well as transformers show electrical efficiencies so nearly 100 per cent., that when the losses due to resistances are considered there is no loss of practical value left for hysteresis or even eddy resistances. Prof. Ewing (page 315) notes from experiments of Mordey, that the apparent loss by hysteresis in the core of an armature is not as great as shown by calculation, and states "the molecular theory makes it probable that the work spent in reversing magnetism will be less when the reversal is accomplished by rotation in a constant field, than when it is accomplished by reducing the magnetic force to zero and restoring it with sign reversed." This explanation, even if sufficient, does not explain how transformers can be so efficient if there be a loss by hysteresis even of a few per cent. In the other cases, however, it does not seem possible, even considering all reactions between field and armature, that the magnetization is not in all cases reversed in the latter. Now, however, Steinmetz shows that it makes no difference even if such reversal does not take place. The apparent loss is due to the total amplitude of change, not to change of sign. This additional evidence makes it proper to assert, as has been my impression for a long time previously, that the loss by hysteresis is not proportioned to the reduction of the magnetization by pulsating and alternating currents, but that the phenomenon of hysteresis merely shows a reduction in the inductive capacity of iron; that the change of magnetic potential, merely operates to change the permeability, and though the curve of magnetization is reduced by the area of the loop showing the effects of hysteresis, this does not produce loss of energy in any greater sense than is involved in the difference of permeability for different degrees of exciting force under other circumstances. In my recent paper on "Magnetization", magnetic phenomena are examined on the basis that magnetism is due to etheric flow which is intensified by the action of molecular magnets. The phenomenon of hysteresis can only affect this intensification, or what is called by Ewing the "metallic induction", and on the basis stated we can well explain hysteresis on the principles of inertia and delayed action between cause and effect, knowing that the molecular magnets are masses, even though minute; that they are also subject to molecular constraint, and consequently that there is such a thing as "time lag" in magnetism (page 322 of Ewing), so that the result is exemplified very familiarly by the delayed action of the tides.

It may be claimed that loss must ensue on account of the resistance, or the "reluctance" (if the majority wish so to call it), of a magnetic circuit, and that energy must be absorbed in overcoming such resistance. This is true, but it is provided for by the extra turns which produce additional exciting force sufficient to overcome the resistance. If the reluctance is increased by changes in the magnetic potential, the number of lines that can flow are reduced, the same as if the air-gaps in the circuit were increased. The energy represented by the extra exciting force is a loss which must appear as heat, but such heat is not due to hysteresis in any more direct sense than an increase of reluctance caused by air-gaps or by crowding more lines through a given area. It seems evident, therefore, that the loss by hysteresis is to be measured not by the loss in magnetization but by the proportional increase in exciting force necesssary to overcome the increased reluctance, exactly as losses are now measured for reluctances due to other causes. It is thought best to group all the causes which decrease the permeability, or in other words increase the reluctance, in one group, when it will be found, as has been the case with both dynamos and transformers, that it is most economical to increase the weight of the iron, of course within reasonable limits, and thus reduce the intensity of magnetization and secure the advantage of the great increase in permeability due to forcing fewer lines through unit area.

The generalizations in the paper by which the magnetic properties of different materials are expressed as constants in various equations are very interesting, and will undoubtedly serve valuable purposes. It cannot, however, be allowed that one application of the Frölich function is sufficient to express through wide ranges the relation of the exciting force to the magnetization. Ewing (page 257) designates the reciprocal of the permeability by the character ρ and calls it "the specific magnetic resistance." To this quantity Kennelly applied the term "reluctance" (crediting it originally to Heaviside), and derived its value from one of the forms of the Frölich function, calling particular attention to the fact that it showed a linear relation between the reluctance and the exciting force. Steinmetz, however, adopts the original application of this function to the *metallic* induction as given by Ewing (page 320). Kennelly found for the experiments examined by him that the equation for the reluctance required two applications to approximately represent the experimental relations, whereas Steinmetz appears to claim that if the metallic induction be used instead of the total induction, the relation can be satisfactorily represented through satisfactory limits by one application. The function in all cases is that of Frölich, and the fact that it is stated in different terms makes no difference. The result finally, when the relations of B and H are plotted in a curve, must be the same as if the Frölich function in its original form were employed to compute points in such curve. S. P. Thompson in his work calls attention to the fact that the Frölich function is not satisfactory in all cases, and in Part II of my recent paper on "Magnetization," Fig. 3 shows the application of this function, with Mr. Kennelly's constants, to the experiments from which such constants were derived. The result is, that the calculated and experimental curves coincide at two assumed points (independent of the origin from which all curves of this kind must start), and approximately near such points, but for the higher values the curves are rapidly separating. The adoption by Steinmetz of Ewing's application of the Frölich function to the metallic induction instead of the total induction used by Kennelly is quite insufficient to make the function applicable to a much greater extent to different materials, for the reason that within ordinary practical limits the metallic induction forms a very large proportion of the total induction, as may be seen readily by referring to Fig. 6 in my recent paper previously referred to, where the metallic induction designated L by Steinmetz is called I, following the lead of Ewing (page 320) where he states the form of the Frölich function. This, however, should have been designated by I_1; or some other distinguishing character, as it is not the same I used by Ewing in the earlier chapters of the same work. Both refer to the metallic induction, but I is first used by Ewing to express the "intensity of magnetization," or the induction, in turns of current in absolute units, whereas it is employed the second time, and so used by myself, to express the metallic induction or concentrating influence of the iron in magnetic lines. In writing Part II of my paper on "Magnetization," I endeavored to bring together the latest information as to the relation of magneto-motive forces and the resulting magnetizations, so as to give empirical formulae showing with satisfactory accuracy such relations. Among other things I selected a most complete table published by Mr. Steinmetz in Part I of the paper on hysteresis, now under discussion, relating to experiments with sheet-iron and agreeing well with two accompanying tables referring to the same material, but when the results had been tabulated in connection with other experiments, I was obliged to state (Sec. 28) that the initial results were so low and the others so high, that it was necessary to hesitate in accepting them without further investigation. In the present paper, Part II, Mr. Steinmetz gives a similar table showing the average magnetic properties of five samples of sheet-iron, obtained, so far as can be gathered from the paper, by the use of the same experimental methods, but the higher values are 18 per cent. less than those given in the first table, and others accompanying for the same class of material. Several values taken from the two tables are given in parallel columns in the accompanying table with corresponding data from other sources; for instance, results given by S. P.

MAGNETIZATION OF SHEET-IRON.

Exciting Forces.		Steinmetz On Hysteresis.		Hopkinson. Thompson.	No. 8 Cornell.
H_1 or		Paper I.	Paper II.	(Wrought Iron)	
F	H	B	B	B	B
5	6.3	9200	7706	10600	10150
10	12.6	13070	11723	13300	13100
20	25.1	15200	13975	14750	14450
40	50.3	17050	15525	15950	15500
60	75.4	18650	16135	16600	16100
80	100.6	20080	16480 calc.	....	
83.5	105	20300	16420	17000	
278.4	350	....	17350	19000	

Thompson with wrought-iron, and one of those recently obtained at Cornell University with sheet iron and referred to specifically in Part II of my paper as the "Cornell experiments." The comparison shows distinctly that the higher results first given by Mr. Steinmetz were altogether too high. The intermediate results from the later table correspond more closely to those given by others, but the initial ones are still very low, and if we calculate the higher values with the constants given, we find that these are also low compared with those given by Thompson based on Hopkinson's experiments. It may be that Mr. Steinmetz is right and others are wrong, but the discrepancies pointed out are sufficient to make us fear that in undertaking work of such magnitude, errors due to calibration of instruments, and those due to particular methods, have crept in so that we cannot be certain of absolute results at all limits, though the value of the comparative results for different materials cannot be questioned. The application of the Frölich function in Fig. 3 of my paper shows that it tends to reduce the higher values, and in applying the same in a foot note, Sec. 32, I was obliged to apply the function twice to approximate the experimental results. With our present information, therefore, we must claim that the Frölich function, even in the form used by Mr. Steinmetz, is not always applicable, and the generalizations based thereon cannot as a whole be accepted, though the tabulated values are undoubtedly of great value for comparison with other results obtained with the same apparatus, and with instruments standardized on the same basis.

MR. TOWNSEND WOLCOTT:—I think one of the most interesting results of Mr. Steinmetz's investigation is that the loss of energy for which he has constructed his formula is not necessarily hysteresis loss at all, but the molecular friction loss. That is to say, there is no necessary relation between the hysteretic loop and the loss by alternating polarity in the iron. A number of years ago, before the different permeabilities of iron and air were so thoroughly investigated, there were a number of inventors devoting their attention to making machines without any iron in the armature. Among them was Dr. Chas. A Seeley. I had some business connections with him. We thought at that time that there was, in addition to the loss in the iron by Foucault currents, some sort of loss by the reversal of polarity. We had no very definite ideas on the subject, but so far as our ideas did go, we considered that the loss was due simply to the change of polarity of the iron. In other words, the changing of the value of induction. As far as we knew, there was no necessary connection between that and any phenomena of lag like hysteresis. Later on, we learned from Ewing that the energy dissipated by hysteresis is represented by the area of the loop. Now, Mr. Steinmetz proves that that is an error, and we come back to the original condition of affairs—that the energy dissipated by magnetization of the iron is not, strictly speaking, energy dissipated by hysteresis. There is no necessary relation between the two. That is, the hysteresis can be abolished by vibration, and still the dissipation of energy is just the same.

MR. STEINMETZ:—Mr. Kennelly's supposition with regard to Fig. 1 is right. This figure is diagrammatical only, and therefore shows the magnetic circuit as a ring with separate exciting and exploring coil. In reality, certainly both coils were wound together with the same number of turns, both wires wound simultaneously to avoid magnetic leakage between them, as explained in the paper.

With regard to the second point which Mr. Kennelly mentions, I entirely agree with him that our present system of units, though certainly having many defects, is still the best we can devise at present, and I did not intend to introduce a different system of units. But these researches had been undertaken, first, for a strictly practical purpose, and there, ampere-turns are the units derived from the tests; ampere-turns are the units used for designing electric machines, and hence the circuitous over "field intensity" H is unnecessary. The experiments have since developed into scientific research, and in publishing them I hesitated whether I should not reduce the whole to absolute units H. But then I came to the conclusion that the original results are necessarily more exact than the derived values and, besides, the time failed me for the reduction of some thousand readings. So I simply drew attention repeatedly to the units used, giving the reductional factor between them, and while retaining the customary symbols H, μ, $\varkappa$ for the established units, I introduced the symbol F for the "ampere-turn per unit length of magnetic circuit" as an auxiliary unit. "Reluctivity" not yet having a symbol of its own, I saw no objection in using ρ for the function $\frac{F}{L}$, believing that anybody who reads a paper of some hundred pages through should avoid mistaking symbols F and H, while for practical purposes the use of F may be very often convenient.

With regard to aluminium, I noticed the same point referred to by Mr. Kennelly, for a qualitative analysis of the mitis metal revealed no perceptible trace of aluminium, and this very fact brought me to the opinion expressed in the appendix, that the aluminium improves the magnetic quality of the iron only in-so-far as it acts as de-oxidizer of the oxides of iron dissolved in the fused metal, in a similar way as titanium or manganese, but passes out again in the slags, while when remaining in the iron, it spoils it magnetically.

With regard to the decimals given in the figures, I have, with few evident exceptions, followed the rule of astronomical calculation—to give one decimal more than can be relied upon, to make the figures fit for further calculation—so that the last decimal is within the errors of observation, the forelast usually correct.

I am sorry not to be able to give Mr. Stanley a picture showing how it is that the area of the hysteretic loop is independent of the absolute values of the limits, and can only say that I did not expect this result at all, and was very much surprised as I first noticed in the electro-dynamometer tests the voltmeter and wattmeter readings remaining in a constant ratio, independently of the ammeter reading. I can only think that induction and hysteresis must depend somehow or other upon the same law and thereby show this constant relation.

With regard to the increase of hysteresis in soft iron by "aging," I never had occasion to observe this phenomenon, but I think that it may be due to incipient crystallization caused by the constant and prolonged molecular vibration, which may increase the magnetic hardness and hysteresis. It would be highly interesting to see whether in such a case the magnetic characteristic has changed also and a has increased.

In the tests made with iron filings, I believe a shifting of the field was excluded. It certainly was in the magnetometer tests, and they show the largest increase of coefficient η.

With regard to Mr. Stanley's experiment with condenser in shunt to open circuit inductor, I can not believe that the difference between high frequency and low frequency, is due to a change in the phase of the inductor current. For if the current is the same, and eddy-currents excluded, the hysteretic loop, and consequently the wave-shape and the phase of the inductor current, are the same for all frequencies. But perhaps the dielectric hysteresis of the condenser—which, though small, is not negligible compared with the small hysteretic loss of an open circuit inductor—has something to do with the phenomenon. The dielectric loss in the condenser seems to be proportional to the square of E. M. F. and square of frequency. But, for a given current, the E. M. F. is inversely proportional to the frequency. Consequently, for a given current, the dielectric hysteresis of the condenser is constant for all frequencies, while the hysteretic loss in the inductor—for a given current—is proportional to the frequency. This may have something to do with the cause of this phenomenon.

With regard to L_∞, Mr. Mailloux has misunderstood the symbol. L_∞ is not infinite at all, but ∞ merely an index, and L_∞, as explained in the paper, denotes that very finite numerical value which L approaches for infinitely increasing M. M. F.'s, F. Hence $H_\infty = \eta L_\infty^{1.6}$ is not infinity to a higher power, but entirely finite.

Now a few words on the remarks of Dr. Emery. First, I am highly astonished to see him give a loss of over thirteen per cent. in the armature core of a dynamo, as calculated from my tests. I am inclined to think that, due to the short time left between the distribution of the advance copies and the reading of the paper, an error must have crept into his calculations. I have made many calculations of armature losses, for all sizes of machines, and have almost always found the hysteretic loss amount to a *fraction of one per cent.*, so that I am almost inclined to think that Dr. Emery has mistaken the number of revolutions per *minute* for the number of cycles per *second*, which would bring his figures down to one-sixtieth, or about one-quarter of a per cent., a value found in practical dynamo machines. Here I must correct a mistake also. The hysteretic and eddy-current losses in *dynamo machines* do *not* enter into the *electrical* efficiency at all, but only into the *mechanical* efficiency, there showing as an *apparent* increase of the *mechanical friction*.

With regard to transformers, their design has reached now a development where the iron losses are not only calculated by the law of 1.6th power, but found by experiment to agree with the calculation, so that there can be no more doubt about their constancy, and they amount in the Ganz and Company transformers (42 periods, $B \sim 5{,}000$) to $2\frac{1}{2}$ to $5\frac{1}{2}$ per cent.; in the Siemens-Halske transformers, to 2 to 6 per cent. (according to the size); in the new Stanley transformer (17,500 watts, 133 periods—Cornell University tests), to .9 per cent.[1]—so that Dr. Emery will see that this hysteretic loss does not exclude the high efficiency of the transformers.

There are, however, now quite a number of efficiency tests of transformers published, where the losses are separated so that the hysteretic loss can be seen to agree with the formula and still to agree with as high an efficiency as 97 per cent. in the Stanley transformer.

With regard to the notion that the hysteretic loop merely represents a variation of the reluctance but no loss of energy, I can be short, because it has been proved by Warburg, and by Ewing, that if a magnetic circuit undergoes a cyclic variation, an amount of energy disappears out of the M. M. F., which is equal to the area of the hysteretic loop, and consequently if neither external work is applied to, nor work done by or in the magnetic circuit, from the *law of conservation of energy* follows that this energy is consumed in the iron by what we call molecular friction. We can not get over this well-established fact. With regard to the correspondence between induction and M. M. F., the hysteresis indeed appears as a cyclic variation of reluctivity, but it represents nevertheless a consumption of energy equal to the area of its loop.

The "time lag" in magnetism, observed by Ewing, is an entirely different phenomenon from what has been called "viscous hysteresis." This time lag takes place after seconds, and even minutes, and consequently it has nothing whatever to do with the inertia of the molecules, which does not show up noticeably at frequencies of over 200 complete periods per second, neither can it be expected.

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1. The smallest loss I ever saw in transformers.

With regard to the extra turns, no such thing exists in the modern transformer, but the ratio of the turns is the ratio of transformation.[1] They may have been necessary in some older types with extreme magnetic leakage.

The magnetic resistance, or "reluctance," does not consume any energy, as Dr. Emery seems to think, like the electric resistance, but a magnetic circuit can remain constant for any length of time without expenditure of energy therein, as is well-known, for otherwise the permanent magnet would represent a perpetual source of energy.

Consequently, the loss by hysteresis can not be measured by the proportional increase in exciting force, nor by the loss of magnetization, as Dr. Emery misinterprets my explanation, but it was proved long ago to be identical to the area of the hysteretic loop, by the law of conservation of energy, which, I believe, stands beyond doubt.

With regard to Fröhlich's function, or the linear law of reluctivity, Dr. Emery makes a mistake by saying that Mr. Kennelly applied the name "reluctance" to the reciprocal value of the permeability, and called attention to the fact that it shows a linear relation to the M. M. F., while I applied this linear law to the metallic reluctance. I must decline this honor, for Mr. Kennelly has expressly and clearly stated, in his classic paper,[2] that he applies the linear law to the "*metallic reluctivity*," but *not* to the *inverse value of permeability*, and has brought such ample proof for the agreement of this linear function with the tests that I did not think it worth while to give the experimental proofs for it, but thought it sufficient to simply state the fact of the agreement of my tests with the linear law.

Fröhlich's function, though very satisfactory within a limited range, had to be abandoned, because it did not hold for high values of M. M. F., and it was Kennelly's merit to prove that by substituting for "*induction*" the term "*metallic induction*," the hyperbola laid through any two points—beyond a minimum value of M. M. F.—of the *metallic* magnetic characteristic, *coincides with the whole characteristic within the errors of observation* and *does* NOT *separate rapidly for the higher values*, as Dr. Emery says, and as indeed the whole induction B does, and I found the same.

Neither has Mr. Kennelly made two applications of Fröhlich's formula, nor did I intend to express the whole function by one

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1. **Ganz and Company 7,500 watt transformers :**

Ratio of turns, $\frac{1080}{60} = 18.$

Terminal pressure, $e = 1,929$ volts ; $e' = 105$ volts.
Consumed by resistance, $4.2 \times 4.28 = 25.7$ volts ; $.018 \times 75 = 1$ volt.

Hence, ratio of E. M. F.'s, $\frac{1900.3}{106} = 17.93.$

2. TRANSACTIONS, vol. viii., p. 435.

hyperbola, but Mr. Kennelly has tried to express the reluctivity at the initial inwards bend by the function $\rho = a - b H$; I, by the addition of the term $\gamma e^{-\delta F}$, but not with quite satisfactory result in either case.

With regard to Dr. Emery's remark, that he has, in his paper, "applied Mr. Kennelly's constants to the experiments from which such constants were derived," but had found them to disagree with the tests, Dr. Emery is mistaken, for he did *not* apply the constants to the curve from which they were derived, since Kennelly expressly stated that his linear law of reluctivity applies to the *metallic induction*, which reaches a finite value of saturation, as Ewing proved, and Dr. Emery consequently could not expect to see it agree with the whole induction, which continues to rise infinitely, as Ewing proved also.

With regard to the symbol I, Dr. Emery's quotation from Ewing, page 320, is wrong, for neither there nor anywhere else does Ewing use I for "metallic induction," but consistently applies this symbol to "intensity of magnetization," the same as I and everybody else did, so that there is no need for a distinguishing index for Ewing's I.

The magnetic characteristic of sheet-iron, in my present paper, which Dr. Emery refers to, is *not* the average of five samples, as he says, but derived from one sample only, and one of less than average permeability, as the value $L_\infty = 17.24$ proves.

Now, with regard to the values given in Dr. Emery's table. In the highest values taken from my first paper, the M. M. F. is given by far too low, as explained in the appendix to my present paper. These values were derived by the electro-dynamometer method, specially explained in my former paper, and in this method the M. M. F. calculated from the effective ammeter reading comes out too low for high saturation, due to the discrepancy of the current wave from sine-shape, as will be seen by plotting the curve. This was the reason why, in the present paper, where I laid more stress upon the determination of the magnetic characteristic, I abandoned the dynamometer method for reluctivity determinations at higher saturations altogether, and used the magnetometer method, after having determined its reliability at these saturations by comparative tests with ballistic galvanometer.

That the numerical values of B for different observers differ, I can not help, since different samples of iron differ quite considerably. For instance, Ewing (page 107) finds for a very soft iron wire for $H = 75.2$ only $B = 15{,}560$, much less than any of the figures Dr. Emery refers to, while the tests given in my present paper show values of absolute saturation from $L_\infty = 15{,}750$ up to $L_\infty = 20{,}100$. The reason of these discrepancies is simply that different kinds of iron differ considerably in their magnetic qualities. For lower M. M. F.'s especially, Dr. Emery will find this still more noticeable. For $H = 10$, for instance, the Norway iron in my tests gives $B = 13{,}300$, even more than the value Hopkinson gives.

For lower M. M. F.'s, however, the values found by the method of reversals, which I exclusively use because it gives results not influenced by the remanent magnetism of former tests, are always lower than by the step-by-step method (*cf.* Appendix I).

In consequence hereof, I can not concede that I have made any mistakes in the calibration of my instruments, but I rather prefer to stick to my former opinion, that different kinds of iron have somewhat different magnetic characteristics; the more, as quite a number of such different characteristics are given in my paper.

Coming, now, to the conclusion, I can only say that as far as our present knowledge goes, the linear function $\rho = a + \sigma F$ expresses the *metallic* reluctivity correctly within the errors of observation, without requiring a repeated application; and that, since Dr. Emery was not able to bring any experimental proof whatever for his assertion, that the linear law does not apply to the *metallic* induction, after the complete and classic researches of Kennelly, which I found corroborated by my own experiments, I am sorry to disagree with Dr. Emery's assertion.

Some smaller mistakes which crept into his critical remarks, I may be allowed to pass unnoticed here.

THE CHAIRMAN:—[Vice-President Hammer]. We will now hear the report of the Committee on Revision of the Rules, respecting the election of officers.

MR. T. C. MARTIN:—The report is in the hands of the Institute and accepted, and referred back to this meeting from the meeting at Chicago. The Committee has nothing to do with it at the present time, except to vote in support of the recommendation.

THE CHAIRMAN:—I believe all the members have received copies of the Report of the Committee. I think it is scarcely necessary to read that report, unless specially requested. [See page 460.]

THE SECRETARY:—It was the sense of the meeting at Chicago that the final discussion of this matter should take place at the next regular meeting in New York, and the Secretary was instructed to have the report printed and circulated and this has been done.

MR. PHELPS:—I move that the report of the Committee be adopted. [Seconded.]

THE CHAIRMAN:—It is moved that the report as presented by this Committee be adopted.

[The motion was carried.]

MR. PHELPS:—That makes the report a part of the law of the Institute.

THE CHAIRMAN:—Yes sir. In view of the lateness of the hour it may be desirable to adjourn, but if the members desire that Mr. Steinmetz should proceed with his remarks, he may do so.

[On motion the meeting adjourned.]

APPENDIX II.

1. *Efficiency of Electro-Magnetic Conversion of Energy.*—Since now the loss of energy by molecular friction in the iron is found to be proportional to the 1.6th power of the magnetic induction,

$$H = \eta \, L^{1.6},$$

while the energy converted from electric to magnetic energy, and vice versa, is known to be expressed by the equation

$$W = \int_{B_1}^{B_2} F \, d \, B,$$

we are enabled to calculate the *efficiency* of this electro-magnetic conversion of energy.

The *transfer of energy* during a complete magnetic cycle between the limits $+L$ and $-L$ is approximately

$$4 \; W = 4 \int_{0}^{L} F \, d \, L$$

(so far as the transfer takes place by the *metallic* induction).

The *loss of energy is*

$$H = \eta \, L^{1.6};$$

consequently the *efficiency of the electro-magnetic conversion of energy*

$$\delta = \frac{4 \; W - H}{4 \; W}.$$

Such an efficiency curve, referring to the sheet-iron in Chapter I., is given in Fig. 30.

This electro-magnetic efficiency has a very important bearing upon the storage of energy by magnetic potential, as it is frequently made use of for the shifting of phase of alternating currents, for it determines the unavoidable loss encountered in such a storage. For in the case represented by Fig. 30, of the amount of electric energy stored by magnetic potential in the range of medium induction, not more than about 88 per cent. can be derived back as electric energy. Consequently, shifting of phase of alternating currents by means of magnetic potential must be rather uneconomical. It must be understood, however, that the curve in Fig. 30 refers only to the one sample of sheet-iron.

2. *Limits of the Law of* 1.6*th Power.*—I have shown that the law of the 1.6th power holds within the errors of observation for the whole range of magnetic induction from $B = 85$ lines of magnetic force up to over 19,000 lines per cm.² Outside of this wide range the law has not yet been tested, and though it is not

likely that for very high saturations an exemption will take place 19,000 being already very near to absolute saturation, the case $B < 85$, that is, extremely low magnetization, requires a further investigation.

The loss of energy per cycle is

$$H = \eta \; B^{1.6}. \qquad (1)$$

The energy derived per cycle from the M. M. F. is

$$2 \; W = 2 \int_0^F F \, d \, B. \qquad (2)$$

Now, evidently the value H can not be larger than 2 W, that is, not more energy can be lost than is available, and if there

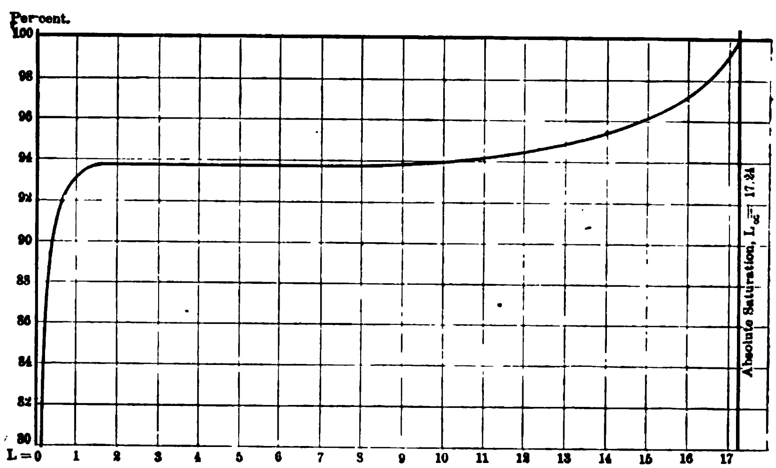

FIG. 80.

exists a point where (1) becomes equal to (2), below this point one of the two equations, (1) and (2), must cease to exist, and since (2) is based upon the law of conservation of energy, it can only be (1), that is, at the point where for extremely low M. M. F.'s (1) becomes larger than (2), there we must expect a limit for the empirical law of the 1.6th power.

This really seems to be the case, for the lower we come down in the value of F, the fuller and "fatter" the hysteretic loop becomes.

For extremely low M. M. F.'s, the reluctivity ρ seems to approach a finite limiting value ρ_0 (Rayleigh).

Then $B = \dfrac{F}{\rho_0}$. Consequently we get (approximately),

$$2\,W = 4\int^{B} \rho_0\,B\,d\,B = 2\,\rho_0\,B^2 \qquad (3)$$

as available energy.

The lost energy being $H = \eta\,B^{1.6}$, at the point

$$H = 4\,W, \qquad (4)$$

the law of 1.6th power must have ceased to exist.

From (4) we derive

$$2\,\rho_0\,B^2 = \eta\,B^{1.6}, \qquad \text{or}$$

$$B_0 = \left(\frac{\eta}{2\,\rho_0}\right)^{2.5}, \qquad (5)$$

as the lowest limit of the law of hysteresis.

Substituting in equation (5) the values for the sheet-iron in Chapter I.

$$\eta = .0035 \qquad \rho_0 = .00343,$$

we derive

$$\left.\begin{aligned} B_0 &= .19 \\ F_0 &= .00067 \end{aligned}\right\}. \qquad (6)$$

Such low values, equal to $\frac{1}{200}$ the intensity of the magnetic field of the earth, are still rather out of reach for experimental research, the magnetic potential representing there only .00006 ergs.

Yonkers, N. Y., October, 1892.

Table of 1.6th Powers.

B in 10^3. $B^{1.}$ in 10^6.

B	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Δ
	$B^{1.6}$	=									
0	.0	.00159	.00480	.00919	.01457	.02082	.02787	.03566	.04416	.05330	2—10
1	.06310	.073	.084	.096	.108	.121	.134	.148	.162	.176	10—15
2	.1913	.206	.222	.238	.255	.272	.290	.308	.327	.346	15—20
3	.366	.386	.406	.427	.448	.469	.491	.513	.535	.557	20—23
4	.580	.603	.627	.651	.675	.700	.725	.750	.776	.802	23—26
5	.828	.855	.882	.909	.937	.965	.993	1.022	1.051	1.080	27—29
6	1.109	1.139	1.169	1.199	1.230	1.261	1.292	1.324	1.356	1.388	30—32
7	1.420	1.453	1.486	1.519	1.552	1.586	1.620	1.654	1.688	1.723	33—35
8	1.758	1.793	1.829	1.865	1.901	1.937	1.974	2.011	2.048	2.085	35—37
9	2.122	2.160	2.198	2.236	2.274	2.313	2.352	2.392	2.432	2.472	38—40
10	2.512	2.552	2.593	2.634	2.675	2.716	2.758	2.800	2.842	2.884	40—42
11	2.926	2.969	3.012	3.055	3.098	3.142	3.186	3.230	3.274	3.318	43—45
12	3.363	3.408	3.453	3.498	3.544	3.590	3.636	3.682	3.728	3.775	45—47
13	3.822	3.869	3.916	3.964	4.012	4.060	4.108	4.156	4.205	4.254	47—49
14	4.303	4.352	4.401	4.451	4.501	4.551	4.601	4.652	4.703	4.754	49—51
15	4.805	4.856	4.908	4.960	5.012	5.064	5.116	5.169	5.222	5.275	51—53
16	5.328	5.381	5.435	5.489	5.543	5.597	5.651	5.706	5.761	5.816	53—55
17	5.871	5.926	5.982	6.038	6.094	6.150	6.206	6.263	6.320	6.377	55—57
18	6.434	6.491	6.548	6.606	6.664	6.722	6.780	6.838	6.897	6.956	57—59
19	7.015	7.074	7.133	7.192	7.252	7.312	7.372	7.432	7.492	7.552	59—61
20	7.613										

CORRESPONDENCE.

DR. CHAS. E. EMERY :—It is not desirable after the author of a paper has closed a discussion to reopen it by merely reiterating any points previously brought out. In this case, however, the author, who has been pleased to call my remarks critical, has certainly answered them quite critically, and has taken particular pains to treat as mistakes every criticism, except perhaps one. It therefore becomes necessary to respond to the reasons which have been given, and I thereby expect to show that the original criticisms are fully sustained. The author's statement that he has made many calculations of the loss by hysteresis and found it less than one per cent., is directly responsive, but his suggestion that therefore I possibly have neglected to divide the revolutions per minute by 60, in order to obtain the number of complete cycles per second, and therefore obtained an erroneous result, w hile it may to our auditors be considered a good joke, is rather one-sided. No such mistake has been made. The difference in result may undoubtedly be explained by the fact that the loss is stated "in watts per cubic centimetre," which is evidently independent of the output or the number of watts in the main circuit. By substituting the particular values given in the first discussion in the equation of Mr. Steinmetz, the loss will be found to be 0.031 watts per cubic centimetre.[1] This loss would occur in the armature core of a dynamo revolving in a magnetic field under conditions stated, when no current was circulating through the armature coils and when, therefore, there was no output to compare with the loss; but in the case of a motor with separately excited field and a very small current through armature, the whole work might be absorbed in friction and hysteresis, so that the proportional loss due to the latter would be very large. Evidently, in any case, the

1. A calculation based on the formulæ of Mr. Steinmetz, for the conditions originally stated, is herewith presented.

1st Eq., p. 685. $W = \eta N 10^{-7} \left(\frac{L_1 - L_2}{2}\right)^{1.6}$

Bottom p. 685. W = watts lost per cubic centimetre.

Top p. 685, N = number complete periods per second.

$L_1 - L_2$ = maximum values of magnetic induction in lines per cm.² (bottom of page 685; page 658 and elsewhere the same characters refer to kilolines).

From first line referring to sheet-iron, Table XLVII., page 680, $\eta = 0.0035$.

Therefore, to find loss by above formula in the core of an armature making 1,000 revolutions per minute, with the magnetization alternating between minus and plus 16,000 lines per square cm., we have $L_1 = 16{,}000$, $L_2 = -16{,}000$; hence,

$$(L_1 - L_2) \div 2 = 16{,}000,$$

$$N = 1{,}000 \div 60 = 16.67\text{; so}$$

$$W = 0.0035 \times 10^{-7} \times 16.67 \times (16{,}000)^{1.6} = 0.031.$$

proportional loss would decrease as the output was increased, and the percentage merely depend upon the relative output of the particular machine for which the comparison was made. It should be borne in mind that I do not attack Mr. Steinmetz's admirable discovery that the loss in induction due to hysteresis is proportional to the 1.6th power, etc. I simply point out that, by analogy, hysteresis only increases the reluctance and, like the increased reluctance due to an air-gap, the loss of energy should be measured only by the necessary increase of exciting force.

2. Mr. Steinmetz states, next:—"Here I must correct a mistake also. The hysteresis and eddy-current losses in dynamos do *not* enter into the electrical efficiency at all, but only into the mechanical efficiency, there showing as an apparent increase of the mechanical friction." The latter statement is of course correct, but the impropriety of founding the first conclusion on a mere "apparent increase" becomes evident in distributing the electrical energy delivered to a motor. The mechanical friction is easily separated by a transmitting dynamometer and may be added to the exterior mechanical work performed when motor is loaded, as shown by any form of dynamometer, but when the total mechanical work, including friction, is subtracted from that due to the watts in the circuit there is, even when the volts lost by resistance are considered, a residual loss, or a certain proportion of the electrical energy unaccounted for, and this only is available for application to hysteretic, eddy-current and other electrical or electro-magnetic losses. The same distribution should be made in the case of a dynamo. It is certainly wrong to call everything a mechanical loss that merely appears to be so, because the friction of the apparatus is not commonly separated.

3. The preliminary remarks of Mr. Steinmetz about transformers are interesting, but again avoid the true question, which is not to dispute the facts about hysteretic losses, but to ascertain whether the equations, for given conditions, show simply the loss of induction or the direct loss of energy.

4. The next statement by Mr. Steinmetz, that it has been proved by calculation that an amount of energy disappears out of the M. M. F. equal to the area of the hysteretic loop, is subject of course to the uncertainty of calculations on such a subject, and the statement is apparently directly in conflict with No. 3 above, where he claims that the hysteretic loss does not affect the electrical efficiency.

5. My reference to "time lag" was merely an illustration, not a definition, and the elaboration of Mr. Steinmetz on the latter basis only makes the former more apparent.

6. Mr. Steinmetz calls attention to the fact that no such thing as "extra turns" exists in transformers, and by showing that the ratios of transformation depend upon the relative number of turns in the primary and secondary, argues therefrom that my suggestion is incorrect, viz: that the loss by hysteresis should be

measured by the extra exciting force necessary to overcome the increased reluctance, instead of being measured by the decrease of magnetization. Evidently, however as both primary and secondary operate in connection with the same iron, any increase in the reluctance thereof must affect both primary and secondary alike, and not change the ratio of transformation, but simply reduce the efficiency of the apparatus as a whole, as is found in practice. Either circuit may evidently be the primary or the secondary, and technically the extra turns to overcome reluctances of all kinds are found in both.

7. Mr. Steinmetz kindly calls my attention to the fact that I have improperly given him the credit, which belongs to Mr. Kennelly, of first applying a reluctivity formula derived from Frölich's function to the *metallic* induction. On again consulting Mr. Kennelly's paper, I find that Mr. Steinmetz is right as to the credit, and I cheerfully make the correction, but that I am right in my illustration and Mr. S. is wrong in his conclusion relating thereto. Mr. Kennelly did make his first application to the total induction, as I supposed, and later developed the application to the metallic induction. Fig. 3, in my original paper, was based on an example given in the first part of Mr. Kennelly's paper, where the reluctances are the actual reciprocals of the permeabilities;[1] so that my illustration as to the inapplicability of the Frölich function in that particular case is correct, and for the low magnetizations shown, a consideration of the metallic induction would not have changed the results. The further discussion of Mr. Steinmetz as to the applicability of this function, is somewhat a repetition of the original discussion, but will be reverted to later.

There is a chance for a difference of opinion in regard to the use of the symbol I, and in any case the matter is of no further consequence than I have already stated.

Mr. Steinmetz states in substance, that the particular experiments on wrought-iron which I refer to in his paper, were not the average of experiments from five samples, nor a fair average of all the experiments. I find that the experiments selected were from but one sample, but that such experiments were those also specially selected by Mr. Steinmetz himself, and placed in a separate table near the beginning of his paper (page 626) as if representing a typical kind of wrought-iron, while the results of other experiments are given in the large table at page 680. I do, however, find on page 692 a statement of the "Magnetic Properties of Average Materials," in which the value for wrought-iron for $F = 60$, $B = 16{,}700$, or 65 lines higher than for the sample tabulated at page 626, but this value still shows that the corresponding value, viz., $B = 18{,}650$, given in the first paper, was much too high, so my criticism is sustained. This part of the criticism is,

1. TRANSACTIONS, vol. viii., p. 504.

however, finally acknowledged in general terms by Mr. Steinmetz after a tedious reference to details, as he explains in substance that the higher magnetizations given in his first paper for wrought-iron plates were different because determined by the electro-dynamometer method. This is satisfactory. I, however, also stated in my first discussion that the higher magnetizations shown by the *later* experiments are too *low* compared with the results reported by other observers. Differences of material will account for some variations, of course, but not for those practically changing the shape of the curves. The result may possibly be partly explained by the fact that Mr. Steinmetz used cores built up of rectangular plates to form a complete magnetic circuit on the log-house principle of piling, so that there was necessarily some reluctance at the joints, and it is gratifying to know that such a construction produces no more reluctance. It seems proper that all these differences should be pointed out and with the coincidences, clearly stated.

As the electro-dynamometer apparatus offers facilities for multiplying experiments to a degree not possible with any other method, we cannot too highly appreciate its value so long as the fact is known as was hinted in my first discussion that the instrument gives relative, but not absolute, results through all ranges. The latest discovery of Mr. Steinmetz, that the hysteretic loss as he terms it is proportional to the amplitude and not to the absolute values of the changes in magnetization, is one entirely of comparison and its confirmation by two methods entirely satisfactory; but the evidence is by no means clear, that in a general sense the elements of curves of magnetization may be derived from a linear reluctance formula. Most of the experiments which seem to prove the law through wide ranges, appear to have been made with the electro dynamometer, though both Mr. Kennelly and Mr. Steinmetz give many others that approximately follow the law for short ranges. It is a pleasure to acknowledge that the function as applied, furnishes good approximate formulæ, but from the present evidence we must consider such formulæ empirical rather than rational. I am gratified to say that Mr. Kennelly, though he first pointed out the coincidences, was more cautious in assuming the law general than Mr. Steinmetz has been.

Mr. Steinmetz:—Referring to Dr. Emery's communication, I may add a few remarks:—Leaving aside all the metaphysical speculation, which I consider as of rather little interest, and everything which calls for a simple repetition of former remarks, I intend to deal only with some misunderstandings. For instance, I did not say that the hysteretic loss in the dynamo machine is a mechanical loss. It is neither a *mechanical* nor an *electric*, but a *magnetic* loss. What I said was, that this hysteretic loss enters as term into the *mechanical* efficiency only, but not into the *elec-*

trical efficiency. As well known, the *electrical* efficiency is the ratio:

$$\frac{\text{whole electric energy} - \text{electric losses}}{\text{whole electric energy}},$$

while the *mechanical* efficiency is the ratio:

$$\frac{\text{whole supplied energy} - \text{whole losses}}{\text{whole supplied energy}}.$$

That in the electric motor, the magnetic just as well as the frictional or any other loss of energy is in the end derived from electric energy, is self-evident. But even in the electric motor the energy lost by molecular magnetic friction is not directly derived from the *electrical* energy supplied, but from *mechanical* energy, which in turn is produced by electrical energy. Consequently, in calculating the losses in electric motors, the calculated loss by hysteresis has to be increased by the coefficient of loss of the electro-mechanical conversion of energy, to get the corresponding expenditure of electric energy. In alternating apparatus, however, the hysteretic losses are generally directly derived from electrical energy

With regard to the 13 per cent. of hysteretic loss given by Dr. Emery, I could not suppose indeed that he gave the percentage of loss *for a dynamo running light.* At least the 90 per cent. efficiency mentioned by him did not point that way.

With regard to Dr. Emery's belief in the uncertainty of Ewing's and Warburg's calculations of the meaning of the area of the hysteretic loop, I can refer to Ewing (p. 99), and Warburg (Wiedemann's Annalen, 1881, p. 141). But Dr. Ewing's remark that "I claim that the hysteretic loss in transformers does not affect the electrical efficiency," is just the opposite from what I did, for I gave the percentage of power lost by hysteresis for a number of types of transformers.

Referring to the "increase of reluctance," which consumes the hysteretic loss according to Dr. Emery: first, molecular friction produces no increase of reluctance; and second, since reluctance does not consume energy, neither could its increase consume energy, and if the problem of constant secondary potential, and the reac ion of the "leakage current" of the transformer upon the generator would not require a very low reluctance, the reluctance of the transformer may be very much increased without any decrease of efficiency, as it is done in the hedgehog transformer of Swinburne.

The agreement or disagreement of the "metallic induction" in Kennelly's paper (p. 504), with Fröhlich's formula, is a matter of opinion as to what constitutes a decided disagreement, and what is within the errors of observation. Dr. Emery's comparative curves in his paper "On Magnetization" (TRANS., vol. viii., p. 206), look unfavorably indeed, showing at some points differences of three to four per cent. To decide the question, I may give here the readings from Kennelly (p. 504), with the values of ρ, calculated by the formula $\rho_0 = .1 + .058\ H$,[1] given by Kennelly, and the differences between observed and calculated reluctivities.

TABLE LXI.

ROWLAND WROUGHT-IRON RING.

H	ρ obs.	ρ calc.	Δ	= %
2.877	.272	.267	−.005	−1.8
5.52	.412	.420	+.008	+1.9
7.426	.522	.531	+.009	+1.7
9.894	.664	.674	+.010	+1.5
17.30	1.104	1.103	−.001	− .1
33.72	2.083	2.056	−.027	−1.3
46.32	2.747	2.787	+.040	+1.4
Average			±.014	±1.4

The maximum difference between observed and calculated values is 1.9 per cent. The differences are irregular, but show the behavior generally noticeable on ballistic test by the step-by-step method, to lie alternately below and beyond the curve, which I ascribe to the cumulation of the errors introduced by the "sluggishness" of the iron For a classic sample of this tendency see Kennelly, p. 498. [TRANSACTIONS, vol. viii.]

Dr. Emery's opinion that most of the tests which seem to prove the linear law of reluctivity through very wide ranges, appear to have been made by the electro-dynamometer, can hardly be upheld, for of all the numerous tables collected in Mr. Kennelly's paper, *not one* has been derived by the electro-dynamometer method, but all by the ballistic, or by the magnetometer method. My experience with this instrument was just the opposite of Dr. Emery's opinion of it, for I found the electro-dynamometer very suitable—and perhaps the best instrument—to get *absolute values* of reluctivity within a *limited* range, but *entirely unsuitable* to give *relative results through all ranges*, so that for the latter purpose I was obliged to discard it altogether. Electro-dynamometer readings agree with the linear law of reluctivity only within a limited range, so that this law can not be due to this particular method.

With regard to the air reluctance introduced in my electro-dynamometer tests by building the magnetic circuit up of rectangular pieces of iron, I certainly have not forgotten to calculate the reluctance of these air-gaps and to determine the influence, but

1. The value of σ, of this sample tested by Rowland, and consequently the value of absolute saturation $L_\infty = 17.24$ is accidentally just the same as that of the sheet-iron in Table I. of my paper, which Dr. Emery considered so low a value as to suspect a mistake. Ewing indeed found, in his "very soft iron wire," a still much lower value, $L_\infty = 15.75$.

TABLE LXII.

IRON, COBALT AND NICKEL IN STRONG MAGNETIC FIELDS.

(Dubois, Ewing, p. 158.)

Soft Swedish Iron, Annealed.

F	L	ρ obs.	ρ calc.	Δ	= %
80	17.70	4.5	4.7	+ .2	+4.3
160	19.10	8.4	8.4		
240	19.8	12.1	12.0	− .1	− .8
320	20.4	15.7	15.6	− .1	− .6
400	20.8	19.3	19.3		
480	21.1	22.8	22.9	+ .1	+ .4
560	21.2	26.5	26.5		
640	21.3	30.0	30.1	+ .1	+ .3
800	21.4	37.4	37.4		
960	21.45	44.8	44.6	− .2	− .5
	Average			± .08	± .7

$\rho = 1.13 + .0453\, F.$

$L_\infty = 22.1.$

Nickel at 100° C.

F	L	ρ obs.	ρ calc.	Δ	= %
80	3.92	20	20		
160	4.70	34	34		
240	5.08	47	47		
320	5.37	60	59	−1	−2
400	5.52	72	72		
480	5.63	85	85		
560	5.71	98	98		
640	5.75	112	111	−1	−1
800	5.85	137	137		
960	5.90	163	163		
	Average			± .2	± .3

$\rho = 7.6 + .162\, F.$

$L_\infty = 6.17.$

Cobalt at 100° C.

F	L	ρ obs.	ρ calc.	Δ	= %
80					
160	10.7	15.0	15.0		
240	11.65	20.7	20.5	−.2	−1.0
320	12.3	26.0	26.0		
400	12.8	31.3	31.5	+.2	+ .6
480	13.0	36.9	37.0	+.1	+ .3
560	13.2	42.4	42.5	+.1	+ .2
640	13.3	48.1	48.0	−.1	− .2
800	13.55	59.0	59.0		
960	13.7	70.1	70.1		
	Average			±.08	± .26

$\rho = 4.0 + .0688\, F.$

$L_\infty = 14.5.$

found it negligible, which is explained by the fact that the cross-section of each air-gap is 12 cm.[2], that of the sheet-iron piece only .11 cm.[2], so that the joint reluctances of the four breaks represent approximately an increase of reluctivity of $\rho = .0014$ milli-units per cm. length of the magnetic circuit, which has been subtracted from the readings.

Since the discussion has shifted to this question of the exactness of the empirical linear law of reluctivity, it may be of interest to give some tests made by DuBois on iron, nickel and cobalt, since these tests cover an enormous range of M. M. F., and just the critical range, between $F = 80$ and $F = 960$, where a deviation from the linear law, if existing, must be expected. For beyond $F = 1000$, absolute saturation is practically reached, and is:

$$B = H \times L_{\infty}.$$

These tests were made by the magnetometer method, on prolate ellipsoids (Ewing, p. 158), and gave the results shown in Table LXII

A range from $F = 80$ to $F = 960$ can hardly be called short.

I do not wish to be understood, however, as claiming the linear law of reluctivity for all magnetic circuits. While proved for homogeneous materials, it is well known not to apply to complex magnetic circuits, as, for instance, the characteristic of the dynamo machine. A discussion of this case, of the *metallic reluctivity of heterogeneous materials*, is given in the annexed Appendix.

APPENDIX III.

3. *Limits of the Linear Law of Metallic Reluctivity.*—Within the range of the tests communicated in the foregoing paper we have seen the metallic reluctivity $\rho = \frac{F}{L}$ follow—beyond a certain minimum value of M. M. F.—the linear law,

$$\rho = a + \sigma F.$$

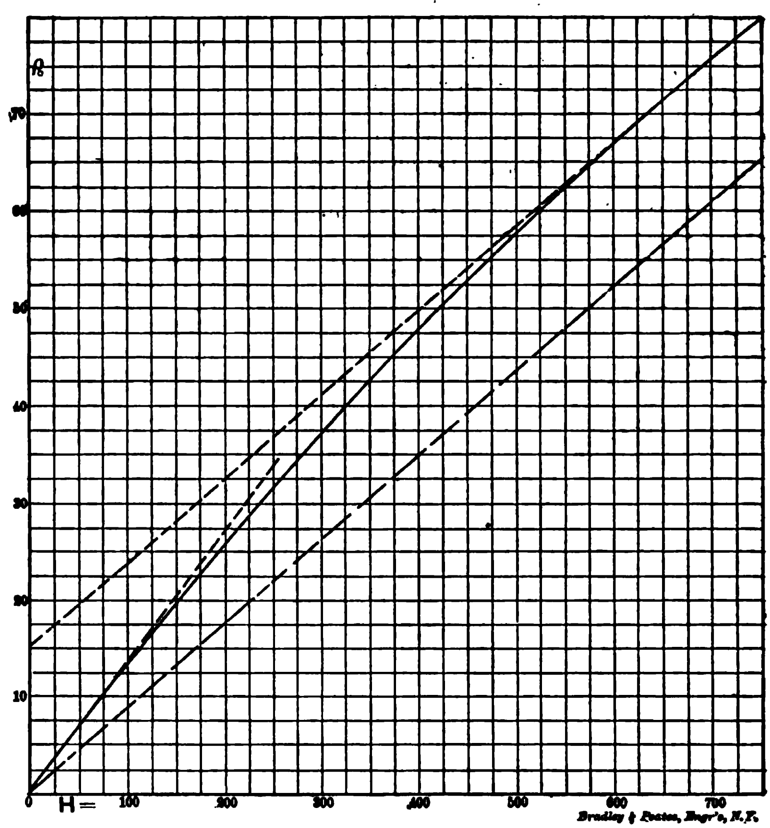

FIG. 81.

Below this minimum value of M. M. F. the metallic reluctivity of the alternating and of the ascending branch of the magnetic characteristic rise above, the reluctivity of the descending branch drops below the straight line represented by $\rho = a + \sigma F$, ap-
l y due to the phenomenon of energy consumption by molec-
on.

Since Kennelly has shown that this linear law holds good up to the highest values of magnetization ever reached by Ewing in iron, steel, nickel and cobalt, and I found it proven also by my tests, this linear law of reluctivity seems to be established beyond doubt for all *homogeneous materials.*

Of *heterogeneous materials*, the only tests I know of are those of iron filings, on pages 702 to 710 of my paper. They agree with the linear law of reluctivity also, for the limited range of tests, but the remarkable fact is that in one and the same material the tests point to very different values of saturation, according to the speed of cycle. Besides, while in iron, steel, etc., by Ewing, absolute magnetic saturation has practically been reached; in these iron filings the highest readings are still far below the saturation limit. If, consequently, the linear law of metallic reluctivity ceases to hold anywhere, we can expect this only for heterogeneous materials.

Subjecting the case of such heterogeneous materials, composed of magnetic material of the equation $\rho = a + \sigma F$, and of unmagnetic material of the equation $\rho =$ constant, to an analytical formulation, we arrive at complicated mathematical expressions, the discussion of which, however, I must postpone for a later occasion. In general, in this case, the correspondence between ρ and F is no longer linear. That means:

The linear law of reluctivity, $\rho = a + \sigma F$, does not hold for all heterogeneous materials, except in a limited range."

A particular case of the reluctivity curve of a heterogeneous material, containing 70 per cent. of iron, is represented in Fig. 31. As seen, this curve differs greatly from a straight line, though being rectilinear at the initial part and becoming rectilinear again for very high M. M. F.'s.

But while the initial part of the curve points toward a saturation value, $L_\infty = 7.5$, being represented by

$$\rho = .7 + .133\ H,$$

the higher parts of the curve point to an absolute saturation $L_\infty = 12.5$ and can be represented by

$$\rho_0 = 16 + .080\ H,$$

giving very different values of a and σ.

The most interesting question which arises here is *whether, and how far gray cast-iron behaves as heterogeneous material.*

For field intensities of 100 to 200 it does not do that yet, neither can it be expected, from the foregoing consideration. But with regard to very high magnetizations, the disagreement between Ewing's values of absolute saturation ($L_\infty \sim 16.0$) *observed* at extremely high M. M. F.'s and my own values, *calculated* from tests between 25 and 200 field intensity ($L_\infty \sim 11.0$), seems to point that way.

If a deviation of the cast-iron reluctivity from the linear law exists, it must be expected at values of M. M. F. somewhere between $H = 400$ and $H = 2{,}000$ approximately. Unfortunately, within this range of M. M. F.'s, no tests seem to have been made with cast-iron. This point is open to further investigation.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, October 25th, 1892.

The 70th meeting was held this date at 12 West Thirty-first street, and was called to order at 8.15 P. M., by President Sprague.

THE SECRETARY:—At the meeting of the Council held this afternoon, the following associate members were elected.

Name.	Address.	Endorsed by
ARNOLD, BION J.	Consulting Engineer, General Electric Co., 4128 Prairie Ave., Chicago, Ill.	Elmer A. Sperry. Geo D. Shepardsan. Edw. L. Nichols.
JEFFERY, D. HERBERT	Secretary and Treasurer, Crocker-Wheeler Electric Co, 430 West 14th St., New York City.	F. B. Crocker. S. S. Wheeler. Gano S. Dunn.
MEYER, JULIUS	Consulting Engineer, North American Co., Mills Building, New York City.	F. J. Sprague. C. T. Hutchinson. Louis Duncan.
PEARSON, F. S.	Chief Engineer, West End Street Railway Co., 439 Albany Street, Boston, Mass.	Thos. D. Lockwood. Chas. A. Coffin. Eugene Griffin.
SPENCER, GEORGE JARVIS	Electrician, The Yale & Towne Mfg. Co., Stamford, Conn.	H. W. Leonard. Ralph W. Pope. Alex. S. Brown.
TAPLEY, WALTER C.	Electrician in Government Printing Office, Care of Public Printer, Washington, D. C.	Fred. W. Royce. Geo. C. Maynard. Ralph W. Pope.
VAN BUREN, GURDON C.	Electrician, 5 Wilson Street, Albany, N. Y.	F. L. Woodward. Wm. C. Miller. Wm. H. Hamilton.
WALLACE, GEO. S.	Telegraph Office Manager, Chesapeake & Ohio Ry. Co., Box 214, Clifton Forge, Va.	M. B. Leonard. J. W. Lattig. Ralph W. Pope.
WEAVER, NORMAN R.	Supt. of Repair Department, General Electric Co., 173-5 Adams St., Chicago, Ill.	A. L. Rohrer. J. B. Cahoon. E. C. Boynton, Jr.

Total 9.

The following associate members were transferred to full membership, their applications having been approved by the Board of Examiners.

PIKE, CLAYTON W.	Jas. W. Queen & Co,, Philadelphia, Pa.
BISHOP, JAS. D.	Electrical Expert, J. A. Roeblings' Sons Co., 345 W. 34th St., New York City.
BARBERIE, E. T.	Electrician, Safety Insulated Wire Co., 234 W. 29th St., New York City.
HEINRICH, RICHARD O.	Electrical Engineer, Weston Electrical Instrument Co., Newark, N. J.
RAE, FRANK B.	Electrical Engineer, 27 Cleland Building, Detroit, Mich.

Total 5.

The next meeting of the Institute will be held on the 15th of November, when Dr. J. B. Williams, who read a paper on Insulation, at Chicago, will give some experiments in the testing of insulation in connection with his paper, which has not yet been published, but which will be in print before the meeting. It will be in the nature of a confirmation of the paper by showing the experiments, and also a discussion, which was not had at Chicago by reason of lack of time. In connection with these experiments, Dr. Williams will request that members bring or send samples of wire of their own selection, to be tested. The particulars in regard to these samples will be given out in advance, so that members may avail themselves of this opportunity. His idea in doing this is that some of the tests may be a revelation to either the manufacturers of wire, or other people, and therefore he would prefer that the samples be handed in by others than himself.

ELECTRIC RAILWAYS.

JOINT DISCUSSION OF THE PAPERS READ AT THE GENERAL MEETING OF THE INSTITUTE, CHICAGO, JUNE 8TH, ON "SERIES ELECTRIC TRACTION;" "A NEW SYSTEM OF ELECTRIC PROPULSION," AND "ELECTRIC RAILWAY MOTOR TESTS."

New York, Oct. 25th, 1892.

The 70th meeting was held this date at 12 West Thirty-first Street, and was called to order at 8.15 p. m. by President Sprague.

THE PRESIDENT:—There are three papers under discussion to-night—papers which were read at the Chicago meeting. The first is on "Series Electric Traction," by Mr. Nelson W. Perry; the second on "A New System of Electric Propulsion," by Mr. H. Ward Leonard; the third on "Electric Railway Motor Tests," by Professor Geo. D. Shepardson and Edward P. Burch. The discussion will be opened by Dr. Cary T. Hutchinson. There was practically no discussion at Chicago on account of the limitation of time, and the discussion to-night should be as full as necessary to bring out either the merits or the faults of the systems.

DR. CARY T. HUTCHINSON:—I had not the good fortune to be at the Chicago meeting, and therefore do not know exactly how Mr. Perry's paper was received; but I must confess that when I found such a paper had been read I was very much surprised; I thought this plan had been abandoned by everybody long ago. I dare say there were not very many people there who were entirely familiar with the beginnings of the series system and with the curious claims that were put forward for it at the time. A little history does no harm now and then. I have before me a circular issued by a series electric company in 1888 which is really unique and which I think should be preserved. It is entitled: "Why Is Electricity Not Used for Street Car Propulsion?" [Laughter.] The circular purports to give an account of the operating expenses of the three different systems of using electricity—the storage battery system, the divided current, parallel, or multiple arc system, as it was variously called, and the series system. There is very little use in going into the storage battery question. We have not sufficient data yet to tell us whether he is right in regard to that. But when the parallel system is discussed some rather curious statements are made. I wish to read one or two. It is said, among other things, that "the parallel system works under the following disadvantages:

"First. The well known law that the power lost on a con- " ductor is proportional to the square of the current on that con- " ductor; so if it cost one dollar per day to send current enough " over a given conductor to run one car, to run two cars twice the " current must go over this conductor, which will cost not two, but " four dollars; for three cars it would cost nine dollars; five, " twenty-five dollars, and for ten cars, it would cost one hundred " dollars to force sufficient current over these wires to drive " them."

If that had been true we should not have run any cars. There are several delightful assumptions in this. The first is that the size of the conductor is kept the same, irrespective of the number of cars. The second is, that all the cars are bunched at the far end of the line, and the third is that the $C^2 R$ loss in the copper costs one dollar per day per car; as a matter of fact it costs a good deal less than one cent.

Then a second disadvantage is that "A system of this kind is " subject to a complete stoppage of traffic at any moment, by a " wire falling across the two parallel conductors, and every car " on the entire system would immediately come to a full stop " and there remain until the wire is removed. In the meantime, " the generator at the driving station would have its armature " burned or break its driving belt."

"Third. Upon this parallel system if a car was, for any rea- " son, completely stalled, which is a common occurrence with " street cars, either from an overload, being derailed or having " the brakes set, and the current be then turned full into the " motor, it would be immediately destroyed by having its coils " burned out.

"In this system the motors have a large amount of power " at or near the driving station, but the power falls very rapidly " as the distance from the station increases, and upon compara- " tively long lines, the cars are scarcely able to move at the " extreme ends of the line." [Laughter.] "Cars should have " the same power throughout the entire length of the circuit, " in order to allow them to run faster towards the outskirts of " the city and make up their time.

"Each motor on a parallel circuit depends for its power and " speed upon the movements of the rest of the motors on the " circuit, making it vary in speed, and require constant atten- " tion from the car driver."

Touching another point, of which I may have something to say later in the evening, the circular says:

"The regulation of the motors operated on these parallel "circuits is accomplished by means of resistance coils being "thrown into and out of the circuit. As it always requires "power to send a current through a resistance, these coils are, "from their very nature, intended to be power dissipators, and "therefore consume coal without returning any useful equiva- "lent. They are the most unscientific contrivances ever devised "by man, and cannot be permitted in any perfect system of elec- "trical distribution of power. In addition, these resistance coils "are dangerous, as they become very hot, and have often set fire "to the woodwork of the cars." [Laughter.]

It adds :—"This system of distribution of electricity has been "tried for many years in incandescent electric lighting, and has "proved a financial failure [laughter] wherever many lights have "been run upon circuits of even moderate length."

The gist of the paper is the calculation of the cost per day of running twenty cars on a ten mile line. The only item, so far as I can make out, that is considered in calculating the cost of running the cars is the loss on the conductors. Of course this cost, at $1.00 a day, counts up. It shows a waste of 1455 horse power in the conductors and 250 horse power to be used in the cars; this requires altogether 2450 I. H. P. at the power-house to run twenty cars. The cost of this is something like twenty-five dollars a day for coal alone.

The series system has none of these disadvantages. It works at something like two dollars a day. Of course this all seems very ridiculous now, and at least one person knew it to be ridiculous then. Mr. Sprague at once wrote an article criticizing it, in which he said substantially just what I have said. He stated therein that the thing was actually done, and that it cost only about one dollar a day instead of twelve, and required 200 odd horse power instead of 2500.

Referring to Mr. Perry's paper itself, if anybody has followed all those diagrams through carefully as I have done, he must have seen that Mr. Perry has made an extremely ingenious arrangement of switches. As Mr. Perry himself says, the thing works beautifully—on paper. I might add that it never will work anywhere but on paper. Some kind of movable switches must be used, with magnets to open and close them, with two circuits on the magnets. Trolley wheels have to run on and connect three wires at the same time in many cases, making contact with all of them. These wires of course have to be insulated when the trolley wheel is not on them. Altogether the thing is extremely complex, and, I can say, absolutely impracticable. In addition to this, of course, there are the objections which apply to any and all series systems—very serious objections. In using a constant current one must vary the potential difference at the car; a car which would take 100 amperes at 500 volts, as many do, will, if run on 40 amperes, require 1250 volts. As one cannot run a dynamo over 5000 volts with any sort of decency, it is necessary to section the line. The sections must be so short that it is impossible for two cars to be on the same section at the same time. For city work, therefore, the sections must be very short, which means more of these switches.

Mr. Perry neglects completely what probably is the most important objection to the series system—that is the motor itself. The constant current motor is a very different sort of thing from a constant potential motor. A constant potential motor can be run, of course, at double its nominal capacity for a short time, but when a constant current motor is at its point of maximum work—that is to say, when the brushes are in the maximum position—if the load is greater than that for which the machine is designed, it will at once come to a dead standstill. There is no margin of overload in a constant current motor, hence the machine must be built for the very greatest load it can ever possibly get. To regulate it one must vary the field or shift the brushes. Shifting the brushes causes sparking. One might shunt the magnetic circuit; but that means beastly magnetic design. Moreover, a series system is necessarily a double trolley system, and this of itself is enough to condemn it utterly, without regard to the numerous other objections cited.

Although it seems as if it were hardly worth while to resurrect this, yet certainly Mr. Perry does deserve a great deal of credit for the ingenuity with which he has worked it out. He has made a very readable article. It is well, however, to keep in mind that the only point at which it is even claimed the series system has the advantage is in the saving of copper. But the cost of copper, although a large item, is by no means the total cost, and even the reduction of the copper cost to one-half or one-fifth of its present value would not be such a great advantage as to counterbalance the other disadvantages which it entails.

The next paper is Mr. Leonard's "A New System of Electric Propulsion." I think, however, I shall leave this until I have finished with the other paper, because some things I wish to say about the other paper will have a bearing on Mr. Leonard's.

The third paper is on "Electric Railway Motor Tests," by Professor Shepardson and Mr. Burch. These experiments were made apparently in the shops of one of the railway companies at Minneapolis. They are evidently made with crude apparatus, and as far as I can make out from reading the paper rather carefully, the conditions of the tests are not accurately specified. In many cases one cannot tell at what voltage the test was made. No attempt is made to note the temperature; that is to say, the resistance of the circuits at the time the efficiency was measured; altogether I should not regard them as of the very highest degree of accuracy. Nevertheless I think the results given are in substantial agreement with others. On page 579, in Fig. 1, is shown the curve of efficiency for the old No. 6 Sprague motor. The numbering of the clips is slightly different from what is usual; clip 2 would ordinarily be called clip 1. The tests were made on all the clips, that is 2, 3, 4, 5 and 7. As I stated some time ago, in an article I wrote, it is more than harmful, it is criminal carelessness to use these switches on any but the first, fourth and seventh clips, the reason being that the sixth clip has the same number of ampere turns as the seventh and a very much higher resistance. The same is true of the third and fourth. One gets practically the same speed with the fifth, sixth and seventh, but a very much better efficiency on seven. Many roads run on the sixth constantly. They are afraid to use the seventh, so they stick to the fifth and sixth and run with a resistance of about 0.6 ohms more than there is any necessity for.

I have compared these tests made by Shepardson and Burch with some which I published myself the other day; [1] they were published under my name, although they were really made by my company These tests were all made by an electric method. We adopted this method after trying in vain to get consistent results from Prony brake measurements; we tried various forms of the Prony brake, but were unable to get satisfactory results; impossible efficiencies were frequent. Finally we gave up all attempts to make mechanical measurements, and used the electrical method altogether. This method demands very few simultaneous readings, only two, and allows the correction for temperature to be made very easily. That is, one can reduce all efficiencies to the standard temperature, so that the efficiency curve is given for the standard temperature. Tests, to be strictly comparable, should be made under some such conditions as this. The suggestion, by the way, to make these tests at a constant resistance, and the method of deducing the formula, which is not as simple as it seems, are both due to Dr. Duncan. It will be seen from these curves that the No. 6 Sprague motor has an efficiency of 83 per cent. at 20 amperes, falling to 80 per cent. at 35, and running down in the other direction to 80 per cent. at about 12 amperes. That is to say, between 10 and 35 amperes the efficiency at the armature shaft is above 80 per cent. The efficiency with gears from 35 to 15 amperes is pretty constant at about 75 per cent. This is a very much better efficiency and better results in every way than I have seen published for any motor except some which apparently were distributed at the meeting of the street railway convention in Cleveland the other day. These were of the Short company's new gearless motor. Results are there given for four gearless motors, and one, if the curve is correct, is by all means the most admirable motor I have ever seen in the way of efficiency. It reaches a maximum of about 87 per

1. *Electrical Engineer*, Oct. 12, '92.

cent. at 7.5 H. P., and is practically constant to 14 H. P. The curve crosses 80 per cent. at 5 H. P. and again at 21 H. P., so the efficiency from 5 to 21 H. P. would average about 83 per cent. This motor then has a very high efficiency at low loads, a feature greatly to be desired. We all know that the street car motors run for nine-tenths of the time at very low loads. A motor which has high efficiency at low loads and drops down even to 60 per cent. at full load is very much better than one that goes up to 80 at full load and drops down to 50 per cent. at a quarter load. The authors of the paper call attention to the fact that these results are not strictly comparable among themselves for the reason that the voltage varied in the different tests. They give tests which I think none of us can interpret—such as Fig. 2—for the reason that the different curves there are taken with either two-thirds or one-third, as the case may be, of a T.-H. rheostat in series with the motor, the resistance of the rheostat is not stated anywhere, nor is there any means of getting P. D. at the armature.

Fig. 3 gives two rather interesting test curves of a No. 6 Sprague motor, showing how the efficiency at low loads can be raised by increasing the number of turns on the field; that is to say by working at a greater excitation at light loads than is usual. This is rather interesting and would be a very good thing if it were possible to work in that way. But unfortunately it does not take speed into account, really the ruling consideration. It is often said that the commutated field method of working is absolutely wrong, because it gives the maximum number of turns at the very worst time. The authors have brought out that point, and to a certain extent it is true. They make one observation on page 585 which I think is extremely pertinent and which everybody will have something to say about sooner or later; that is that an average of twelve tests on a road, showed that with two motors on a car it required 27 per cent. less current when only one was working. I dare say that most of us think that one motor is the proper thing now that motors can be so built that there is no longer danger of serious accidents. It is easy to see how the saving comes about. If from the current and torque curve of any motor one finds the current for a car under any conditions on the assumption of one motor, and then on the assumption of two, the result will show greater current when using two motors. This means simply that the motors are working at lighter loads, and consequently at lower efficiency.

I do not think there is much to be surprised at in the load diagrams given in Figs. 8, 9, 10 and 11. Although it is said that when there is a large number of cars on a line the loads tend to equalize, nevertheless on every road where I have watched the ammeter there has been an extremely large variation. I do not think that with any method of direct working, a variation of 25 to 50 per cent. can be avoided.

There is another point which Professor Shepardson touches rather lightly on page 585. He speaks of the comparative value of the rheostat and "commutated field" methods of regulating. There have been two other papers published recently, one by Mr. Thorburn Reid. the other by Mr. Wellman, touching on that subject. Mr. Reid says the motor with the commutated field is much more efficient; Mr. Wellman says it is not. I rather wished to be convinced that Mr. Reid's argument was right; but I confess I could not understand it, and I could not make much more of Mr. Wellman's.

This matter has been argued back and forth for more than three years, but in this time no one, apparently, has thought of appealing to experiment to settle it. It seems to me that the matter can be definitely decided very simply, and to this end, that we may hear no more of the subject, I have prepared the following table showing the case of

COMMUTATED FIELDS VS. RHEOSTATS.

C.	Position.	S.	φ	φ_2	φ_3	$\varphi_1 - \varphi_3$
20	VII.	9.1	84%	..%	84%	0%
20	IV.	6.3	69	63	60	9
20	I.	4.4	50	44	42	8
15	VII.	10.6	83	..	83	0
15	IV.	7.3	73	64	61	12
15	I.	5.4	59	48	45	14
10	VII.	13.3	78	.	78	0
10	IV.	8.8	75	63	60	15
10	I.	7.0	66	50	48	18

Here φ_1 is the efficiency of a No. 6 Sprague motor for the various current values and corresponding speeds taken from my tests referred to above; values are given for the three switch positions: φ_2 is the electrical efficiency with rheostat for the same current and speed. This is calculated by reducing the E. M. F. of the motor in proportion to the reduction of speed. The efficiency φ_2 is then the ratio of the reduced E. M. F. to 500. This of course takes no account of hysteresis, eddy current and friction losses. Putting these all at five per cent., *i. e.*, taking 95 per cent. as the efficiency of conversion from electrical into mechanical energy, we get the column for φ_3; that is, $\varphi_3 = .95\ \varphi_2$.

It will be seen that in every case the commutated field method gives an efficiency higher even than the electrical efficiency with rheostat, and much higher than the best probable value of the actual efficiency.

This comparison is made with the same motor and involves no element of doubt. There can be no question that with these motors the commutated field is the more efficient, and it is very clear to me that it must always be so.

There is one other point I will speak of. Professor Short published on the 16th of April, 1892, in the *Electrical World*. an account of the practical operation of a gearless motor. This was either his first or second gearless motor. He shows as a contrast the efficiency of the double reduction motor on the armature shaft, on the intermediate, and on the car axle. I am sorry those efficiency curves cannot be shown, but the net result is that the efficiency of his gearing is extremely low. He calls attention to it by saying, "You will find on going over these curves that the load varies considerably with the speed." "You will find the efficiency is very low at heavy loads at slow speeds, and rises to its highest at medium speeds and medium loads." Of course in that particular case his object was, not to make a very good showing for the double reduction motor. Now taking that curve as he gives it, I find for a load of five horse power on the Short double reduction motor, on Professor Short's own testimony, the efficiency of the gearing is 78 per cent. only. We found on the Sprague motor 87 per cent. At 10 horse power his curve gives 74 per cent. as against our 92, and at 16 horse power his gearing efficiency falls to 63 per cent. as against our 91. He cannot be right; it is absolutely out of the question that it should be so.

The third paper is Mr. Leonard's: "A New System of Electric Propulsion." We all have heard this method talked of a good deal in its various aspects; I think Mr. Leonard has made a mistake in calling it a "new system of electric propulsion." There is nothing new about the electric propulsion. It might be called a "new system of electric regulation." The whole object is to replace the regulating apparatus of the ordinary street car equipment. A slight explanation of it may not be out of place, though I dare say everybody has read it. In Mr. Leonard's method there are three or four machines on a car. The first machine is a shunt motor run with a constant field, excited directly from the line. This I shall call the "line motor." The line motor is directly connected to another shunt machine which runs as a generator; the generator in turn supplies current to a third shunt machine (or to two machines) which drives the car axle, either through gearing or without it. The field of the generator is excited directly from the line, but has a rheostat in its circuit for regulation. The field of the driving motor is constant, and is excited directly from the line. The armature circuit of the driving motor thus has no connection to the line ordinarily. The regulation is effected by varying the field of the generator and thus varying the P. D. at the terminals of the driving motor, and hence its speed. The generator is driven at practically constant speed by the line motor, and hence its E. M. F. depends only on its field strength; this is varied within any limits by a small rheostat; it can also be easily reversed. The car will start very easily, and the current will not rise above the value required for moving the car. It gives a method of starting a car gradually, of running at any speed desired on any grade, seemingly without the great waste caused by using up somewhere or other the difference between 500 volts and that which is applied to the terminals of the driving motor. To this extent it is extremely useful.

Mr. Leonard says: "If we could operate, from the constant potential system, a shunt wound motor running at a constant speed, and could interpose between this motor and the axle some device equivalent in its effect to an infinite number of different sets of mechanical gears, so that we could make use of any reduction desired, it would enable us, while using a constant power, to increase the torque as we decrease the speed, and *vice versa*, which is just what is desired in railroad practice."

As he says, numerous devices have been invented for accomplishing this variable mechanical reduction. I dare say there are half-a-dozen under way at present. Mr. Leonard makes out a very good comparison between the ordinary method and the method which he proposes, ideally considered. As we all know, the power required to drive a car is made up of two factors, the torque and the speed; consequently, even with a great torque the power may be quite small if the speed is kept low. If 60 amperes is sufficient to start the car, and the resistances are such that 40 volts will give 60 amperes, then only 2400 watts is used at the instant of starting, instead of $60 \times 500 = 30{,}000$. These figures, 2400 *vs.* 30,000 represent the ideal case; now let us see how nearly they would be approached in practice. Take, for purposes of comparison, the second column in Table 1, p, 571; *i. e.* eight tons at three miles per hour on a five per cent. grade. Eight tons at three M. P. H. on a five per cent. grade with one per cent. for traction is 7.7 H. P.; this is at the car axle. This is the output of the system—7.7 H. P.=5750 watts. Mr. Leonard specifies that his driving motor shall develop full torque with 60 amperes, and that its full speed shall be 12 M. P. H.; the armature resistance is .55 ohms. The counter E. M. F. at full speed is then 467 volts, and at one-fourth speed is 117 V. $117 + 33 = 150$ V. which is the P. D. at the armature terminals; $150 \times 60 = 9{,}000$ watts delivered to the driving motor:

$$\frac{5750}{9000} = 64 \text{ per cent.},$$

the efficiency of the driving motor according to Mr. Leonard's own figures.

The resistance of the generator is .55 ohms; therefore, its E. M. F. at 60 amperes is 183 volts and its output 9000 watts. Assuming an efficiency of conversion of 90 per cent., the input will be 12,200 watts. The efficiency of the generator is then

$$\frac{9000}{12{,}200} = 74 \text{ per cent.}$$

Taking the efficiency of the line motor as 80 per cent., a high figure, its input will be 15,250 watts; the efficiency of the system after Mr. Leonard's figures, interpreted, will be

$$\frac{5750}{15,250} = 37.6 \text{ per cent.}$$

I have in the above purposely ignored field losses. They are 560 watts, equivalent to about 4.5 per cent., and the net efficiency becomes 33 per cent. (say). This is as against 54 per cent., which Mr. Leonard arrives at by guessing the individual losses.

It will be instructive to show the efficiency of this same driving motor governed by rheostat.

Its output is 5750 watts: current, 60; counter E. M. F. 117 v., therefore, efficiency with rheostat

$$= \frac{5750}{60 \times 500 + 250} = 19 \text{ per cent.}$$

With commutated fields, from what I have shown above, it would probably be 27 per cent.

The difference between 33 and 27, *i. e.*, six per cent., is the gain in this case. This is trifling, and by no means worth the complication involved. It is clear on the face of it that in the first case, *i. e.*, running at full speed, the efficiency must be lower than the direct system. Mr. Leonard meets this by throwing the driving motor across the line when full speed is desired.

So far, I have used Mr. Leonard's figures as a basis of comparison, but in dealing with his third case—eight tons at one and a quarter miles on level—I am forced to depart from them. The figures given for the various losses are 10 watts for friction and 10 for other armature losses. Using these figures, I get

$$\frac{400}{480} = 83 \text{ per cent.}$$

for the efficiency or conversion of a 30 K. W. motor operating at one-quarter part of full load!

It must be remembered when considering these 10 watts for friction, hysteresis, etc., that this plan of Mr. Leonard's does not permit of gearless motors any more readily than the ordinary equipment does. Exactly the same considerations would determine whether a gearless or a geared motor should be used. Mr. Leonard states that he would use a gearless motor—why, I can't see. The efficiency in this third case would probably not exceed 10 per cent., instead of 29 per cent. as given.

There is one point of difference between this electrical arrangement of Mr. Leonard's and an actual variable speed gear—a point which it is worth dwelling on. A variable speed gear that will give an infinite series of changes between the speed of the driving motor and the car axle would be put, of course, between the motor and the car axle, and if one were content to run up heavy grades at very slow speed, a maximum of 15 H. P. might be used. The driving motor would then be only 15 H. P. With this arrangement of Mr. Leonard's the driving motor must be exactly of the same capacity as it would have been otherwise; for this reason, on going up a heavy grade the motor takes its ordinary current—for instance, on a five per cent. grade 60 amperes. At some time it has to stand 60 amperes. It may have only 50 or 100 volts on it. At other times it runs at small current and at its full 500 volts. So taking these two considerations together, the machine must be of the same capacity as it would be otherwise. Exactly the same reasoning applies to the generator; that is to say, these two machines have to be of the full capacity of the ordinary car equipment; but with the line motor the case is different. Here there is the advantage of the saving in the actual power required to drive the car. In the line motor there is no need of greater capacity than the maximum power required on the car. If the limit is eight tons at three miles an hour on a 5 per cent. grade then the line motor should have a capacity of about 11 K. W., taking Mr. Leonard's figures in the second column of Table 1, or 15 K. W., taking my figures. Mr. Leonard, however, has ignored his own calculations, and made this a 7.5 K. W. motor; it will of course be much overloaded even assuming the correctness of his figures. I think that it will be found in all cases that the line motor should be the same size as the others.

One of the chief claims for this system is the reduction in power-house equipment. Mr. Leonard thinks he can use 6 H. P. per car at the power-house, and consequently greatly reduce the copper needed. This is based on the assumption that railway managers will be satisfied with such speeds as three miles per hour on heavy grades. This I believe to be absurd. There is the strongest demand for higher speeds, and 60 H. P. equipments are now put in, not to be safe in starting, but because 40 H. P. is actually needed to haul the heavy cars up the grades at the speed they must go to maintain a decent schedule. I dare say we have all heard railway men, *i. e.* non-electrical ones, praise a car because it went up a heavy grade at the same speed, approximately, as on the level. But even taking Mr. Leonard's 6.3 K. W. for a car on a level, and using 90 per cent. for line, 90 for generator and 87 for engines, it would require 12 H. P. instead of 6. This takes the work on a level as the average, and is under the mark.

I believe thoroughly in the desirability of a variable speed gear, provided it can be obtained without sacrificing too much; but I do not think this particular one fulfills that condition.

On page 576 is given a table intended to show the first cost of the two systems; from what I have already said, the following modifications of the table follow:

TABLE 2 (AMENDED.)

showing probable comparative first cost per car by present and proposed system; the latter as estimated by H. W. L. and C. T. H.

	Details of Plant.	Present System.	Proposed System.	
			By H.W.L.	By C.T.H.
1	Steam plant, generators and conductors	$2200	$1100	$2200
2	Motors, two 15 H. P. equipment	1800	1400	1800
3	Power converter	0	900	2400
5	Switches, etc.	200	30	30
	Total	$4200	$3430	$7430

I estimate the power converter as 60 H. P. at $40, not a high figure for tramway motors, and put the power-house output the same in both cases. This makes a total of $7,430 as against $4.200.

Another point which has not been brought out, and which works against the idea that the cars will use the same current, is the very much greater weight of this equipment. There will be say 30 horse power on your driving motors, 30 horse power for the generator and 30 horse power for the line motor, making 60 horse power additional machinery. This 60 horse power will weigh in the neighborhood of 6000 pounds. That is a load of 45 passengers, a heavy load.

On page 577 Mr. Leonard gives his summary of the advantage of this system. It reads:

"The features of the proposed system, which seem at first sight to be very objectionable, are:—The increased cost of the car equipment, and the fact that we are adding an additional machine, having two fields, two armatures and three bearings; but, as we have seen, there is only an apparent increase in the first cost, for the saving in the generators and distributing plant far exceeds the additional cost of the car equipment; and the use of the motor generators for elevators, for traveling cranes, etc., has demonstrated that, as regards the attention it requires and the depreciation it suffers, it has a marked advantage over the rheostat or commutated field used in the present methods of operation."

Against this I think the disadvantages are:

Increased cost of total equipment per car.

The adding of two more machines, with the consequent increased cost of repairs, depreciation and maintenance.

The greatly increased weight of the car, with the consequent increased power required.

The very small saving over commutated field regulation, due to the low efficiency of large machines lightly loaded;

And, greatest of all, sacrifice of simplicity.

The advantages are:

Excellent speed regulation.

Ability to return energy to the line.

And ability to use electric braking.

I should agree very strongly then with Mr. Leonard in the third paragraph of his paper in which he insists on the desirability of some method of accomplishing this object, but I should not approve the means adopted. [Applause.]

Dr. Chas. E. Emery:—I discussed one of these papers in Chicago and did not expect to say anything this evening, but Dr. Hutchinson's remarks bring to mind some points upon which I have information that may be of service. It is well in all brake experiments to criticize the apparatus very closely. I have seen it recommended to throw a rope over a pulley, fasten one end and apply a spring balance to the other. Evidently this cannot be accurate, except when the fast end of the rope is slack, and yet sufficient friction remains to show a tension on the spring on the other side. A rope passed with several turns about a pulley, and provided with a spring scale at each end, has been very strongly recommended, but the two scales must be read exactly at the same instant, if not absolutely steady. It would evidently be better, therefore, to replace one with a weight. The Appold brake, which has been spoken of in connection with the experiments of Prof. Short, was much used in experiments with agricultural engines twenty odd years ago. The tension is self-regulating; the two ends of the strap connect to the short end and fulcrum of a lever, and the long end is held stationary. One side of the strap is loaded, and tends to move the lever in such direction as to tighten the grip. When the turning effort of the wheel is sufficient, the weight is lifted, and the short end of the lever carried around until the strap is loosened so that the wheel turns within it, and the adjustment is thereafter automatic. This arrangement has been criticized from the fact that a portion of the force required to strain the belt, is received by the stationary point at the end of the lever, and as its amount is not known, it cannot be deducted from the load as it should be. In an article on dynamometers written for Appleton's *Cyclopedia of Applied Mechanics*, I showed that the above defect could be obviated either by putting a spring scale at the end of the lever, or by the use of an additional lever which automatically subtracted the force required to produce the strain. The article is referred to for further information. I have seen a great many clamp brakes, merely screwed up by hand, which operated quite reliably. I have found it of advantage, however, to have a spring under one of the bolts, or otherwise provide means to make the grip on the pulley elastic.

I happen to have some information on another point that may prove interesting in this connection. The desirability of having a variable gear, which Mr. Leonard speaks of in his paper, and which has been referred to by Dr. Hutchinson, has been attempted by a great many, among others by myself, and my experience may be of value to others who are thinking in the same direction. If we use an electric motor to operate a pump of variable capacity, and then with the fluid operate a hydraulic motor on a car axle, the variation in the quantity of fluid delivered in a given time will evidently vary the speed of the car axle, and we have the variable gearing, or at least the variable mechanical connection desired, subject to the disadvantage of friction in the apparatus. It was thought that by properly proportioning the pipes so as to utilize the high fluid pressures now in vogue, probably the saving electrically would be greater than the mechanical loss. I spent no money in testing this fact. I first determined to make a reconnoissance and ascertain what had been done in the same direction. The simplest way of doing this, as I had found in other cases, was to put an application in the Patent Office complete enough to cover the general idea, which brought out the fact that there had been dozens of applications on the subject; that the general principle had been well covered years ago, and that a number of interferences were pending with parties who proposed to use modifications of the system. I, moreover found in this way, a man who had actually made tests on the subject, who had actually used. on a car, a pump with variable capacity to drive a hydraulic motor fixed on the axle, but the fluid soon became so highly heated that it was necessary to stop every little while and allow it to cool off. To be sure, the inventor ran the pump with a steam-engine instead of an electric motor, but evidently this had no effect on the function of the fluid connection. The sizes he selected were, moreover, nearly the same as I had fixed upon in my mind as being about right, he using a maximum pressure of about 300 pounds, and distributing the fluid through four-inch pipes, while I had expected to use about 500 pounds and pipes of the same size. This difference may be sufficient to overcome the difficulty, or at least it may be practicable to use large pipes and high pressures with smaller volumes and prevent serious heating. The car as equipped, is housed within a few miles of New York, and I could readily obtain permission to apply an electric motor to it, but on account of the difficulties above mentioned, and the fact that the fluid gearing was completely anticipated, I have taken no further interest in the matter.. Curiously, I have met Dr. Edison within a few days, and in the course of a conversation he outlined an almost identical arrangement which he said he had never had time to work out, but which he assured me was the right way to do it. There were a number of persons in interference with the inventor I have referred to, who proposed to employ the same idea for clutches, permitting the fluid from a pump operated by the motor to escape freely through a shunt opening in starting, and gradually closing such opening to bring the speed of the motor and driven shaft together. I have heard from other sources that some of these devices heated badly, but in such case this would not be so much of a disadvantage, as the device is practically only used in starting, like a rheostat, and considerable time will be available for cooling.

THE PRESIDENT:—May I ask if the method of changing the capacity of the pump was by varying its internal arrangements or simply varying the speed of the pump?

DR. EMERY:—He could vary the speed of the pump but that was not in either Dr. Edison's mind or mine.

THE PRESIDENT:—Was there any attempt to throttle the passage of the liquid?

DR. EMERY:—I think he used a shunt. No, he used several pumps of different capacities, and by means of a change valve could readily operate either, or all, at will.

The only other point which it occurs to me to mention here is, that while we admire the regulating system of Mr. Leonard as presented in his paper, and we expect he will probably be able to defend it from the practical criticisms that have been made, still he has a very strong competitor in shunt motors, which, though thoroughly understood, have not to my knowledge been heretofore applied in such a thorough way as recently by Messrs. Siemens Bros. and Co. on the new locomotives of the City and South London Electric Railway.[1]

Apparently these motors have been made heavy enough—in other words, iron enough put into them—so that considerable changes of speed can be made by simply varying the strength of the field without any material sacrifice in economy, and the dead resistance of a rheostat is only used for a few seconds in starting. At first sight this would appear to be a system applicable to street car motors, but on careful consideration it will be seen that there must be a sufficient section of iron in the field and armature, to utilize the whole strength of the field at a reasonable point below saturation so as to obtain the low speeds satisfactorily, and there must be a sufficient number of ampere turns on the field at the high speed to prevent sparking. It does not appear that both these conditions can be obtained without the use of more iron than is ordinarily employed with series motors of less range. Such an arrangement should not, however, be objectionable when the motors are put upon a special car to form an electric locomotive.

MR. C. O. MAILLOUX:—I have but very little to say on this matter; because it is mainly a branch of the subject where I am, so to speak, tabooed, as I have had the misfortune (so my friends say) of being connected with one phase of the electric traction problem which is not popular just now—though I think it will be more so later on. However, there is one point which occurred to me as Dr. Hutchinson was speaking; it is in relation

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1. See *Electrical World*, Aug. 27, 1892.

to facilities for regulation as affecting the probable success of the storage battery. If we stop to think for a moment we realize that the storage battery is certainly not deficient in regard to the means of regulation which it affords. In fact that is one of its strongest points. If it were as strong in all other points as it is in the facilities which it affords for regulation, there would be no trouble and no doubt as to its success. One of the readiest means it affords and one of the earliest ways which was thought of for regulating storage battery motors, was to divide the storage batteries into a number of groups and to group the circuits in parallel at the start, and then gradually group them into different arrangements of series, multiple and so on. In that way you get a variable electromotive force, so that you attain, to a considerable extent, the very object which Mr. Leonard undertakes to obtain with his machinery, viz.: a variable electromotive force of supply.

But there is another point coming in there which I think argues in favor of using two motors on a car, even though there may be, as we recognize, an economy in using only one. The use of two motors lends itself beautifully to regulation, as it enables us to start with them in series, and to couple them in parallel later, and play similar changes with the batteries, and thus we get a whole chain of regulation, so that we can get the same thing practically as if we had four or five different initial electromotive forces. In other words, if we have an electromotive force of 200 volts maximum with all batteries in series, we can start with what virtually amounts to about 20 volts electromotive force by making, say, four groups of batteries all connected in parallel at the start with the two motors in series; and we can successively couple the motors in parallel, and the batteries in series, for increasing the speed, and finally reach the maximum potential. The method of using batteries in parallel and motors at the same time was first tried, I think, by myself on Fourth Avenue in 1887, and has been used more or less since by all having to use storage batteries. It has not come into use in connection with trolley roads until quite recently. I think that it is only this year that it has been agitated and brought into practical use. However, to-day there are very few roads that do not practice it and with considerable success. I saw some later forms of regulators by the companies exhibiting at Cleveland which showed a marked increase in the extent to which combining commutation of the field and commutation of the motors themselves has been used as a substitute for resistance in getting the intermediate steps between starting and full speed.

I might say something in relation to the variable speed ratio method of regulation, because, as I was saying to a friend of mine at Cleveland, it is like the measles—I think we all have to have it; and I do not suppose there is any electrical engineer who has given any considerable thought to electric traction but that has at some time or other in his career come across several attempts at variable speed ratios, and perhaps has devised three or four himself, and tried a few. I have not been more fortunate than others in having to undergo the experience. I have also tried some. The conclusion that I have come to is, that while there is a fancied or perhaps a real trifling economy in their use, as long as we are able to accomplish substantially the same object in other ways, namely by varying the number of cells in series by grouping the sets, or else by varying the motors, or both, it does not pay, while, moreover, the extra complication is very objectionable. The cost of coal is not such a large item after all, while the amount of money involved in the depreciation is usually a very important item which frequently exceeds that of the cost of coal. It is, therefore, a serious question whether it is worth while to think of using such methods, at least in the present state of the art of mechanics. It is possible that some new application of mechanical principles that we do not know of yet may be discovered, which will enable us to accomplish in a simple, uncomplicated way what we all dream of as an ideal, but I know of nothing of the kind now. The nearest I know of is a method which Dr. Edison published of an epicyclical gear, the two movable members of which are each operated by motors. I happened to work in the same direction for a long time. and probably should have had an interference with Dr. Edison on the subject if I had been a little more diligent in the direction of patents. But I am not at all sorry. I am willing Dr. Edison should have all the glory there is in it. I tried the same device on a street car, though moving only one of the gears of the epicyclical gear train and having a friction clutch on the other movable one. By that means you can obtain any ratio from infinity down to the ratio for which the gear train is arranged. I found that the device worked very satisfactorily, but the complication was objectionable, and the friction band on the loose gear and the difficulty of keeping it in adjustment under all conditions, and things of that kind were objectionable. The motorman very soon got out of the habit of using it at all if he possibly could avoid it. The motorman seems to find in practice that the fewer handles and levers you give him to manipulate the better off he is, even though I had this arranged so that it could be operated with the brake handles. The man would put on his motor and it would start it running, but with the clutch loose. Then by turning his brake in the reverse direction the clutch was gradually put on and the motor gradually clutched on, and the ratio gradually decreased from infinity down to its normal value. The car very nicely started and followed on. But I found that even this arrangement, though as simple as it could be, was not simple enough for the average motorman, because oftentimes he would start the wrong way to do it.

At any rate I consider that I am cured of the fever for some time to come, and I am willing to be content with systems of regulation, perhaps less economical of power, though also less expensive to build and to maintain.

Dr. Emery:—I wish to ask one question before the subject changes. I understand that series parallel, or series multiple traction is pretty well covered by patents. If my information is correct I do not see how the various applications spoken of by the last speaker can be made by engineers generally and will be pleased to hear the statements of others more fully informed on the subject.

[Vice-President Hammer took the chair.]

Mr. Sprague:—If I can depart from the chair for one moment I will make one reference to this subject. The series system was tried at Richmond five years ago. Twenty cars were fitted with multiple series switches used with the commutated fields. They worked perfectly so far as increased torsional effort, the slowing down of the machine, and all that, was concerned. The method was not patented. Where it failed was when on heavy grades the attempt was made to run the machines in series, and to start on a slippery track. In that case, if there was slipping on one portion of the track on account of ice or sleet or for any other reason, one motor would begin to race and the other motor would slow down. The claims made for series multiple regulation have afforded me a good deal of amusement. As to the effectiveness there is no question, but the series multiple system, when running at full service, will make little difference in the coal burned. So we simply threw away our series multiple switches and ran our machines invariably in multiple. The action of two machines in series is easily understood. Of course, the total counter-electromotive force built up, is the sum of the counter-electromotive forces of the two motors, and if one runs fast, the other must necessarily run slow, so that sometimes we had one running one or two hundred revolutions a minute and the other standing dead still.

Mr. Mailloux:—We are never troubled that way with storage battery cars. They are always heavy enough to give plenty of grip with the rails.

Mr. Sprague:—In the latter part of 1886 Mr. Wharton of Philadelphia was supplied by me with a couple of motors operated on the storage battery system, and the switches supplied provided not only for a change in batteries from operating four sets in various combinations but also for multiple and series arrangements of both armatures and fields. It was not very satisfactory, because it was found altogether too complicated.

Professor Francis B. Crocker:—One point that Dr. Emery referred to, I think can be explained, and that is the use of shunt motors on the City and South London Railway. On any line where you have a clear track there are usually only three conditions to consider. One is standing still, one is starting, and the other running at full speed. Now those three are, any or all of them, easier to take care of than running at very slow speed for a long time. That is the hardest thing to do for an electric locomotive or electric street car. That is what strains the rheostat, reduces the efficiency, and puzzles the electrical or mechanical engineer most. But when there is a clear track, as in the underground railway, the tunnel of which is used exclusively for this particular railroad, they can run nearly always at full speed. I happened to ride on that road this summer. It takes perhaps half a minute to start, and then they are at full speed. Consequently there is no period of any length that is considerable, where they are running at slow speed. It will be seen that the losses, the inefficiency of commutated fields or rheostats, etc., are not to be considered at all, because they enter for only a few seconds, and this is a very small part of the run, and a still smaller part of the actual work of the system. So what is true of a train that can always run at full speed when it gets started, is by no means true of a street car system where perhaps you may have to run at half speed, or even quarter speed for a long period of time, if you are behind a truck or going through a crowded street, or under various conditions that will suggest themselves to any one who has ridden on a surface city railroad. The experience on the City and South London Railway would be a very poor thing to adopt as the standard of street car practice. On the other hand, the success of this railway is a very encouraging thing to the electrical engineer, who looks forward to seeing electric locomotives used on long distance service, where we have a free right of way and the ordinary condition of working is full speed. I think this is quite an interesting point, and one which should be borne in mind by anyone who is putting in the street car system, or one who is putting in the long distance or other "clear track" system.

In regard to the relative efficiency of commutated fields and rheostats, I early conceived the idea that it is very objectionable to have this dead resistance. In fact in 1884 I was one of the patentees of several inventions which had for their principal object the elimination of the loss in the dead resistance, and commutated fields was our system. But this is somewhat a question of words. That is to say, the resistance exists there, and we have got to consume the difference between the counter-electromotive force and the direct, or most of it, in some way or other, and there is no very efficient way to consume it. We can use it more or less satisfactorily in exciting the field. But since a motor will work with such a small percentage of current in the field, it is pretty obvious that we have got to consume a considerable amount of energy in our dead resistance, if we use it, or in our system in some other way if we try to avoid dead resistance. Of course the rheostat, although it is the simplest form of using up this energy, is not the most efficient in theory, and perhaps not in practice. If a certain amount of that lost energy can be saved, why so much the better; if not, we have got to bear with that loss until some better system is devised.

DR. EMERY:—In regard to the subject of shunt motors, I quite agree with what Professor Crocker says, but evidently he has not read the article to which I refer. The efficiency tests of the Siemens motors referred to were necessarily made in the shop with a brake resistance, and the different speeds given, merely translated into car speeds by calculation. These tests showed an efficiency of 90 to 92 per cent. for variations of speed between 12½ and 30.6 miles per hour. Complete diagrams were given, showing the particulars as to actual speeds, volts and amperes. The maximum speeds in practice varied generally from 17 to 19 miles per hour according to the direction of the grade, and the averages for the round trips, exclusive of stops, were about 13 miles per hour. I find it possible from the changes in the initial slopes of the velocity diagrams to determine, with reasonable probability, the several operations performed by the engine runners; for instance, it can be seen when the dead resistance was probably taken out and the motor therefore running with full field and the acceleration a maximum. Soon, however, the speed rises more slowly and other changes may be observed, showing doubtless when resistance was put in the shunt field so as to further increase the speed.

MR. CHARLES HEWITT:—The use of the shunt motor for street cars has not been entirely neglected in this country, and is certainly not original with Siemens and Halske. I am not sure but that the President has tried it in the early days, and although Siemens and Halske may be able to use their locomotive successfully in London on that particular road, it certainly will not be a success here, until we get a much smoother running trolley than we have at the present time. Any one noticing a trolley running here will find that at almost every hanger there is a slight sparking. That is due to the slight contact and sometimes no contact at all, due to the jolting of the trolley from the wire. I have been on cars with a voltmeter when I could count every clip by the swing of the needle. With a shunt motor every time the trolley leaves the wire, the shunt field is discharged, and when it strikes the wire again you get a short-circuit through the armature. This trouble is still worse when the trolley wheel jumps off, as it frequently does at switches. I believe in London they use a third rail and a top-running trolley wheel, perhaps two of them, and are sure to get a contact all the time.

With regard to Mr. Leonard's arrangement, I do not intend to go into any details of it except as to the complication involved. We all know the difficulty of having two motors on a car properly cared for. Only recently, within a very short distance from here, I knew of a case of a hot journal where the motorman got off, scooped up dust in his hands and threw it in, and said that

that would cool it off. When we put a complicated arrangement such as this must be, into the hands of men like that, we increase those difficulties very much. The whole tendency of street car practice to-day, it seems to me, is toward greater simplicity. I am very nearly convinced that we are coming to the day when we shall use a single motor on street cars—I won't say on locomotives, but on street cars—for small powers.

I want to call attention to what Dr. Hutchinson spoke of on page 585: "An average of twelve tests on the road shows that with two motors on a car it requires 27 per cent. less current if only one is working." Dr. Hutchinson seemed to think that that was chiefly due to the motor working at a very small part of its power. From a great many tests which I have made myself and have seen others make, the average power taken by the motor when it is actually doing work is somewhere in the neighborhood of 50 per cent. of its rated maximum. You take these tests that are shown here—I have not averaged them, but I have averaged a great many others. The No. 6 motor, I believe, is wound for 25 amperes. On a great many tests I have found that the average current while the motor was actually being worked varied from about 20 to 30 amperes per car, that is the average of all the readings. Say the average for the car is 25 amperes, and assuming that each motor does its proportionate share, that would be 12½ amperes per motor, or 50 per cent. of the full load of the motor, and at 50 per cent., granting that this curve here is approximately true, the output would be seven and a half H.P. They have carried out this curve farther than we usually consider it. Say the motor is a 15 H. P. motor, at half load it gives over 80 per cent. efficiency. Even if the power used is only between five and six, you see the efficiency is over 80 per cent. So that I do not think the difference between the one and two motors is due so much to the low efficiency, as it is to the difficulty of making two motors run together as the motors on this road were connected. It is a well known fact now, that with two motors, connected according to Mr. Sprague's design, with a connection from one motor to the other between the fields and the armatures, it is very difficult, especially with the double reduction type, to get them to equally divide the load. This difficulty brought out the equalizing coils which were invented, I believe, by Dr. Hutchinson. The matter has been simplified more recently on the new motors by giving each motor a distinct circuit. I have known cases where not only one motor has done no work at all, and the other has done all the work, but cases where one motor has turned into a generator, and generated as high as 10 or 11 amperes, and the other done all the work. So that the difference between one motor and two motors in that case would be very apparent, and not due to the low load at which the motors were working. I have had such a case as that within a couple of weeks.

DR. HUTCHINSON:—Of course I know that a great deal of the loss is due to the fact that one motor drives the other as a generator. But still if you take the efficiency curve at the car axle you will find a difference of about 15 per cent. But the tests given by Professor Shepardson and just quoted are tests on the armature shaft, not on the car axle, and consequently not applicable.

MR. MAILLOUX:—I would like to ask if Dr. Hutchinson has any information on motors when they are equally balanced by having each run with an independent circuit. I was astonished myself to discover that this method of running independently was not sooner brought into use, because I have never run motors in any other way but in an independent circuit for each. Of course, it would be apparent right away that there would be some difficulty. I would like to know what difference there is in running them balanced, each motor having its own circuit.

DR. HUTCHINSON:—You have a certain total horizontal pull. You divide this between two motors and find the current for one motor and multiply it by 2 The difference would be about 15 per cent. It is hardly worth while going into, but you will see the point at once.

MR. SPRAGUE:—I have a few remarks to make on those subjects. Those who have visited the beautiful Moravian cemetery in Salem, North Carolina, or that in New Orleans, where they bury the dead above the ground in tombs, or in country towns where lovers stroll on Sundays, have doubtless often noticed one inscription on the stones which mark the resting places of those who in life perhaps were filled with great hopes and ambitions. That inscription is "*Requiescat in pace.*" When in Chicago some four months ago I heard Mr. Perry's paper on "Series Electric Traction," and Mr. Leonard's on "A New System of Electric Propulsion," that thought came to me—better let them "rest in peace." In these four months there has been no resurrection. I feel now as I felt then. If there was good in these systems it would work out its own salvation, and if the defects which seemed to be apparent were there, they would of themselves eventually condemn them. So satisfied am I on that I see no reason to change my opinion. The series system of electric propulsion is absolutely dead. Every now and then an attempt is made to revive it. It has been tried on one or two roads in England. It has been tried on one or two roads in this country, but if I may make reference to Prof. Short's own work, his experience has been a suggestive one. He started five or six years ago on the series system in Denver and elsewhere, and about four years ago in West Virginia. It is dead. And then he went on to the double-wire multiple arc system overhead, as did the Thomson-Houston company in Cincinnati to accommodate the local requirements of the telephone interests, and that plan is practically dead, and we have come, on the five hundred railroads in operation in the United States and elsewhere, to one single method of operation, a multiple arc system of distribution with a single wire overhead—and that is where we will stand. I have no hesitation in putting myself down as a prophet in some of these matters. There have been great advances made in the last three or four years in electric railways. My own connection with them for the past two years has not been active. I am now going into a different class of work. But while there have been improvements in price, and improvements in mechanical applications, more perfect machinery, greater interchangeability of parts, there has been little if any increase in the actual economy. Four years ago forty cars were running on the Richmond road with engines of 375 horse power, in other words, nine horse power per car at the central station. Every car on that line was doing all that it could do. We have in fact retrograded in some respects, and the number of accidents which are to-day cited, sometimes justly and sometimes unjustly, in opposition to the trolley system, is due in a large part to turning backward, and to the additional complication of apparatus. The plan which seemed to me to be the proper one was to give the man who ran the car, as little as possible to think of. All that he should be required to do is to move a lever—as small as convenient—one way to go ahead and to pass through all the gradations of starting, increasing the speed, going at full speed, and by reversing that movement by a single stroke of the hand to pass through the retrogression of those changes, to reverse his machine and to run in the opposite direction. That plan has been abandoned. Two levers must now be used, and many a life has been the forfeit. The demands of street car service have continually increased. We can no more creep up a five per cent. grade at three miles an hour to-day than we can put a horse on the car to pull it up. The schedule time of roads will not permit of that operation. At first it was 15 horse power to a car; to-day it is 20, 30 and sometimes a 40 horse power equipment. Why? Not because of the requirements at starting, but simply because when running at the full speed at which the machine will run when loaded, with the cars, with the trucks, with the passengers carried, the motors are required to do that amount of work when working under the highest possible efficiency for which they are built. We cannot go back.

Referring a moment to the question of control, I have noticed in recent observations of some of the roads, that the motorman is required to operate two sets of apparatus. He has his regulating apparatus for varying the speed of the car. He has his independent switch apparatus for varying the direction of motion. What is the result? A man is pulling along at 12 or 15 miles an hour with a tow car behind him. He is travelling a car length in a second. Another car comes along in an opposite direction, and some man dull of hearing or short-sighted steps in the way. If the car is controlled by a single movement, which responds instantly to the wish of the motorman, he has got the power, independent of his brakes and quicker than they can operate, of bringing his car to rest before he has run over that passenger. But if he has got first to cut off his current, move the reversing switch, and put on his current again, he has passed double the length of the car before he can stop it. I say in that respect we have retrograded in street car work when we have added two movements instead of running with one.

I had intended to comment in detail on this system of Mr. Leonard's. Independent of any possible merits of the plan, there are, I am sorry to say, many inaccuracies; some have been pointed out by Dr. Hutchinson, and there are others which Mr. Leonard himself may notice in looking over his notes. There is much assumed in the matter of economy, but when we consider the time limit involved in starting, I unhesitatingly assert that the amount of coal burned in the central station will be fully as great, if not greater, by this plan, than with the system of direct supply, because of the amount of energy needed for the continuous rotation of the power converter.

He has made one reference to elevator work. It is an unfortunate allusion. An elevator is in some respects the hardest sort of railroad service. I have a record made over a period of about eleven months on an elevator driven by a motor which is a compound machine, governed purely by a rheostat. This motor runs for ten hours a day. It is a very fair example of good elevator service so far as the element of time is concerned. It stops at five floors of a building, carries both freight and passengers, and is practically in continuous service. Its operation is much more continuous than very large numbers of hotel elevators and many office building elevators. That record shows that for ten hours duty a day there is used at the terminals of the motor the equivalent of about 100 amperes at 240 volts for one hour. These are from meter records, and meters were never known to lie in favor of the customer. We run about 250 feet a minute, stopping at every 10, 20 or 30 feet, and oftentimes running slowly. There is not used in the rheostat itself over ten per cent. of that energy; that is, 10 amperes at 240 volts for one hour. An elevator of that lifting capacity, if driven on a three motor scheme, would have to be supplied with a motor and dynamo of at least equal capacity driven by a motor of about 30 horse power. Two of these machines would normally, of course, have to run all the while. Of the size specified, they could not be run from a 240 volt circuit for less than about 15 amperes. Consequently we have the equivalent of 150 amperes at 240 volts for one hour. In other words, for the system of regulation alone to take the place of the rheostat, there would be used 150×240 watts against a total present use of only two-thirds of that, and against a use of one-fifteenth part of it for the rheostat. So I say this is probably a clear illustration of how the time element enters to continually cut off the efficiency of the system where you have anything that runs continually.

With regard to the method of operating by shunt machines, I would say that in 1886 on the elevated railroad I operated two machines which were of this character. Subsequently they had a small series field introduced. The speed of the car was controlled there first by the rheostat, and second by variation in field strength, and part of the energy of the car was delivered back to the line in slowing. Later, if I remember rightly, we introduced the series method of regulating the machines as well. In Richmond, the following year, I did do that. With machines of even ordinary weight, that is 100 lbs. to the horse power, if the series multiple method is used with the armatures alone, and there is a variation of the field strength, you can get a variation of from one to three in the speed without any difficulty whatever, and that eliminates all difficulty in starting. In other words if the maximum speed you wish to run is 15 miles an hour, you can easily run at a high efficiency at five miles by simply strengthening the field and throwing the machines in series where you have got a good track and a sure method of contact. When taking into account the fact that you can return a certain amount of energy to the line, I question very seriously if the shunt method will not hold its own in time even on a great many lines of street car service.

The difficulty which Mr. Hewitt has pointed out, that the two motors were not in ordinary street car practice run on different circuits is explained in this way:—When motors were first built, there was an assumption that the motors could be built to run alike. The current was made to divide itself in the two fields equally and then meet and divide itself in the armatures. Afterwards we found the difficulty which is pointed out by Mr. Hewitt, but it was too late to change our switches, because we had some thousands in operation. In fact we were under the same conditions that every manufacturer of apparatus made under stress is. If the two circuits are separate, then a large part of the difficulty, I should say three-fourths if not more of it would disappear at once.

DR. HUTCHINSON:—There is one word which might be added to what Mr. Sprague says about speed on grades and the power required in the power station. We are running a line, as he knows, in Baltimore, on a 6 per cent. grade and carrying cars up that grade at eight miles an hour. Then there are in use 60 horse power equipments on a car instead of 40. We make on that road a daily mileage of 205 miles with one car, the highest I ever heard of. The rest of the cars make 190 miles. I have in my hands a lot of tests which I made two years ago, showing the indicated horse power per car measured from engine cards on the old Sprague double reduction motors. The lowest was 6.2 I. H. P.; the highest, 8. If you measure the same thing now you will get anywhere from 12 up to 18 and 19 I. H. P.

Mr. Mailloux:—There is one point which I think has been neglected entirely in connection with this discussion; though it has perhaps equal importance, at least, with the methods of motor regulation so far as the economy of running and cost of the power is concerned. I said a little while ago that the cost of power itself was very small, and it was usually smaller than the cost of the depreciation. It seems to me that if we want to make it still smaller, if we want to reduce the cost of power pure and simple still further, that there is a much wider margin to work upon in the station itself than in the cars or motors. A number of engineers have investigated this subject, and it has been shown that owing to the constant fluctuation of the load, and the fact that the power is constantly varying; that the engine is cutting off at full stroke and then at very short stroke, in very rapid succession, the average (mean effective) economy, so to speak, of the engine, is very poor. For that reason, more than any other, compound engines have not turned out the results which were expected of them, and we do not obtain from the coal used, the horse-power that we ought to—not by 15, 20 or 25, sometimes 40 per cent. It seems to me that it is there we must look for any radical improvement in the amount of power consumed to propel the cars. The amount of energy wasted in starting, as has been sufficiently shown, is relatively insignificant, but in the station we have a large margin to work upon—a leak at the bung hole, as it were, as compared with the spigot (regulator) loss. I believe various methods have been submitted for increasing the station efficiency. I advanced one myself some two years ago, which has not been popular because the storage battery was used as a factor in it. There is, in my opinion, a good time coming when the storage battery will have its innings, and will be used in every electric power generating station; but meanwhile there may be other ways available or possible of equalizing the load, and thereby increasing the efficiency of the plant. A method has been advanced, depending on a peculiar form of steam-engine, by a concern which makes an engine that is said to give almost constant economy under very wide ranges of load. The makers claim to have been able with their engine to reduce the water consumption for given duty from 40 pounds per horse-power per hour, to 26 and 30, which results, if correct, ought to receive the attention and consideration of electrical engineers.

Mr. Sprague:—I may speak of one or two matters that have recently come to my knowledge. As regards the amount of coal used in central stations, it is undeniable that the central station presents great possibilities of improvement. People who are building to-day any large isolated plant can easily get from engine builders a guarantee of a horse power delivered to the shaft of a dynamo directly connected for not exceeding 25 pounds of water, and the dynamos are now rated at 92 per cent. We are going to have increased efficiencies in our central stations when we adopt direct connected machines.

As to the method of regulating larger machines, my own impression is this:—That for the larger railroad work of course it is essential that there should be at least two, and possibly four machines in operation, on account of the weight, methods of attachment, etc. The series multiple system will be used for running at variable speeds. The machines will be compound wound. The rheostat will be a very small factor. I am now concerned with some others in building an electric locomotive of about 700 horse power that has four motors of 175 horse power each. The adoption of four machines in place of two was determined, not by the difficulty of building two machines, nor by the difficulties of regulation, but simply because the space at our command required that arrangement. Suppose these machines run at 30 miles an hour under full load and best conditions, that is when all four are multiple; they will run about 14 miles an hour when run two in series and two parallel; they will run six miles an hour when all four are in series. When you get down to six miles an hour you have got down nearly as far as you want to go. If now we have in addition, the method of control by varying the field, we increase these variations of speed at least 50 per cent. I think that in the work now being done by the General Electric Company for the B. and O. R. R. under the original Thomson-Houston plan they will use four or six machines in these various combinations. It seems to me that the best method when properly connected is to run them in series multiple combinations. There is no difficulty in changing from one to the other provided you have got proper field regulation in addition.

MR. H. WARD LEONARD:—Mr. Chairman and Gentlemen:—I think that never since I first thought of this system of regulation have I felt quite so much encouraged as this evening, for after having had my figures, for several months at any rate, and having examined them, that Dr. Hutchinson should find that I only claimed 97 per cent., and when he is willing to grant that it may possibly be 20 per cent. and upwards, it shows me that I have something to work for, and with the possibility of success. The fact, joking aside, in regard to the question of efficiencies, is that quite accurate tests have been made of the system by a concern so well equipped for making tests as Wm. Sellers and Co., of Philadelphia, and that the efficiencies shown by the tables in this paper have been quite well borne out. I may say, while I am on that subject, that the losses in the fields and the friction, and the Foucault current and hysteresis losses which I have assumed, are derived principally from the tests of the Franklin Institute, and are also checked by the data of the test averages of the Edison dynamos, and I think they will bear the closest scrutiny. As regards the figures I have given in the tests, Dr. Hutchinson has pointed out one or two apparent errors, but I think it is due to a misunderstanding of one or two points by him. One point which he spoke of was the impossibility of having a central station equipped with only six horse power per car when in one of the most favorable cases he figures out eleven and a half horse power as required by a car. Without stopping to check that figure, I would say that I did not intend that six horse power in the central station would be enough if every car were in operation simultaneously at its full power, but that six horse power per car would be an average figure, some of them being at rest or going slowly, and some coming down grade, under which conditions they would assist the central station.

Another point that Dr. Hutchinson spoke of was the fact that in the table No. 1 there are eleven and a quarter kilowatts which he says had to be entirely absorbed by the motor of seven and a half kilowatts. But I call attention to the fact that the eleven and one quarter kilowatts is not all absorbed by the first motor, but a large portion of it is in the field and armature circuits of the second and third machines, and that the first machine is not overloaded. Similarly, without checking the figures up, that 97 per cent. efficiency, which he figured out, must be the result of some error.

Dr. Hutchinson:—I beg your pardon—87—I may have said 97; I meant 87.

Mr. Leonard:—87 would be about correct, because that corresponds to the efficiency of the Edison machine of that size. The saving at the central station due to the size of apparatus of course is a factor which we can only theorize on, but I think that in view of Prof. Shepardson's curves it is rather evident that if we could supply a system in which the very large changes of load due to the starting of the car could be avoided, we could get along with less dynamo and engine capacity in the central station, and by the results of tests on traveling cranes and a few elevators, and by the figures of railway tests I am convinced that the central station capacity in engines and dynamos could be cut in two. However, I wish to call attention to the fact that the cost of the street car apparatus to-day is not such an important factor as to very materially affect the cost of the entire equipment. In one installation that I am making to-day the entire cost of the street car motors is only about 5 per cent. of the cost of the complete work, and if any very great advantage, either in economy, control or in any point might be obtained by making that 5 per cent. 10 per cent., it still would be quite an advantage. In other words, if the cost of the motors should be doubled, and we could get any decided advantage, the money would be well spent, and it would be well spent if we could even get rid of the lack of economy in the consumption of steam due to the variable cut-off incidental to rapidly changing loads that we have with the present system. Mr. Mailloux touched upon this, and it is a thing which is quite important, because it is utterly impossible to use to-day engines of the highest economy, such as are used in other practice, for the reason that the supposed economy vanishes altogether in the use of compound engines, etc., because of the variable loads. The proposed system here, certainly will tend to give an almost constant load in the central station and effect a very large economy by the possibility of using engines of the highest type and operating them at the most economical cut-off.

As regards the depreciation of machinery, which I find I have made a memorandum of, there is, apparently, three times as much depreciation in three machines as in one; but when two of those machines are placed out of the influences which are the principal cause of depreciation, and when the third one is in a condition such as to have a minimum of sparking, and a minimum of heating of its field, and when the motor generator portions are also under the best conditions as regards sparking, etc., such will not be the case. The fact is, that in practice the operation of the system shows that the machinery requires almost no attention. And I know of instances in which electric elevators, which as Mr. Sprague has pointed out represent the worst kind of street car service, have been in operation for three or four months at a time without the slightest attention of any kind whatever. They have self-oiling bearings, and being entirely sparkless, they have had no attention whatever for months at a time.

The importance of a single lever rather than a multiplicity of things to handle on a street car has been touched upon both by Mr. Sprague and Mr. Mailloux in a rather forcible manner, and I call attention to the fact that in this system there would be but one lever which would accomplish all the changes of speed in either direction, and also apply the brakes, as the production of energy and the restoring of energy to the line, is the braking action for the car, and under any normal use of the system no mechanical brakes of any kind would be used, and the instance cited by Mr. Sprague of something on the track which makes reversal necessary can be dealt with by this system with the greatest of ease and the utmost rapidity.

I judge by a comment of Mr. Sprague's that he imagines that the time element in getting under way by this system is far more than it really is in practice. The fact is, that having a separately excited field for the generator, there is no cumulative action in the excitation of its field, and the change of field of the generator, and consequently the speed of the motor is extremely rapid. With the ordinary type of even cast-iron fields the action is extremely rapid.

A point which may possibly be of interest, in view of the discussion of the application of the shunt motor at high speeds on a level, is not in the paper, but it is a possibility in this method. When we have reached the full speed of operation on a level, we can avoid the necessity of running at Dr. Hutchinson's 2 per cent. efficiency by changing over from 500 volts of our generator to the 500 volts represented by the trolley and the ground by a movement of the switch without the least sparking, and without any difficulty; because in changing over we have the electromotive force of our propelling motor as before, and that will eliminate any inefficiency of the generator, and by operating as a shunt motor, especially on the trolley system, it would enable us to make long runs with an efficiency of probably 90 per cent.

As regards the question of efficiency again, Mr. Sprague mentioned the probability of 16 amperes being required for merely the excitation of the field to accomplish the regulation. I may say in this regard that a quite recent test within the past ten days shows that the entire amount of energy required at 230 volts—that is the system in this city—that the total number of amperes required not only to excite the field but to move the elevator at its lowest speed is not 16 amperes but 8 amperes.

There are so many points of importance in the system which I called attention to in the paper which have not been touched upon, that I assume they are considered of some value. I am pleased to notice that the gentlemen agree that the objects in general are desirable even if the method used is not the best of arriving at them; but it is one way of arriving at them and at present the only way, and the efficiency of that way can only of course be determined by practice.

The use of the system upon traveling cranes has gone sufficiently far to enable us to say that the efficiency of this method is very well known. There will be in use at the World's Fair a traveling crane, perhaps the largest ever constructed, which will operate by means of a motor generator between the source of supply and the final motors as the best modification of the method, although there are several others that might have been adopted. The use of this method on passenger elevators will shortly be tested thoroughly in the case of the *Herald* Building and the United Charities Building in this city and in two or three other buildings about town though some of them are private residences where the apparatus would not be available for observation.

One of the best points in connection with the system, in my opinion, is the ability to restore energy to the line in coming down grade or stopping, and what follows directly from that, the stopping of the car by an electric brake which is not only an electric brake in the sense of being operated by electricity but a brake which is an efficient means of stopping the car. It is the only brake I know of which will enable one to stop a car from its full speed down to a dead rest, and at all times during that period the application of the brake causes a positive saving on the system by the production of energy to assist in operating other devices. There are numerous modifications of this system, and, as you will notice, one good point is due to the fact that the secondary circuit has no connection with the line, which makes it possible to use any voltage desired in this circuit, and if in railway practice it became desirable to use a thousand volts for our trolley, we would still be able to use upon our commutators in the propelling motors, 250 volts or 300 volts or 500 volts, or anything desired. We might make our motor such, that it would run perhaps at ten miles an hour under ordinary conditions on this system. While running at ten miles an hour we could switch over to the trolley line and continue running at ten miles an hour direct; then open our generator field, which would leave our generator with no voltage at its terminal; then we could insert it in the line between the trolley and the ground in series with the final motor, at a time when there would be no additional voltage by its introduction, and then, by raising the voltage with the generator again to 500, we have the means of securing a thousand volts on the motor armature and also securing a counter voltage of 500 to bring it to rest. A good many of these modifications will be of particular importance in certain applications. The principal point of importance, to my mind, is the flattening of the load diagram and what it accomplishes. That means, I believe, the cutting in two of the engine and dynamo, a very great increase in the economy of steam in the steam plant, especially in view of the energy restored to the line, which also assists in cutting down the capacity required in the station. This system will soon be tried on a street car. I was rather in hopes that it would be in practical operation before this time, and had it not been for unexpected delays it would have been,and it will be now probably within the next six weeks, and when I have had the system in operation practically, under expert hands certainly not prejudiced in its favor, I will be able to submit figures which are far more conclusive than those which I have assumed, and which may have errors in them. Of course the method is totally independent of the figures I have submitted, and if those figures are inaccurate in any way the result will be not affected by them.

I do not think of any other points that I wish to mention.

DR. HUTCHINSON:—I have only a word further to say. I am glad Mr. Leonard does not feel discouraged; it shows his real expectations were not high. I must call his attention, though, to the fact that he has made a mistake in the statement that a large part of the eleven and one-quarter kilowatts is supplied from the line; the only part to be deducted is the excitation of the driving motor and generator fields; that is, a total of 310 watts—practically nothing. Everything else comes from the line motor. Taking his own efficiencies this makes 21 I. H. P. in one case, and in the other. 11 I. H. P.

About efficiency in general, Mr. Leonard takes efficiencies of central station dynamos of fairly good size as a basis for the efficiency of street railway apparatus. This is no basis of comparison at all. It does not seem to me that any deduction can be made from one to the other.

Again, he did not answer the criticism that the equipment of a street car is determined not by the power for going up a five or six per cent. grade three miles an hour, but by the fact that the car must go on heavy grades at from six to nine miles per hour.

I think the plan is ingenious, and I have not the slightest doubt it will work—just as I might say storage batteries work.

THE CHAIRMAN:—I would like to call the gentlemen's attention to the fact that it is about a quarter to eleven, and as the Secretary has a little matter to bring to your attention before adjournment, it is desirable that the discussion should be as brief as possible.

MR. MAILLOUX:—I have only one question to ask Mr. Leonard. I am running cars with a storage battery which did weigh seven and a half tons, or say seven tons, and I am compelled to run them up a five per-cent. grade and carry fifty passengers, which would make the total weight not far from twelve tons. I would like to know what would be approximately the extra weight added to my car machinery, of which I already have enough on the car, by the converter—the motor dynamo of Mr. Leonard. It is evident it would have to be very much larger than that which he describes here. I should expect it to add at least as much weight as the storage battery itself.

MR. LEONARD:—I did not quite understand the question. If I understand it correctly, I would answer it by saying the method which I indicate of using a motor generator, and transmitting all of the energy to the final motor through it, would probably make it necessary to use a machine which would have a combined weight of about 120 pounds to each horse power delivered. In other words, a motor generator, at its highest speed and special design, I have no doubt could be designed and built so that the combined weight would be about 120 pounds to the horse power delivered. A motor generator would not, however, be used in the case of storage batteries.

MR. SPRAGUE:—May I ask where Mr. Leonard proposes to put the power converter? I do not want to be too inquisitive about it.

MR. LEONARD:—The question of location would be determined by the style of truck. It has been laid out to be placed between the axles of the cars, so that the axis of the motor generator would be parallel to the track.

MR. SPRAGUE:—I thought if it was in that position it would not get the care and attention which is demanded for it. If it was placed in the car body, the cost of the space sacrificed for passengers would be somewhat more than the possible saving of such a system. But practical experiments determine more than all the arguments in the world. I think I am right in my prophecy that there will not be less pounds of coal consumed per car mile run by that, than by the present system.

MR. F. V. HENSHAW:—I would like to ask why it is that the motor end of the motor dynamo transformer is so much smaller than the rest of it—that is to say, about seven and a half K. W. against something like 20 or 21.

Mr. Leonard:—The size of the motor for the line will be determined only by the power represented by the moving load—the size of the final motor and the generator must be determined by the torque at the time when the load is heaviest, and by the volts represented by the highest speed. But if you were to run your load at a low speed comparatively, on the grades, and high speed on the levels, you would not have those two factors coincident in the first motor.

Mr. T. C. Martin:—The other item on the programme is the report presented by the Standard Wiring Committee and revised by the Committee on Units and Standards. I would like to offer a resolution that this report be now accepted, and referred to the Congress Committee, and transferred by it to its Sub-committee on Provisional Programme for the Congress in Chicago in 1893. That, I think, will dispose of it in the only satisfactory way in which it can now be disposed of, and will give that Committee and its Sub-committee something definite to work upon. I would be glad to have the resolution seconded.

The motion was seconded by Mr. Kennelly and carried.

The meeting then adjourned.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, November 15th, 1892.

The 71st meeting of the Institute was held, this date, at 12 West 31st street. The meeting was called to order at 9 P. M. by Vice-President Hammer. In accordance with the notice issued, Dr. James Bowstead Williams made insulation tests of samples of various wires, using the apparatus described in his paper on "Oil versus Air as an Insulating Medium," beginning on page 601 of this volume.

The following associate members were elected at the meeting of Council:

Name.	Address.	Endorsed by
ARNOLD, CRAIG R.	Electrician and Treasurer Arnold Electric M'f'g Co., Chester, Penn.	Carl Hering. H. C. Townsend. C. O. Mailloux.
BOHM, LUDWIG K. *Ph.D.*,	Consulting Electrical & Chemical Expert, 81 Nassau St., New York City.	Carl Hering. Edwd. Caldwell. Wm. A. Rosenbaum.
DURANT, EDWARD	Electrician, with F. Pearce, 115 E. 26th St., New York City.	James Hamblet. Geo. F. Durant. R. W. Pope.
GALE, HORACE B.	Consulting Electrical and Mechanical Engineer, 40 California St., San Francisco, Cal.	E. J. Molera. W. F. C. Hasson. F. G. Cartwright.
HUNTING, FRED S.	Electrical Engineer, Fort Wayne Electric Co., Fort Wayne, Ind.	R. H. Read. A. S. Kimball. R. W. Pope.
MCELROY, JAMES F.	Mechanical Sup't, The Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	W. C. Miller. F. L. Woodward. R. W. Pope.
STAHL, TH.	Creusot Works, Creusot, France.	C. P. Steinmetz. S. D Field. R. W. Pope.
Total, 7.		

The following associate members were also transferred to full membership, their applications having been approved by the Board of Examiners.

BOURNE, FRANK	Electrical Engineer, Field Engineering Co., 143 Liberty St., New York City.
THOMAS, BENJ. F.	Professor of Physics, Ohio State University, Columbus, Ohio.
WURTS, ALEXANDER J.	Electrical Expert, Westinghouse Electric & M'f'g. Co., Pittsburg, Pa.
METCALFE, GEORGE R.	Electrical Engineer, Editor, *Electricity*, New York City.
STILLWELL, LEWIS B.	Electrical Engineer, Westinghouse Electric & M'f'g. Co., Pittsburg, Pa.

otal, 5.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK CITY, December 21, 1892.

The Seventy-second meeting of the Institute was held this date, and in the absence of the President, was call to order by Vice-President Hammer, who acted as Chairman.

THE SECRETARY:—The next meeting of the Institute will be held on January 17th, when a paper will be read by Mr. Caryl D. Haskins of Lynn, Mass, on "Recording Electrical Meters."

At the meeting of Council, held this afternoon, the following Associate Members were elected:

Name.	Address.	Endorsed by
BLUME, JOHN C.	Assistant Electrician, American Telegraph and Telephone Co., 23 East 31st St., New York City.	F. A. Pickernell. Geo. A. Hamilton. Thos. D. Lockwood.
BOUGHAN, EDWARD L.	Supply Agent, American Telephone and Telegraph Co., 18 Cortlandt St., New York City.	F. A. Pickernell. T. D. Lockwood. Geo. A. Hamilton.
CARSON, DAVID I.	Sec'y and Gen. Supt., the Southern Bell Telephone and Telegraph Co, 18 Cortlandt St., N. Y. City.	F. A. Pickernell. G. A. Hamilton. Thos. D. Lockwood.
CREHORE, ALBERT CUSHING	Instructor in Physics, Cornell University, 117 East Buffalo St., Ithaca, N. Y.	Edw. L. Nichols. Ernest Merrit. Harris J. Ryan.
DUNBAR, F. W.	Assistant Electrician, American Telephone and Telegraph Co., 153 Cedar St., New York City.	G. A. Hamilton. F. A. Pickernell. Thos. D. Lockwood.
MAURO, PHILIP	Counsellor-at-Law in Patent Causes, (Pollock & Mauro), 620 F. St., Washington, D. C.	F. L. Freeman. E. Berliner. Thos. D. Lockwood.
MORROW, JOHN THOMAS	Electrical Engineer, General Electric Co., Lynn, Mass.	Elihu Thomson. E. W. Rice, Jr. H. F. Parshall.
PARKHURST, LIEUT. CHARLES D.	Inspector, Watervliet Arsenal, West Troy, N. Y.	Louis Duncan. E. G. Bernard. Geo. O. Squier.

Total, 8.

At the meeting of Council, held in Chicago, June 7th, the following Associate Members were elected.

BUBERT, J. F.	Electrical Engineer, The Mather Electric Co., 116 Bedford St., Boston, Mass.	W. A. Anthony. John Waring. W. H. Powell.

CLAFLIN, ADAMS D.	General Manager, The Mather Electric Co., 116 Bedford St., Boston, Mass.	W. A. Anthony. John Waring. W. H. Powell.
FORD, WM. S.	Assistant to Chief Engineer, The American Bell Telephone Co., Room 73, 125 Milk St., Boston, Mass.	T. D. Lockwood. I. H. Farnham. J. J. Carty.
SHAIN, CHARLES D.	District Manager, Edison General Electric Co., 44 Broad St., Box 3067, New York City.	Geo. M. Phelps. T. C. Martin. Jos. Wetzler.
THOMAS, BENJAMIN F.	Professor of Physics, Ohio State University, Columbus, O.	R. W. Pope. T. C. Martin. Jos. Wetzler.
WELLS, DOUGLAS	Sup't of Telegraphs, and Engineer to Government, Nassau, Bahamas.	Herbert L. Webb. G. A. Hamilton. R. W. Pope.

Total, 6.

The following Associate Members were transferred to full membership, their applications having been approved by the Board of Examiners.

MOLERA, E. J.	Civil Engineer, 40 California St., San Francisco, Cal.
WILSON, HARRY C.	Sup't. of P. O. Telegraph with the Government, Kingston, Jamaica, W. I.
CHANDLER, CHARLES F.	Professor of Chemistry, Columbia College, New York City.

REPORT OF MEETING OF BOARD OF EXAMINERS, DEC. 6TH, 1892.

Present—Messrs. W. B. Vansize, Chairman, E. T. Birdsall, G. A. Hamilton, C. O. Mailloux and E. P. Thompson. R. W. Pope, Secretary, present *ex officio*.

New applications considered.	Applications reconsidered.	Approved and reported to Council.	Disapproved.	Laid over for further consideration.	Total considered.
	9	7	2		9
23		4	11	8	23
Totals, 23	9	11	13	8	32

THE CHAIRMAN:—[Vice President Hammer.] Probably you all have noticed little slips of paper on the seats and wondered what they referred to. The Council has, for several years, endeavored to secure something in the way of a badge which would meet the approval of the members of the Institute. Various committees have been appointed and the most recent committee, of which I happen to be a member, has presented quite a variety of wax models and sketches and drawings of different badges, and at the Council meeting this afternoon one of these badges was presented, and I asked the permission of the Council to put these papers in the seats with a view of spreading this matter more fully among the members and bringing out the suggestions that they may have to make. There is a feeling that we should adopt something in the way of a badge, especially in view of the approaching World's Fair and the meetings connected therewith. All the engineering societies, with the exception of ours, have special badges. The Committee has under consideration also, a certificate of membership. I have here a small badge made up according to the paper that you find in the seats, and after the meeting is over I shall be very pleased to show it to any of the members who desire to see it. It is a thing which we cannot discuss now, but the Council through the Secretary will be very glad to receive any suggestions from any of the members as to improvements in this design, or criticisms upon it in any way. All that we wish to do is to secure the best thing and something that is endorsed by a majority of the members. I might say that the little sketch on the blackboard, which is, however, very crude, gives a slight idea of it. After the meeting is over, the badge, made up exactly as it is represented, can be seen.

We will now have the pleasure of listening to a paper entitled "Micanite, and Its Application to Armature Insulation," by Mr. Edward P. Thompson, Member, for Messrs. C. W. Jefferson and A. H. S. Dyer.

The following paper was then read by Mr. Jefferson:

A paper read at the seventy-second meeting of the American Institute of Electrical Engineers, New York, December 21st, 1892. Vice-President Hammer in the chair.

MICANITE, AND ITS APPLICATION TO ARMATURE INSULATION.

BY EDWARD P. THOMPSON, M. E., FOR CHARLES W. JEFFERSON AND ARTHUR H. S. DYER.

An armature and its commutator consist of the combination of two elements; namely, electric and magnetic conductors and insulators. In the earlier days of armatures, the electrical and mechanical dimensions and proportions of the conductors were considered of prime importance. The first armatures were small and the electromotive force low, and consequently little attention, comparatively, was given to the element, insulation. Lately, simply paper, cloth, convolutions of ligatures, or these materials impregnated with shellac or similar insulating varnish or paint, were employed for the purpose of preventing leakage or short-circuit. To remove the solvent of the shellac, the armatures were baked for twenty-four hours. Judging from the variety of materials used at present, and the changes from one material to another, it would seem that the insulators are now receiving their share of consideration, while the core, wires, commutator-sections and other conducting portions are secondary details. Why so much difficulty with armature insulators and so little with other insulators, such as line insulators? Because, in the former, not only must the material be of extremely high resistance, but also unaltered under the effects of heat, and must be crowded into very small quarters. Space must be economized. If the electric current or heat alone were present, and if space were not so much limited, the problem would be easily solved. It yet remains to be proved that any known substance is absolutely a non-conductor—nor is the resistance of a given conductor constant. Unfortunately for the armature constructor, the worse the conductor, the less the resistance with increase of temperature. An extra current is produced in metals upon variations of current. A diminishing of current occurs when first entering a substance of high resistance. Finally, and gradually the current becomes constant. This action for convenience is often called polarization. As this property is noticeable only in long lengths of the insulating material, it has little bearing upon any of the armature elements other than in connection with the covering of the wires. The substance possessing the property of polarization in a marked degree is gutta-percha.

Paper or fabrics by themselves, should never be used as an insulator, because when moist they conduct a current so well that they may properly be termed semi-conductors. A coating of shellac or oil upon almost any substance enormously increases its resistance, and protects porous and deliquescent substances from water. Paper thus covered, serves with machines of low electromotive-force, the purpose of preventing leakage, but, by no means perfectly in practice, with large machines. Its advantages are more in the nature of convenience and cheapness than of efficiency.

Paper which has been thoroughly dried is of very much higher resistance—so high that it falls under the head of non-conductors, and therefore, the shellacs should not be applied until after the paper has been subjected to a thorough drying process.

It is a peculiar property that a given substance in a compact condition is of very marked higher resistance than when powdered or comminuted; for example, pulverized glass is a semi-conductor, while sheet glass is as high in resistance as silk. This property has been noticeable in armature practice. If the insulating material is cracked here and there, it is unfit for armature use. The cracks are in the nature of interstices between the particles of a powder, and at the cracks the material is in part ground. The explanation may lie in the distinction that the pulverized material has more surface, or that damp air exists in the spaces between the particles, or that a spark can traverse a gas better than a solid, or that each particle becomes coated with a film of moisture. The last seems the most probable, because the best surface concentrators of water usually exhibit the property most strongly.

The locations of insulation in an armature are between the armature disks to prevent eddy and Foucault currents; between the core and the windings to prevent the current from short-circuiting the coils through the core and burning out the armature; between the commutator-sections to prevent leakage from one coil to another; over projections or in grooves in the core; and around the wire to guide the current in convolutions. All these parts, even in the best made armatures become more or less abnormally hot. Means have been planned and sometimes put into practice for cooling the parts, and thereby saving the insulation. One method consists in constructing the armature after the style of a fan or with large radiating surface; another, in equipping a device to blow out the sparks at the commutator, and again, in using cooling insulating liquids. With whatever precautionary means the machine is equipped, the parts, either accidentally or through inefficiency of means, will become abnormally hot. The machine will be injured if combustible materials form the bulk of the insulator. The materials of an ideal armature consist of copper, iron, and a heat-proof and water-proof non-conductor. If the material is combustible, or altered in its chemical nature, by heat, its resistance is changed and generally lowered. Manufacturers of incandescent lamp filaments know that complete carbonization cannot take place except at a very high temperature, like 3000 degrees Fahrenheit. An armature may rise to 500 degrees. At this temperature, easily carbonizable materials, such as linen, cotton and other forms of cellulose are weakened, blackened and the resistance reduced. Shellac, although blackened at this temperature, is converted into those compounds whose resistance is not lowered. Shellac forms an exception therefore, in being charred by such a temperature without reduction of resistance.

There is a greater detriment than chemical change by heat. The material cracks, becomes somewhat comminuted, and the resistances, both mechanical and electrical, are therefore greatly reduced. If paper or cloth, or even shellac is depended upon as the insulating material rather than as the binding material, it is not electricity proof; because principally, it becomes, when charred fractured at numerous points, if not completely pulverized. As to why shellac is not appreciably lowered in resistance by partial carbonization may be because it is an animal substance.

One of the most important attributes of an armature should be its rigidity. It should be like a rock in this particular. If the insulation should consist of a soluble material, for example, and the same dissolved out after the completion of the armature; or of some material that would be reduced in size by heat; then the wire and bolts would soon become loose from the rapid rotation and vibration, and finally the armature would be useless. Change in volume of the insulators has caused nine-tenths of the armature break-downs.

In the matter of insulation between the disks it was found that oxidized or rusted laminated armature disks would insulate without any addition of paper or similar insulating films. The only difficulty with such a construction is one of degree. Iron rust insulates, and it is heat-proof; but it does not insulate sufficiently to compensate in most instances for its simplicity and cheapness, and besides it is not applicable to any other part of the armature than between the laminæ of the core. The great advantage lies in the extreme thinness of the oxide coating, whereby a large amount of iron is obtained in the core. A modification has been suggested, which consists in placing thin mica sheets between every half-dozen of the disks. Again, iron wire, or ribbon rusted has been employed for armature cores. The wire or ribbon is formed into a ring, around which is the electric conductor. Another modification consists in case-hardening the iron, and also in japanning the surface. As to commutator insulation, natural mica sheets have been almost universally employed.

If it were not for the matter of mechanical construction and heat, glass would make a good armature insulator. It could be molded into any form and made of any degree of thinness. Its objections, however, are well known. Very gradually, and more so than would be conjectured, mica made its appearance in armatures. The introduction of mica into practice appears to have been brought about in the following manner:—An accident would happen to an armature, and before the next night it must needs be repaired. In order to make the temporary remedy, mica sheets or bars would be interposed. In the case of subsequent accidents, the portion repaired by mica was the last to yield. Therefore it was proposed to build the armature primarily with mica. But this change took place very, very gradually, but surely. Manufacturers of stoves, the leading houses being also importers of mica, soon experienced a growth in the mica department of their business, until at present some import more for the electrical industry, especially for armature use, than for stoves. Why it was not employed from the first, no one could positively assert, otherwise than to guess that no one probably thought of it, or insulation was not considered of much comparative importance, or cheapness of material in construction was allowed to counterbalance efficiency of action and durability.

Of all substances, mica probably is the best material for use in armatures, if it is desired to obtain not only efficient electric insulation, but also durability under the influence of heat. The highest temperature to which an armature is subjected, even by short-circuit or bad construction, will have no injurious effect upon mica. Mica, thick or thin, may be held in a gas flame without cracking, burning or melting. It remains unaffected. The reason of this is better understood when it is remembered that it consists of aluminic silicate, containing also potassic, sodic and lithic silicates, and some ferrous and ferric and manganic oxides. Its chemical constitution varies.

One quality of mica is that which is commercially termed amber mica, and is usually mined in Canada. It is so named from its appearance and not because it is amber or in any other way similar to it than in its color. India mica is a commercial form noted for its uniform cleavage, extreme thinness of its laminæ, flexibility without fracture and its resistance, which is much higher than that of amber. Carolina mica is another variety. It is obtained in sheets in the western part of North Carolina. It is the best mica for stoves, but it is too hard for some electrical purposes. Mica occurs in so many specific forms that particular names have been given to it.

Muscovite is one of the most common varieties. It occurs in different colors, namely, a dark green, yellow, brown, white and gray. This is the form usually found in small scales in granite, gneiss, and mica schist, and at the same time it occurs in larger, tougher sheets than any other form. A complete scale is irregularly hexagonal in shape. Lepidolite, or lithia mica, has a pearly lustre, as distinguished from the vitreous luster of muscovite. Its scales are usually very small, and it is found in limited varieties of granite and gneiss. Cryopholite is a subvariety of lepidolite. A characteristic feature of the form meionite consists in its occurring much cracked within. It has been found in geodes. Biotite is a form found in volcanic rocks in small scales. It contains much iron and magnesia compounds. Phlogopite occurs usually in limestone. Its subvarieties are aspidolite and manganophyllite. A very brittle variety is lepidomelane. It is also practically opaque. Its subvariety is astrophyllite.

The insulating power of mica is superior to that of any other substance applicable to armatures. An advantage, peculiar to itself, is its even, laminated structure. How wonderful is the thinness of its individual layers! A piece of ordinary writing paper is about .005 inch. Mica layers have been obtained of a thinness of .00003 inch. Mechanical difficulties prevent its being split thinner. By pasting it upon a hard surface and splitting it off as much as possible, the remaining fragments are so thin as to become beautifully iridescent. The builder of armatures can therefore split the sheets into any desired and uniform thickness with great ease and accuracy. An interesting property of mica and one not generally recognized, is its homogeneity of structure and clear transparency, although so black when thick. The writer used a piece one-quarter of an inch thick for observing the late solar eclipse. The effect was better than with smoked glass and as efficient as black glass much thicker.

A valuable property of mica in connection with commutator insulation is its proper degree of hardness, whereby it does not wear away too rapidly under the action of the brushes. If rubber were used, for example, even if it did not burn, yet it would wear off and sparking result, because the commutator surface would not be truly cylindrical. The brushes would be set into vibration. Again, mica is capable of the finest pulverization, so that any wearing which does take place does not result in the liberation of gritty particles, which would also cause sparking. Such mishaps occur with hardened artificial plastic insulators. The insulation should be just so thick that the current cannot jump across from one section to the other.

Although so superior for armature insulation, mica is, in its natural structure, accompanied by certain objections, which, in trying to overcome, were more serious than had been anticipated, as it was not until after a long series of trials that a successful article was produced, and not until a novel apparatus for cheapening the process of manufacture was devised. The apparatus is now in operation on a large scale. The description at present is confined, however, to the article, and to full information of its structure, manner of using and properties.

The objections alluded to are:—Mica, as found in nature, occurs in flat sheets only. It has a high degree of elasticity, so that when once bent and released, it assumes its original form. If folded, its brittleness causes fracture. If the natural sheets are compressed in a mold, to try to form armature insulator heads for instance, it is completely broken up.

Secondly. Natural mica sheets correspond financially to plate glass. The larger the sheet, the higher the cost per square inch. Mica in small pieces, from four to six square inches, is exceed-

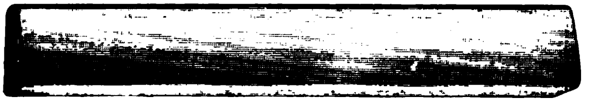

FIG. 1.—Micanite tube for insulating core projections.

ingly abundant and very cheap. It is often called waste mica, because very limited in its uses, and consisting often of trimmings from larger and more useful sheets. In medium and large sizes of armatures, the naturally built up mica is so expensive as to be objectionable, although not so much so as to entirely prevent its employment.

Thirdly. Between the hundreds, nay, thousands, of thin layers, damp air can enter, and also water, accidentally, which cannot easily or effectually be removed.

Fourthly. Mica splits so easily that handling causes injury.

Fifthly. Mica cannot be cut transversely to advantage. The edges are unworkmanlike, being ragged and jagged. Neatness in drilling, sawing and turning is difficult.

Among the attempts which have been made to overcome these

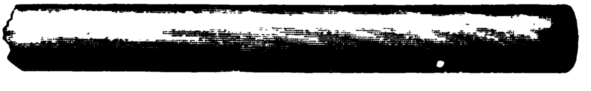

FIG. 2.—Micanite tube.

objections are those involving the use of pulverized or comminuted mica, which is mixed with a liquid cement and stirred into a paste. While still soft the mixture is rolled or compressed into any desired form, as if consisting of so much plaster-of-paris. In order to give it sufficient strength, one-third of the product is cement. The mica sparkles here and there on the surface, as it glitters on granite. This article should be called a cement insulator, and not a mica insulator, because the current can flow in a straight circuit through the plate without encountering any mica. The cement forms numerous rectilinear paths for the current, independently of the mica; and therefore the product is in no sense an equivalent of mica.

A modification of this type of insulator consists of a coarse and thick textile fabric, whose pores and meshes are filled with a mixture composed of comminuted mica and a suitable adhesive substance. Another consists of finely divided asbestos mixed with pulverized mica, silicate of soda, and sulphur compounds. It is molded by pressure into any desired form.

The comminuted mica-cement type is useful in trolley wire supports and similar insulators, but for dynamos it is useless not only for the reason stated, but because of its softening and running under slight heat, being so necessarily rich in cement. If the cement is that kind that chars, the mica crumbles apart. Mineral powders have been mixed with it, to render it more fireproof.

An example of the manner of using non-comminuted mica between the core and the windings consists in covering the core

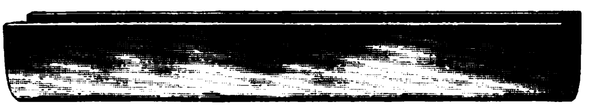

FIG. 8.—Micanite armature slot insulator.

with paper, laying sheets of mica over the paper, then laying on another sheet of paper, fastening the whole together by convolutions of cord or similar ligatures, and finally applying the coils. During operation, the paper and mica may shift from their positions, and thereby affect the rigidity of the armature as a whole. Again, the process of applying the pieces, and keeping them temporarily in position, requires repeated efforts and results in a display of crude workmanship.

The exhibits before you show practical results of work carried on for the purpose of overcoming the objections named.

Large Plates.—One of these plates is a yard square and .035 inch thick. Another is of the same size and 1 in. thick, and another about 4 in. by 12 in. and 1 in. thick. They have nothing to do directly with the armature; but could serve as foundation plates for a dynamo or motor. They are practically all mica. A *natural* plate of mica of the larger size would be a curiosity—a rarity. Any of the sheets may be cut up into any desired size and shape. The layers cling together much more tenaciously than in the natural plate. The path of least resistance from one side of the plate to the other is in a straight line, and a straight line intersects numerous mica sheets, and, therefore, the article is a mica insulator and not a cement insulator. These plates are made by such steps and apparatus

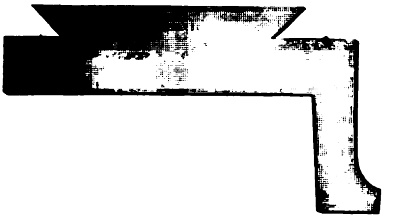

FIG 4.—Micanite commutator-segment insulator

that when subjected to heat in the armature, no injury whatever is produced.

Further, they are superior to a sheet of mica as it comes from the quarry, in that they do not absorb water or damp air; in that they are stronger to resist either pressure or tension; in that they may be neatly and easily sawed and drilled; in that they are enormously less costly; and in that they are of about the same resistance. By picking the exhibit apart, you can easily learn the structure. The mica of which it is composed is non-comminuted, but the pieces are exceedingly thin. The thickness is, by measurement, about .001 in., *i. e.*, about as thin as tissue

FIG. 5.—Complete drum-armature core protected with micanite.

paper. The sizes vary from 2, to 6 or 8 square inches. In each layer of mica, you may notice that the sheets overlap at their edges, and the cement between the layers is hardly noticeable. The former mentioned plate weighs about 4 lbs., and the latter over 100 lbs. It is a convenient quality in connection with mica that it can be split into pieces of the thickness required for the particular device under the process of construction. This property is also possessed by the plates exhibited. A thin and long knife may be caused to force its way in any of the many planes parallel to the surface, for the purpose of reducing the thickness or obtaining several thinner sheets from one thick plate.

Some tests were carried on to determine the relative values of these plates, and plates of comminuted mica and cement. Using the words of the electrician who originated and performed the tests, he says:—"For the purpose of insulating armatures, any solid insulating material should possess considerable strength and should maintain its strength when submitted to a moderate degree of heat. One piece tested consists of ground mica and shellac, mixed together and rolled or pressed between plates to a uniform thickness. In order to test it, I placed it upon a steam-table and left it for a minute, at the end of which period I tested its strength

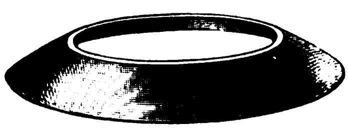

FIG. 6.—Micanite ring for commutator.

FIG. 7.—Micanite washer.

by pressing the end of a piece of wire against its surface with very light pressure. The end of the wire, which was blunt and made of copper, easily pushed its way through the sheet and left a hole when removed. In removing the sheet from the steam-table it warped. The second plate consists of layers of sheets of mica, cemented together with overlapping joints. This sheet I placed on the same steam-table used for the other sheet, and after one minute had elapsed, tried to thrust the same piece of copper wire through the plate, but without success, though exerting all the strength that could be brought to bear upon it by my hand. After the sheet had been on the steam-table for five minutes, I placed it on a thick iron plate, laid a piece of the same copper wire upon its upper surface, put a second sheet of wrought-iron on top of it, and put the whole into a hydraulic press. It was then submitted to a pressure of 2,000 lbs. per square inch for one minute, and the result was the flattening of the wire and a very slight crumpling of the mica sheet on the opposite side. The plate was then placed between two copper plates, and a weight of about four lbs. placed on the upper plate. The insulation resistance of the plate was then tested and found to be 25,500 megohms. I have used similar plates, similarly prepared, in motors, upon which a load of 50 H. P. has been placed, the entire thrust of the motor being received by the plates, which in this case were less than one-sixteenth of an inch thick. The temper-

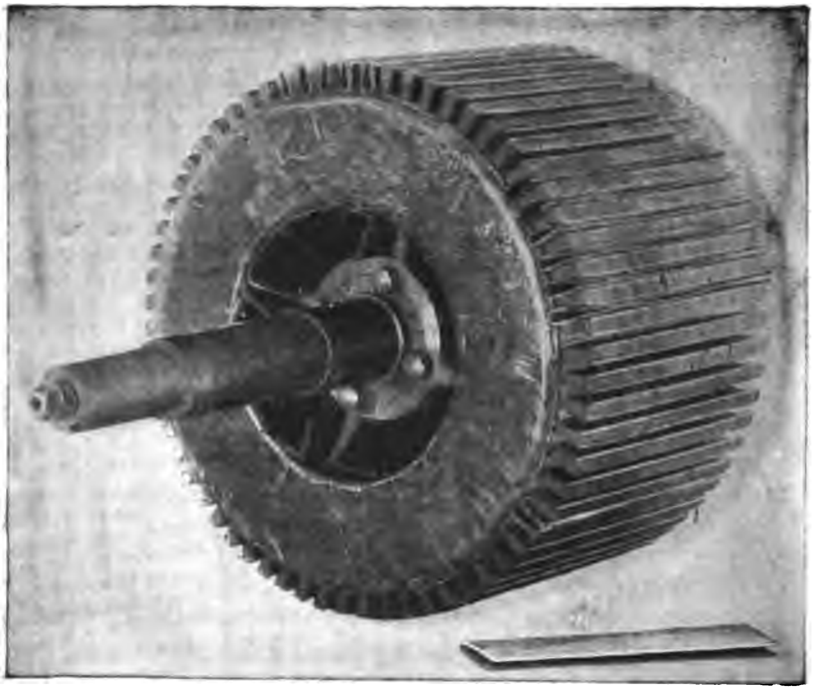

FIG. 8.—W. P. armature core showing application of micanite slot insulators, and annular flanged micanite head.

ature was brought up to 650 degrees Fahrenheit, sufficient to burn cotton and melt hard solder without injuring the insulation."

Curved Specimens.—Similar remarks substantially, may be made about these, as about the large plates. Natural mica plates could never be given a permanent set, or molded into curved forms. The armature head consists essentially of an annular disk, provided with flanges around one or both peripheries. It is in one sense a continuous piece. The flanges, you may notice, are not made separably and then fastened to the disks. There are no joints. Some of the peculiarly curved forms are furnished in order to illustrate that the article may be manufactured in any imaginable form of uniform structure, and in single pieces of uniform properties throughout.

Tubes.—In order to show the unlimited forms into which the material may be molded, a tube several feet long is exhibited. It may be cut up for use in certain types of armature, or when long, for use on board ship, and in general interior conduit installations in certain limited cases.

Stamped Forms.—The flat pieces of peculiar form could be made from the beginning in individual pieces, but are much more economically stamped from larger plates. Before using the large plates for any purpose where an exact thickness is required, they are burnished or surfaced off by machinery. Some of the plates before you, are in the crude state, and little scales here and there can be peeled off. The others are so different as to resemble a metallic surface, and when struck, ring like metal. Some of the forms are for large commutators. Others are flat rings for field-magnet cores. The very irregular flat pieces are for certain types of commutators. On account of the almost metallic qualities the product can appropriately be termed an "insulating metal." For convenience, it is called micanite.

Commutators.—In equipping a commutator with this material, it is necessary to know something which has been learned by early users, only through experience. The insulating and metal sections are put together in the usual manner, and the whole is heated to a temperature higher than that which it will reach in actual practice. While still hot, the elements are clamped tightly together.

Among the exhibits, is a mass of odd pieces of mica sometimes called waste mica; also, you will find similar pieces split as fine as possible. These are the result of the first operation. The next step consists in putting them together in the manner shown in the exhibits; that is, in layers with overlapping edges. Between them are layers of a cement having those qualities which fit the product for the purpose intended. Until only recently, these pieces were always laid on by hand. One girl could produce only one cubic foot per day. Now, one girl can do the work which formerly required twenty. The girl feeds the machine, and it does the rest. The amount of cement employed is practically infinitesimal, because while in a plastic condition, the mass is subjected to such pressure that a mere trace remains, and yet sufficient to obtain proper adhesive qualities. From the beginning to the present, improved processes and new machinery have been required.

Dr. James Bowstead Williams has carried on a long series of tests upon the comparative specific resistance of mica and micanite. The data and results are as follows:

The conditions of the tests were absolutely the same in all cases. The potential was constant, being over 3,000 volts, A dynamometer served to maintain the same pressure for different materials. All the samples were kept at the same temperature and under the same hygroscopic conditions for several days. Samples were of uniform thickness. The best samples of micanite gave approximately the same reading as the best India mica, indicating that the resistance of micanite is equal to that of the best commercial mica.

I will close this paper by presenting certain topics which appear to be suitable for discussion, but which need not be adhered to. I hope you will discuss among yourselves as much as possible.

Suggestive Topics.

Armature.—Rigidity and its dependence upon insulating material employed. What has been learned by observation and special tests?

Preservation of Insulation.—Is it better to try to remove the cause of heating, or to neutralize the heat?

Burning Out Armatures.—What does insulation have to do with it, and what are the remedies? Also, what are the causes?

Durability of Insulation.—Differences in connection with armatures for inside use, such as installations and outside, *i. e.*, railway, mining and elevator use. Effects of atmosphere, motion and rough treatment.

Financial.—Does the expense of insulation, if the best, have an appreciable effect upon the cost of construction, and, on the other hand, will it pay in the end to put in a cheaper material?

Comparative Merits of Insulating Materials for Different Conditions.—Effects of high potential. Power to resist spark puncturing. What have tests shown as to properties of materials to withstand "break-downs," independently of high ohmic resistance?

DISCUSSION.

THE CHAIRMAN :—I am sure the members of the Institute have been much edified by the exceedingly interesting paper Mr. Thompson has presented to them this evening, and for my part I should like to see more papers of this practical character presented to the Institute together with exhibits such as Messrs. Jefferson and Dyer show here to-night.

Will Vice-President Hering please take the chair in order that I may open the discussion upon the paper?

[Vice-President Hering here took the chair.]

MR. HAMMER :—We see to-night what seems to be a most important advance in the art of armature insulation, which, while it may be new to many has, I understand, been thoroughly tested, endorsed and adopted by the largest electrical company in this country.

Some who are here can doubtless date their experience in armature insulation back a dozen years or longer, and tell tales of experiments with mica, paper, ebonite, plaster-of-paris, of fields bored out to receive armatures intended for other machines, and more often armatures swollen by heat, moisture, or mechanical expansion until the chafing against the pole-pieces necessitated such a step; of coils burnt out and rewound, burst bands replaced; of dynamos which would not energize their fields because of low resistance, crosses in the armature circuit, of experience with high bars, soft bars, disconnected bars, short-circuited and grounded bars in the commutator, and other troubles too numerous to mention, many of which, by reason of increased knowledge and improved methods the electrical engineer to-day knows little of.

Mr. Thompson very truthfully remarks "that change of volume has caused nine-tenths of the armature break-downs." This change of volume has been mainly due to mechanical strains and heat.

Moisture by lowering the insulation between adjacent coils, framework and coils, commutator and shaft, etc, causes grounds and short-circuits followed by overload, charring and burning of insulation and disastrous results; besides this, the swelling of substances used upon the armature which absorb moisture create serious mechanical difficulties, such as bursting of wire bands, chafing against field magnets, putting armature out of balance, etc.

Insulating materials which absorb oil and moisture should never be used. Paper and vulcanized fibres have been largely used in armature construction, and are pretty fair mechanically, and while suitable in constructing the core, are unsuitable for commutator insulation, as are plaster-of-paris, asbestos, and such substances. Air-gaps are sometimes employed but necessitate constant cleaning to prevent the copper or other metallic dust from the brushes and commutator collecting between and short-circuiting the commutator bars.

Heat affects insulating substances by contracting, expanding, charring and burning, according to the degree of heat and character of materials employed, and in armatures heat is produced by the resistance in the armature windings, overload on machine, heavy grounds, short-circuits, hysteresis, Foucault or eddy currents in iron cores, armature windings, conductors and magnet pole-pieces, and by the use of commutator bars or brushes of insufficient size or imperfect contact between the same; and in armatures of both dynamos and motors, heat will to some extent always be present, and as it cannot be entirely eliminated and is often excessive under conditions of overload and accident, the neutralization of the heating effects by the employment of high-class materials is of vital importance.

Increasing the speed, involves increase of mechanical difficulties due to contrifugal force, which strains connections at commutator bars, lugs and radial bars, endangers the insulation of overlapping coils at ends of the armature, and strains the bands of piano or other wire enclosing the coils. Furthermore, there is the "drag" produced upon the armature coils by the magnetic field which is constantly varying, causing a strain, and a racking strain is produced by armatures being out of balance, a fault which is still sometimes met with. Besides all these difficulties, high speed increases the friction of rubbing surfaces, and the difficulty and expense in lubrication of the same.

From the foregoing it is self-evident that it is of paramount importance in armature construction that materials be employed possessing strength, rigidity, excellent qualities to resist heat and moisture, and to the highest degree insulators of electricity. These qualities, experience has shown us mica possesses perhaps to a greater degree than any substance known, and apparently the inventors of the process which has resulted in the remarkable samples we see here to-night, have by using "scrap mica" silenced the objections to its extensive use on account of its price, and by the methods of manufacture, enabling them to form this refractory material into almost any shape, have very greatly enlarged mica's sphere of usefulness and conferred a great benefit upon the electrical profession and the world at large. It would be interesting to know the specific inductive capacity and specific resistance of the micanite or combination of mica and shellac.

Fleming Jenkins gives the specific inductive capacity of mica as compared with air as 5, while that of gum lac or shellac is as low as 1.95.

Gordon and Silow give shellac a value as compared with air of 2.74. Mica not given.

Culley gives shellac fourth place in the list of materials of highest resistance and lowest conductivity, rating dry air first, ebonite second and paraffin third.

Munroe and Jamieson give the same rating excepting in case of certain kinds of glass, which they rank as second.

Ayrton and Perry give as the approximate specific resistance of shellac after several minutes' electrification as over 100 times that of mica.

Extension of alternate current practice, and use of high potentials, especially in power transmission work, gives a far greater importance to insulating substances, such as are here shown and they should meet with an extensive application.

Besides its application to dynamo and motor work, there are other fields of great importance, such as in the construction of alternate current transformers, this method admitting of the forming of the insulating substance for separating the high and low potential coils, insulating the core and encasing the high potential leading-in wires, and in the construction of direct current motor transformers, which I look to as developing a large field in this country, this material should find an extensive application in insulating the high and low potential wires in the armature.

In physical apparatus, such as induction coils of large power, the problem of insulation is of vital importance. It is interesting to observe that the largest two coils ever made in the world, the Apps or Spottiswood coil in England, and the Wallace coil of this country, have both been pierced, due to insufficient insulation at the high potentials employed, notwithstanding the great care in manufacture. I have here a photograph of the great Wallace coil, made by William Wallace of Ansonia, Conn., in 1869–70, which gave a spark 27″ in length.

In the construction of powerful condensers, lightning arresters, switch-boards, instrument and machine bases, a field is open to the employment of such materials.

As an indication of the high tension which will ultimately be employed in power transmission and other work, and the necessity of high-class insulation, it is interesting to note that the Ferranti company in England is now supplying electricity for lighting purposes from the Deptford station at a potential delivered direct from the dynamos to the Ferranti mains at 10,000 volts.

These mains consist of concentric tubes of copper insulated by paper and run underground to sub-stations where step-down transformers are employed. The manager informed me that they had had considerable difficulty in keeping up the insulation in the armature. Each day the fields are slid apart and the armature carefully cleaned. The paper-insulated tubes apparently worked very well, but judging from the row of burned out transformers I saw being repaired, there is an excellent field for micanite in the high-tension transformer industry.

I understand that this material is produced very cheaply, and while in armature work we must consider mechanical and electrical perfection first, some comparative figures showing the cost of the material would be interesting and appropriate in this paper.

Mr. Thompson refers to the use of micanite in long tubes aboard ship and in general interior conduit installations. I should like to learn if it can be made cheaply enough in this form to fill such requirements.

The Chair will call upon Mr. Harold Binney to continue the discussion.

MR. THOMPSON:—Mr. Binney has sent a note saying that he is prevented from appearing this evening. He had some notes written out, but not in proper form to be read. He expected to come at the last minute, but the doctor would not let him on account of sickness.

As to interior insulation for shops and houses, a micanite tube, I suppose, would be used in the most important places, as through partitions, if too expensive to use generally. I simply mentioned that as a possible use of it. The principal object in bringing the tubes before the meeting was to show in what curious forms the substance could be produced, the tube being probably the most difficult one. natural mica being never known in a tubular form. In ships its cost would not prevent its use, because so superior to cheaper insulators. The *best* should be employed in ships, regardless of cost.

MR. CHAS. P. STEINMETZ:—We have listened to-night and at the last meeting to some very interesting statements regarding that quality which is called electrical resistance—not the resistance offered to the currents flowing in our electric circuits which we want as low as possible, but that resistance which hinders the escape of current from our circuits, which resistance we want as high as possible. That is, in other words, the insulation resistance. I have given the problem of electric insulation a good deal of attention also in the last year, and have made quite a number of tests which I hope to be able at a future meeting to report more fully.

My experience, however, has led me to an opinion somewhat different from that generally expressed. *I believe very little in insulation resistance.* It is a very nice thing indeed—on paper—to read that the insulation resistance of a machine is twenty or thirty megohms, or even higher. But, when you have determined the insulation resistance in the usual way, by the deflection of the galvanometer using a storage battery of say 100 volts, and then starting the machine, relying upon the "insulating resistance" of 30 megohms, it is not so nice upon breaking the circuit for the first time to see the inductive discharge from the series field break clear through your 30 megohms, reducing the insulating resistance to nil, and burning out the armature.

While, at the other hand, the insulation resistance of the machine may be suspiciously low, only a few hundred thousands of ohms, and still the machine may run continuously for years and years, under all conditions of load and overload, without breaking down, nay, getting better all the time, the more the insulating material dries by the heat developed in the machine.

What we want is, to insulate the electric circuits of the machine so that the machine will stand and work without breakdown under all conditions of usage; and as long as air, which is the *poorest* insulation, that is which breaks down easiest, has an *infinite* electric resistance, while just the *best* insulating materials—best in "disruptive strength," that is standing electric stresses without giving way—as mica, have a comparatively *low* electric resistance, the insulating resistance gives us no indication as to the reliability of the insulation of the machine. To see this more plainly, let us examine the behavior of different insulating materials.

Take, for instance, two plates, put them against each other at a distance of, say, one-tenth of a millimeter, that is .004 of an inch of air between them. Now, measure the resistance at say 100 volts difference of potential between the plates. It is infinitely high. For I do not think anybody ever measured the true resistance of air and found any other result than infinite. Now, raise the potential difference between the plates to 500 volts. A spark will pass across the gap and this insulating resistance which a moment before was infinite, is now reduced to nil; it has broken down. Now, replace the air-gap by a piece of dry fibre of the same thickness, and measure again the insulating resistance in the usual way. You will find the resistance measurable, hence infinitely smaller than the resistance of your air-gap. Still you may raise the potential to 500 or to 1,000 volts, and the fibre will stand the pressure. It will break down under a stress of about 1,300 volts. Now, replace the fibre sheet with a sheet of mica. The resistance is very much smaller than the resistance of the fibre, to say nothing of the air. But you may raise the difference of potential at the terminals to 10,000 or 20,000 volts and the mica sheet will stand. The electricity will rush out from the terminal plates upon the mica sheet in long, glowing streamers, beating against the mica with a hissing noise, and forming a broad, electrostatic aurora of violet light, and still the mica will not break down. This is the property we want, but this disruptive strength has nothing to do with insulating resistance. On the contrary, those insulating materials which have the highest resistance, like air, just happen to have the lowest disruptive strength, while those materials which are relatively inferior in insulating resistance, like mica, stand electric stress best. I have never found another material which will stand such enormous electrostatic stress, for the same thickness, as mica will stand, and still its electric resistance is comparatively low. The consequence, therefore, is, if we insulate a machine or any other apparatus, the measured insulating resistance will say nothing to us about the disruptive strength of the machine. There may be, perhaps, two bare wires almost touching each other, with a thin film of air between; a galvanometer test will show a resistance of heaven knows how many megohms, and still the machine will break down instantly, while you may insulate this whole machine with, say, ordinary fibre or mica and you will find—if the fibre is a little damp—perhaps only a few hundred thousands of ohms resistance; still the longer the machine runs, the higher its resistance becomes, and the better the machine gets, and it will not break down. So a very high insulating resistance is not a measure of the reliability of the machine against breakdowns. If we consider it from this point of view, we may learn something even from the civil engineer, though we generally boast—properly—that we are much far the advanced in exactness of methods. When the civil engineer wants to build a bridge for instance he does not measure the elongation of a test piece of the iron to be used by a micrometer, but he loads it until it breaks, and then determines the breaking strain, and thereupon bases his calculations. That is what we want to do also—to expose our material to an electrostatic stress until it breaks down, and judge it thereby, but not by its specific electric resistance. For even if the specific resistance is very low—comparatively—the current which may leak through the insulation is by far too small to do any harm. Resistance tests of the machine insulation are of a relative value in so far only, as they may give us a clue as to whether there is a weak spot somewhere in the insulation, but not necessarily so.

They will not show how safe the machine is. But it will show if we connect the copper part to one terminal and the iron part to the other terminal of a circuit carrying a potential of 3,000 volts and then see the machine not broken down. The megohms might be all right—the fire underwriters occasionally require them. But otherwise it is safer to test by applying a higher potential than the machine has to carry. Because if an insulation stands a potential of 3,000 volts we are sure it will stand a potential of 500 volts. But then there are other points to consider in insulation—the mechanical behavior of insulating materials. While mica has enormous strength against breakdowns, the least kink in a mica sheet, the least bend, will reduce the strength enormously, and while a single sheet of mica will stand enormous potential, simply bend it over a couple of times —you hardly see any kink—still it breaks down at a much smaller potential. But still it is very much better than air or even dry fibre.

Furthermore, you have to consider how the insulating material behaves not only against heat but against electric arcing, because in many cases, for instance at the commutator or the breaking-switch you want insulating material which is fire-proof, and keeps up its insulating qualities against the electric arc. All organic compounds are not fire-proof and consequently not fit for places where the electric arc strikes. Take any one of these mixed compounds, even micanite, put it between the discharge plates and raise the potential difference until a spark, followed by the arc, strikes across—it is set on fire. Micanite may stand the heat of the armature all right where the spark does not touch it. The temperature may rise several hundreds of degrees, so that the micanite gets black, the cement is charred, and it will continue to insulate, but still the arc will set it on fire. While if you take a sheet of genuine mica and let the arc strike across, along the edges of the mica sheet, the arc simply melts the mica down farther and farther, but it cannot set it on fire. Most of the other organic compounds are very much worse indeed, because they are set on fire by the least arc, some even with a kind of explosion. This is another point to be considered.

Hence we must make up our minds that there is no insulating material which is fit for every purpose; that each insulating material has its special application; what is very good for one case is not good for another. So for places, where arcing is to be expected, as on commutators or switches, I do not think that we can ever get anything better than genuine mica, or asbestos paper, or soap-stone, porcelain, or any other mineral compound. In all places, where not exposed to arcing, mixed organic compounds will be very good. The disruptive charge will not pass through micanite at even more than moderate potential. It is not as strong as genuine mica—perhaps not more than one-half or one-quarter as strong, but even then far superior to any other similar material. In other cases ordinary dry fibre is a very good insulating material. It has come into discredit more than it deserves, because it gets damp, and when it gets damp, it no longer insulates, but in places where it cannot get damp, especially where it is kept slightly warm, it is a very reliable material and has a much higher value than is very often supposed. Again, where very high insulating resistance is required, as in electrostatic apparatus, there is paraffin and hard rubber, which surpass, I believe, all materials except air. So we have to find out which insulating material is the best for a particular use; there is no insulating material which is good for every purpose.

MR. A. E. KENNELLY:—I would like to say, in reference to the subject last mentioned, that the value of a material like micanite does not seem to lie wholly in its insulating capabilities, but rather in the fact that enables us to employ in it a substance with say one-fourth of the resistance to electrostatic rupture that true mica has, at a far lesser cost; and it is surely better to have something which has a quarter of that capability and which is within your commercial means than to know that a substance exists having the full capability, but which is so precious that you cannot use it at all. I think the paper is an interesting one, because it gives us a number of details which can only be gained by experience.

In regard to mixtures, I should think that any material which contained silicate of soda would be a suspicious one, for silicate of soda is not an insulator. It is, of course, a high resistance material but it conducts quite appreciably.

PROF. W. A. ANTHONY:—I am very much interested indeed in this material, and the company for which I have been working for the last few years has been making some use of it in the construction of machines, and have found it a very excellent material in a great many places. I agree with Mr. Steinmetz that the measurement of the insulating power of the material is no test of its value in the machine. The effect of this high insulation, of course is good. But the important fact is, that it will stand a great deal of mechanical wear and tear, and a very high temperature without breaking down in insulation; and you may even have something of a short-circuit without burning through it, while almost any of the other insulating materials are at once burnt out and destroyed by any short-circuiting. It seems to me that this is one very great step in advance, in the structure of insulating materials, enabling us to use what is practically as perfect an insulator as mica, and obtaining it in just such forms as we want it. I confess that I was very much surprised when I first saw the great variety of forms in which it could be made.

MR. CARL HERING:—I would like to ask a question about the tubes made of this material. I notice that they have lap and butt joints, and they are apparently not made of a continuous sheet. Will such a joint stand well; is it not apt to open?

MR. CHAS. W. JEFFERSON:—This tube [indicating,] for instance, is made from a thin sheet rolled out. The sheet was about five feet long; so, really, it is not a butt joint. *These* [indicating] are not made from a large sheet, but they have an over-lapping joint of about an inch or an inch and a-half, and it is the same with all these. But the tubes we make from thin sheets or thin strips have quite a considerable length.

MR. HERING:—I had reference to this particular tube [indicating] which seems to have a regular butt joint.

MR. JEFFERSON:—That large tube is made like this small tube. It may appear as if it was a butt joint; but it is not.

MR. RALPH W. POPE:—It appears to me that the remarks of Mr. Steinmetz on this question are a very fine illustration of the difference between theory and practice. That is, we measure the insulation very carefully in the laboratory, and calculate that it is going to answer a certain purpose. It is then introduced in practice, and we learn by experience that not merely insulation resistance, but other qualifications are required, showing, as he says, that different insulations are adapted for different conditions.

My object in rising was to call attention to a reference in the paper which has been corrected once, but the error has been so widely circulated that it seems almost impossible to eradicate it. The paper says on page 800:—"All these parts, even in the best "made armatures become more or less abnormally hot. Means "have been planned and sometimes put into practice for cooling "the parts, and thereby saving the insulation. One method con-

"sists in constructing the armature after the style of a fan, or with "large radiating surface; another in equipping a device to blow "out the sparks at the commutator."

This blowing out of the sparks is the point to which I refer, for the reason that Prof. Thomson, at the meeting held in May, 1891, in his discussion of the paper by M. E. Thompson, on "An open coil arc dynamo," spoke as follows:

"I called Mr. Thompson's attention to his statements in regard "to the blowing out of the sparks as expressing an erroneous "idea in relation to the machine. This erroneous idea he will "find expressed in Prof. Silvanus P. Thomson's 'Dynamo-electric "Machinery' that the air-blast in the Thomson-Houston three coil "machine is for the purpose of blowing out the spark. That is "not at all the case; it never was the case; and the air-blast was "introduced for no other purpose than to make it possible to "run the machine steadily at high differences of potential with a "commutator that could be freely oiled."

This is on page 389 of vol. viii. of the TRANSACTIONS. As this error is creeping into dictionaries, and other works which are supposed to be standard, we should all take pains to correct it wherever possible.

PROFESSOR FRANCIS B. CROCKER:—I think that what Mr. Steinmetz said about tests of insulation at different voltages is the key-note of the problem. But I think he went a little too far in saying that the usual test of insulation showed nothing or showed next to nothing. It seems to me that although a test of insulation resistance is not conclusive, I would much prefer to run a dynamo or a system of conductors, or any other electrical apparatus or system, when it showed 100 megohms insulation than when it showed 100,000 ohms insulation. In fact if it showed 100,000 ohms insulation, I should be afraid to start up. If it showed 100 megohms I should have considerable confidence that it would run all right. It seems to me that the best way to do, is to test the insulation at the voltage at which you intend to work. That covers both points. You test the insulation, which has been the customary thing to do for some decades now, and you also subject it to a potential, or power to break down, which Mr. Steinmetz rightly considers very important. There is no objection to it except the practical difficulty of getting a potential of whatever is necessary—one or two thousand volts, or whatever it may be. But Mr. Williams showed us at the last meeting an electrostatic method of doing that, and for some months past I have been making tests of insulating materials, at several thousand volts with a direct current dynamo machine, without any difficulty whatever. We pass the current from the dynamo machine through the given insulation and a galvanometer according to the ordinary direct deflection method well known to all of us, and observe the insulation resistance—the old-fashioned insulation resistance which Mr. Steinmetz thinks amounts to nothing—and at the same time we test the power to withstand disruptive discharge. It seems to me that that kills two birds with one stone. We get a quantitative result and also a test of the power to withstand the stress, and that stress of a potential which is applied to actually break down an insulator is very similar to a mechanical stress. It is a good deal the same kind of a stress as a point would exert resting on the centre of a pane of glass—at a certain pressure it will break through. That, of course, is simply an analogy, but it is quite close.

In testing the disruptive resistance or the breaking strain, Mr. Steinmetz said very truly that we ought to put it on the same basis as all other engineering problems, and that is to make an actual breaking strain test. In mechanical or civil engineering we simply take a test piece and subject it to a breaking test. Now, we can do the same in electrical engineering, and I think it should be the custom—I know it has in the practical work that I have been engaged in—to subject machines intended for 500 volts strain, to, 1,500 volts test pressure. That is no more than is proper. It is simply a factor of safety of 3. If you raise the factor of safety to 5, so much the better. Electrical engineers should have their factor of safety, and should consider it part of their work just as much as civil or mechanical engineers.

A dynamo machine or electrostatic machine can easily be obtained which will give any reasonable voltage, from one to five thousand. I have a small machine that gives 5,500 and will run all day long at 5,000 volts. Such machines can easily be obtained. Why not subject any insulation to such a test, and at the same time pass the current through some galvanometer or other device to show quantitatively the insulation resistance at the same time that we test its power to withstand the potential? In regard to the galvanometer, I will point out one difficulty due to electrostatic disturbance, that is, the needle of a galvanometer connected to a dynamo or electrostatic machine, giving 5,000 volts, or anything approximating that, will be acted upon just the same as a pith ball in the vicinity of an electrostatic machine—it will fly around and you will get a false deflection. That is quite confusing sometimes and very difficult to eliminate. The proper way to overcome this seems to be either to ground the terminal of the source connected to the galvanometer so as to reduce the potential to zero, or else to make the potential of the coils equal to that of the needle by connecting the needle to the coils by a little wire passing down into a bath of sulphuric acid, or something of that sort. The electrostatic disturbance will be much greater than the current-effects, in a great many cases. Mr. Williams uses purely electrostatic means—an electrometer—and observes how long it takes to discharge at a given charge. But it seems to me that purely electrostatic strain is not so severe on a given insulator as the current from a dynamo machine. I think that 5,000 volts applied from a dynamo machine is a more severe test than 5,000 volts applied from an electrostatic source. There is some power behind in one case, and nothing behind in the other. That sounds a little absurd. But I think there is something there that we are not quite familiar with. So far as my experience goes, a potential applied with the backing of a dynamo machine, so to speak, is a more severe test than a simple electrostatic potential without any dynamo.

THE CHAIRMAN:—It seems to me that the remarks of Professor Crocker upon backing up the insulation tests with the current from the dynamo and the remarks which Mr. Kennelly made relative to the using of this material and its advantage over mica and other expensive substances, *i. e.*, that it can be not only formed, but that it has the great advantage of being considerably less in cost are very pertinent and I think from the remarks of Professor Anthony and of others here and from statements made to me by the gentlemen who presented these samples to-night, that this material is not in an altogether experimental stage, that it has been worked commercially and on a considerable scale for a number of years. I would like to ask Mr. Thompson if he can give us a little information as to the relative cost of this material, taking any particular size or sizes, as compared with mica.

MR. THOMPSON:—Mr. Brooks or Mr. Kingsley, I think, would be better able to give figures on that. They are posted on the business points better than I am.

MR. LEWIS W. KINGSLEY:—I would state that on sizes, say 6 by 8, the cost would be one-half that of mica. In very small sizes it costs more than small mica, but with large sizes it costs one-half, and you can get, of course, any size much larger than you can obtain it from the mine.

MR. STEINMETZ:—I do not want to be misunderstood with regard to my opinion about insulating resistance. I do not mean to say that insulating resistance is of no value whatever. It has some value. It shows whether everything may be all right or whether something may be wrong. We are all familiar with the insulating resistance of materials, and know about what resistance we have to expect, and where we find exceedingly low insulating resistance we must suspect something is wrong. Very often we find that the insulating resistance becomes all right by a couple of hours sojourn in the steam box, especially where fibre or asbestos paper was used. Hence the low insulating resistance is a good hint to look things up and see whether everything is all right. But it is no reliable test of the safety of the machine.

Then with regard to exposing all the materials to a break-down test, that is what we have done for several years, and found it very reliable. But if we want to combine it with the resistance tests, then the only safe way would be to make the tests at a potential considerably higher than the normal, because as long as we have inductances in our circuit we cannot avoid occasionally a sudden rise of potential beyond the normal value, as in breaking circuits, etc., and we have to take this in account because this insulating resistance especially of air does not vary as a continuous function of the potential, but is infinite up to a certain point, and then suddenly drops to zero, practically. So we have to make the insulating tests considerably above the normal potential.

I am glad to see Professor Crocker propose the same factor of safety as we have used a long time, testing 500 volt machinery by 2,000 volts.

But with regard to the source of these testing potentials, I do not think we need to bother much about continuous current dynamos. For what purpose do we have the alternating current transformer? From ordinary 50 volt mains we can obtain any potential difference, of 2,000 volts just as well as of 3 000 volts, and I even think the alternating potential test is more reliable, because alternating stress is more severe than continuous electrostatic stress. Lately I looked up the literature for tests about disruptive discharges through the air and found quite a disagreement of that kind, so that I am almost inclined to believe that the disruptive strength of air is less with alternating potentials and decreases with increasing frequency. So if we use a frequency of 150 periods and 2,000 volts, we are sure the insulation will break down if it is liable to break down. *Power* indeed must be behind the *potential.*

With regard to micanite I can only say that I found it very reliable—superior to all the other insulating materials except genuine mica, but it is not absolutely fire-proof, so that I prefer to keep it away from the arc.

THE CHAIRMAN :—I think the gentlemen of the Institute will agree with me that we know a great deal more about mica tonight than we ever did before, owing to Mr. Thompson's admirable paper and the discussion which followed its reading. If there are no further remarks I will call upon Mr. Thompson, if he desires to say anything on the points discussed by the gentlemen present.

MR. THOMPSON :—I will not take time to say anything further. I think I have had my say in the paper. But Mr. Jefferson probably may have some further practical experiences to disclose.

MR. JEFFERSON :—I would like simply to state that a great number of armatures have been insulated with this material and have always been tested on 3,000 volts alternating, with what they call a transformer up to 10,000 volts. We had a great number of armatures that would stand that potential with this micanite with a resistance of 190 megohms which is as high as we have, all the way from 190 down to 50 megohms.

THE CHAIRMAN :—Have any mechanical tests been made further than those referred to in the paper? There is a mechanical test referred to here in which the mica is placed under a great strain.

Mr. Jefferson:—Yes, sir; the armature has been bound with a ribbon and the layers of the ribbon insulated with micanite and asbestos and then the current passed through the wire—sufficient to burn, almost melt the wire, and we found that the insulation has kept very well indeed.

The Chairman—Did it set fire to it?

Mr. Jefferson:—No; there was nothing to set fire to. It did not blaze.

Mr. Thompson:—I might add in regard to shellac or cement which was referred to, that those experienced with glue and its uses know that, in general, the less the cement and the greater the pressure, the better the adhesion. The amount of cement in these articles is almost infinitesimal. So it almost comes up to Mr. Steinmetz's standard about genuine mica being so superior. If the cement is so minute in quantity it is almost the same thing as mica.

The Chairman:—If there are no further remarks, we will take pleasure in listening to Dr. Williams who is going to show us some interesting experiments in connection with these and other insulating materials.

Dr. J. B. Williams:—There have been quite a number of specimens of different materials sent in that are claimed to be good for armature insulation, and I propose this evening to compare their resistance with that of pure mica by the electrostatic method. I will test them at a potential of nearly 4,000 volts. I will take the pure mica first. The thickness of this sheet which I am about to test is 45 mils. The disks between which it is placed—the equivalents of metallic disks—are about one-half inch in diameter. I will use just sufficient pressure to spread the buckskin-covered electrodes out firmly onto all portions of the surface of the tested material.

I would state that I believe there is a good deal in Professor Crocker's remark about having the power behind, and it is my intention in the near future to bring apparatus here before the Institute, and show the effects of alternating currents of one and two hundred thousand volts on different insulating material.

[Dr. Williams then went on with the tests, and when he had finished the meeting adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

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FEBRUARY 1ST, 1893.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
FARMER, PROF. MOSES G.	Electrician and Inventor, Eliot, Me.	A April 15, 1884 H.M. Oct. 21, '90
GREEN, DR. NORVIN	(*Past President*). Pres't Western Union Telegraph Co. P. O. Box 3393, 195 Broadway, New York.	A April 15, 1884 M Oct. 21, 1884 H.M. Dec. 3, 1889
KELVIN, *Lord*	LL.D., F. R. S. S. L. and E. The University, Glasgow, Scotland,	H. M. May 17, '92
PREECE, WM. H. *F. R. S.*	Electrician, General Post Office, London, Eng. Residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

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MEMBERS.

ACHESON, EDW. G.	President, The Monongahela Electric Light Co., Monongahela City, Pa.	A Jan. 3, 1888 M May 1, 1888
AHEARN, T.	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ANTHONY, PROF. W. A.	(*Past President.*) Consult'g Electrician. The Mather Electric Co., Manchester, Conn.	A Dec. 9, 1884 M Jan. 6, 1885
AYER, JAMES I.	General Manager, Municipal Electric L. & P. Co., 322 Pine St., St. Louis, Mo.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec 16, 1891 M Mar. 15, 1892
BARBERIE, E. T.	Electrician, 2021 Lexington Ave., New York City.	A Jan. 19, 1892 M Oct. 25, 1892
BATCHELOR, CHAS.	Electrical Engineer, 33 West Twenty-fifth St., New York.	A June 8, 1887 M July 12, 1887
BATES, J. H.	Vice President, Moore Electrical Manufacturing Co., 652 Hudson St., New York City.	A Sept. 6, 1887 M Oct. 1, 1889

Name.	Address.	Date of Membership.
BATES, MAURICE E.	Manager, Western Electric Construction Co., 13th and Greenbush Sts., Lafayette, Ind,	A Aug. 6, 1889 M Oct. 1, 1889
BAUER, A. H.	Electrical Engineer, Pullman Palace Car Co., Room 307, Pullman Building, Chicago, Ill.	A Feb. 7, 1890 M Apr. 21, 1891
BAYLES, ROBERT N.	Electrician, The "C & C" Electric Motor Co., 404 Greenwich St., New York.	A Oct. 1, 1889 M May 17, 1892
BAYLY, B.	Surveyor and District Engineer, Western District Colonial Gov't. Cape Town, Cape of Good Hope, Africa.	A Oct. 4, 1887 M Dec. 6, 1887
BELL, PROF. A. GRAHAM	(*Past-President.*) Beinn Bhreagh, Victoria Co., Cape Breton, N.S.	A April 15, 1884 M Oct. 21, 1884
BELL, DR. LOUIS,	(*Manager.*) Electrical Engineer, Thomson Houston Electric Co., Lynn, Mass.	A May 20, 1890 M June 17, 1890
BENJAMIN, PARK	Electrical Expert and Engineer, 32 Park Place, N. Y. City.	A Dec. 16, 1891 M Feb. 16, 1892
BERNARD, EDGAR G.	Electrical Engineer, E. G. Bernard & Co., Hall Building, Troy, N. Y.	A Jan. 5, 1886 M July 12, 1887
BINNEY, HAROLD	Assistant in the Practice of Patent Law, with Gilbert M. Plympton, 245 Broadway, New York City.	A Sept. 16, 1890 M Dec. 16, 1890
BIRDSALL, E. T. *M. E.*	Electrical Engineer, 18 Broadway, New York.	A June 8, 1887 M Nov. 1, 1887
BISHOP, JAMES DRAPER	Electrical Expert, John A. Roeblings' Sons Co., 345 W. 34th St., New York City.	A Dec. 16, 1891 M Oct. 25, 1892
BLAKE, EDWARD	361 Temple Street, New Haven, Conn.	A May 24, 1887 M Sept. 3, 1889
BLAKE, FRANCIS	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
BLODGETT, GEO. W.	Electrical Engineer B. & A. R. R. and Consulting Electrician, Boston, Mass.	A July 12, 1887 M Sept. 6, 1887
BOSCH, ADAM	Sup't, Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
BOURNE, FRANK	Electrical Engineer, The Field Engineering Co., 143 Liberty St., New York City.	A April 21, 1891 M Nov. 15, 1892
BOYNTON, EDWARD C. JR.	Electrician of the Lowell Mfg. Co., Ltd., Erie, Pa.	A Aug. 6, 1889 M Nov. 24, 1891
BRADLEY, CHAS. S.	Electrical Engineer, Wayne Hotel, Fort Wayne, Ind.	A May 24, 1887 M Dec. 6, 1887
BROOKS, MORGAN	Secretary and Treasurer, The Electrical Engineering & Supply Co., 413 Jackson St., and 529 Holly Ave., St. Paul, Minn.	A May 20, 1890 M June 17, 1890
BROWN, J. STANFORD	Consulting Electrical Engineer, Neftel & Marsh Company, 126 Liberty St., New York City.	A Sept. 6, 1887 M Nov. 1, 1887

Name.	Address.	Date of Membership.
BRUSH, CHAS. F.	Electrical Engineer, 956 Euclid Ave, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
BURLEIGH, CHAS. B.	Sup't. Isolated Dep't. Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.	A April 21, 1891 M Feb. 16, 1892
BYLLESBY, HENRY M.	Northwest Thomson-Houston Electric Co., 403 Sibley St., St. Paul, Minn.	A Sept. 7, 1888 M Oct. 2, 1888
CAHOON, JAS. B.	Electrical Engineer, Thomson-Houston Electric Co., 68 Baker St., Lynn, Mass.	A June 17, 1890 M May 19, 1891
CARROLL, LEIGH	President and General Manager, The Edison Electric Illuminating Co., Birmingham, Ala.	A Oct. 1, 1889 M Nov. 12, 1889
CHAMBERLAIN, J. C.	(*Manager*.) Electrical Engineer, 136 Liberty St., and 135 East 18th St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
CHANDLER, CHARLES F.	Professor of Chemistry, Columbia College, and Prof. of Chemistry and Physics, College of Physicians and Surgeons, New York City.	A Jan. 20, 1891 M June 7, 1892
CHURCHILL, ARTHUR.	Engineering Dept., Schenectady Works, General Elec. Co., 23 Front St., Schenectady, N. Y.	A April 15, 1890 M Jan. 17, 1893
CLARK, ERNEST P.	Electrical Engineer, Clark Electric Co., 192 Broadway, New York City.	A Jan. 8, 1887 M Nov. 1, 1887
CLARKE, CHAS. L.	Mechanical and Electrical Engineer, 55 Liberty St., New York City.	A April 15, 1884 M Jan. 6, 1885
COLBY, EDWARD A.	Lock Box 313. Newark, N. J.	A April 2, 1889 M May 7, 1889
CONDICT, G. HERBERT	General Manager, The Electric Car Co. of America, 4720 Green St., Germantown, Pa.	A July 12, 1887 M Sept. 6, 1887
COTHREN, WM. H.	[Address unknown.]	A Aug. 6, 1889 M Oct. 1, 1889
COWLES, ALFRED H.	Technical Adviser to the Cowles Smelting and Aluminum Co., 656 Prospect St., Cleveland, O.	A Mar. 5, 1889 M May 7, 1889
CROCKER, FRANCIS B. [Life Member.]	Instructor in Electrical Engineering, School of Mines, Columbia College, and 54 W. 21st Street, New York.	A May 24, 1887 M April 2, 1889
CROSS, PROF. CHAS. R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
CURTISS, GEORGE F.	Electrician, Bureau of Information, General Electric Co., 620 Atlantic Ave., Boston, Mass.	A April 2, 1889 M Nov. 24, 1891

Name.	Address.	Date of Membership.
CUTTER, GEORGE	Dealer in Electrical Supplies, 315 South Canal St., Chicago, Ills.	A June 17, 1890 M May 19, 1891
CUTTRISS, CHAS.	Electrician, The Commercial Cable Co., 1 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
DAFT, LEO	Consulting Electrical Engineer and Contractor, Burke Building, Seattle, Wash.	A Dec. 9, 1884 M Jan. 6, 1885
DANVERS, ALAN	Managing Director and Chief Electrician, The Anglo-Portugese Telephone Co., L't'd. 60 Travessa Santa Justa, Lisbon, Port'l.	A Nov. 1, 1887 M Sept. 3, 1889
DANVERS, ERNESTO	Electrical Engineer, Casilla 74, Rosario, Argentine Republic.	A Jan. 3, 1888 M May 1, 1888
DAVIES, JOHN E.	Professor of Physics, University of Wisconsin, 523 Carroll St. Madison, Wis.	A Jan. 7, 1890 M Mar. 18, 1890
DAVIS, CHARLES H.	Consulting Electrical Engineer, 120 Broadway, New York City.	A Mar. 18, 1890 M June 17, 1890
DELAFIELD, A. FLOYD, *Ph.D.*	Electrical Engineer, Noroton, Conn.	A May 7, 1889 M Oct. 1, 1889
DELANY, PATRICK BERNARD, (*Manager*).	Inventor, South Orange, N. J.	A April 15, 1884 M Nov. 24, 1891
DICKENSON, SAMUEL S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N.S.	A Mar. 6, 1888 M Oct. 1, 1889
DIEHL, PHILIP	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
D'INFREVILLE, GEORGES	Electrical Engineer and Expert, 434 Canal St., New York City.	A Nov. 1, 1887 M Dec. 6, 1887
DOIJER, H.	Consulting Electrical Engineer, Oude-delft 222, Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
DONNER, WILLIAM H.	Sprague Elevator Co., 114 W. 30th St., New York City.	A Nov. 18, 1890 M Dec. 16, 1890
DUDLEY, CHARLES B.	Chemist and Scientific Expert, Penn R. R. Co , 1219 Twelfth Ave., Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
DUNCAN, DR. LOUIS	(*Vice-President*). Johns Hopkins University, Baltimore, Md., Firm of Sprague, Duncan & Hutchinson, 15 Wall St., New York City.	A July 12, 1887 M Sept. 6, 1887
DUNSTON, ROBERT EDWARD,	Room 86, Foster Block, Hartford, Conn.	A Oct. 27, 1891 M Feb. 16, 1892
DYER, R. N.	Patent Attorney, 36 Wall St., New York City.	A July 12, 1887 M Sept. 6, 1887
EDISON, THOMAS A.	Mechanician and Inventor, Orange, N. J.	A April 15, 1884 M Oct. 21, 1884
EMERY, CHARLES EDWARD	Consulting Engineer, Bennett Building, cor. Fulton and Nassau Sts., New York City.	A June 26, 1891 M April 19, 1892
EUSTIS, HERBERT H.	President and Electrician, Eastern Electric Cable Co., 61 Hampshire St., Boston, Mass.	A April 15, 1890 M Nov. 24, 1891

Name.	Address.	Date of Membership.
FARNHAM, ISAIAH H.	Electrician for the N. E. Telephone & Telegraph Co., 125 Milk St., Boston, Mass.	A June 8, 1887 M July 12, 1887
FESSENDEN, REGINALD A.	[Address unknown.]	A Oct. 21, 1890 M Dec. 16, 1890
FIELD, C. J.	President and General Manager Field Engineering Co., 143 Liberty St., New York City.	A June 8, 1887 M Nov. 1, 1887
FIELD, STEPHEN D.	Electrician and Inventor, Yonkers, N. Y.	A April 15, 1884 M Oct. 21, 1884
FLEMING, WILFRID H.	Trask Avenue, Bayonne City, N. J.	A Dec. 6, 1887 M Jan. 3, 1888
FOSTER, HORATIO A.	(*Manager.*) Electrical Engineer, 548 E. 164th St., New York City.	A June 8, 1887 M Sept. 6, 1887
FREEMAN, DR. FRANK L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889
GEYER, DR. WM. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
GRAY, ELISHA DR.	Electrician and Inventor, Highland Park, Ill.	A Feb. 16, 1892 M May 17, 1892
GRISCOM, WM. W.	Haverford College P. O., Montgomery Co., Pa. President, The Electro Dynamic Co., 224 Carter St., Philadelphia, Pa.	A June 5, 1888 M Mar. 18, 1890
HALL, CLAYTON C.	Civil Engineer, 810 Park Ave., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884
HAMBLET, JAMES	(*Manager*)Manager Time Service, W. U. Tel. Co., 195 Broadway, P. O. Box 3393, New York City.	A Nov. 1, 1887 M Dec. 6, 1887
HAMILTON, GEO. A.	Electrician, Western Electric Co., 22 Thames cor. Greenwich St., New York, and 532 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884
HAMMER, W. J.	(*Vice-President.*) Consulting and Supervising Electrical Engineer, 527 Temple Court, N. Y., and 23 Rowland St., Newark, N. J.	A June 8, 1887 M July 12, 1887
HASKINS, CHARLES H.	Electrician, 80 Broadway, New York City.	A April 15, 1884 M Oct, 21, 1884
HAYES, HAMMOND V.	Electrician, American Bell Telephone Co., 127 Purchase St., Boston, Mass.	A Nov. 12, 1889 M Mar. 18, 1890
HAYNES, F. T. J.	Divisional Telegraph Engineer, Great Western Railway, Taunton, Eng.	A Dec. 6, 1886 M Jan. 3, 1887
HEINRICH, RICHARD O.	Electrical Engineer, Weston Electrical Instrument Co., 114 William St., Newark, N. J.	A Oct. 1, 1889 M Oct. 25, 1862

Name.	Address.	Date of Membership.
HERING, CARL	(*Vice-President.*) Editor *Electrical World*, and Consulting Electrical Engineer, 3816 Spring Garden St., Philadelphia, Pa.	A Jan. 3, 1888 M June 5, 1888
HERRICK, CHARLES H.	Manager and Electrical Engineer, Wright Electrical Engineering Co., 196 Summer St., Boston, Mass.	A April 21, 1891 M Jan. 17, 1893
HERZOG, DR. F. BENEDICT	President Herzog Teleseme Co., 30 Broad St., New York City.	A May 24, 1887 M July 12, 1887
HEWITT, CHARLES	The Edison General Electric Co., Edison Building, Broad St., Box 3067, New York City.	A Sept. 16. 1890 M May 17, 1892
HIBBARD, ANGUS S.	(*Manager*). General Superintendent, American Telephone and Telegraph Co., 18 Cortlandt St., New York City.	A Nov. 24, 1891 M Feb. 16, 1892
HIGGINS, EDWARD E.	Street Railway and Financial Counsel, Mills Building 35 Wall St., New York City.	A June 8, 1887 M July 12, 1887
HOUSTON, PROF. EDWIN J.	Prof. of Physics, Franklin Inst., Prof. of Physics and Physical Geography, Central High School, 1809 Spring Garden St., Philadelphia, Pa.	A April 15, 1884 M Oct. 21, 1884
HOWELL, JOHN W.	Electrician, Edison Lamp Works, Harrison N. J.	A July 12, 1887 M June 5, 1888
HOWELL, WILSON S.	Electrical Expert, Edison Lamp Works, Harrison, N. J.	A Sept. 3, 1889 M Mar. 18, 1890
HUNTER, RUDOLPH M.	Mechanical and Elect'al Engineer, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
HUTCHINSON, DR. CARY T.	Electrical Engineer, 56 West 25th St., Firm of Sprague, Duncan & Hutchinson, 15 Wall St., New York City.	A Feb. 7, 1890 M Dec. 16, 1890
HYDE, JEROME W.	Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
INRIG, ALEC GAVAN	Rue St. Gommaire, 23, Antwerp, Belgium.	A Jan. 19, 1892 M May 17, 1892
JACKSON, DUGALD C.	Professor of Electrical Engineering University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890
JACKSON, FRANCIS E.	With Edison Lamp Works, Harrison, N. J.	A Jan. 3, 1888 M June 17, 1890
JANNUS, FRANKLAND	Solicitor of Patents, 928-30 F. St. Washington. D. C.	A Nov. 12, 1889 M Mar. 18, 1890
JENKS, W. J.	Technical Department, General Electric Co., 44 Broad Street, Box 3067, New York City.	A June 8, 1887 M Nov. 1, 1887
JONES, FRANCIS W. [Life Member.]	Assistant Gen'l-Manager and Electrician, Postal-Telegraph Cable Co., 5 Dey St., New York City.	A April 15, 1884 M Oct. 21, 1884

Name.	Address.	Date of Membership.
KNOWLES, E. R.	Chief Electrician, The Schuyler Electric Company, Middletown, Conn.	A June 8, 1887 M July 12, 1887
KNUDSON, A. A.	Manager, Eastern Electric Co., St. John, N. B. Room 37, Drexel Bldg., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
LANGE, PHILIP A.	Assistant Superintendent Westinghouse Electric and Manufacturing Co., Newark, N. J.	A Mar. 6, 1888 M June 5, 1888
LANGTON, JOHN	Electrical Engineer, Canada Life Building, Toronto, Ont.	A Mar. 6, 1888 M June 5, 1888
LATTIG, J. W.	Electrical Engineer, National Switch & Signal Co., and 1029 Arlington Terrace, Easton, Pa.	A June 8, 1887 M July 12, 1887
LAWSON, A. J.	Electrical Engineer and Contractor, Grantown, Scotland.	A Mar. 18, 1890 M June 17, 1890
LEONARD, H. WARD	(*Manager*). General Manager, The H. Ward Leonard Co., 136 Liberty St., New York City.	A July 12, 1887 M Sept. 6, 1887
LEONARD, M. B.	Electrical Engineer, and Supt. of Telegraph, Chesapeake & Ohio R'y. Co., Richmond, Va.	A Nov. 6, 1886 M May 1, 1888
LIEB, JOHN W., JR.	Chief Engineer, Società Generale Italiana di Elettricita (Sistema Edison). Via S. Radigonda N. 4, Milan, Italy.	A Sept. 6, 1887 M Nov. 1, 1887
LOCKWOOD, THOMAS D. [Life Member.]	(*Vice-President.*) Electrical Engineer, and Advisory Electrician, P. O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LYNE, LEWIS F.	Mechanical and Elect'al Engineer, 307 Grove St., Jersey City, N. J.	A Jan. 3, 1888 M June 5, 1888
MACFARLANE, ALEXANDER	Professor of Physics, University of Texas, Austin, Texas.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O.	Consulting Electrical Engineer, 45 William St., New York City.	A April 15, 1884 M Oct. 21, 1884
MARKS, WILLIAM DENNIS,	*Ph. B., C. E.* Edison Electric Light Co., Philadelphia, Pa.	A Feb. 7, 1888 M May 1, 1888
MARSHALL, J. T.	Inspector of Lamp Manufacture, Edison Lamp Works, Harrison, N. J.	A Oct. 1, 1889 M Nov. 12, 1889
MARVIN, HARRY N.	Secretary and Expert, Marvin Electric Drill Co., Schenectady, N. Y.	A April 19, 1892 M Jan. 17, 1893
MAVER, WILLIAM, JR.	Electrical Expert, 31 Nassau St., New York City.	A July 12, 1887 M Apr. 21, 1891
MAYNARD, GEO. C.	Electrical Engineer, 1409 New York Ave., Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
McCAY, H. K.	Electrician, 106 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891
METCALFE, GEORGE R.	Electrical Engineer, Editor *Electricity*, 6 Park Place, and 404 W. 22d Streets, New York City.	A April 19, 1892 M Nov. 15, 1892

Name.	Address.	Date of Election.
MILLIS, JOHN	Lieutenant of Engineers, U. S. Army, 1 Prytania St., New Orleans, La.	A July 7, 1884 M Mar. 3, 1885
MILLS, FRANK P.	Superintendent Cleveland Iron Mining Co., Ishpeming, Mich.	A Jan. 6, 1885 M Mar. 3, 1885
MOLERA, E. J.	Civil Engineer, 40 California St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892
NICHOLS, DR. EDWARD L.	Professor of Physics, at Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
PAINE, SIDNEY B.	Manager, Mill Power Dep't, General Electric Co., 620 Atlantic Ave., Boston, Mass.	A June 8, 1887 M Nov. 1, 1887
PAINE, F. B. H.	Siemens and Halske Co., Room 803, Bank of Commerce Bldg., St. Louis, Mo.	A Dec. 16, 1890 M Nov. 25, 1891
PARKS, C. WELLMAN	Electrician, 1825 Fifth Ave., Troy, N. Y	A July 12, 1887 M May 1, 1888
PARSHALL, H. F.	Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass.	A Sept. 7, 1888 M Mar. 18, 1890
PATTISON, FRANK A.	Firm of Pattison Bros., Consulting and Constructing Electrical Engineers, 135 Broadway, New York City.	A Sept. 22, 1891 M Dec. 16, 1891
PERRINE, FREDERIC A. C.	Care Germania Electric Co., 620 Atlantic Ave., Boston, Mass.	A Sept. 16, 1890 M Dec. 16, 1890
PHELPS, GEO. M.	(*Treasurer*). President, *Electrical Engineer*, 203 Broadway, New York.	A April 15, 1884 M Oct. 21, 1884
PICKERNELL, F. A.	Sup't. of Equipment, Amer. Tel. & Tel. Co., 153 Cedar St., New York City.	A Feb. 7, 1890 M Mar. 18, 1890
PIKE, CLAYTON W.	James W. Queen & Co., 1010 Chestnut St., Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892
POPE, FRANKLIN L.	(*Past President*). Consulting Electrical Engineer and Expert, 15 Wall St., N. Y. Residence, Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884
PORTER, J. F.	Representing J. G. White & Co., of New York, Heist Building, Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
PRATT, ROBERT J.	Electrician. Treas. and Mgr. Electric Mfg. Co. and Gas Engine Co., Greenbush, N. Y.	A July 12, 1887 M Sept. 6, 1887
PRESCOTT, GEO. B., JR.	Electrical Engineer. The Stanley Laboratory Co., Pittsfield, Mass.	A July 12, 1887 M Nov. 1, 1887
RAE, FRANK B.	Electrical Engineer, 27 and 28 Cleland Building, 31st St., Detroit Mich.	A April 15, 1884 M Oct 25, 1892
RAYMOND, CHAS. W.	Civil, Electrical and Mining Engineer, Monte Vista, Col.	A June 8, 1887 M May 17, 1887

Name.	Address.	Date of Election.
RECKENZAUN, ANTHONY	Electrical Engineer, 7 Albert Terrace, Hemberton Road, Stockwell, London, S. W. England.	A Nov. 1, 1887 M Dec. 6, 1887
RECKENZAUN, FREDERICK,	Electrician, Box 225, West Hoboken, N. J.	A Mar. 6, 1888 M June 5, 1888
RICE, E. WILBUR, JR.	Technical Director, The General Electric Co., Lynn, Mass.	A Dec. 6, 1887 M Jan. 3, 1888
RIES, ELIAS E.	Electrician and Electrical Engineer, 430 South Broadway, Baltimore, Md.	A July 12, 1887 M Sept. 6, 1887
ROBB, WM. LISPENARD	Professor of Physics, Trinity College, Hartford, Conn.	A Dec. 16, 1891 M Mar. 15, 1892
ROBERTS, E. P.	Electrician and Sup't, Swan Lamp Co., Belden St., Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
ROHRER, ALBERT L.	Electrical Engineer, with General Electric Co., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, [Life Member.]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W., England.	A Feb. 7, 1888 M May 1, 1888
SCHULZE-BERGE, FRANZ	44 Monroe Place, Brooklyn, N. Y.	A Nov. 12, 1889 M Mar. 18, 1890
SCOTT, CHARLES F.	Assistant Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893
SHALLENBERGER, O. B.	Electrician, Westinghouse Electric Co., Pittsburg, Pa.	A Sept. 7, 1888 M Dec. 4, 1888
SHELDON, SAMUEL, *A. M. Ph. D.*	Professor of Physics and Electrical Engineering, Polytechnic Institute, 170 State St., Brooklyn, N Y.	A Dec. 16, 1890 M Oct. 27, 1891
SHEPARD, WM. E.	Lincoln St. Ry. Co., Lincoln, Neb.	A Feb. 7, 1890 M Mar. 18, 1890
SLATER, HENRY B.	Manager and Sup't, The Canon City Electric Light and Power Co., Canon City Col.	A April 15, 1884 M Dec. 9, 1884
SMITH, JESSE M.	Consulting Electrical Engineer and Expert in Patent Causes, 36 Moffatt Block, Detroit, Mich.	A April 15, 1884 M June 26, 1891
SMITH, T. CARPENTER	Partner in firm of M. R. Muckle Jr. & Co., 212 Drexel Building, Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891
STANDFORD, WILLIAM	Ass't Sup't Telegraphs, Colonial Gov't, Cape Town, Cape of Good Hope, Africa.	A Oct. 4, 1887 M Dec. 6, 1887
STEBBINS, THEODORE	Superintendent Railway Construction, General Electric Co, 620 Atlantic Ave., Boston, Mass.	A July 9, 1889 M June 17, 1890
STEINMETZ, CHARLES P.	(*Manager.*) Electrician, Osterheld & Eickemeyer, 124 Waverly Place, Yonkers, N. Y.	A Mar. 18, 1890 M April 21, 1891
STIERINGER, LUTHER	Electrical Expert, 1873 Lexington Ave., New York.	A June 8, 1887 M Nov, 1, 1887

Name.	Address.	Date of Election.
STILLWELL, LEWIS B.	Electrical Engineer, Westinghouse Electric and M'f'g Co., Pittsburg, Pa.	A April 19, 1862 M Nov. 15, 1892
TAINTOR, GILES	Division Supt., Western Division New England Telephone and Telegraph Co. Springfield, Mass.	A June 26, 1891 M Dec. 16, 1891
TALTAVALL, THOS. R.	Editor, *Electrical Age*, World Building, New York City.	A Jan. 20, 1891 M Oct. 27, 1891
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and M'f'g. Co, Pittsburg, Pa.	A April 5, 1887 M May 17, 1887
THOMAS, BENJAMIN F.	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, PROF. ELIHU	(*Past President*). Electrician, Thomson Houston Electric Co., and Thomson Electric Welding Co., Lynn, Mass.	A April 15, 1884 M April 21, 1891
THOMPSON EDWARD P.	Consulting Electrician and Patent Attorney in Electrical Cases, 5 Beekman St., New York City.	A April 15, 1884 M Dec. 3, 1889
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 7 Rue du Louvre, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TURNER, WILLIAM S.	President, Woodbridge & Turner Engineering Co., 47 Times Building, New York City.	A Dec. 7, 1886 M Oct. 2, 1888
UPTON, FRANCIS R.	General Manager, Edison Lamp Works, Harrison, N. J. Residence, 107 Day St., Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VAIL, J. H.	Ass't Engineer in Chief, General Electric Co., Edison Building, P. O. Box 3067, New York City.	A June 8, 1887 M Nov. 1, 1887
VANSIZE, WILLIAM B.	Solicitor of Patents, 44 Broad St., New York City.	A April 15, 1884 M Oct. 21, 1884
WADDELL, MONTGOMERY	Engineer, The Waddell-Entz Electric Co., Bridgeport, Conn.	A Feb. 7, 1888 M May 1, 1888
WALDO, DR. LEONARD	Electrical Engineer, Firm of Waldo & Stout, Aluminum, Silicon and Manganese Bronze Founders, Bridgeport, Conn.	A June 5, 1888 M Dec. 4, 1888
WALKER, SYDNEY F.	Electrical Engineer, 195 Severn Road, Cardiff, Wales.	A June 2, 1885 M May 17, 1887
WEAVER, W. D.	32 West 31st Street, New York City.	A May 17, 1887 M May 17, 1887
WEBB, HERBERT LAWS	(*Manager*) 26 West 34th Street, New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEEKS, EDWIN R.	General Manager, Kansas City Electric Light Co., National Bank of Kansas City Building. Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Railroad Inspector, The General Electric Co., Edison Building, Broad Street, New York City.	A Oct. 21, 1890 M Nov. 24, 1891
WELLS, DOUGLAS	Hurstfield Ave., Gipsy Hill, London, Eng.	A June 7, 1892 M Jan. 17, 1893

Name.	Address.	Date of Election.
WESTON, EDWARD	(*Past President.*) Vice-President, Weston Electrical Instrument Co., 120 William St., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884
WETZLER, JOSEPH	Editor *Electrical Engineer*, 203 Broadway, New York City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	82 Bond St., London England.	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER S., *Sc.D.* [Life Member.]	President Crocker-Wheeler Electric Motor Co., 430-432 West Fourteenth St., Electrical Expert; Board of Electrical Control, 1266 Broadway, New York City.	A June 2, 1885 M Sept. 1, 1885
WILKES, GILBERT	Chief Engineer, Detroit Electrical Works, Detroit, Mich.	A Jan. 7, 1890 M Mar. 18, 1890
WILSON, CHARLES H.	General Superintendent, Chicago Telephone Co., 203 Washington Street, Chicago, Ill.	A Nov. 24, 1891 M Feb. 16, 1892
WILSON, FREMONT	Consulting Electrical Engineer, Times Building, and 293 Lenox (6) Ave., New York City.	A Mar. 6, 1888 M June 5, 1888
WILSON, HARRY C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892
WINCHESTER, A. E.	Designer of Steam Electrical Plants, Wilton, Conn.	A June 8, 1887 M Nov. 1, 1887
WOLCOTT, TOWNSEND	Consulting Electrician, 849 Greene Ave., Brooklyn, N. Y.	A Mar. 6, 1888 M Dec. 16, 1890
WOODBRIDGE, J. L.	Secretary and Treasurer, Woodbridge & Turner Engineering Co., 47 Times Building, New York City.	A June 8, 1887 M Nov. 1, 1887
WURTS, ALEXANDER JAY,	Electrical Expert, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
YOUNG, C. GRIFFITH	Electrical Engineer, Care J. G. White & Co., 29 Broadway, New York City.	A Jan. 3, 1889 M April 21, 1891
ZETZSCHE, PROF. DR. CARL EDUARD,	Telegraph Engineer, Carlstrasse 13, Dresden, N., Saxony.	A Nov. 1, 1887 M Jan. 3, 1888

Members, - - - 195.

ASSOCIATE MEMBERS.

Name.	Address.	Date of Election.
ABERNETHY, J. P.	Superintendent of Telegraph, 53 City Hall, Cleveland, O.	July 7, 1884
ABBOTT, ARTHUR V.	Mechanical Engineer, North Ave. Railway Co., Blackstone Building, Baltimore, Md.	Oct. 21, 1890
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., 227 S. Clinton St., Chicago. Ill.	Sept. 27, 1892
ALDEN, JAMES S.	Assistant Manager, with L. H. Alden, 486 River Drive, Passaic, N. J.	May 19, 1891
ALDRICH, WILLIAM S.	Burlington, N. J.	Mar. 15, 1892
ALEXANDER, HARRY	Electrical Contractor, 126 Liberty and 340 W. 145th St., New York City.	April 21, 1891
ALEXANDER, P. H,	Southern Electric Co., Hoen Building, Baltimore, Md.	Dec. 16, 1890
ANDREWS, WM. S.	General Electric Co., Montreal, Canada.	Mar. 5, 1889
ANTHONY, WATSON G.	Electrician, 32½ Webster St., Newark, N. J.	Feb. 24, 1891
ARMSTRONG, CHAS. G,	Electrical Expert and Electrical Architect, 1301 Auditorium Tower Chicago, Ill.	Sept. 27, 1892
ARNOLD, BION J.	Consulting Engineer, General Electric Co., 4128 Prairie Ave., Chicago, Ill.	Oct. 25, 1892
ARNOLD, CRAIG R.	Electrician and Treasurer, Arnold Electric Mfg. Co., Chester, Penn.	Nov. 15, 1892
ATWOOD, GEORGE F.	Orange, N. J.	Sept. 16, 1890
BADT, LIEUT. FRANCIS B.	Manager, Mining Dep't. T.-H. Electric Co., 6506 Lafayette Ave., Englewood, Ill.	April 19, 1892
BAILLARD, E. V.	Equitable Mfg. and Electric Co., 611 West 36th St. and 363 Manhattan Ave., New York City.	Dec. 3, 1889
BARNARD, JOHN H.	Vice President and General Manager, Wilmington Street Railway Co., Wilmington, N. C.	June 26, 1891
BARTON, ENOS M.	President Western Electric Co., 227 South Clinton St., Chicago, Ill.	July 12, 1887
BARRETT, JOHN A.	Electrical Engineer and Expert, 13 Park Row, New York City.	June 8, 1887
BATES, F. C.	Electrical Engineer, with Thomson-Houston Electric Co., Lynn, Mass.	Jan. 20, 1891
BAUER, W. F.	Electrician, 62 Steuben St., East Orange, N. J.	April 15, 1890
BEALS, PASCAL P.	Electrical Contractor and Agent for the Waddell-Entz Electric Co., 50 Terrace, Buffalo, N. Y.	May 17, 1892
BEATTIE, JOHN, JR.	Manager and Superintendent, The Beattie Battery, Zinc and Electric Co., Fall River, Mass	Sept. 6, 1887

Name.	Address.	Date of Election.
BEDELL, FREDERICK, DR.	Physical Laboratory, Cornell University, Address, 118 Elm St., Montclair, N. J.	April 21, 1891
BENNETT, J. C.	Electrician, General Electric Co., Box 3067, 44 Broad St., New York City.	Mar. 18, 1890
BERHGOLTZ, HERMAN	Secretary and Treasurer, Ithaca Street Railway Co., Ithaca, N. Y.	April 2, 1889
BERLINER, EMILE	Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C.	April 15, 1884
BERTHOLD, VICTOR M.	With T. D. Lockwood in Patent Department of American Bell Telephone Co., 16 Upton Street, Cambridgeport, Mass.	May 17, 1892
BLACK, CHAS. N.	Brush Electric Co., Belden St. Cleveland, O.	Feb. 7, 1890
BLADES, HARRY H.	General Sup't., The Detroit Motor Co., 1343-55 Cass Ave., Detroit, Mich.	April 19, 1892
BLAKE, HENRY W.	The Street Railway Publishing Co., World Building, New York City.	Nov. 13, 1888
BLAKENEY, W. H.	Firm of Blakeney and Rennie, Mechanical and Electrical Engineers, 33 Bath St., Glasgow, Scotland.	Mar. 15, 1892
BLISS, DONALD M.	Electrician, The Canada Electric Co., Amherst, N. S.	Feb. 7, 1890
BLISS, WM. J. A.	820 Connecticut Ave., Washington, D. C.	Jan. 20, 1891
BLOOD, W. HENRY, JR.	The Franklin Electric Co., 535 Delaware St., Kansas City, Mo.	April 2, 1889
BLUME, JOHN C.	Assistant Electrican, American Telegraph and Telephone Co., 23 East 31st., New York City.	Dec. 21, 1892
BOGART, A. LIVINGSTON	Electrical and Patent Expert, 22 Union Square, New York City.	July 10, 1888
BOGUE, CHARLES J.	165 West Eighteenth St., New York.	Dec. 3, 1889
BOHM, LUDWIG K. *Ph.D.*,	Consulting Electrical & Chemical Expert, 81 Nassau St., New York City.	Nov. 15, 1892
BOSSON, FREDERICK N.	Electrician, Calumet and Hecla Mining Co., Calumet, Mich.	May 17, 1892
BOTTOME, TURNER D.	Electrician and General Manager, White House Mills, Hoosick, N.Y.	April 21, 1891
BOTTOMLEY, HARRY	Electrical Engineer, Marlboro, Mass.	April 2. 1889
BOUGHAN, EDWARD L.	Supply Agent, American Telephone and Telegraph Co., 153 Cedar St., New York City.	Dec. 21, 1892
BOWMAN, FRED A.	Supt , New Glasgow Electric Co., New Glasgow, Nova Scotia.	May 19, 1891

Name.	Address.	Date of Election.
BRACKETT, PROF. CYRUS F.	Princeton, N. J.	April 15, 1889
BRADDELL, ALFRED E.	Electrical Inspector, Underwriters' Association, Middle Dep't, 308 Walnut St., Philadelphia, Pa.	Sept. 1, 1890
BRADLEY, FRED. W.	Electrical Engineering Dep't. Jackson Park, Chicago, Ill.	May 20, 1890
BRADY, PAUL T.	State Agent, Thomson-Houston Electric Co., Syracuse, N. Y.	July 12, 1887
BROPHY, WILLIAM	17 Egleston St., Jamaica Plain, Mass.	Mar. 5, 1889
BROWN, ALEX. S.	Electrical Engineer, 136 Liberty St., New York City.	Jan. 7, 1890
BROWN, ALFRED S.	Electrical Engineer, Western Union Telegraph Co., 195 Broadway, New York City.	Mar. 18, 1890
BROWN, CHARLES A.	Attorney, Firm of Barton & Brown, Attorneys and Counsellors, 1428 1430 Monadnock Bldg., Chicago, Ill.	July 12, 1887
BUBERT, J. F.	Electrical Engineer, The Mather Electric Co., 116 Bedford St., Boston, Mass.	June 7, 1892
BUCKINGHAM, CHAS. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O Box 3393, New York City.	April 15. 1884
BUNCE, THEODORE D., JR.	[Address unknown.]	May 20, 1890
BURNS, ELMER Z.	Consulting Electrical Engineer, Niagara Falls, N. Y.	Feb. 7, 1890
BURTON, GEO. D.	President, Electrical Forging Co., 194 Washington St., Boston, Mass.	April 21, 1891
BUYS, BERT.	Electrician, Rutherford B. S. & C. Elec. Co., Rutherford, N. J.	Feb. 7, 1890
CALDWELL, EDWARD	Editor, *Street Railway Gazette*, Phœnix Building, Chicago, Ill.	Jan. 20, 1891
CALDWELL, FORDYCE S.	Proprietor Western Electric Construction Co., 503 Delaware St., Kansas City, Mo. and 151 Henry St., Brooklyn, N. Y.	Sept. 22, 1891
CALLENDER ROMAINE	Electrician, Brantford Electrical Laboratory, Brantford, Canada.	Sept. 27, 1892
CARSON, DAVID I.	Sec'y and Gen. Supt., the Southern Bell Telephone and Telegraph Co., 18 Cortlandt St., New York City.	Dec. 21, 1892
CARTWRIGHT, FRED'K. G.	Electrical Engineer, and Agent Fort Wayne Electric Co., 35 New Montgomery St., San Francisco, Cal.	Sept. 22, 1891
CARTY, J. J.	Electrician, Metropolitan Telephone and Telegraph Co., 18 Cortlandt St., New York City.	April 15, 1890

Name.	Address.	Date of Election.
CASE, WILLARD E.	6 Fort St., Auburn, N. Y.	Feb. 7, 1888
CASPER, LOUIS	Wheatstone Repeater Chief, Western Union Telegraph Co., Cheyenne, Wyoming.	April 21, 1891
CHAMBERLAIN, F. H.	Electrician. Metropolitan R. R. Co., 2411 P St., N. W. Washington, D. C.	June 17, 1890
CHENEY, FREDERICK A.	Sec'y, Treas'r and General Manager, The Elmira Illuminating Co., Elmira, N. Y.	Oct. 1, 1889
CHENEY, W. C.	Electrical Engineer, Willamette Falls Electric Co., Portland, Oregon.	Sept. 22, 1891
CHERMONT, ANTONIO LEITE,	Manager Telephone Co. of Para, Para, U. S. of Brazil, Care Herbst Bros, Box 1377, New York City.	Mar. 18. 1890
CHILDS, W. H.	Bookkeeper for The Estey Organ Co., Brattleboro, Vt.	Sept. 6, 1887
CHINNOCK, C. E.	General Electric Co., Edison Building, P. O. Box 3067, New York City.	April 15, 1884
CHUBBUCK, H. EUGENE	Sec'y and Treas'r, The New Omaha Thomson-Houston Electric Co., Omaha, Neb.	Dec. 4, 1888
CLAFLIN, ADAMS D.	General Manager, The Mather Electric Co., 116 Bedford St., Boston, Mass.	June 7, 1892
CLEMENT, LEWIS M	1013 Central Ave., Oakland, Cal.	April 21, 1891
CLEVELAND, WM. B.	Electrical Engineer, 309 Perry-Payne Building, Cleveland, O.	April 15, 1884
COBB, JOHN S.	[Address unknown.]	June 17, 1890
COFFIN, CHAS. A.	Vice-President and Treasurer, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.	Dec. 6, 1887
COGSWELL, A. R.	Electrician and Superintendent, Halifax Illuminating and Motor Co. Ltd., 34 Bishop St., Halifax, N. S.	April 21, 1891
COLGATE, GEO. L.	[Address unknown.]	June 17, 1890
COLLEY, BENJAMIN W.	First Ass't. Superintendent, The Commercial Cable Co, Hazel Hill, N. S.	Oct. 21, 1890
COLVILLE, FRANK C.	Electrician and Inventor, 1503 Seventh Ave., Oakland, Cal.	May 19, 1891
COMPTON, ALFRED G.	(*Manager.*) Professor of Physics, College of the City of New York, 17 Lexington Ave., New York City.	Nov. 1, 1887
COOLIDGE, CHARLES A.	Sup't and Electrician, Northern Improvement Co., Centralia, Washington.	April 19, 1892
CORNELL, CHAS. L.	Electrical Engineer, Cornell Engineering Co., 45 Broadway, New York City.	Feb. 7, 1890

Name.	Address.	Date of Election.
CORSON, WILLIAM R. C.	Assistant Electrician, The Eddy Electric Mfg. Co., Windsor, Conn.	Jan. 17, 1893
CORY, CLARENCE L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892
CRAM, HENRY B.	Treasurer, Bernstein Electric Co., 620 Atlantic Ave., Boston, Mass.	June 26, 1891
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 227 South Clinton St., Chicago, Ill.	Sept. 27, 1892
CRANE, W. F. D.	Manager Electrical Dep't. H. W. Johns Manufacturing Co., 87 Maiden Lane, New York City, and 24 Halstead Pl., East Orange, N. J.	Feb. 7, 1888
CREHORE, ALBERT CUSHING	Instructor in Physics, Cornell University, 117 East Buffalo St., Ithaca, N. Y.	Dec. 21, 1892
CROSBY, OSCAR T.	(*Vice-President.*) General Manager Railway Department, General Electric Co., 620 Atlantic Ave., Boston, Mass.	Mar. 18, 1890
CUNTZ, JOHANNES H.	Assistant to Pres't Henry Morton, Stevens Institute of Technology, 137 Hudson St., Hoboken, N. J.	Mar. 5, 1889
CURTIS, CHAS. G.	63 Broadway, New York City.	April 15, 1884
CUSHING, F. W.	General Western Agent, Day's Kerite Wire and Cables, 225 Dearborn St., Chicago, Ill.	Nov. 24, 1891
CUSHMAN, HOLBROOK	Instructor in Physics, Columbia College, 337 West 22d St., New York City.	June 5, 1888
DAME, FRANK L.	Engineer, The Northwest Thomson-Houston Electric Co., 114 James St., Seattle, Wash.	June 26, 1891
DANA, R. K.	Agent Washburn and Moen M'f'g Co., 16 Cliff St., New York City.	April 15, 1884
DANIELL, FRANCIS G.	Electrical Engineer, Evansville Street R. R. Co., Evansville, Ind.	Nov. 12, 1889
DAVENPORT, GEORGE W.	General Manager, Thomson-Houston International Electric Co., 44 Broad St., New York City.	June 4, 1889
DAVIDSON, EDW. C.	Patent Lawyer, Room 179 Times Bldg., New York City.	Feb. 7, 1890
DAVIS, DELAMORE L.	Superintendent, Salem Electric Light & Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
DAVIS, JOSEPH P.	Consulting Engineer, Care of Phœnix Construction Co., 115 W. 38th St., New York City.	April 15, 1884
DAVIS, MINOR M.	Ass't Electrician, Postal Telegraph Cable Co., 5 Dey St., New York City.	April 6, 1886

Name	Address.	Date of Election.
DE KHOTINSKY, CAPT. ACHILLES,	Superintendent, Germania Electric Co., 505 Exchange Bldg., Boston, and Marlboro, Mass.	Oct. 27, 1891
DELAND, FRED	Editor, *World's Fair Electrical Engineering*. The Rookery, Chicago Ill.	Feb. 16, 1892
DENTON, JAMES E.	Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J..	July 12, 1887
DESMOND, JERE. A.	Supt. and Electrician, Kingston Electric Light and Power Co., Kingston, N. Y.	Jan. 19, 1892
DICKERSON, E. N.	Attorney-at-Law, 15 Wall St., New York City.	April 15, 1884
DION ALFRED A.	Manager, Ahearn & Soper, 72 Sparks Street, Ottawa, Ont.	Jan. 7, 1890
DOANE, S. EVERETT	Thomson-Houston Electric Co., Swampscott, Mass.	Aug. 6, 1889
DOBBIE, ROBERT S.	Consulting Electrical Engineer, 1014 Bergen Ave., Jersey City, N. J.	Feb. 5, 1889
DOREMUS, CHARLES A.	*M. D. Ph. D.* Chemist and Physicist, Bellevue Hospital Medical College, College of the City of New York and American Veterinary College, 92 Lexington Ave., New York City.	July 7, 1884
DRESSLER, CHARLES E.	Maker of Scientific and Electrical Apparatus, College of the City of New York, 17 Lexington Ave., New York City.	Dec. 16, 1890
DUNBAR, F. W.	Assistant Electrician, American Telephone and Telegraph Co., 153 Cedar St., New York City.	Dec. 21, 1892
DUNDERDALE, CLEAVELAND F.	Agent Westinghouse Electric Co., 146 Adams St., Chicago, Ill.	June 17, 1890
DUNN, GANO S.	Electrical Engineer, of the Crocker-Wheeler Electric Co, 430 West 14th St., Residence, 223 Central Park, West, New York City.	April 21, 1891
DURANT, EDWARD	Electrician, with F. Pearce, 115 E. 26th St., New York City.	Nov. 15, 1892
DURANT, GEO. F.	Vice-Pres't of Bell Telephone Co. of Mo., 322 Pine St., St. Louis, Mo.	April 15, 1884
EDWARDS, JAMES P.	Graniteville, S. C.	April 19, 1892
EKSTROM, AXEL	Electrician, Thomson-Houston Electric Co., Lynn, Mass.	June 17, 1890
ELEY, HARRIS H.	Electrical Workshop Sup't. W. C. & S. W. Telephone Co., 88 Colston St., Bristol, Eng.	Jan. 7, 1890
ELMER, WILLIAM, JR.	Under-graduate in Electrical Engineering, Princeton University, Princeton, N. J.	Mar. 18, 1890
EMMET, HERMAN L. R.	Publisher and Printer, 36 Cortlandt St., New York City.	April 15, 1884

Name.	Address.	Date of Election.
ENTZ, JUSTUS B.	Electrical Engineer, The Waddell-Entz Co., Bridgeport, Ct.	Jan. 7, 1890
ESSICK, SAMUEL V.	Electrician, The Essick Printing Tel. Co., 1 Broadway, New York City, and Yonkers, N. Y.	May 19, 1891
EVEREST, AUGUSTINE R.	Electrical Expert, Thomson Electric Welding Co., 89 State St., Boston, Mass.	May 19, 1891
FAY, THOMAS J.	39 King St., New York City.	June 26, 1891
FIELDING, FRANK E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
FISCHER, GUSTAVE J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	Jan. 20. 1891
FISH, WALTER C.	Manager, Bernstein Electric Co., 620 Atlantic Ave., Boston, Mass.	June 26, 1891
FISHER, GEORGE E.	Secretary and General Manager, Commercial Electric Co., 55-57 Gratiot Ave., Detroit, Mich.	Sept. 27, 1892
FISKE, HENRY G.	Electrician, Croton Magnetic Iron Mines, 45 E. 22d St., New York City.	Nov. 12, 1889
FISKE, J. P. B.	Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass.	June 17, 1890
FLACK, J. DAY	Ass't Electrician in charge of Tests, Edison Lamp Works, Harrison, N. J.	Dec. 6, 1887
FLATHER, JOHN J.	Professor of Mechanical Engineering, Purdue University, Lafayette, Ind.	April 19, 1892
FLESCH, CHARLES	Electrical Engineer, Melbourne, Australia.	Sept. 27, 1892
FLOOD, J. F.	Supt. Steubenville Street Railway Co., Steubenville, O.	Mar. 18, 1890
FLOY, HENRY	168 North Ave., Allegheny, Pa.	May 17, 1892
FOOTE, ALLEN R.	Special Agent, Electrical Industries, U. S. Census, Takoma Park, D. C.	April 21, 1891
FOOTE, CHARLES W.	General Manager, The Nicholson Electric Hoist Co., 84 Champlain St., Cleveland, O.	Sept. 22, 1891
FOOTE, THOS. H.	153 John St., Bridgeport, Ct.	April 21, 1891
FORBES, FRANCIS	Lawyer, 137 Broadway, New York City.	Sept. 16, 1890
FORD, WM. S.	Assistant to Chief Engineer, The American Bell Telephone Co., Room 73, 125 Milk St., Boston, Mass.	June 7, 1892
FRANCISCO, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890

Name.	Address.	Date of Election.
FREEDMAN, WILLIAM H.	Honorary Fellow in Electrical Engineering, Columbia College, 120 West 125th St., New York City.	Mar. 18, 1890
FRENCH, E. L.	Stanley Laboratory Co., Pittsfield, Mass.	Dec. 16, 1890
FULLER, LEVI K.	Vice-President, Estey Organ Co., and Governor of Vermont, Brattleboro, Vt.	Mar. 5, 1889
GAINES, J. D.	Second Ass't. Superintendent, The Commercial Cable Co., Hazel Hill, N. S.	Oct. 21, 1890
GALE, HORACE B.	Consulting Electrical and Mechanical Engineer, 40 California St., San Francisco, Cal.	Nov. 15, 1892
GILES, WALTER A.	Engineer and Contractor, 416 Lewis Block, Pittsburg, Pa.	Nov. 1, 1887
GILLILAND, E. T.	Pelham Manor, N. Y.	April 15, 1884
GOLDMARK, CHAS. J.	473 Park Ave., New York City.	June 5, 1888
GORTON, CHARLES	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
GORDON, REGINALD	Assistant in Physics, Columbia College, Residence, 76 Park Ave., New York City.	Feb. 24, 1891
GRANER, ADOLF	Electrical Patent Agent, 529 North 35th St., Philadelphia, Pa.	Feb. 16, 1892
GRAY, W. N.	Electrical Engineer, 12 Chamber of Commerce, Cincinnati, O.	Oct. 1, 1889
GREENBERG, ADOLPH G.	Salesman, Washburn & Moen M'f'g. Co., 16 Cliff St., New York City, 216½ 17th Street, Brooklyn, N. Y.	Mar. 17, 1891
GROSS, S. ROSS	Electrician, Tennessee Coal, Iron & R. R. Co., Ensley, Ala.	May 17, 1892
GROWER, GEORGE G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
GRIFFIN, CAPT. EUGENE	Thomson-Houston Elec. Co., 295 Commonwealth Ave., Boston, Mass.	Feb. 7, 1890
GRUNOW, WILLIAM JR.	Expert Mechanician and Manufacturer of Special Machinery and Instruments, 204 and 206 East 43d St., New York City.	Jan. 19, 1892
GUTMANN, LUDWIG	Electrical Engineer, P. O. Box 118, Cleveland, O.	Sept. 14, 1888
HADLEY, WARREN B.	Supt. Wiring Dept., Edison Electric Illuminating Co., 431 Fifth Ave., New York City.	June 26, 1891
HALL, EDWIN H.	Assistant Professor of Physics, Harvard College, Gorham St., Cambridge, Mass.	Sept. 3, 1889
HALL, JOHN L.	Manager, Western Union Telegraph Co., 300 Market St., Wilmington, Del.	Sept. 22, 1891

Name.	Address.	Date of Election.
HALL, WILLIAM P.	President, The Hall Signal Co., 50 Broadway. New York City.	Sept. 16. 1890
HALSEY, WILLIAM B.	Inspector. Postal Telegraph-Cable Co., 94 Leonard St., New York City.	Mar. 18, 1890
HAMILTON, WILLIAM H.	Hamilton Electrical Works, 100 State St., Albany, N. Y.	Sept. 22, 1891
HANCOCK, L. M.	Supt. of Construction, Western Electric Co., 22 Thames St., New York City.	May 19, 1891
HANDLEY, ARTHUR	Electrical Engineer, Electrical Engineering Co. of Ireland, Limited, 61 Dawson St., Dublin, Ireland.	Dec. 16, 1890
HARDING, H. McL.	Railway Dep't, Westinghouse Electric & M'f'g Co., 120 Broadway, New York City.	May 24, 1887
HARRINGTON, WALTER E.	Consulting Electric Railway Engineer, 2131 North 12th St., Philadelphia, Pa.	Mar. 17, 1891
HART, FRANCIS R.	Supt. of Construction, Mass. Electrical Engineering Co., 4 P. O. Square, Boston, Mass.	April 21, 1891
HASKINS, CARYL D.	Manager Meter Dep't., General Electric Co., 620 Atlantic Ave., Boston, Mass.	Mar. 18, 1890
HASSON, W. F. C.	Consulting Engineer, 104 Sutter St., San Francisco, Cal.	Mar. 18, 1890
HATZEL, J. C.	Electrical Engineer and Contractor, 114 Fifth Avenue, New York City.	Sept. 3, 1889
HEALY, LOUIS W.	The Wightman Electric Co., 1205 Marion St., Scranton, Pa.	June 26, 1891
HENSHAW, FREDERICK V.	Assistant Electrician, The "C.& C." Electric Motor Co., 402 Greenwich St., New York City.	Feb. 5, 1889
HERING, HERMANN S.	Associate in Electrical Engineering, Johns Hopkins University, Baltimore, Md.	April 21, 1891
HEWLETT, EDWARD M.	Electrical Engineer, Isolated Dept. Thomson-Houston Electric Co. 65 Columbia Heights, Brooklyn, N. Y.	May 19, 1891
HIGGINS, EUGENE	Assistant Electrical Engineer, with Frank B. Rae, 27 and 28 Cleland Building, 31st St., Detroit, Mich.	April 19, 1892
HILL, GEORGE	Chief Engineer and General Manager, Carrere and Hastings, 44 Broadway, New York City.	April 19, 1892
HOCHHAUSEN, WILLIAM	Electrician, The Excelsior Electric Co., 196 Willoughby St., Brooklyn, N. Y.	April 15, 1884
HOFFMAN, SAMUEL V.	Post-graduate Student, Johns Hopkins University, Baltimore, Md.	Jan. 20, 1891

Name.	Address.	Date of Election.
HOLCOMB, EUGENE R.	Engineering Dept., Edison Gen'l Elec. Co., Portland, Ore.	June 17, 1890
HOLMES, FRANKLIN S.	Electrical Engineer, with C. H. Davis, 120 Broadway, N. Y., 445a Macon St., Brooklyn, N. Y.	April 21, 1891
HOLT, MARMADUKE BURRELL.	Mining and Electrical Engineer, The Colorado Smelting Co., Pueblo, Col.	April 15, 1890
HOOPES, ARTHUR	Edison Electric Illuminating Co., Westchester, Pa.	April 19, 1892
HOSFORD, HENRY H.	Electrical Engineer, 84 and 86 Champlain St., Cleveland, O.	Sept. 22, 1891
HOWSON, HUBERT	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
HUBRECHT, DR. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
HUFF, S. W.	General Manager, The Raleigh Street Railway Co., Raleigh, N. C.	Nov. 24, 1891
HUMPHREYS, C. J. R.	Manager, Lawrence Gas Co., Lawrence, Mass.	Sept. 6, 1887
HUNTING, FRED S.	Electrical Engineer, Fort Wayne Electric Co., 322 Washington St., Fort Wayne, Ind.	Nov. 15, 1892
IDELL, FRANK E.	Mechanical Engineer 41 Dey St., New York City.	July 12, 1887
IHLDER, JOHN D.	Electrical Engineer, with Osterheld & Eickemeyer, Manuf'rs of Dynamos and Motors, Yonkers, N. Y.	Oct. 2, 1888
INSULL, SAMUEL	President, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Dec. 7, 1886
IVES, EDWARD B.	Lieutenant U. S. A., Electrical Engineer, 139th St. and Grand Boulevard, New York City.	April 2, 1889
IZARD, E. M.	Electrical Engineer, The Electrical Engineering Co, 320 Dearborn St., Chicago, Ill.	Mar. 5, 1889
JACKSON, J. P.	Assistant Professor of Electrical Engineering, Penn. State College, State College, Pa.	Sept. 27, 1892
JAMES, JOHN N.	Electrician, Naval Observatory, Washington, D. C.	Feb. 16, 1892
JEFFERY, D. HERBERT	Secretary and Treasurer, Crocker-Wheeler Electric Co., 430 West 14th St., New York City.	Oct. 25, 1892
JOHNSTON, A. LANGSTAFF	Civil and Consulting Engineer in the the General Construction of Electric Railways, 1105 E. Main St., Richmond Va.	April 21, 1891
JOHNSTON, W. J.	President. The W. J. Johnston Co., Ltd., Times Building, P. O. Box 3332, New York City.	April 15, 1884

Name.	Address.	Date of Election.
JONES, PROFESSOR F. R.	University of Tennessee, Knoxville, Tenn.	May 20, 1890
JUDSON, WM. PIERSON,	U. S. Civil Engineer, Oswego, N. Y.	June 8, 1887
KEEN, WILLIAM M. B. *M.D.*	85 Varick Street, New York City.	Sept. 16, 1890
KELLOGG, JAMES W.	Assistant to District Engineer, General Electric Co., 140 E. 27th St., New York City.	June 26, 1891
KENNELLY, A. E.	(*Vice-President.*) Electrician, Edison Laboratory, Orange, N. J.	May 1, 1888
KIMBALL, A. S.	Professor of Physics, Worcester Polytechnic Institute, Worcester, Mass.	Sept. 3, 1889
KINNEY, H. A.	[Address unknown.]	Mar. 18, 1890
KINSMAN, FRANK E.	Electrical Engineer, Plainfield, N. J.	Sept. 27, 1892
KREIDLER, W. A.	Editor and Publisher, *Western Electrician*, 6 Lakeside Building, Chicago, Ill.	Oct. 4, 1887
LAIN, DAVID E., *B. S.*	Electrical Engineer, Yonkers, N. Y.	Nov. 13, 1888
LAND, FRANK	69 Park St., Lynn, Mass.	Sept. 22, 18[illegible]
LAUDY, LOUIS H.	Assistant in Applied Chemistry, School of Mines, Columbia College, Residence, 239 West 52d St., New York City.	Feb. 24, 1891
LAW, MYRON D.	Electrical Engineer, Love Electric Traction Co., Chicago, Ill.	Feb. 7, 1888
LEDOUX, A. R.	Chemical Expert, 9 Cliff St., New York City.	Dec. 7, 1886
LEE, JOHN C.	Chemist and Electrician, American Bell Telephone Co., Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
LEMP, HERMANN, JR.	Electrician, Thomson Electric Welding Co , Lynn, Mass.	April 2, 1889
LENZ, CHARLES OTTO	2625 Wabash Ave., Chicago, Ill.	Mar. 15, 1892
LEVY, ARTHUR B.	Assistant Engineer, Arc Light Dep't, General Electric Co., 810 Lexington Ave., New York City.	Jan. 20, 1891
LEWIS, HENRY FREDERICK WILLIAM.	8 Meridian Road, Redland, Bristol, Eng.	Mar. 5, 1889
LIEBIG, GUSTAV A., JR.	Elec'l Testing Bureau, Johns Hopkins University, Baltimore, Md.	Mar. 6, 1888
LITTLE, FRANKLIN P.	Manager, F. P. Little & Co., 141 East Seneca St., Buffalo, N. Y.	May 17, 1892
LLOYD, ROBERT MCA.	Electrician, 2 W. 36th St., New York City.	Oct. 21, 1890
LOGAN, CHARLES H.	[Address unknown.]	Nov. 18, 1890
LOOMIS, OSBORN P.	Electrician, Eureka Electric Co., 530 Nostrand Ave., Brooklyn, N.Y.	Sept. 16, 1890
LOVEJOY, J. R.	Electrical Engineer, Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.	April 21, 1891

Name.	Address	Date of Election.
LOW, GEORGE P.	Electrical Inspector, Pacific Insurance Union, 307 Sansome St., San Francisco, Cal.	Jan. 17, 1893
LOWREY, GROSVENOR P.	Lawyer, 1 Broad St., Residence 121 Madison Ave., New York City.	Nov. 1, 1887
LOZIER, ROBERT T. E.	Electrical Expert, The General Electric Co., Broad Street, Box 3067, New York City.	May 20, 1890
LUFKIN, HARVEY L.	General Agent, Crocker-Wheeler Electric Co, 430 West 14th St., New York City.	June 17, 1890
LUNDELL, ROBERT	Electrical Engineer, Interior Conduit and Insulation Co., 44 Broad St., New York. Residence 1309 Bedford Ave., Brooklyn, N. Y.	Feb. 7, 1890
LUQUER, THATCHER T. P.	Asst. in Surveying and Practical Mining, and Student in Electrical Engineering, Columbia College, N. Y., and Bedford, N. Y.	June 26, 1891
MACFADDEN CARL K.	Electrical Engineer, Taylor, Goodhue & Ames, 827 Monadnock Block, Chicago, Ill.	Sept. 27, 1892
MACMULLAN, ROBERT HEATH,	Treasurer and General Manager, Brush Electric Lighting Co., Lafayette, Ind.	Sept. 22, 1891
MAC QUESTEN, W. D.	Electrical Engineer and Contractor, 15 Cortlandt St., New York City.	April 15, 1890
MADDEN, O. E.	136 Liberty St., New York City.	April 15, 1884
MAGEE, LOUIS J.	Electrical Engineer, in charge of European Office of Thomson-Houston International Electric Co., Michaelisbrücke 1, Hamburg, Gy.	April 2, 1889
MAGENIS, JAMES P.	Editor the *Adams Freeman* Adams, Mass.	Sept. 27, 1892
MALCOLM, PHILIP S.	Western Agent, Gibson Electric Co., Portland, Oregon.	Mar. 18, 1890
MANSFIELD, GEO. W.	Electrical Engineer, with Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.	June 2, 1885
MARKS, LOUIS B.	Washington Carbon Co., Washington, Pa., Residence, 51 East 67th St., New York City.	May 20, 1890
MARPLE, LUCIUS E.	Associate Editor, the *Street Railway Gazette*, Phœnix Building, Chicago, Ill.	Sept. 22, 1891
MARTIN, A. J.	General Supt., West End Electric Co., 1310 N. 29th St., Philadelphia, Pa..	Mar. 15, 1892
MARTIN, F.	Electrical Engineer, Madison Square Garden Company, New York City.	Oct. 21, 1890
MARTIN, J.	Electrician, 16 Oak St., Newark, N. J.	Oct. 21, 1890

Name.	Address.	Date of Election.
MARTIN, T. COMMERFORD	(*Past President.*) Editor, *The Electrical Engineer*, 203 Broadway, New York City.	April 15, 1884
MASON, JAMES H.	Electrician and Supt., Mason Battery and Electrical Co., 120 Park Ave., Brooklyn, N. Y.	May 19, 1891
MAURO, PHILIP	Counsellor-at-Law in Patent Causes, (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
MAYER, GEORGE M.	Mechanical Draughtsman, Electrical Department World's Columbian Exposition, Chicago, Ill.	Dec. 16, 1890
MCBRIDE, JAMES	Superintendent, N. Y. & Boston Dye Wood Co., 146 Kent St., Brooklyn, N. Y.	Sept. 27, 1892
MCCARTHY, LAWRENCE A.	Western Union Telegraph Co., New York City, 1053 Bedford Ave., Brooklyn, N. Y.	Jan. 19, 1892
MCELROY, JAMES F.	Mechanical Sup't, The Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
MCKIBBIN, GEORGE N.	Chemist and Electrician, Reed & McKibbin, Consulting Electrical Engineers and Contractors, 2 Wall St., New York City.	June 8, 1887
MCKINSTRY, J. P.	185 Seneca St., Cleveland, O.	April 15, 1884
MCKISSICK, A. F.	Professor of Electrical Engineering, The A. & M. College of Ala., Auburn, Ala.	Feb. 16, 1892
MCRAE AUSTIN LEE	Professor of Physics, Missouri School of Mines, Rolla, Mo.	May 17, 1892
MERCER, ANDREW G.	Treasurer and Electrician, Waterloo Electric Co., Waterloo, N. Y.	Sept. 3, 1889
MERRITT, ERNEST	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	Sept. 16, 1890
MEYER, JULIUS	Consulting Engineer, North American Co., Mills Building, New York City.	Oct. 25, 1892
MILLER, JOSEPH A.	Civil and Consulting Engineer, 25 Butler Exchange, Providence, R. I.	Dec. 9, 1884
MILLER, WM. C.	General Manager, Watervliet Turnpike & R. R. Co., 3 South Hawk Street, Albany, N. Y.	Oct. 21, 1890
MINER, WILLARD M.	Electrician and Inventor, 89 East Second St., Plainfield, N. J.	July 12, 1887
MITCHELL, JOHN MURRAY	Lawyer, Box 3712, 45 Wall St., New York City.	June 2, 1885
MITCHELL, SIDNEY Z.	Manager, Oregon, Washington and Idaho Agency, General Electric Co., Fleischner Building, Portland, Or.	Nov. 12, 1889

Name.	Address.	Date of Election.
MIX, EDGAR W.	Electrician, with Thomson-Houston International Electric Co., 7 Rue du Louvre, Paris, France.	Sept. 3, 1889
MONELL, JOSEPH T.	With F. B. Crocker, 236 W. 22d Street, New York City.	Oct. 27, 1891
MOORE. JOHN J.	425 E. Twenty-fourth St., New York City.	Nov. 12, 1889
MORDEY, WM. MORRIS	Electrician, Brush Electrical Engineering Co , 34 Montserrat Road, Putney, London, Eng.	Sept. 22, 1891
MORRISON, J. FRANK	15 South St., Baltimore, Md.	April 15, 1884
MORSS, EVERETT.	Electrician, Simplex Electric Co., 297 Beacon St., Boston, Mass.	Sept. 22, 1891
MORROW, JOHN THOMAS	Electrical Engineer, General Electric Co., Lynn, Mass.	Dec. 21, 1892
MORTON, HENRY, *Ph. D*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
MOSES, DR. OTTO A.	Electrician. 1037 Fifth Ave., New York City.	May 17, 1887
MOSS, GEO. W.	Station Manager, C. & S. A. Tel. Co., Coatzacoalcos, Mexico.	Jan. 7, 1890
MOSSCROP, WM. A. *M. E.*	Electrical Engineer, 128 Oliver St., Boston Mass.	May 7, 1889
MYERS, GEO. FRANCIS	Electrical and Mining Engineer, Penn Bldg. Pittsburg, Pa.	June 17, 1890
NESMITH, S. D.	[Address unknown.]	Sept. 16, 1890
NEWELL, ARTHUR J,	Electrical Engineer, R. T. Oakes & Co., 366 High St., Holyoke, Mass.	Mar. 18, 1890
NICHOLS, ARTHUR E.	Student in Electrical Engineering, Columbia College, 16 E. 35th St., New York City.	Mar 18, 1890
NOLL, AUGUSTUS	New York Electric Equipment Co., 59 Duane St., New York City.	Sept. 27, 1892
NUNN, RICHARD J., *M. D.*	Physician, 119½ York St., Savannah Ga.	July 12, 1887
OCKERSHAUSEN, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887
O'DEA, M.	Electrician, University of Notre Dame, Notre Dame, Ind.	June 8, 1887
OTTEN, DR. JAN D.	Engineer, Thomson-Houston International Electric Co., Hollmann Strasse 31V. Berlin, S. W. Germany.	Nov. 18, 1890
OWENS, R. B.	Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.	June 17, 1890
PAGE, A. D.	Assistant Manager, Edison General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892
PALMER, G. W., JR.	[Address Unknown.]	April 15, 1890
PARCELLE, ALBERT L.	Electrician and Inventor, 157 Washington St., Boston, Mass.	Dec. 16, 1891

Name	Address	Date of Election.
PARKER, HERSCHEL C.	Assistant in Physics, Columbia College, 21 Fort Green Place, Brooklyn, N. Y.	April 19, 1892
PARKHURST, LIEUT. CHARLES D.	Inspector, Watervliet Arsenal, West Troy, and Troy House, Troy, N. Y.	Dec. 21, 1892
PARSELL, HENRY V., JR.	31 East Twenty-first St., New York City.	Nov. 12, 1889
PAUL, CHAS. M.	Electrician, 172 Remsen St., Brooklyn, N. Y.	May 7, 1889
PEARSON, F. S.	Chief Engineer, West End Street Railway Co., 439 Albany Street, Boston, Mass.	Oct. 25, 1892
PECK, EDWARD F.	General Sup't Citizens Electric Illuminating Co, Cor. Rockwell Place and DeKalb Ave., Brooklyn, N. Y.	May 20, 1890
PECK, SAMUEL C.	Electrician, Thomson-Houston Electric Co., 620 Atlantic Ave, Boston, Mass.	Sept 6, 1887
PEIRCE, WM. H.	Assistant Manager, Baltimore Smelting and Rolling Co., Keyser B'ld'g, German and Calvert Sts., Baltimore, Md.	Sept. 7, 1888
PERKINS, FRANK C,	209 Central Ave., Dunkirk, N. Y.	Oct. 21, 1890
PEROT, L. KNOWLES	Consulting Electrical Engineer, 308 Walnut St., Philadelphia, Pa.	Mar. 15, 1892
PERRY, NELSON W., *E. M.*,	Assistant Editor, *Electrical World*, Times Building, New York City.	May 17, 1892
PHILLIPS, EUGENE F.	M'f'r Insulated Electric Wire, Providence, R. I.	July 13, 1889
POOLE, CECIL P.	Contracting Electrical Engineer, 812 Church St. Lynchburg, Va.	Jan. 3, 1888
POOR, CHAS. LANE	Johns Hopkins University, Baltimore, Md.	Dec. 16, 1890
POPE, RALPH W.	Secretary to the American Institute of Electrical Engineers, 12 W. 31st St., Editor *Electric Power*, 136 Liberty St., New York City. Residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885
POWELL, WILLIAM H.	Manchester, Conn.	June 17, 1890
PUPIN, DR. MICHAEL I.	(*Manager.*) Instructor in Mathematical Physics, Columbia College, 68 W. 72d St., New York City.	Mar. 18, 1890
PUTNAM, H. ST. CLAIR	[Address unknown.]	Sept. 16, 1890
RANDALL, JOHN E.	Incandescent Lamp Dep't, Thomson-Houston Electric Co., 5 Vine St., Lynn, Mass.	May 7, 1889
RAY, WILLIAM D.	Electrician of Local Line of Northern Pacific R. R. Co., at Chicago, 308 Home Ave., Oak Park, Ill.	Sept. 27, 1892

Name.	Address.	Date of Election.
READ, ROBERT H.	Patent Attorney, with *Electrical Review*, 13 Park Row New York City.	Jan. 19, 1892
REED, CHAS. J.	Electrician, 224 High St., Orange, N. J.	Mar. 5, 1889
REED, HENRY A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East Twenty-fifth St., New York City.	June 4, 1889
REID, THORBURN	Electrical Engineer, 24 Chase St., Lynn, Mass.	Oct. 21, 1890
REILLY, JOHN C.	General Sup't, N.Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
REINMANN, A. L.	Electrician, 45 Linden St., Brooklyn, N. Y.	June 8, 1887
REIST, H. G.	Electrical Engineer, Thomson-Houston Electric Co., 11 Baker St., Lynn, Mass.	June 17, 1890
RIKER, ANDREW L. [Life Member.]	Electrical Engineer, 737 Madison Ave., New York City.	Nov. 1, 1887
ROBINSON, ALMON,	Draughtsman, Expert in Methods of Gearing, P. O. Box, 943, Lewiston, Me.	Sept. 6, 1887
RODGERS, HOWARD S.	Electrical Engineer, Eddy Electric Mfg. Co., Windsor, Conn.	Sept. 27, 1892
RODMAN, SAMUEL, JR.	Lieut. 1st Artillery, U. S. A., 17 Quincy St., Chicago, Ill.	Sept. 16, 1890
ROEBLING, FERDINAND W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887
ROESSLER, S. W.	Captain, U. S. A., U. S. Engineer Office, Memphis, Tenn.	Dec. 3, 1889
ROGERS, EDWARD H.	Patent Lawyer, firm of Pope and Rogers, 15 Wall St., New York City.	Sept. 22, 1891
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, 107 Mutual St., Toronto, Ont.	June 26, 1891
ROSENBAUM, WM. A.	Electrical Patent Solicitor, Care of *The Electrical World*, Times Building, New York City.	Jan. 3, 1889
ROSENBERG, E. M.	The Yale and Towne Manufacturing Co., Stamford, Conn. Residence, 784 Lexington Ave., New York City.	Oct. 21, 1890
ROSS, ROBERT A.	Engineer in charge of Engineering Dept., Edison General Electric Co., Petersborough, Ont.	Sept. 27, 1892
ROYCE, FRED W.	Electrician and Patent Solicitor, 1408 Pennsylvania Ave., Washington D. C.	April 15, 1884

Name.	Address.	Date of Election.
RUTHERFORD, W. M.	Toronto Construction and Electrical Supply Co., 63 Front Street, W. Toronto, Can.	Sept. 22, 1891
RYAN, HARRIS J.	Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.	Oct. 4, 1887
SACHS, JOSEPH	Electrician, The American Engineering Co.. 109 World Building. Residence, 1839 Lexington Ave., New York City.	Mar. 15, 1892
SANBORN, FRANCIS N.	Manhattan Electric Lighting Co., 13 Spencer Place, Brooklyn, N. Y.	Nov. 24, 1891
SARGENT, W. D.	General Manager, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
SAWYER, FREDERICK J.	381 Boylston St., Boston, Mass.	June 8, 1887
SAXELBY, FREDERICK	Electrical Engineer, 288 Summer Avc., Newark, N. J.	June 5, 1888
SCHLOSSER, FRED. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 1038 Leffingwell Ave., St. Louis, Mo.	Sept. 22, 1891
SCHMID, ALBERT	Superintendent, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	Oct. 21 1890
SCHMIDT, FREDERICK	Managing Director, The Schmidt-Douglas Electric Co., L'td., 31 Blenheim Rd., Bradford, England.	Jan. 3, 1888
SCHMIDT, GIACOMO	Ass't General Manager, Richmond Light, Heat and Power Co., New Brighton, N. Y.	April 21, 1891
SCHREITER, HEINR	Editor, *Drr Techniker*, 11 Chambers St., New York City.	Jan. 17, 1893
SEARING, LEWIS	Shepard & Searing, Mechanical and Electrical Engineers, 513 and 514 Mining Exchange, Denver, Colorado.	April 3, 1888
SEE, A. B.	A. B. See Manufacturing Co., 1235 Bedford Ave., Brooklyn, N. Y.	Jan. 17, 1893
SEELY, J. A.	General Manager, Complete Construction Co., 10 Cortlandt St., New York City.	April 15, 1884
SERRELL, LEMUEL WM.	Mechanical and Electrical Engineer, 10 Wall St., New York City.	Nov. 1, 1887
SHAIN, CHARLES D.	136 Liberty St., New York City.	June 7, 1892
SHAW, EDWIN C.	General Superintendent, Thomson-Houston E. L. and P. Co., 40 Court St., Buffalo, N. Y.	May 17, 1892
SHAW, GEORGE B.	General Manager, National Electric Mfg. Co., Eau Claire, Wis.	April 15, 1890
SHEBLE, FRANKLIN	Electrical Engineer, Thomson-Houston Electric Co., Lynn, Mass.	Oct. 21, 1890
SHEEHY, ROBERT J.	Electrical Engineer, Equitable Mfg. and Electric Co., 24 West St. and 101 W. 76th St., New York City.	April 21, 1891

Name.	Address.	Date of Election.
SHEPARDSON, GEORGE D.	Dep't. of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	April 21, 1891
SINCLAIR, H. A.	Electrical Engineer. The Tucker Electric Co., 950 Bedford Ave., Brooklyn, N. Y.	June 17, 1890
SISE, CHARLES F.	Vice-President and Managing Director, Bell Telephone Co., of Canada, and Canadian Telephone Co., Ltd., P. O. Box 1918, Montreal, Canada.	June 8, 1887
SMITH, FRANK STUART	Supt. of Carbon Dept., Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	Sept. 27, 1892
SMITH, FREDERICK H.	Civil Engineer. 227 East German St., Baltimore, Md.	Nov. 12, 1889
SMITH, HAROLD BABBITT.	Barre, Mass.	Nov. 24, 1891
SMITH, J. ELLIOT	Superintendent Fire Alarm Telegraph, 122 West 73rd St., New York City.	April 15, 1884
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N J.	May 19, 1891
SMITH, T. JARRARD	Manager Electrical Dep't., The E. S. Greeley & Co., 5 and 7 Dey St., New York City.	April 19, 1892
SOUZA, CARLOS MONTĒIRO e	Rio de Janeiro, Brazil.	Sept. 6, 1887
SPAULDING, HOLLON C.	P. O. Box 454, Exeter, N. H.	April 21, 1891
SPERRY, ELMER A.	Electrical Engineer, Sperry Electric Mining Machine Co., 39th St. and Stewart Ave., Chicago, Ill.	April 19, 1892
SPICER, CHAS. W. W.	136 W. 21st Street, New York City.	Nov. 12, 1889
SPIKE, CLARENCE J.	Halifax, N. S.	Mar. 18, 1890
SPRAGUE, FRANK J.	(*President.*) Electrical Engineer and Inventor, 182 West End Ave., Firm of Sprague, Duncan & Hutchinson, 15 Wall St., New York City.	May 24, 1887
SPRUSON, WILFRED J.	Member of the firm of Hepburn & Spruson, Consulting Engineers and Electricians, 169 King St., Sydney, Australia.	Dec. 16. 1890
SQUIER, GEORGE O.	Lieut. U. S. A., Student of Physics, Box 243. Johns Hopkins University, Baltimore, Md.,	May 19, 1891
STADELMAN, WM. A.	Vice-Prest. and Chief Engineer, Equitable Engineering and Construction Co., Drexel Building, Philadelphia, Pa.	Feb. 7, 1890
STAHL, TH.	Creusot Works, Creusot, France.	Nov. 15, 1892
STANLEY, WILLIAM, JR.	Electrician, Pittsfield, Mass.	Dec. 6, 1887

Name.	Address.	Date of Election.
STEARNS, CHARLES K.	Sup't of Construction, N. W. Thomson-Houston Electric Co., 403 Sibley St., St. Paul, Minn.	Aug. 6, 1889
STOCKBRIDGE, GEO. H.	Patent Attorney, and Editor *Electric Power*. 136 Liberty St., New York City.	May 24, 1887
STOCKLY, GEO. W.	President, Brush Electric Co., Cleveland, O. Lakewood, N. J.	April 15, 1884
STONE, CHARLES A.	Manager with E. S. Webster, Mass. Electrical Engineering Co., 4 P. O. Square Boston, Mass.	May 19, 1891
STRONG, FREDERICK G.	Lowe Gas and Electric Co., Colorado Springs, Colo.	Oct. 27, 1891
STUMP, CLARENCE E.	Vice-President and Business Manager, Street Railway Publishing Co., World Building, New York.	May 17, 1887
SULLIVAN, M. C.	Electrical Engineer, 136 Liberty St., New York City.	Dec. 16, 1890
SUMMERS, LELAND L.	Electrician, Postal Telegraph Co., 211 Phœnix Building Chicágo, Ill.	Feb. 16, 1892
SWEET, HENRY N.	Chief of Patent Bureau, Thomson Electric Welding Co., 89 State St., Boston, Mass.	May 20, 189c
TABER, ROBERT B.	Gas Engineer, Special Agent Thomson-Houston Electric Co., 620 Atlantic Ave., Boston, Mass.	Sept. 16, 1890
TAPLEY, WALTER H.	Electrician in Government Printing Office, Care of Public Printer, Washington, D. C.	Oct. 25, 1892
TAYLOR, CHARLES	Metallurgist, U. S. Assay Office, 30 Wall St., New York City.	Nov. 1, 1887
TEMPLE, WILLIAM CHASE	Mechanical and Electrical Engineer, Lewis Block, P. O. Box 800 Pittsburgh, Pa.	May 3, 1887
TESLA, NIKOLA	(*Vice-President.*) Electrical Engineer and Inventor, The Gerlach, 55 West 27th St., New York City.	June 5, 1888
THOMPSON, WILLIAM GEO. MACNEILL,	Resident Engineer, Sault Ste. Marie Canal, St. Catherines, Ont.	July 12, 1887
TISCHENDOERFER, FRED W.	Electrical Engineer, 116 Buena Vista Ave., Yonkers, N. Y.	April 19, 1892
TOBEY, WILLIAM BOARDMAN	The Stanley Laboratory Co., Pittsfield, Mass.	Sept. 16, 1890
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 5 Beekman St., New York City.	July 10, 1888
TREGONING, JOHN	32 Belmont Ave., Providence, R. I.	April 2, 1889
TROTT, A. H. HARDY [Life Member.]	Electrical Expert, with Thomson-Houston Electric Co., Lynn. Mass.	Jan. 20, 1891
TUTTLE, GEORGE W.	Storekeeper, Sawyer-Man Electric Co., 510 West 23d St., New York City.	Mar. 17, 1891

Name.	Address.	Date of Election.
UEBELACKER, CHAS. F.	Brush Electric Co., and 1299 Euclid Ave., Cleveland Ohio.	Feb. 7, 1890
UEHLING, T. A.	179 Sawtell Ave., Cleveland, O.	May 19, 1891
UHLENHAUT, FRITZ, JR.	139 North 15th St., Philadelphia, Pa.	May 7, 1889
VAIL, THEO. N.	18 Cortlandt St., New York City.	April 15, 1884
VAN BRUNT, WALTER	Manager, Duluth Telephone Co., Duluth, Minn.	Sept. 6, 1887
VAN BUREN, GURDON C.	Electrician, 5 Wilson Street, Albany, N. Y.	Oct. 25, 1892
VANCE, A. ST. CLAIR	General Superintendent, The H. Ward Leonard & Co., 136 Liberty Street, New York City.	April 2, 1889
VANDERGRIFT, JAMES A.	Assistant Supt. and Electrician, Sawyer-Man Electric Co., 534 W. 23d St., New York City.	Nov. 24, 1891
VAN TRUMP, C. REGINALD	Wilmington City Electric Co., Wilmington, Del.	Feb. 5, 1889
VAN VALKENBURGH, F. S.	906 Second St., Seattle, Wash.	June 5, 1886
VAN VLECK, FRANK	Executive Engineer, Pacific Railway Co., Los Angeles, Cal.	Nov. 16, 1886
VAN WYCK, PHILIP V. R., JR.	Room 13, 18 Cortlandt St., 127 W. 58th St., New York City.	April 21, 1891
VARLEY, RICHARD, JR.	Electrician, Okonite Insulated Wire Co., Passaic, N. J.	Mar. 18, 1890
VERLEY, HORACE S. L.	With Dr. Wm. E. Geyer, as Laboratory Assistant, Stevens Institute, Hoboken, N. J.	May 17, 1892
WACKER, GEORGE G.	Electric Organs, 3644 Third Ave., New York City.	Sept. 6, 1887
WALLACE, GEO. S.	Telegraph Office Manager, Chesapeake & Ohio Ry. Co., Box 214, Clifton Forge, Va.	Oct. 25, 1892
WALLACE, WILLIAM	Wire Manufacturer, Ansonia, Conn.	April 15, 1884
WALTER, HENRY E.	3 Princes Mansions, Victoria St., London, Eng.	April 2, 1889
WARDELL, GEORGE P.	19 Cedar St., Newark, N. J.	Nov. 12, 1889
WARING, RICHARD S.	Standard Underground Cable Co., 61 Westinghouse Bldg., Pittsburg, Pa.	April 15. 1884
WARING, JOHN	Consulting Electrician, The Perkins Electric Lamp Co., Manchester, Conn.	Dec. 16, 1890
WASON, CHAS. W.	Electrical Engineer, East Cleveland R. R. Co., 1154 Euclid Ave., Cleveland, O.	May 19, 1891
WATERHOUSE, FRANK G.	Room 6, No. 302 Asylum St., Hartford, Conn.	Sept. 6 1887

Name.	Address.	Date of Election.
WATERS, EDWARD G.	Electrical Engineer, Thomson-Houston Electric Light Co, German National Bank Building, Pittsburg, Pa.	Mar. 18, 1890
WATSON, ROBERT	The Elektron M'f'g. Co., 89 Liberty St., New York City.	Oct. 21, 1890
WATTS, H. FRANKLIN.	Electrical Engineer, 10 Cortlandt St., New York City.	May 20, 1890
WEAVER, NORMAN R.	Supt. of Repair Department, General Electric Co., 173-5 Adams St, Chicago, Ill,	Oct. 25, 1892
WEBSTER, DR. ARTHUR G.	Docent in Physics. Clark University, Worcester, Mass.	Jan. 19, 1892
WEBSTER, EDWIN S.	Mass. Electric Engineering Co., 4 P. O. Square, Boston, Mass.	April 21, 1891
WESSELS, EDWARD J.	New York Agent, The Short Electric Railway Co., 44 Broad St, New York City.	Mar. 15, 1892
WELLES, FRANCIS R,	Manufacturer, Bell Telephone Manufacturing Co., Antwerp, Belgium	Sept. 6, 1887
WHITE, GEO. MONTAGU	Agent for West Indies, Thomson-Houston International Electric Co., Kingston, Jamaica, W. I.	Sept. 22, 1891
WHITE, H. C.	Manager, Phœnix Iron Works Co., 15 Cortlandt St., New York City.	April 15, 1884
WHITE, J. G.	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway New York City.	April 2, 1889
WHITE, WILL F.	Electrical Engineer, Sec'y and Treas. Western Engineering Co., 415 So. 15th St., Omaha, Neb.	Feb. 7, 1890
WHITMORE, W. G.	Electrical Engineer. General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
WHITNEY, HENRY M. [Life Member.]	President, West End Street Railway Co., 81 Milk St., Boston, Mass.	July 12, 1887
WIGHTMAN, MERLE J.	Vice-President and Electrician, The Wightman Elec. Mfg. Co., 4 Commonwealth Bldg., Scranton, Pa.	Mar. 5, 1889
WILEY, WM. H.	Scientific Expert, 53 East 10th St., New York City.	Feb. 7, 1888
WILLIAMS, ARTHUR S.	53 Devonshire St., Boston, Mass.	Nov. 24, 1891
WILLIAMS, CHARLES, JR.	Electrician, 100 Sudbury St., Boston, Mass.	April 15, 1884
WILLIAMS, JAMES B. *M. D.*	44 Broadway, and 120 West 57th St., New York City.	Sept. 7, 1888
WILLYOUNG, ELMER G.	Electrician, James W. Queen & Co., 924 Chestnut Street, Philadelphia, and Ardmore, Pa.	Nov. 24, 1891
WINKLER, CHARLES F.	Electrician, Troy Electric Dynamo Co., 4 Park Ave., Troy, N. Y.	Sept. 3, 1889

Name.	Address.	Date of Election.
WINSLOW, I. E.	Manager, Roundhay Electric Tramway, 146 Roundhay Road, Leeds, Eng. Address, 457 Produce Exchange, New York City.	Nov. 12, 1889
WINTRINGHAM, J. P.	Theorist, 36 Pine St., New York City.	May 7, 1889
WIRT, CHARLES.	(*Manager.*) Electrical Engineer of the Electrical Supply Co., 102-104 Michigan Ave., Chicago, Ill.	Sept. 8, 1888
WIRT, HERBERT C.	Electrician, Marine Dept. Thomson-Houston Electric Co., 12 Millmont St., Roxbury, Mass.	June 26, 1891
WOLVERTON, B. C.	Electrician, N. Y. & Pa. Telephone & Telegraph Co., Elmira, N. Y.	Mar. 18, 1890
WOOD, E. J.	Consulting Engineer and Contractor, 243 Broadway, New York City.	July 12, 1887
WOODRUFF, H. O.	Manager, Sioux City Electric Co., Sioux City, Iowa.	Oct. 2, 1888
WOODWARD, FRANCKE L.	Student in Electricity, 13 Kirkland Place, Cambridge, Mass.	June 26, 1891
WOOLF, ALBERT E.	Electrician and Inventor, Woolf Electrical Co., 110 Pearl St. and 864 Lexington Ave., New York City.	Sept. 16, 1890
WRIGHT, JOHN D.	[Address Unknown.]	Oct. 21, 1890
ZALINSKI, EDMUND L.	Captain of Artillery, U. S. A., Care of War Dept., Washington, D. C.	May 17, 1887

Associate Members, - - - - 447.

OFFICIAL STENOGRAPHER.

RYAN, RICHARD W., 300 Mulberry St., New York City.

SUMMARY.

Honorary Members, - - - - - - - - -	4
Members, - - - - - - - - - - - -	195
Associate Members. - - - - - - - - -	447
Total - - - - -	646