# INCANDESCENT

# ELECTRIC LIGHTS,

WITH PARTICULAR REFERENCE TO THE

## EDISON LAMPS AT THE PARIS EXHIBITION.

By Compte Th. du Moncel and Wm. Henry Preece.

TO WHICH IS ADDED

"THE EDISON ELECTRIC LIGHT METER,"
BY FRANCIS JEHL;

"THE ECONOMY OF THE ELECTRIC LIGHT BY INCANDES-
CENCE." BY JOHN W. HOWELL;

AND ON THE

"STEADINESS OF THE ELECTRIC CURRENT,"
BY C. W. SIEMENS.

SECOND EDITION, REVISED AND ENLARGED.

*Reprinted, with additions and new illustrations, from*
VAN NOSTRAND'S MAGAZINE.



NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STREET.
1882.

## PREFACE TO SECOND EDITION.

THE rapid exhaustion of the first edition of this book has led to the present one.

The matter is arranged in slightly different order, and corrections and additions to accord with recent progress have been carefully made.

Of Compte du Moncel's original review only an abstract is presented here.

Mr. Preece's paper appears as it was presented to the Society of Arts, together with the discussion which followed it.

Dr. Siemens' paper is given also entire.

Mr. Jehl's paper on The Edison Electric Light Meter, and the notes relating to late trials of incandescent lights did not appear in the first edition.

# INCANDESCENT

# ELECTRIC LAMPS

AT THE

## International Exhibition of Electricity.

BY

### COMPTE TH. DU MONCEL.

*Translated from "La Lumiere Electrique."*

# INCANDESCENT ELECTRIC LAMPS.

## EDISON'S SYSTEM OF ELECTRIC LIGHTING.

THE incandescent system was first rep-
resented by lamps made from an incan-
descent platinum wire, and the interest-
ing experiments made in 1879 by M. de
Changy, should be recollected ; but the
practical workings of this system were not
satisfactory, principally because of the dis-
aggregation and partial fusion of the wires,
and in spite of the numerous improve-
ments brought to bear on this system by
Mr. Edison, who, by one of the most in-
genious of processes, had rendered them
more infusible and harder, still they had
to be absolutely rejected—at least for or-
dinary lamps. Then it was suggested to
employ carbon which, if not allowed to
burn, is infusible in the highest heat de-
veloped in the lamps, and different ar-
rangements of apparatus were put to-
gether at various times by King, Lody-
guine, Bouliguine, Swan, Sawyer, etc.,

some avoiding combustion by enclosing
the lamps in receptacles where a vacuum
had been obtained, others by filling these
receptacles with gases unfit for combus-
tion, as nitrogen or oxide of carbon, or
simply by leaving the air shut up in the
receptacle to be vitiated by an incipient
combustion.

All these attempts had but partially
succeeded, to say nothing more, when,
in 1879, the new incandescent carbon
lamp of Mr. Edison was announced, and
many savants, and myself in particular,
doubted the exactness of the allegations
which came to us from America. The
carbonized paper horse-shoe appeared
incapable of resisting mechanical shocks,
and of supporting incandescence for any
length of time. At this epoch Mr. Swan
himself said that up to that time he
had not been able to obtain any very
satisfactory results by an analagous dis-
position of the incandescent organ.

Mr. Edison, however, was not abashed,
and in spite of the lively opposition made
to his lamps, in spite of the bitter po-

lemic of which he was the object, he did
not cease to perfect it for practical pur-
poses, and has at last produced lamps,
which we have seen at the Exposition,
and which can be admired by all the
world for their perfect steadiness. These
lamps, to the number of 160, light the
two salons reserved for the discoveries of
the ingenious American inventor, and
we shall see still more important results
upon the installation of the great ma-
chine which is expected from America.

As at present made, these lamps are
sufficiently solid and can last a long time.
The originally fragile carbon has become
extremely elastic and hard, and of such
attenuation that it can be well compared
in size to a horse-hair. By a cleverly
combined system of fastening the plati-
num. conducting wires are not exposed
to be cut, and they are so sealed in the
glass receiver that their change of vol-
ume under the action of heat does not
endanger the perfection of the vacuum.
By the way the carbons are treated when
the vacuum is made in the globe, the

bubbles of air enclosed in their pores
and which, in escaping, disaggregate the
surface, are evacuated before closing the
lamp, and at the same time the filament
of carbon acquires a peculiar density and
hardness, as was the case with the plati-
num wires. To obtain this result the
carbonized filament must be brought into
incandescence while the vacuum is being
made. The very nature of the substance
of vegetable origin employed in its
fabrication, has been modified.

Fibers of bamboo are now used instead
of the paper originally employed. These
are carbonized by a certain process, and
the successive transformation of these
fibers into carbon filaments may be fol-
lowed in several collections to be seen at
Mr. Edison's exposition, and which will
gratify the curious, and are worthy of
study. According to Mr. Batchelor and
Mr. O. A. Moses, co-laborers of Mr. Edi-
son, and who represent him at the expo-
sition, the resistance of these filaments
is 125 ohm, when brought up to an in-
candescence corresponding to 16 candles;

but it can vary according to the luminous
power desired of the lamps, for it can be
distributed between two lamps, whose
filaments are correspondingly more or

Fig. 1.     Fig. 2.

less long.   Their extremities, which are
enlarged, are pressed in a kind of pincer
which terminates the platinum conduct-
ors, and which are soldered by an elec-
trolytically deposited copper.   Figs. 1, 2,

3 and 4 represent the actual arrangement of these lamps. Their duration, from what I have been assured, is long enough;



Fig. 3.

however, they must wear out. Although most of them may have served for 1,200 hours, the question may be asked whether a lamp capable of deterioration may be

considered a practical thing; but if it is considered that this lamp can be furnished for 30 cents, that the adjustment
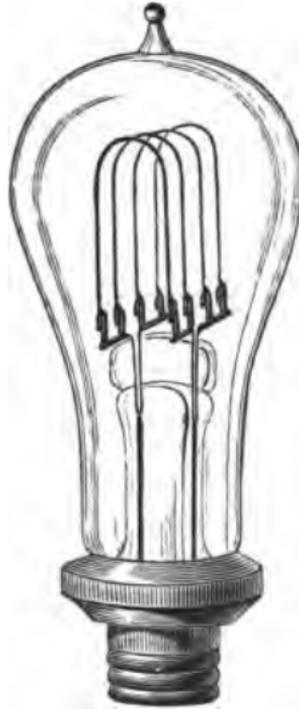


Fig. 4.

on its support cannot be any simpler than it is, which is evident on inspection, it is easily seen there is no more trouble to

replace one than to renew a broken lamp shade.

What constitutes Mr. Edison's system is not alone his lamps, it is the totality of the arrangements referring to them and which have attained such a degree of simplicity that henceforth nothing remains to be desired in practice. Generating machines, distribution of circuits, installation, indicating and regulating apparatus, meters for measuring the amount of current employed are all combined for immediate application. As we have said, this application is about being made in a part of the city of New York, where a great number of houses are to be lighted by this system, by means of a subterranean distribution from a central station, from which also motive power will be distributed to the houses.

This central station will be provided with twelve steam engines of 150 horse power each, actuating dynamo-electric machines, each of which will be capable to supply, it is said, 2,400 lamps of 8

candle power. The current furnished
to these lamps comes through a branch
taken before each house from the large-
sized conductors laid in the streets.
These deviations bring the poles of the
generator into each house, where the
lamp wires can be brought in connection
with them, thus rendering each house
independent of any other, both for a
supply of light and motive power.

When it is considered that the system
of distribution adopted by Mr. Edison,
the total resistance of the exterior cir-
cuit is extremely reduced, and that with
2,400 lamps it is only $\frac{64}{2,400}$, say, about
.026 of an ohm, it can be seen that a very
feeble resistance should be given to the
generating machine; so that its first ar-
rangement has been modified. To begin
with: The field magnets were arranged on
a derivation taken from the commutator,
putting it into the induced circuit as in
Wheatstone's and Siemens' system.
Then the armature was arranged on Sie-
mens' principle, so that the wire con-

sisted of bars of copper. These bars lie close to each other around the cylinder which forms the armature, and they generate the current. Their extremities correspond to discs of copper (at right angles to them) laid one against the other at the ends of the cylinder, and insulated from each other. Each bar is fastened to its corresponding discs in such a way as to form a single circuit enveloping the cylinder longitudinally, and which is made perfect through the coupled bars two and two with the commutator blocks (made after the Grammes pattern). Figs. 5 and 6 give an idea of this new arrangement. The center of the cylinner itself is occupied outside of the rotating axle by a cylinder of wood, which in its turn is surrounded by a thick tube made of a series of very thin discs of iron, separated from each other by tissue paper. This arrangement facilitates the rapid changes of polarity in the plates. This tube is terminated at its two extremities by two thick clamping discs which are made to compress the others

laterally, and the copper discs of the
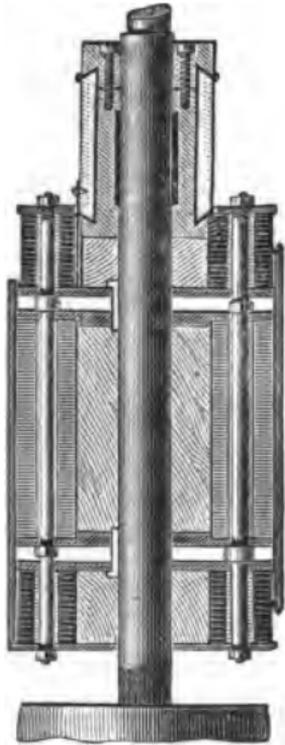working coil occupy the two compart-



Fig. 5.

ments at the extremities of the cylinder
as seen in Fig. 5. Under such condi-
tions as these the resistance of the gener-

ator is small, and permits of great sub-
division of the current in multiple arc;



Fig. 6.

nor is there any insulation to be burned,
and it is even possible, in case of the
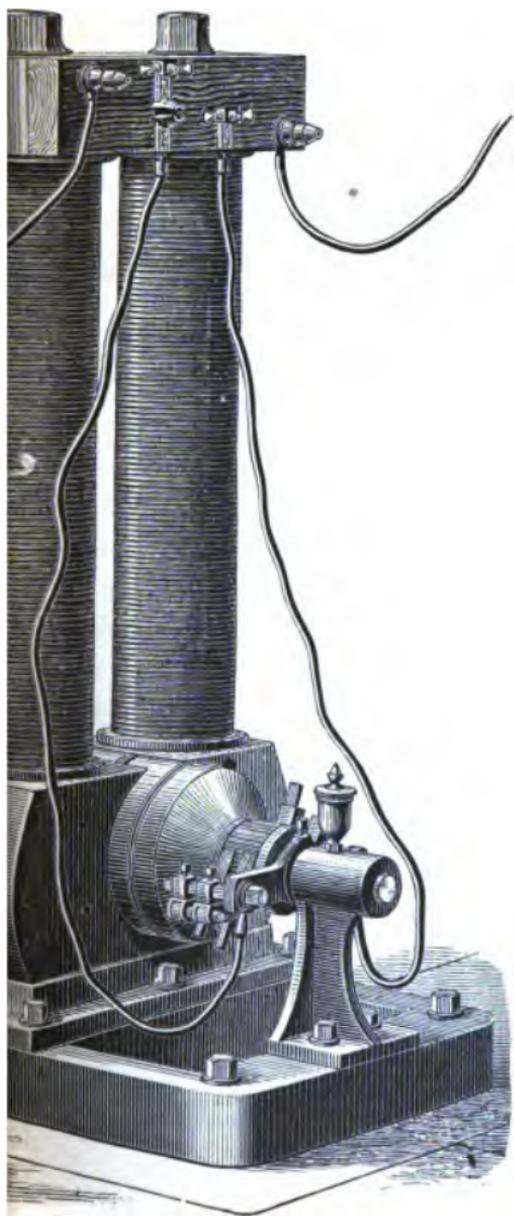deterioration of the bars, to renew them
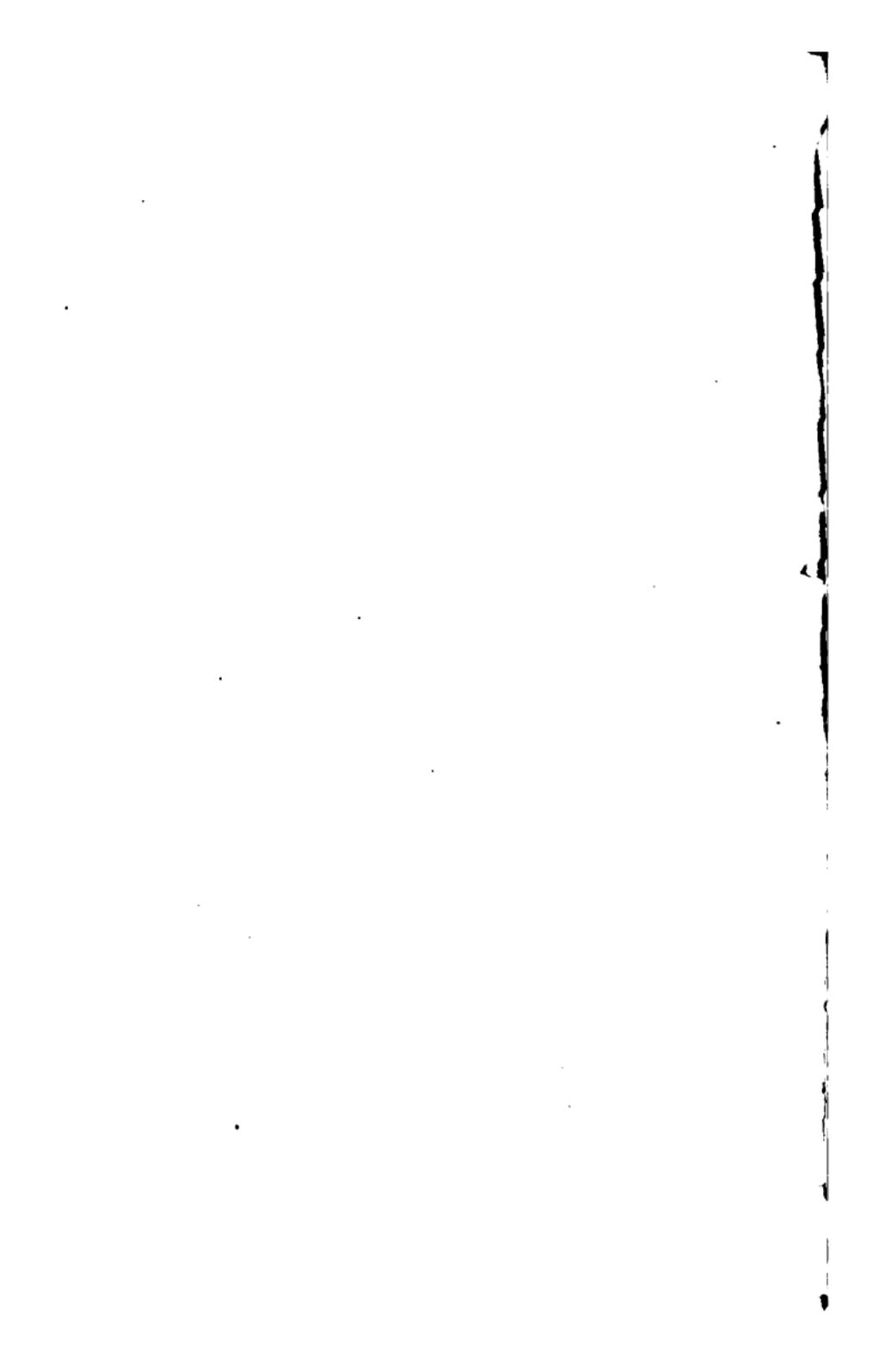
Fig. 7.

easily, for they are simply screwed against the copper discs corresponding to them. In the new disposition adopted by Mr. Edison, the field magnets lie horizontal instead of being placed in the verticle.

Fig. 7 represents the whole machine as now actually working in the Palais de l'Industrie.

We have described the generating machine before completing the description of the system of distribution of the current, because we ought to speak of the system of control used in making the current uniform when its intensity has been modified by a variation in its distribution; that is to say, following after a variation resulting from the unexpected suppression of a certain number of lamps in a part of the system. The necessities of this system are easily understood, if we consider that this suppression can lead to a greater or less increase in the intensity of the current feeding the remaining lamps.

In France several systems have been devised to obtain an automatic regula-

tion, but in America, it seems, it is preferred to effect this by the intermediation of an appropriate controlling agent.

In this system, in whose general arrangement we see in Fig. 8, the current which feeds the lamps furnishes a deviation at the machine *cc*, which enters an electric dynamometer, after having gone through a resistance of 180,000 ohms. The electro-motive force should be about 110 volts, and a difference of one volt should correspond on the scale of the indicating apparatus to three divisions; consequently, for each observed increase of intensity a resistauce capable of compensating for it should be introduced into the circuit. Mr. Edison has established a circular commutator, *e*, with bobbins of different resistance, which permits of an increase of resistance, not in the lamp circuit, which would lead to a loss of work, but in the circuit of field magnets, which weakens their action on the working coil. From the central station also, the condition of the current affecting the lamps can be controlled by means of
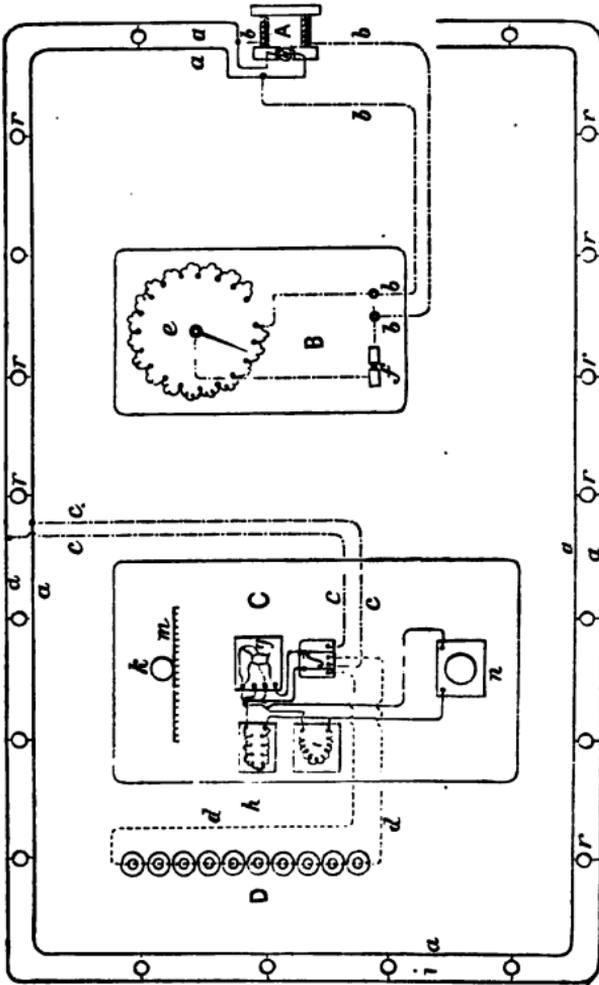
Fig. 8.

a testing photometer, which enables us to see how much the intensity of the current must be diminished or increased to correspond to a given luminous intensity. For this purpose the photometer is mounted on a little railroad, placed in a dark chamber; under and in front of it is placed a scale, arbitrarily divided, so as to indicate immediately the candle power furnished by the current in its normal condition. The left side of Fig. 8 indicates the manner of arrangement of the testing bench, with the explanatory table at the bottom of the figure. Fig. 9 shows it in perspective. The manner in which derivations are taken on the principal conductors merits especial mention. The conductors are composed of two rods of copper of hemi-cylindrical form, flat on one side and round on the other, which are enveloped in cylinders of insulating material, contained in small wrought iron pipes, which are buried under the streets. To take a derivation the cable is laid bare at the spot where the branch circuit is to be established. The two con-
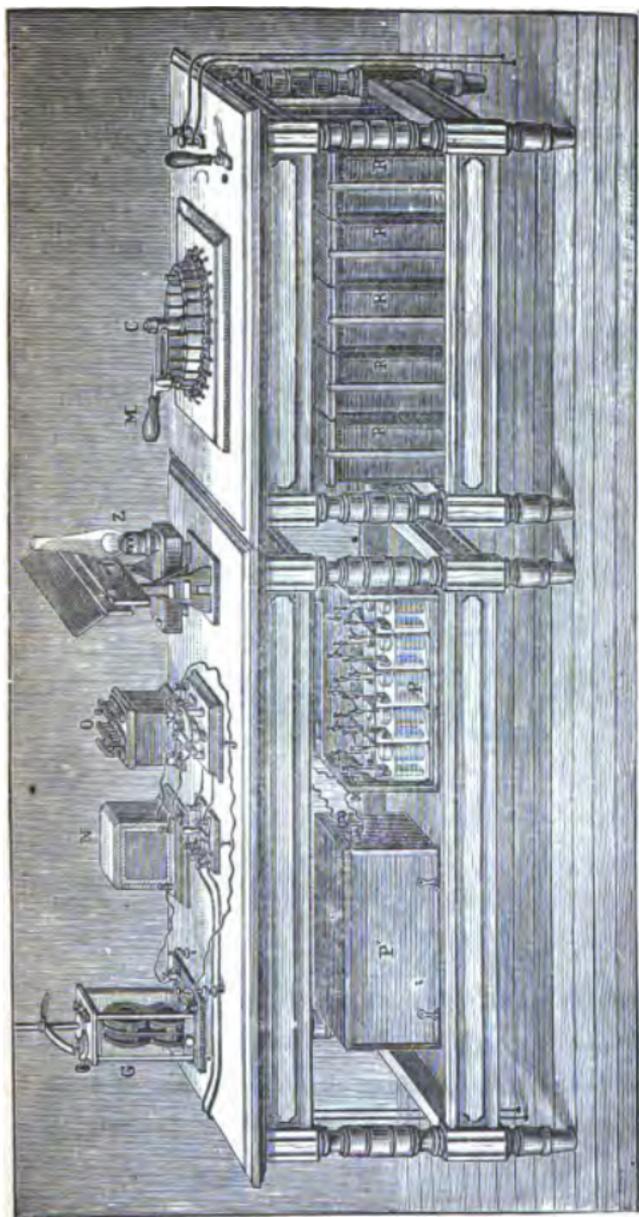
Fig. 9.

ducting rods (coming from the main con-
ductors) are cut and bent outwards and
introduced into a clamp where they are
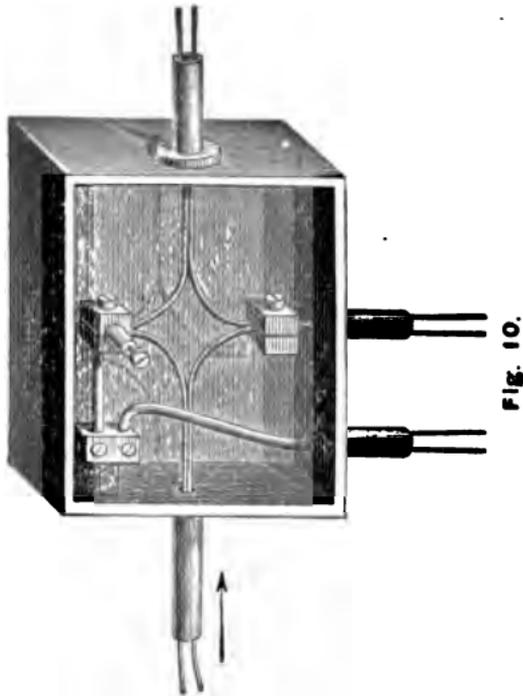


Fig. 10.

soldered to the house wires, as shown in
Fig. 10; but in order that no harm can be
done by two strong currents, one of these
communications is made by intercalating

a lead wire in the branch circuit, shown at the bottom of the figure, and which, by its fusion, interrupts the circuit. This is what is called in America a "cut off;" and in this way it prevents deterioration. The box is then hermetically closed and covered with an insulating coating. In the figure the branch wires are shown double, but it is evident that they could be single.

We said that all arrangements had been made to make the system a perfectly practical one, and of that we will soon be able to judge. Let us examine first how the lamp supports and the lamps themselves are disposed. As has been seen, they are formed of glass globes of ovoid form, cemented into copper sleeves by means of plaster and screwed into cylindrical cavities terminating the supports. These are a kind of arm which can be adapted to brackets or chandeliers, or be arranged around the walls. In the last case, the arm, as is shown in Fig. 11, carry two articulations, A and B, and commutations are made by two plates of the hinges
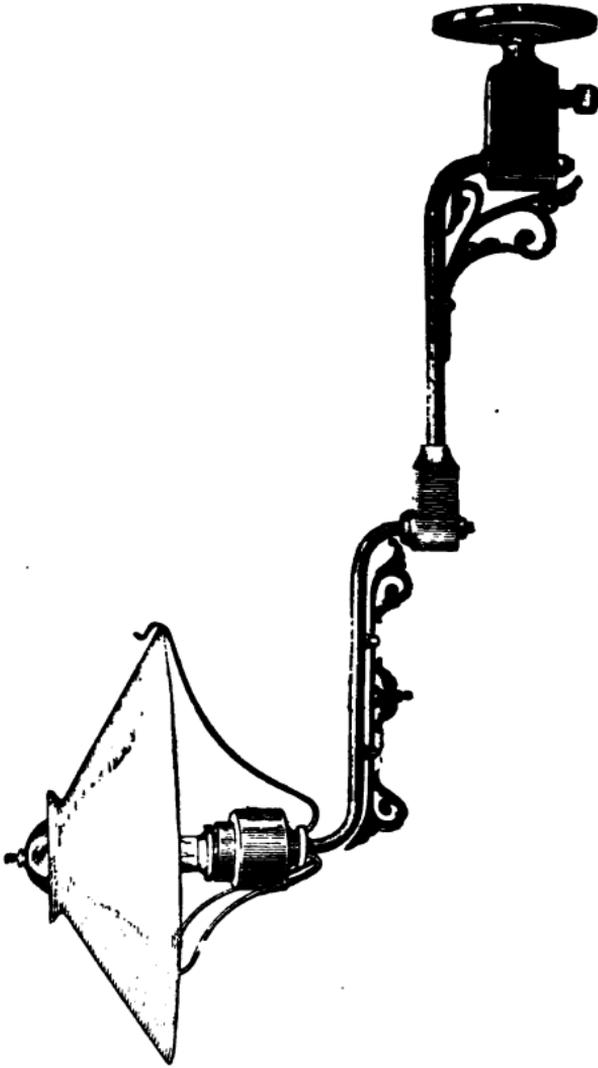
Fig. 11.

which are insulated, and in whose circu-
lar part two springs press, as seen in
Figs. 12 and 13. Connections of the con-



Fig. 12.
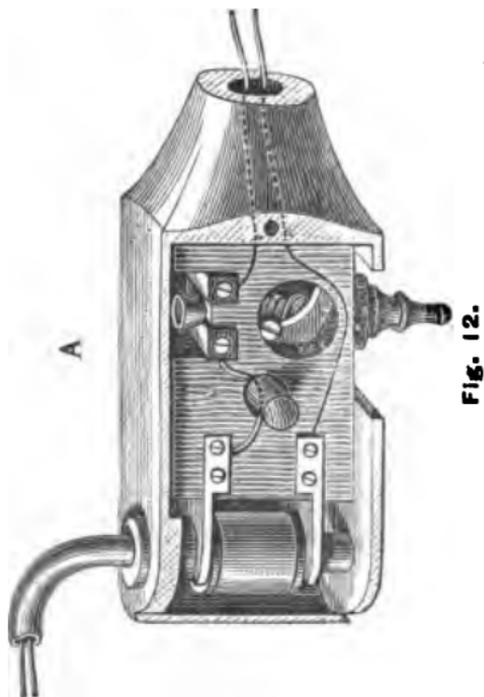
ductors with the lamp, as we have indi-
cated above, are made by a lead wire (cut
off) which may melt and interrupt the

circuit in case a too great quantity of current should endanger the lamp.

In these brackets, as in the three branch chandeliers, represented in Fig. 14, keys have been introduced which allow the extinction of the lamps separ-
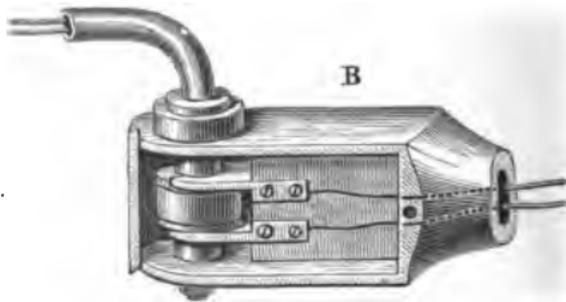


Fig. 13.

ately or together, without causing any spark of the point of rupture or any danger of fire. The movement of the key $a$, as shown in Fig. 12, breaks the contact by means of a conical stopper which terminates the screw of the key, and which, when separated from the two plates, through which the current passes when the stopper is in contact with them,

breaks the circuits at the points and on a surface of sufficient extent to greatly diminish the spark at the point of rupture.
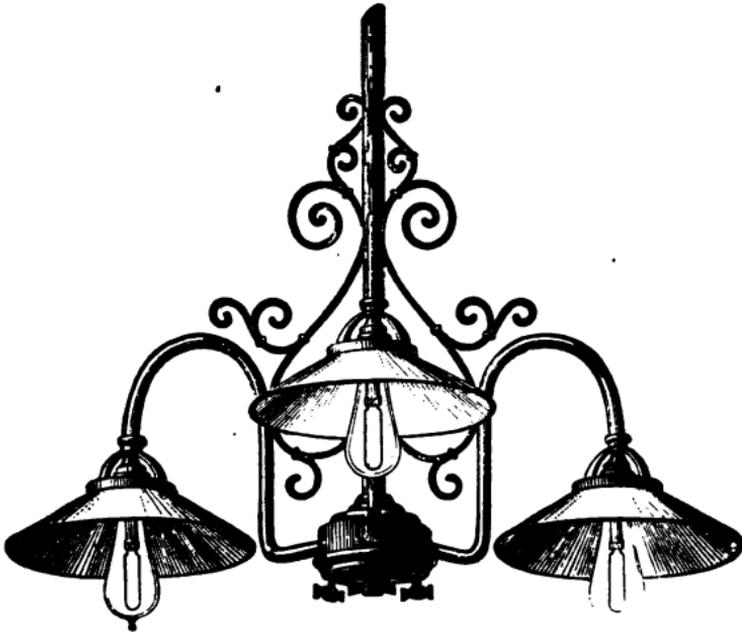


Fig. 14.

The lighting of the two salons of Mr Edison at the Exposition is done by 16 small chandeliers like the above, two grand crystal chandeliers and 80 brackets.

The effect is very beautiful, the steadiness being as complete as could be desired, and if, as I have been assured, the price of this kind of illumination is lower, light for light, than gas, it may be considered that the problem is on the eve of solution, for Edison's system of electric lighting is placed in the same condition as that of gas. He avoids the presence of machines in separate houses, which always are in the way, and which, by their very nature, require care and management not to be obtained from ordinary servants.

As a complement to his system, Mr. Edison has constructed portable chandeliers, represented in Fig. 15, and a current regulator shown in Figures 16 and 17, which permits of reducing the light in any desired proportion. It is a carbon rheostat, composed of carbon pencils of different sections, which, as the current passes through one or the other, allows any desired intensity. The apparatus is enveloped in a cylindrical cover, pierced with holes to allow of the escape

of heat, and surmounted by a lamp
which indicates to the eye the desired de-
gree of luminacy. It is worked by a
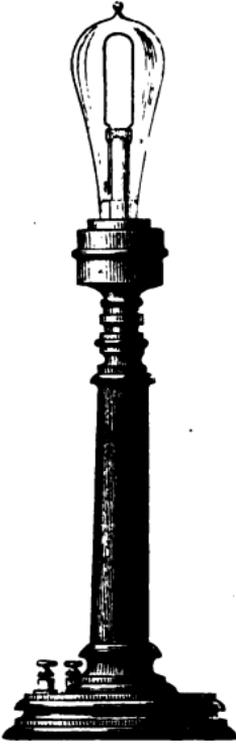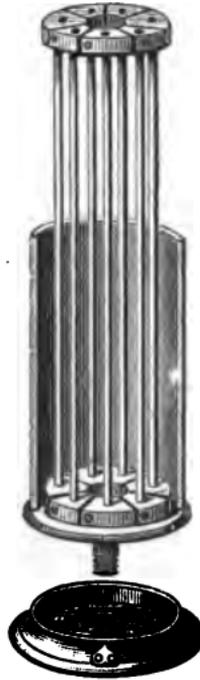


Fig. 15.        Fig. 16.

disc, shown separated in the lower part
of Fig. 16, which can be turned so
as to bring a contact spring on any one

of the supports of the carbon, whose position is indicated by an index and divisions engraved on the base of the cylinder.



Fig. 17.

But what is most interesting of all in those accessories of Mr. Edison's system, is the meter which determines the amount of electricity comsumed by the

lamps. There are two kinds, one auto-
matic like a gas meter, the other requires
weighing. They are, however, both
founded on the same principle, that is to
say, in the estimation of work by the
weight of a copper deposit produced by
the current used. We will describe these
two interesting pieces of apparatus here-
after, and give drawings of them; to-
day we must be content with only men-
tioning the principle involved.

Imagine a balance having at the extrem-
ities of the beam two cylindrically rolled
plates of copper forming two electrodes.
Let us admit that these two systems of
electrodes, which plunge into two vessels
filled with a solution of sulphate of cop-
per and furnished with fixed electrodes,
are traversed in an inverse direction by
the current employed, and which can
cause the balance to operate under a
given weight of copper deposited from
the so'ution. It is easily seen that the
movement brought about by these con-
ditions can set in motion a current re-
verser, which can change the conditions

of the deposits in such a way that the electrode, covered with copper, is transformed into a soluble electrode, while the one which was originally in that condition becomes the reducing electrode. From this time on, an oscillating motion of the beam of the balance is established, and more or less frequently repeated, according to the rapidity of the formation of deposit, that is to say, according to the intensity of the current. As the same movement can bring about the passage of a derived current (taken from the total current) across a special electro-magnet, which commands the movement of a counter, it is easily seen (after the determination of the number of Amperes corresponding to the weight of the deposit, which produces the oscillation of the balance) what is the quantity of electricity consumed.

The realization of this idea has necessitated some electro-magnetic arrangements, which we will describe in detail when we get the drawings of the apparatus.

The other system is more simple, consisting of two voltameters of sulphate of copper, whose electrodes can be easily taken out and weighed, as the work done can be calculated from the weight of copper deposited. One of these voltameters is open to the subscriber, the other is kept closed by the controller. Resistance bobbins introduced into the circuit corresponding to these resistance, permits of the employment of greater or less periods of registration.

A small incandescent lamp placed beneath the apparatus, and which can be thrown into circuit by a simple metallic thermometer, prevents any danger of freezing in extremely cold weather.

There is another application of Mr. Edison's light, which can be seen at his exposition in a model intended for lighting galleries in mines. In this arrangement, represented in Fig. 18, the lamp is introduced in a glass receptacle filled with water and held in suspension. Communication of the apparatus with the circuit is arranged in such a way

that the points of contact are covered by water, which avoids any danger of explosion in mines infested with fire-damp.
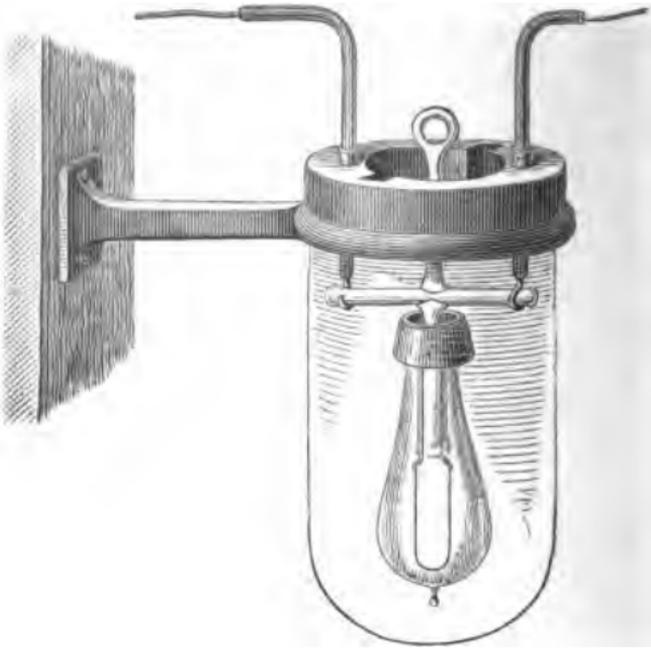


Fig. 18.

Mr. Edison's lamps, are not alone employed in the two salons reserved for him, they are to be found in various places throughout the great nave, nota-

bly at the exhibits of Messrs. Heilman, Ducommon et Stienben (of which we gave a drawing in a previous article) and at the exhibit of Messrs. Sautter and Lemonnier. At these two places the currents are furnished by two Gramme machines, type A, and each one lights about 40 lamps. Now that Mr. Edison's great machine (a drawing of which is shown on frontispiece) has arrived at the Exposition, it will be possible to obtain, with the incandescent system, illuminations of greater magnitude. The landing of the great staircase will be lit in this way. It is proposed to accomplish this by means of a crystal chandelier of 144 lamps, and of others furnished with 25 lamps each, to be hung from the different panels, and of girandoles standing on the 16 pilasters of the staircase. This will produce an enchanting effect and a brilliant illumination. I am not quite sure that this mixture of arc and incandescent lights is a happy thought. It is evident that the latter destroy the effect of the former, and

might lead one to believe that the luminous intensity of the incandescent lamp is less than it really is. Again, the difference in the color of the lights is so contrasted that many persons who reproach the electric for its ghastly aspect, find it too red in incandescent lamps. It is evidently an effect of contrast, for the light of incandescent lamps is whiter than that of gas jets, which, nevertheless, these same people find very agreeable. If required, incandescent lamps can give a dazzling white just as well as the others; it is only necessary to employ a stronger electrical intensity, then they lose their peculiar qualities, that of giving a soft light which does not fatigue the eye and of an easier and more complete subdivision.

It is certainly very difficult to satisfy everybody, and that many persons hardly know what they do want; above all, when the effects of contrast momentarily impair the power of judging correctly. On the other hand, there are certain faultfinding spirits who are never satisfied

with anything; witness the author of that incomprehensible article that recently appeared in a certain journal, who pretended that only discordant sounds and puppet-show voices could be heard in the telephones from the opera. The author in question who could perpetrate such an enormity must have had his ear as sick as his humor. The crowd passing every evening before the telephone rooms at the Exposition, is the best proof of the inanity of such judgments, and by this can once more be seen the value of the scientific lucubrations of certain political journals.

The same thing happens with the electric light, and quite a number of persons who, without previous examination, and without being of the same opinion two days consecutively, come to us and disparage electric lighting. It is certain that new inventions have great difficulty in coming to light and in succeeding, above all when they are opposed by rival interests, but when they are really good they triumph in time over all obstacles.

We would like to give some informa-

tion about Mr. Edison's new machines,
but as they are not yet put up we re-
serve the description for another time;
we will only say that the steam engine
was constructed especially for this appli-
cation, that it makes no noise, and that
the dynamo-electric machine forms one
of its integral parts. The field magnets
of this latter-mentioned, in place of being
vertical as in the model represented
in Fig. 7, is horizontal, and the dimen-
sions of the machine itself are much
larger.

The steam engine, which works the
machine, is of peculiar construction, and
the speed of rotation which is communi-
cated to the working coil is 350 turns a
minute. This is not a very great speed,
but the armature is very heavy, weighing,
as we are told, over three tons and a half.
The magnetic field in which it turns is
formed by three powerful electro-mag-
nets, united so as to form but one at their
extremities. In the *salon* of Mr. Edison
are a collection of photographs, among
which may be seen some of the manufac-

tures where the enormous amount of ma-
terial required in these installations is con-
structed. As we have been assured, one
of these turns out 2,000 lamps a day,
giving occupation to 150 persons. In ac-
companying drawings and collections can
be seen methods of glass blowing, the
carbonizing of the filaments intended for
incandescence, the vacuum pumps and the
mounting and packing of the lamps. The
pumps referred to are set in motion by
dynamo-electric machines.

From all this, we see Mr. Edison's sys-
tem to-day is completed, perfectly studied
out in all its parts, and that nothing more
remains to be done, but to introduce it on
a great scale.

TH. DU MONCEL.

[Note by the Translator.]

DESCRIPTION OF EDISON'S STEAM DYNAMO.

(*See Frontispiece.*)

Peculiar to the Edison system is the
idea of connecting an engine of great
power directly to the armature shaft of a

single dynamo, capable of absorbing the full power of the engine, and of economically converting the same into electrical energy for distribution to the lamps and motors. To obtain the requisite electrical pressure, and avoid the use of magnets and armature of a weight and size which for mechanical and commercial reasons would be excessive, the engine is so constructed as to maintain a speed of 350 revolutions. A boiler pressure of 120 lbs., made absolutely safe by the use of approved sectional boilers, the high speed, and variable cut-off valve, and manner of constructing the engine makes this method of generating electricity absolute?y safe and economical, and the uniformity obtained in regulation of speed insures a corresponding steadiness in the current and therefore in the lights which it supplies.

The following approximate summary of weights and dimensions of various parts of the latest " steam dynamo " constructed will give an idea of its total size and power.

Cast-iron sole plate, in one piece, upon which dynamo and engine are placed, and pillow blocks, 9,600 lbs.; magnets, complete, 24,500 lbs.; armature, complete, and shaft, 8,500 lbs.; engine, 10,000 lbs. Total weight, 44,600 lbs.

The total weight of copper on armature and magnets is 3,600 lbs.

Principal dimensions: Sole plate 12½ × 8½ ft.; length of magnets, 8 ft.; length of armature (commutator makes additional length of 9″) 5 ft.; diameter of armature, 28″; engine cylinder, 11″×16″; capacity, 2,400 gas jets.
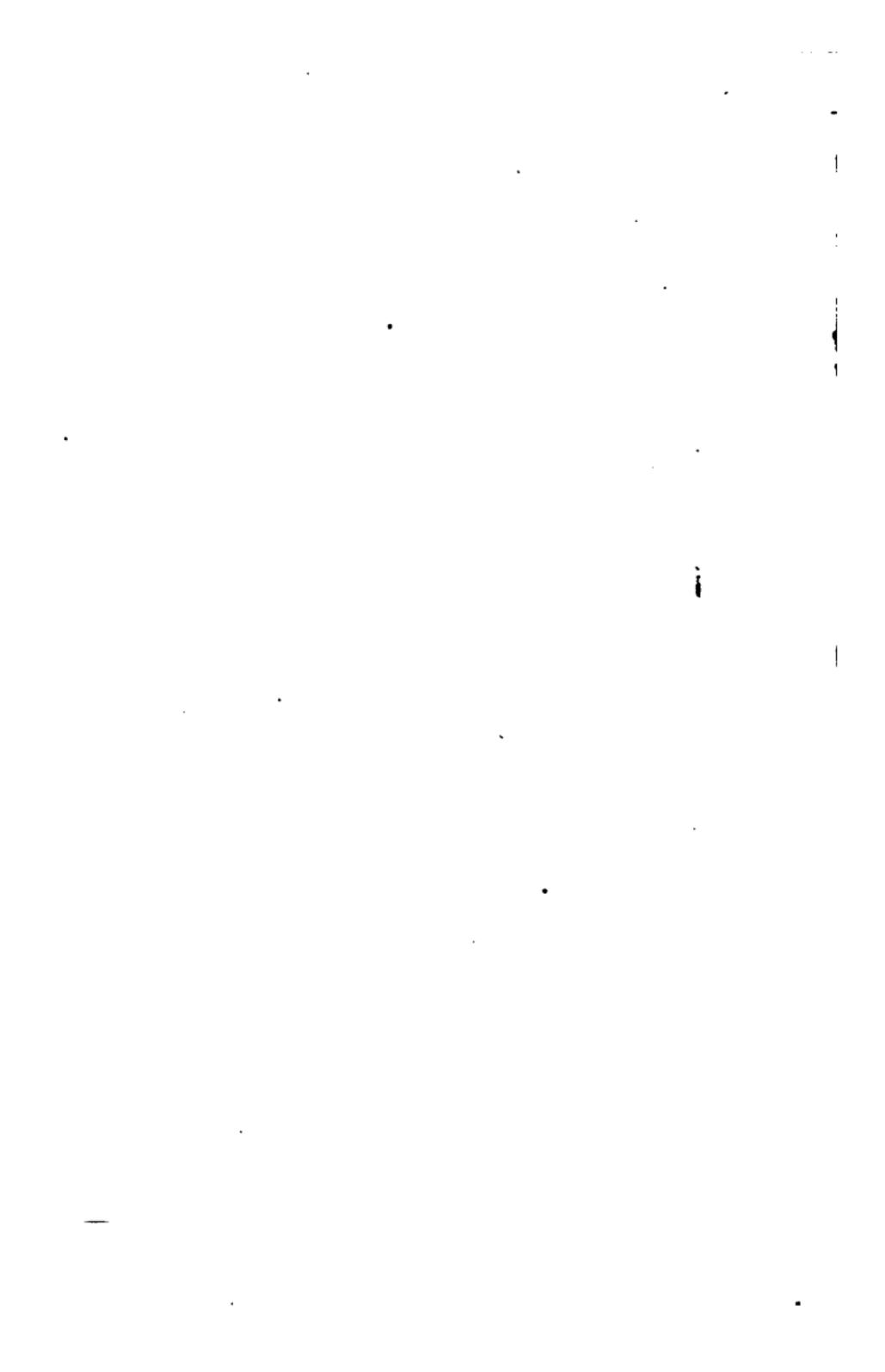
# ELECTRIC LIGHTING

AT THE

## PARIS EXHIBITION.

By WILLIAM HENRY PREECE, F. R. S.
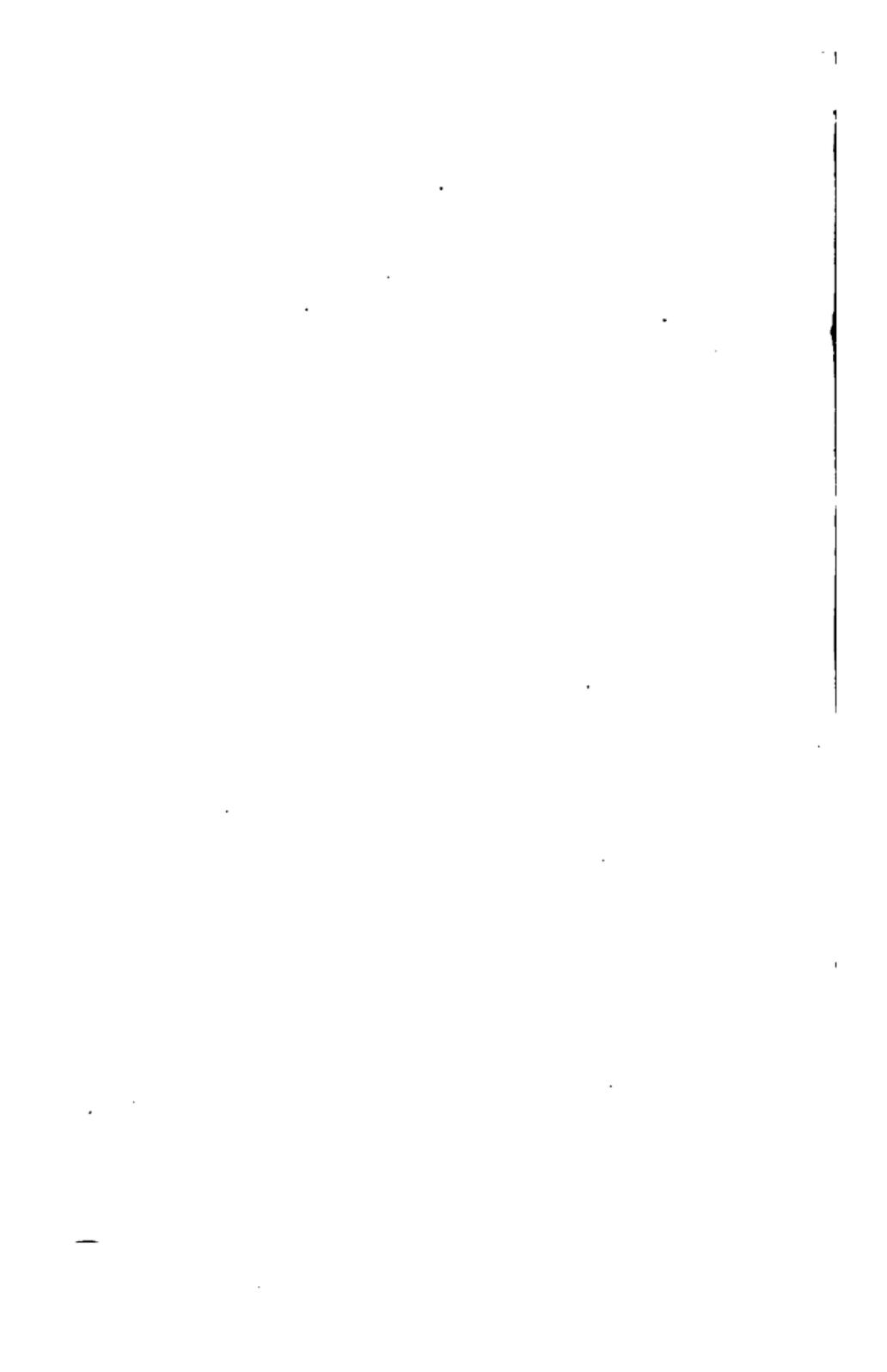
# Electric Lighting at the Paris Exhibition.

THE recent International Exhibition of Electricity in Paris makes an epoch in the history of the practical applications of that science to Arts, Manufactures, and Commerce. I purpose now to refer only to its application to artificial illumination; but there are many other branches fully deserving examination and discussion by this Society. It was, however, as an exhibition of electric lighting that it was principally attractive, and those who saw it for the first time will never forget the vivid impression that the great blaze of splendor produced upon their minds on entering the building. There never can be anything like it again, for as wisdom grows with experience, so no manager of any future Exhibition is likely to repeat that terrific *mélange* of lights that flooded the interior of the Palais de l'In-

dustrie with great brilliancy, but with an impracticable and impossible means of comparing and judging the relative merits of different systems.

For instance, at the forthcoming Exhibition at the Crystal Palace, the building —splendidly adapted for the purpose— will be divided into sections, each section being lit by one, and only one system. But at Paris, Pelion was piled upon Ossa; the British section, for instance, received rays from at least a dozen different sources. To estimate the value of a Siemens lamp you had to eliminate the disturbing influence of a blazing Crompton; and to admire the star-like Jaspar arc, you had to run the gauntlet of a flock of Swans. The fretful Jamin, or the fitful Jablochkoff, was masked by the steady Gülcher or the brilliant Serrin. In the galleries, however, it was different. Here, different *salles* were illuminated by different systems; a small theatre was lit by the Werderman lamp, and a picture gallery most effectively shown up by the *Lampe Soleil;* a buffet was softly and brightly lit up

with the Swan lamp, while Mr. Edison's numerous exhibits, in his own *salons*, were as visible by night as by day, thanks to his own beautiful lamp.

It is not my intention to examine, *seriatim*, the various machines, lamps, and modes of illumination shown. With most of them, you are already familiar. But I purpose to select what appeared to me to be novelties, and what seemed worthy of being brought to your notice, as steps in advance.

On the night of August 29th, there were in operation 277 arc lamps, 116 candles, 44 arc incandescent lamps, 1,500 incandescent lamps, or a total of of 1,837 electric lights in all, at the Paris Exhibition. Towards the end of the period during which the show was opened, this number was very largely increased, and I have little doubt that the number reached 2,500 in the beginning of November. Now this army of lamps required power to convert the energy stored up in coal into energy of motion ; dynamo-machines to convert the energy of motion into elec-

trical energy; conductors to transport this electric energy to the point to be illuminated; lamps to convert the electric energy into energy of heat, and therfore of light.

The exhibition of engines and machinery was very extensive, although our English manufacturers failed to do what they might have done had they thought as highly of the Exhibition at first as they did afterwards. Many of our manufacturers were conspicuous by their presence. The only extensive display was by Messrs. Robey & Co., of Lincoln, who showed eight of their well-known engines, with a total power of 250 horses, and I have every reason to believe that their success has amply repaid them for their enterprise. Mr. Brotherhood made a small show of his well-known three-cylinder engines, and Messrs. Wallis & Stevens, of Basingstoke, sent one of their semi-fixed steam-engines, with their pretty and effective governor for adjusting the speed while in motion—uniformity in speed being an essential criterion of an electric light engine. The foreigners, for a won-

der, far outshone the British in the magnitude of their displays.

One of the most valuable exhibits was made by Messrs. Thomson, Sterne & Co., who showed a new gas engine on a new principle, which attracted a great deal of attention. Gas is destined to play a most important *rôle* in the future of electric lighting. Its function is that of a heat-generator. The energy of the coal exists in gas in a form which can develop more light, when converted into the form of electricity, by the current, than in the form of heat by combustion. Gas engines have a very high theoretical efficiency, and they are free from the dangers of boilers, the neglect of stokers, or the waste of energy in chimneys.

Gas engines on the "Otto" principle, from half-horse power to 50-horse power, were very extensively exhibited by France, but the machine of Thomson, Sterne & Co. (Clerk's patent) excelled them all in lightness, compactness, regularity, and safety. One of these engines may now be seen at work at the Smoke

Abatement Exhibition at South Kensington, and several have been ordered for private houses. As an adjunct to the gas engine, Mr. Dowson exhibited an interesting and valuable process of making cheap gas for motor purposes. Prof. Ayrton reported that in a series of trials made with a $3\frac{1}{2}$ H. P. (nominal) "Otto" engine, driven by the Dowson gas, one H. P. (indicated) was obtained per hour by the consumption of gas derivd from 1.46 lbs. of coal. For larger engines he anticipated a consumption of only 1.2 lbs. per indicated horse power per hour. You will have a paper during the Session by Mr. Dowson himself, describing his mode of manufacture. When perhaps 6 lbs. of coal per horse power per hour are consumed in the present electric-light steam-engines, you can form some idea of the economy to be effected by cheap gas.

Dynamo - machines — machines which convert the energy of motion into electrical energy, through the medium of magnetism—were exhibited in abundance, of all kinds and forms, from the original

apparatus of Faraday, made with his own
hands, to Mr. Edison's latest develop-
ment of this wonderful source of electric
currents. There are two kinds of ma-
chines—the one producing currents from
fixed and permanent steel magnets, the
other from electro-magnets, excited by
the currents which they themselves gene-
rate. Each kind is also sub-divided into
two others, in one of which continuous
currents are produced, flowing in one di-
rection, called the *continuous current
machine;* and in the other alternate cur-
rents, called the *alternate current ma-
chine*, where the current rapidly reverses
and changes its direction. The produc-
tion of currents by these machines is due
to the simple fact discovered by Faraday,
that if a conductor, such as a copper
wire, be moved rapidly through a magnet-
ized space or a magnetic field, as it is
called, this conductor is electrified so
that, if its two ends be connected, a cur-
rent flows. The intensity of this current
depends, first, on the intensity of the
magnetism present, on the velocity with

which the conductor moves through the field, and on the direction with which it cuts the lines of magnetic force which permeate the magnetic field. The magneto-electric kind—the manufacture and invention of M. de Meritens—are very much approved of by our Trinity House for lighthouse purposes, and a very fine display of them was made by M. de Meritens, who seemed to live in the Exhibition, for he was always there, and who never seemed to tire of giving his clear and able descriptions. He exhibited alternate and continuous current machines, and he richly deserved the gold medal that was accorded to him. The exhibition of dynamo-machines was rendered very interesting by the exhibition of an early machine of Elias, of Haarlem, of 1842, and of Pacinotti's machines of 1861. The former was shown in the Dutch Section. and the latter in the Italian. Here we have the germs of all the present machines, and by whatever name a machine may be known, it can be traced back to these original types. The Pacinotti ap-

paratus has been very greatly improved
by Gramme, and by Siemens—forms well
known to every one—but it has received
its greatest development in the Edison
machine, which was one of the wonders
of the Exhibition. As this was one of the
greatest novelties, I must briefly describe
it. In the first place, I must point out
that the machine is larger than any one
that has ever been made before. ·It
weighs with engine and bed plates, 20
tons; and it can produce a current of
electricity of nearly 900 amperes.* As
the largest machine of the Gramme type
weighs scarcely one ton, and produces a
current of but 93 amperes, the difference
becomes striking. Now, Mr. Edison has
struck out three new paths, first—in the
bulk and form of his electro-magnets,
second—in the size and construction of
his armature, and third—in the low re-
sistance of his revolving coil. By the
first, he secures an intense and concen-
trated magnetic field, by the second he

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* The largest Brush machine weighs two tons, and
absorbs 40-horse power.

secures a high cutting velocity for the
moving conductor through this field, and
by the third, he secures a very powerful
current to be distributed among a great
number of lamps with the least possible
waste of energy. The long and bulky
coils, 8 feet long, which constitute his
electro-magnet, have excited the surprise
of many electricians, but there is no doubt
that he has arrived at this form after
many careful practical experiments, sup-
ported by the mathematical investiga-
tions of Professor Rowland—a very high
authority—and that the result is to ob-
tain an intense field in a large space,
with the least absorption of electrical en-
ergy in the coils. With 350 revolutions
per minute he is able to produce an elec-
tro-motive force of 110 volts, which an
ordinary Gramme machine can only at-
tain with over 1,000 revolutions per min-
ute. His field-magnets are wound with
copper wire, which have a resistance of
30 ohms. and which are connected as a
shunt to the main circuit, as was origi-
nally done by Wheatstone, and is now

followed by Dr. Siemens and Sir William
Thomson. The armature is not wound
with wire, but is constructed with solid
bars of copper $\frac{3}{4}$ in. by $\frac{1}{2}$ in. section, and
$3\frac{1}{4}$ feet long, which are well insulated
from each other, and are most ingeniously
connected at their ends by copper discs,
so that all the bars, of which there are
138, form one continuous circuit, whose
total resistance is only 0.008 of an ohm.
The diameter of the armature is 28 inches.
The core of the armature is made up of
1,700 thin iron discs insulated from each
other by paper, and well clamped into a
solid mass by bolts. This is done to
avoid the heating effects due to so-called
Foucault currents induced in the metal
and absorbing or wasting energy. The
iron core of the armature becomes thus
magnetized, and it concentrates the field
to the space through which the conductor
moves, as is done in Siemens' and other
machines.

There are two great troubles in exist-
ing machines, want of uniformity in their
motion and the slipping of belts. The

former is met by governors, and the latter by direct gearing. Steadiness of motion is most essential, otherwise we have that painful throbbing of the light that is so irritating to the eyes. Mr. Edison connects his armature direct to his steam motor, which is a high-pressure engine of the Allen-Porter type, governed by an ingenious centrifugal regulator, and rotating very uniformly at 350 revolutions per minute, without any multiplying gear whatever. When the machine is giving out its maximum commercial effect it absorbes 125-horse power, the external resistance should be 16 times that of the armature, the electro-motive force 110 volts, and the current consequently 860 amperes. It is not safe to exceed this limit, for the armature then becomes unduly heated. A special blower is added to direct cold air on the armature to keep down the heat, when the work of the machine approaches its limit. The brush is a special feature of the machine. The absence of sparking was very striking. Mr. Edison coats his brush and commu-

tator with an amalgam of copper, which
diminishes the electrical resistance of
contact, reduces the heat, and prevents
sparking.

Those who are interested in this ma-
chine—and every one should be, for it is
a decided step in advance—will soon have
an opportunity of seeing it at work at 57,
High Holborn.

There was a very interesting form of
Gramme machine shown, which was main-
tained at a velocity of 2,400 revolutions
per minute, and was said to generate an
electro-motive force of 2,000 volts. It
maintained 60 Jamin candles alight. But
one of the best and most compact forms
of Gramme was that shown by the Brit-
ish Electric Light Company, designed by
their engineer, and made for them by
Messrs. Emerson, in Stockport.

The display of lamps was the display
of the building. There were very few
novelties among arc lamps. An arc lamp
consists of two sticks or rods of carbon,
which are kept apart a small fraction of
an inch while the current flows through

them, but which comes together when
the current ceases. Accross the interval
separating them there is a steady flow of
electricity, accompanied by a slow con-
sumption of the carbon of each rod.
This flow of electricity produces high
temperature, and intense incandescence
and combustion of the carbon particles.
This is the arc. One lamp differs from
another only in the way in which the car-
bons are moved forward as they consume,
so as to maintain the resistance equal
and the light steady. Among arc lamps,
that which signaled itself out among all
its compeers, for steadiness and bril-
liancy, was the Jaspar lamp, exhibited in
the Belgian Section; but it had the dis-
advantage of absorbing all the energy of
one machine. Among those that admit-
ted of having a number on one section,
perhaps the simplest in its construction
was the Gülcher, exhibited in the Aus-
trian Section ; but the most effective and
original was the "Pilsen" lamp, the in-
vention of Messrs. Piette & Krisik. It is
called the "Pilsen" lamp, from the place

of its birth, and from the want of eupho-
niousness in the name of its inventors.
It was exhibited in the Austrian Section,
and also in the British Section, by Mr.
Fyfe. The carbons are kept apart by a
sucking coil when the current flows; they
are regulated by a second sucking coil
worked on a shunt. The peculiarity of
the lamp consists principally in the shape
of the core that controls the carbon—it
is wedge-shaped at each end; in action is
wonderfully regular, and almost perfect.
Six lamps were worked in one circuit by
a Schuckert machine.

The *Lampe Soleil*, which holds an in-
termediate position between arc and in-
candescent lamps, made a very effective
display in the picture gallery, where there
were 20 lamps in 10 lanterns. It is to
be seen in London lighting up the Pano-
rama in Westminster. It is a fixed,
steady, durable lamp, giving a soft yel-
lowish light, which is due to the fact that
the arc maintains in incandescence a
highly refractory substance like marble,
between the two ends at the carbon. It

is a very simple lamp, for it involves no mechanism whatever; but it is said to absorb a great deal of power, though I have seen no reliable figures of its performance. Its consumption of carbon is remarkably small. It is worked by an alternate current machine, which, like most of these machines, made a most unpleasant hum.

Carrè made a very fine display of carbons for arc lights, for the manufacture of which he is so famous, in which the regularity of form, of structure, and of composition, is said to be absolute; but it is very questionable whether this is really the case in practice, for the irregularity of the arc lights is chiefly due to impurities and irregularities in the carbon. Moreover, the very vast discrepancies that are found in the photometric measurements of the same lamp at different times, or by different persons, may be due to the irregularities in the structure of the artificial carbon rods.

No one can deny that the Jablockhoff candle has done good service in the cause

of electric lighting ; but I am afraid that
the Exhibition in Paris has sounded the
knell of all forms of candle, as well as
those of the Werderman type.   The rising
favorite is the incandescent lamp, pure
and simple.   The display made by Mr.
Swan in the buffet, in the Congress Hall,
and in the Pavilion at the Post-office, was
brilliant and effective.   The light was soft,
uniform and yellow.   The incandescent
light is totally free from those bright rays
that are so injurious to the eyes, so un-
complimentary to the complexion, and so
irritating to the worker, if they are accom-
panied with the least unsteadiness.   It is
so readily under control ; it requires no
skilled labor to replace it or attend to it ;
it can be fixed anywhere ; it can be worked
into the fixtures and decorations of a
room. and it does not damage them, as gas
and oil do   Incandescent lamps can be
worked by either continuous or alternate
current machines.   In fact, the chief lesson
of the Paris Exhibition is this, that the
arc light is specially suited for external
illumination, and that incandescent lamps

are eminently adapted for internal and for domestic illumination. This lesson has been carried into practice at the Savoy Theatre, where nothing can be more effective or more efficient than the illumination of the auditorium. One can breathe pure air, feel cool, and can sit out a play without incurring a headache. There were several incandescent lamps shown at Paris besides those of Mr. Swan, notably those of Maxim and Lane-Fox; but that which possessed the greatest novelty, and was decidedly the most efficient, was that of Mr. Edison. The distinctive character of the Edison lamp is the remarkable uniformity of its texture and light-giving power. The lamp consists of a fine filament of carbon inserted as a part of the electric circuit in a glass globe, which has been exhausted of air to the utmost limit of workshop skill. A fine, uniform quality of Japanese bamboo has been selected as that which gives the finest filament for carbonizing. The bamboo is cut by special machinery into the required dimensions, and inserted in a mould, which

is placed in a furnace, and raised to a very high temperature, and from which the filament comes out shaped and carbonized. Naturally grown vegetable fiber has been found to give a more uniform texture than any artificially-formed carbon. The ends are cut flat, and squeezed inside copper clamps, which are then welded together by electro-plating. The copper clamps being soldered to platinum leads that are sealed through the glass, and are connected to the conductors. Perfect sealing is obtained by flattening the mass of the tube, through which the fine platinum wires pass into a solid bar, so as to well fuse the wires and glass together. It is a fortunate thing for the permanence of the incandescent lamp that the co-efficient of expansion, due to heat, of glass and platinum is practically the same.

The normal lamp consists of a filament 6 inches long, which gives a resistance of 240 ohms when cold, and, when permeated by a current of 0.8 ampere, gives a light equivalent to 16 sperm candles. The half lamp is constructed with a carbon filament

of just half the length and half the resistance, and gives eight candles. Other lamps are made with two and four horseshoe filaments, so as to increase the light-giving power. The features of carbon, which render it so highly adapted for incandescence, are its electrical resistance, its high refractory character, and its stability. The illumination of a filament and its durability are functions of the current that passes ; the more intense the current the higher the temperature, and therefore the brighter the light and the shorter its life. At a temperature of about 1,000° carbon becomes red, at 2,000° it is white, and the higher the temperature the whiter it gets, until it fuses. A current of 0.8 of an ampere maintains an Edison filament at about 2,000° when it gives a light of 16 candles, and it lasts on an average 1,000 hours. A stronger current will give a much better light, but the carbon will not last so long. If it were possible to find a form of carbon, or any other material, which would be so refractory that we could transmit through it much strong-

er currents, the incandescent lamp would rival the arc lamp in brilliancy and power.

The destruction of the carbon filament in incandescent lamps is due to what is called the Crookes' effect, a very slow transference of carbon, in a molecular shower, from the one heel to the other heel of the horseshoe, until a breakdown takes place at the former point. The better the vacuum the slower this effect. Alternate current machines are said to lengthen the life of the carbons, by equalizing the distribution of molecules on each heel, but they do so at the expense of efficiency.

Many devices were shown for measuring the quantity of electricity consumed in any place by electric lamps; but that adopted by Mr. Edison is sufficiently simple and accurate for all practical purposes. A glass cell contains two copper plates immersed in a solution of sulphate of copper. A definite proportion (0.001) of the current that passes through the house passes also through this cell, and removes copper from one plate and deposits cop-

per on one plate. The weight of copper
deposited is an exact measure of the cur-
rent used, There are two such cells—
the one in charge of the consumer and the
other of the supplier. They thus check
each other.

Various plans were shown in different
parts of the Exhibition to diffuse the
light, but the most effective was that in
*Salle* 15, where a Jaspar lamp filled the
room with a shadowless light, by throw-
ing a light on to a white screen above the
lamp, whence it was scattered. The lamp
itself was invisible. This plan is not novel.
It was suggested by the Duke of Suther-
land, and has been adopted by Mr.
Schwendler in India.

The proper distribution of light is a
problem that remains to be solved. It is
argued that an arc is so much superior to
an incandescent light, that one-horse pow-
er in the former gives you ten times more
light than in the latter. This is true ; but,
on the other hand, to obtain a subdued
light sufficient for your purpose, you must
either put the arc lamp far away or tone

it down by shades, and therefore waste it; whereas an incandescent lamp can be toned down, by regulating the current, to any color you like, and it can be fixed just where it is wanted. One-horse power will give you 1,500 candles in an arc, and only 160 candles in 10 incandescent lamps; but these 10 lamps can be so distributed about your space to be lit, as to illuminate your surface or objects with a better light than the arc.

Curiously enough nothing whatever was done in Paris to improve the illumination of streets. The Avenue de l'Opera, the first street practically lighted by electricity, stills remains as it was in 1878; but prior to the opening of the Exhibition, a portion of the Boulevard des Italiens was lit up by four De Mersanne lamps, suspended high up, at wide intervals, over the center of the road. The effect was very fine, but the lamps were very bad. This is the true way of illuminating streets, and it is to be regretted that such an experiment is not tried in London. Street illumination in England

by electricity up to the present time is, as a rule, a questionable success.

The question remains for discussion: Has the electric light been brought within the region of practical domestics? I have no hesitation in saying that it has; but whether it can be brought into economical contrast with gas, experience alone will show. Several houses are already illuminated by its agency: others are in hand, my own amongst the number; and when we next meet to consider this subject, I may be able to answer the question with actual facts.

One word as regards the danger of electric lighting. There is no use blinking our eyes to the fact that electricity can be a dangerous servant in the hands of the careless and ignorant; in the hands of the skilled it has less danger than gas, or even oil. The installation of the wires must be controlled by experience and knowledge. I have more than once called attention to this fact, and my warnings have been received with abuse; but in Paris there were no less than five incipi-

ent fires, from the wires coming in contact with each other, in the Exhibition building. The *Times* correspondent in Vienna implies that the frightful disaster to the Ring Theatre was due to this cause. The instances in New York are so numerous that the Board of Fire underwriters have issued the following rules :—

" 1. Wires to have 50 per cent. excess of conductivity above the amount calculated as necessary for the number of lights to be supplied by the wire.

" 2. Wires to be thoroughly insulated and doubly coated with some approved material.

" 3. All wires to be securely fastened by some approved non-conducting fastening, and to be placed at least 2½ inches for incandescent light, and 8 inches for arc lights, from each other, and 8 inches from all other wires and from all metal or other conducting substance, and to be placed in a manner to be thoroughly and easily inspected by surveyors. When it becomes necessary to carry wires through

partitions and floors, they must be secured against contact with metal or other conducting substance in a manner approved by the inspector of the Board.

" 4. All arc lights must be protected by glass globes enclosed at the bottom, to effectually prevent sparks or particles of the carbons from falling from the lamps ; and in show windows, mills, and other places where there are materials of an inflammable nature, chimneys with spark arresters shall be placed at the top of the of the globe. Open lights positively prohibited. The conducting framework of chandeliers must be insulated and covered the same as wires.

" 5. Where electricity is conducted into a building (from sources other than the building in which it is used) a shut-off must be placed at the point of entrance to each building, and the supply turned off when the lights are not in use. Applications for permission to use electric lights must be accompanied with a statement of the number and kind of lamps to be used, the estimate of some

known electrician of the quantity of electricity required, and a sample of the wire (at least three feet in length) to be used, with a certificate of said electrician of the carrying capacity of said wire. The applications should also state where the electricity is to be generated, whether the connection will have metallic or ground circuit, and, as far as possible, give full details of the manner in which it is proposed to equip the building."

These rules are very simple, and are necessarily carried out by every qualified electrician, but an additional security is obtained by Mr. Edison, by inserting in very branch wire a " safety catch," which is a short piece of lead wire that instantly melts if the strength of the current exceeds a certain value, and thus ruptures the circuit, stopping the flow of electricity, and producing safety.

The completeness of Mr. Edison's exhibit was certainly the most noteworty object in the exhibition. Nothing seems to have been forgotten, no detail missed. There we saw not only the boilers,

engine, and dynamo machine, but the pipes to contain the conductors; the conductors themselves, heavy and massive, for Mr. Edison recognizes the waste of energy that must occur in small conductors, the insulation, the fixtures, the brackets, the safety catches, the lamps, devices to avoid the effects of expansion and contraction through changes of temperature, meters to measure the current used, regulators to control the consumption of fuel. In a properly regulated system there ought to be no waste of fuel. The engine driver has an indicator which shows him exactly what current is going out, and he has simply to regulate his firing by this indicator. Moreover, by the use of a rheostat, he is also able to regulate the outgoing current so that he is able to maintain a perfect ratio between the fuel consumed and the light evolved.

The question that determines the size and insulation of conductors is a commercial one, and is regulated by the relative economy of waste of energy or

interest on capital expended. If an expenditure of £100 per mile saves you £10 a year in fuel, it is clearly better to expend £100 on your conductor. If, on the other hand, it would save you only £2 a year, it is better to utilize your capital elsewhere. Every inch of con·ductor means waste of energy; the shorter and heavier it is the less the waste; but as some waste is imperative, it is simply a matter of calculation to determine which shall be wasted least, capital cr fuel

The system is self-regulating, if the electro-motive force is kept constant, and the resistance of the lamps be uniform. We have the dynamo machine at one end of the circuit, and a lamp at the other. The circuit is complete; a small current flows, which is determined by the resistance of the lamp alone, if the main conductors are made sufficiently large to neglect their resistance. Additions and subtractions of lamps only vary the resistance, and, therefore, the current. Turning off one lamp does not interfere

with the rest. The limit of the number of lamps inserted is determined by their resistance and by the heating of the armature; hence the value of high resistance in the lamps, and low resistance in the armature of the dynamo machine. Every lamp induces, as it were, its own current. We have not a store of electricity which has to be sub-divided, but we generate our energy as we want it. This is the promising feature of the system. It is a principle of multiplication, rather than of sub-division, and leads one to anticipate economy in its working. Mr. Edison's system has been worked out in detail, with a thoroughness and a mastery of the subject that can extract nothing but eulogy from his bitterest opponents. Many unkind things have been said of Mr. Edison and his promises; perhaps no one has been severer in this direction than myself. It is some gratification for me to be able to announce my belief that he has at last solved the problem that he set himself to solve, and to be able to describe to the

Society the way in which he has solved
it.

It may be taken as a rule, that any
system dependent on the exercise of ab-
normal energy is certain sooner or later
to break down; we all of us hate personal
supervision, and personal supervision at
home is a species of abnormal energy.
This is the great secret of the success of
gas. It is the cause of the slow progress
of the arc light; but it is because the in-
candescent light promises to rival gas in
this respect, that such a future is open
to it.

The awards at the Paris Exhibition
were liberally bestowed by the jury, per-
haps too much so; but matters were
hurried up towards the end, owing to
political difficulties, and the conclusions
were necessarily hasty. No proper
measurements or tests were made by
any jury, but a committee, presided over
by M. Tresca, has since been formed to
continue the work, and there is no doubt
that most valuable results will be ob-
tained, for the desire of the jury to pro-

cure reliable measurements has been very generally met by the exhibitors. I had great hopes of being able to give you the results to-night, but the reports are not yet complete.

We shall all, very soon, have a repetition on a different scale, and in a different way, at the Crystal Palace, and I have little doubt that, in its way, the Crystal Palace Exhibition will be as fine and as interesting as that of Paris.

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### DISCUSSION.

The Chairman said he could not open the discussion better than by calling on Mr. Johnson, the representative of Mr. Edison.

Mr. Johnson said he did not know that he could supplement what had been so well said by Mr. Preece, so as to add to the interest of the subject, but he should be ready to explain anything which had been left unexplained, and he would also illustrate, further, the use of some of the apparatus. He wished, however, to say

that Mr. Edison's system was not merely a system of electric lighting; but the novelty of his system lay in this, that he contemplated the manufacture of electricity on a large scale at a central station, and its universal distribution throughout the entire area of the city where it was established, to be used by uneducated or unscientific people, without the supervision of trained experts in the employment of the company. They proposed to put the electric light into houses in such a simplified form, and with such provisions, as to render supervision entirely unnecessary; to bring the lamps within the care of ordinary house servants, no matter how ignorant they might be; and in such a way that no damage or waste was possible. The electricity thus converted into light might also be converted into power, by means of an electro motor; and it might be utilized in a variety of ways, such as for ringing bells, &c. The annoyance of maintaining a battery, as well as its expense, had hitherto proved a bar to its general use,

but when electricity could be supplied
and paid for only as used, to be shown
by a meter, an immense deal of work,
such as driving sewing machines, &c.,
would be done by it. There had been a
good deal of talk about a regulator, and
Mr. Preece had shown that one might be
made to maintain an even pressure
throughout an entire district lighted
from one station, no matter how many
lamps were lighted by it. They pre-
ferred to have such a regulator with
personal supervision, just as gas compan-
ies regulated the pressure on their mains
as required, rather than employing any
automatic device, which was liable to get
out of order. [Mr. Johnson here showed
how the amount of current could be in-
creased or diminished at will, so that
when fewer lights were in use, the quan-
tity would be diminished accordingly.]
The man in charge of the central station
would regulate the current by a sample
lamp kept alight there. He had been
asked whether the replacement of the
lamps, when used up, was expensive or

difficult. In answer to that, he might
say that in New York, where they were
making arrangements to light up a
central district of a mile square, they
proposed to supply every consumer with
all the lamps he might use, free from
cost, simply charging the cost of the
lamp in the current supplied and paid
for on his meter. The first cost of the
lamps was very small to them, and they
therefore preferred supplying them to
subjecting the consumer to the annoy-
ance of having to purchase them. [Mr.
Johnson here unscrewed a lamp, and
attached another, to show the readiness
with which a change could be effected.]
A question had also been asked him,
whether a single light could be raised or
lowered; and there was a lamp made in
which this was provided for, but it was
more expensive and complicated, and was
not recommended. There were very few
cases where such would be required, be-
cause you need not leave a light on as in
the case of gas, in order to light up when
required, as you only had to turn it on,
and it lit itself.

On Aug. 21, there was an important installa-
tion of the Edison electric light in the "Press
Department" of the Telegraph Office, St. Mar-
tin's-le-Grand, and the work thus carried out
solves what have hitherto been considered some
difficult problems in the question of electric.
lighting. The first interesting fact is that the
lighting is part of a "system" supplied at a dis-
tance from the place lighted, the Edison Elec-
tric Light Company having its center on Hol-
born Viaduct. The extension to the top room
of the General Post Office, which was accomp-
lished last night, is the greatest yet made from
one center, the distance from the dynamo-room
of the company's office to the "Press Room"
of the General Post Office being 1950 feet. The
"Press Room" to which the Edison electric
light has thus been supplied is a very busy part
of the telegraph department (1,200 persons be-
ing employed there), which occupies the whole
upper floor of the western building in St. Mar-
tin's-le-Grand. The Post Office authorities have
long been alive to the necessity of replacing gas
by electricity, and have tried more than one so-
called "system." Under the advice of Mr.
Preece, the electrical engineer of the Post Of-
fice, the Edison system was attached, and last
night (Aug. 23) commenced its working. The
first lighting was soon after 8 o'clock, and when
the gas in the Press Room was extinguished, a

turn of the switch lighted up fifty-nine incandescent lamps of the well known pear-shaped pattern, with the carbon of the shape of an elongated horseshoe. The effect of the change was very marked. In the telegraph room the atmosphere was heavy and heated. In the room lighted by the Edison lamps an even light without any shadow was thrown all over the tables, while the atmosphere, previously heated by gas, sensibly diminished, even in the short space of about twenty minutes.

*[From Nature, Sept. 7, 1882.]*

Mr. Edison's system of providing an incandescent electric light for domestic use in a given district has just been put to a practical test in New York. The district selected occupies an area of nearly a square mile. Only one source of supply is provided, and that furnishes the illuminating power for sixteen thousand lamps, the electric current passing through eighteen miles of mains. The result is that the severest demands which the consumers have been able to make upon the new system have been satisfied. The *New York Herald* is using in its business premises an isolated plant on the same principle. No new obstacle has presented itself to the success in practice of Mr. Edison's theory ; and scientific men will be interested to know that this first practical experiment dem-

onstrates the soundness of the inventor's application of the multiple arc system, pure and simple, as distinguished from the series system, or the combination of the arc and series systems. Throughout the entire district lighted as described, each lamp was independent of all the others.

The electric illumination of the Vaudeville, on the Boulevard Montmartre, is a great success. The hall is crowded every night. An 11 horse-power gas machine with Faure accumulators is sufficient to illuminate every night about 250 Swan lamps.

# THE EDISON

# ELECTRIC LIGHT

# METER.

BY

**FRANCIS JEHL.**

# The Edison Electric Light Meter.*

THE principle upon which this meter is founded is known as electro-metal-lurgy, that is, the disruption or tearing away of a metal by electricity, from one electrode and its deposition upon the opposite.

### FUNDAMENTAL PRINCIPLES.

If an electric current, no matter how generated, whether by a dynamo machine, or voltaic element, be made to pass by means of platinum electrodes through acidulated water, electrolysis takes place, that is, the current has the power of loosening and separating certain chemical compounds—in other words, it decomposes the compound through which it has passed. Any substance

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* Under the above title this article was originally published in London in pamphlet form. For presentation to the scientific public such parts of the original as pertained to the manipulation of the meter have been omitted, but the complete exposition of the principles upon which it operates are retained.

which is susceptible of decomposition by an electric current is termed an " electrolyte."

By the term electrodes is always understood the two extremities or poles which lead from a source of electricity.

Electrodes are divided into anodes and cathodes.

The positive electrode is called the anode, and the negative the cathode.

The products of decomposition, or the substances which gather at each pole during electrolysis, are termed "ions." That which gathers at the anode is called anion, and that which gathers at the cathode is called cation.

The amount of current required for decomposition varies greatly with different electrolytes.

In the above-mentioned case, where the current passes through acidulated water, oxygen gas is liberated at the anode, and hydrogen at the cathode.

If into this liquid which contains the acid some crystals of sulphate of copper ($CuSo_4$) be thrown, electrolytic action

will still continue, but in a different manner, oxygen will be evolved, and copper will be deposited on one of the platinum electrodes, while the hydrogen takes the place of the copper in the solution. It may be represented chemically by $H_2O + CuSO_4$ before the current has passed, and $O + Cu + H_2SO_4$ after the current has passed.

If in the above experiment, a copper electrode be substituted for the positive, it will be found that no gas will be liberated, the hydrogen, as before, will take the place of the copper in the solution—the oxygen, instead of escaping at the anode, will combine with the copper of the electrode and the sulphuric acid, to form sulphate of copper.

The chemical forces, called into action by the current, are so beautifully balanced, that in our last experiment the quantity of copper, supplied by the positive electrode, exactly equals the quantity withdrawn from our solution and deposited upon the negative electrode.

### LAWS OF ELECTROLYSIS.

The following were demonstrated and discovered by Faraday.

Electrolysis cannot take place unless the electrolyte is a conductor.

The energy of the electrolytic action of the current is the same in all parts.

The same quantity of electricity—that is, the same electric current—decomposes chemically equivalent quantities of all the bodies which it traverses; from which it follows that the weights of the elements separated into these electrolytes are to each other as their chemical equivalents. For instance, in the decomposition of water it will be found that for every 18 parts of water decomposed two parts will be hydrogen and 16 oxygen: in order to form water from its two component gases we must take them in the above ratio.

It also follows from the preceding law that the quantity of the substance which is decomposed is proportional to the total quantity of electricity which passed through it, and is independent of the

time during which the electricity passed;
the quantity corresponding to the pas-
sage of one unit is called the electro-
chemical equivalent of the substance.
Thus, when one unit of electricity passes
through a solution of sulphate of zinc,
having platinum electrodes, one electro-
chemical equivalent of zinc appears at
the cathode, and one electro-chemical
equivalent of oxygen at the anode, while·
one electro-chemical equivalent of sul-
phate of zinc has disappeared from the
solution, but an equivalent of sulphuric
acid has taken its place.   If in the above
experiment, zinc electrodes were used,
the action would be as follows :

For one unit of electricity, one elec-
tro-chemical equivalent of zinc would ap-
pear at the cathode, one electro-chemical
equivalent of oxygen at the anode, there
uniting with the zinc and sulphuric acid
to form another electro-chemical equiva-
lent of sulphate of zinc, and taking the
place of the one just decomposed.   This
action continues, and keeps on depositing

zinc on the cathode, and taking zinc off at the anode.

Upon the preceding law has Mr. Edison based his meter, and no matter how much current passes through it, for every electrical unit or fraction (which unit is called an Ampère), there will be a corresponding number of units or fraction of a unit of the metal deposited.

### POLARIZATION.

If, in a circuit consisting of an electrolytic cell containing acidulated water, having platinum plates for electrodes, we insert a single voltaic element together with a galvanometer to measure the current, we find that the strength of the current rapidly diminishes on closing the circuit.

Neither oxygen nor hydrogen appears in a gaseous form at the electrodes, but the electrodes have acquired new properties, showing that a chemical action has taken place at the surface of the plates. If now the battery be disconnected, and the galvanometer alone, with the electro-

lytic cell, remains in the circuit, it will be found on closing it that a current is traversing, and showing on the galvanometer that it is in an opposite direction to the original current. This current rapidly diminishes in strength and soon vanishes. It can also be seen that this current is not as strong as the primitive one. This acquirement of the electrodes is termed polarization.

In the construction of an electric meter, such elements must be used as will not, under any circumstances, polarize; for suppose an electrolytic cell, which was capable of being polarized was used to ascertain the amount of current that was passing through the line in which it was inserted, it would, in the first place have the tendency to weaken the original current, and, if the instrument was shunted, as is essential in electric lighting, this counter current would all the while resist the original current, causing an erroneous deposit, it depositing less metal than would be deposited if there were no polarization. Then, again,

when the current on the line ceases to flow, this counter current would begin to act and redeposit some of the metal which the original current had deposited. Thus we see why any elements capable of polarization would not do for an accurate meter. Then again, there is another consideration that comes into play, and that is, that nearly all elements when immersed in a solution, generate a small current, for example: Two plates of copper in a solution of sulphate of copper, when connected with a galvanometer, will indicate the presence of a current. Now, in the above case, when the electrolytic cell was shunted it had necessarily, a closed circuit. The circuit being closed this current, as indicated by the galvanometer in the last experiment, would become active, and deposit metal while there was no current circulating in the line. This current, although feeble, will in time deposit a considerable amount of copper, and cause an inaccuracy almost inconceivable. A copper deposition cell, and some other metals, is suitable

for large currents, and when the plates
are taken out of the solution, immedi-
ately after the current ceases to flow;
but when it is required to register a very
small current, such as $\frac{1}{1000}$ of an Am-
père, and when the deposition cell is al-
ways on a closed circuit, it becomes nec-
essary to use some other metal than
copper in order to obtain accurate re-
sults.

In order to get rid of this difficulty of
polarization, Mr. Edison found that by
using electrodes of pure zinc, amalga-
mated with pure mercury and a solution
of chemically pure sulphate of zinc, that
there is almost no polarization, and great
practical accuracy is insured when an
exceedingly small quantity of current is
desired to be measured. The same is
true if the currents be of large dimen-
sions.

I may add that it is advisable in all
electrical researches, whenever it becomes
necessary to ascertain the magnitudes of
an unknown current, and especially if it
be small, that instead of using the copper

deposition method an electrolytic element consisting of pure zincs amalgamated with pure mercury in a chemically pure solution of sulphate of zinc be used.

### RESISTANCE OF ELECTROLYTES AND METALS.

It is very difficult to measure the electric resistance of some electrolytes on account of the polarization of the electrodes. In order to overcome this difficulty one must use, as stated in the preceding article, zinc electrodes. There are other methods for ascertaining the resistance of solutions, but it is not necessary for me here to explain such methods. The temperature of the solution greatly affects its resistance. It will be found that this resistance decreases as the temperature increases, or when the temperature decreases the resistance increases. Thus we see it has properties similar to carbon, for carbon will decrease its resistance when its temperature is increased and *vice versa*. These properties are just the reverse of those exhibited by the metals.

We, therefore, lay down the following laws, namely:

That the resistance of electrolytes diminish as the temperature increases.

The resistance of metals increases as the temperature increases.

Now, it is obvious that, if we ascertain the resistance of a certain solution at different temperatures, we can ascertain the difference of its resistance between such temperatures. For example, if a solution of sulphate of zinc at 0° C., and specific gravity 1.29, offers a resistance of 1.40 ohms, at a temperature of 50° C. its resistance is diminished to 0.32 ohms. Therefore, the difference between those two temperatures is—

$$0° \dots\dots\dots\dots\dots : 1.40$$
$$50° \dots\dots \dots\dots\dots\dots 0.32$$
$$\overline{\phantom{xxxxxxx} 1.08}$$

showing a decrease of 1.08 ohms between the limits of 0° and 50° C. If we remember that this difference is in contrary direction to that of copper, it will be seen that if we take a certain length

of copper wire which changes its resistance between 0° and 50° by the same amount as the solution but in the opposite direction, that by placing the two in series, that is in the same circuit with each other, one would compensate for the other, that while one diminishes the other increases, and the circuit in which they are placed maintains a constant resistance and does not vary with the temperature. Mr. Edison has made use of these principles in his meter, and has a constant resistance in the circuit where the deposition cells are placed, without which an electric meter would be of no value where there is a change of temperature.

### GENERAL DESCRIPTION OF THE METER.

The meter is divided into two compartments. The first, or the one on the left side, is termed the monthly cell. This is taken out every month by some employe of the company, and another cell is substituted for it. The one taken out is returned to the station, where the

plate that has received the deposition is weighed. The cell on the right hand of the meter is termed the quarter yearly cell, and is a check cell. The party that has access to the monthly cell has not to the quarter yearly cell. This quarter yearly cell is taken out every three months and the deposit weighed. Its deposit must bear a certain proportion to the sum of the monthly meter deposit for those three months. If its deposit does not agree in proportion to the monthly cell, there is something wrong, or somebody has tampered with it. Thus we see the object of this auxiliary cell. In the diagram A· is the monthly cell, and A′ is the quarter-yearly cell. B and B′ are the compensating resistances, in series with the cells A′ and A respectively, the object of which has been explained.

C and C′ are the respective shunts, (made of bands of German silver), from which the cells A and A′ receive their current. In all meters, irrespective of their capacity for registering, the resistance of the cell A with its compensating
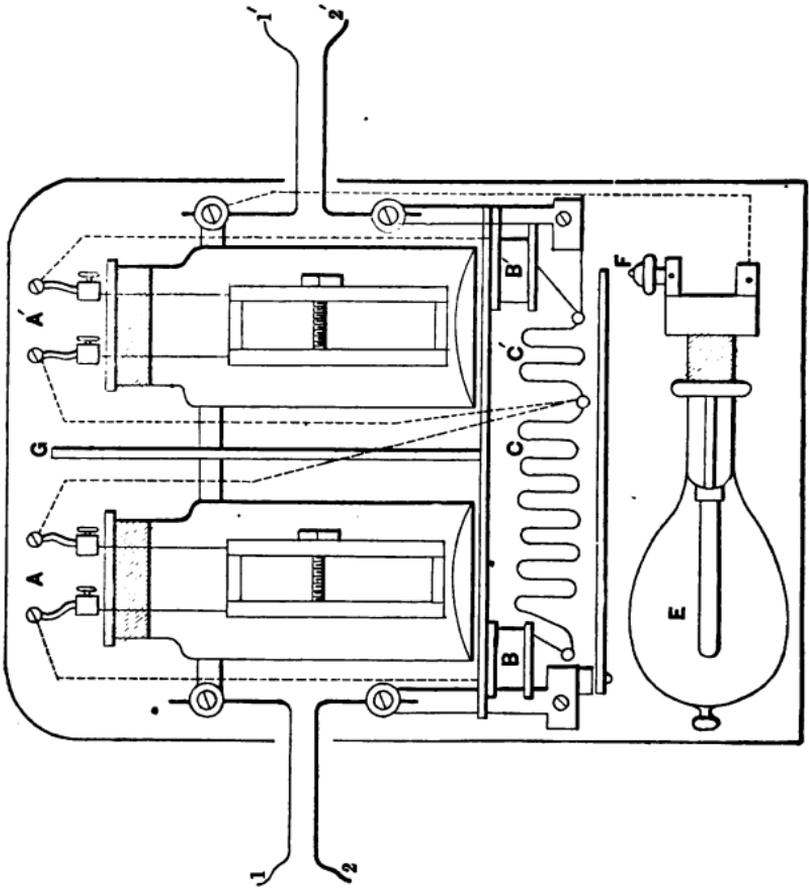
resistance B is 830 times the resistance of the shunt C, and the resistance of A' plus B' (equal to A plus B) is 3320 times the resistance of C' within the ranges of temperature occurring in practice. The resistance of C' is therefore one-fourth that of C and the cell A' will receive one-fourth as much deposit as A.

D is the thermo arrangement which prevents the freezing of the sulphate of zinc solution in the winter, or too low a temperature for accurate registration. It consists of a strip of brass and steel riveted together.

The unequal expansion and contraction of the two metals causes contact to be made at F when the temperature falls to the lowest desired limit to which F is adjusted. This throws the lamp E in circuit, the heat from which raises the temperature in the meter, and acts upon the thermo strip causing it to open the lamp circuit.

### METHOD OF CALCULATION.

Whenever a meter is set up to register the consumption at any place the weight

of the plates is recorded. The weight of the plates from the monthly cell is taken after they have been in use the required length of time, and upon the gain in weight of one plate is based the amount of current used. The gain in the quarter-yearly cell should, in the given time, equal one-fourth the gain in the monthly cell for three months.

It has been stated that the resistance of the circuit containing the monthly cell is 830 times the resistance of the shunt around which it is placed, therefore of the total current passing $\frac{1}{831}$st part will pass through the cell and be registered.

If it is experimentally determined that the $\frac{1}{831}$st part of an Ampère flowing through the cell for one hour will deposit 1.6 milligrammes, then is this the true indication of one Ampère for one hour, because the remaining $\frac{830}{831}$ will flow around the cell and through the shunt without being registered.

To find the number of Ampères for one hour, therefore,

$$\frac{\text{Gain in milligrammes}}{1.6} = \text{Ampères flow-}$$

ing for one hour.

This result may also be expressed as "number of hours for one Ampère."

If one lamp, giving 16 candle-power of light, requires a current of three-fourths of an Ampère, the amount of deposit in the cell in one hour for this lamp would be three-fourths of 1.6 milligrammes = 1.2 milligrammes.

Therefore, to find the number of lamps operating for one hour to produce the deposit,

$$\frac{\text{Gain in milligrammes}}{1.2} = \text{number lamps}$$

for one hour.

This result may also be expressed as "number of hours for one lamp."

Thus the gain of weight in one plate bears a constant ratio to the current which has passed through under a uniform pressure, and also to the energy consumed beyond the meter, and is therefore a register of the amount of energy, irrespective of the particular use to which it was applied.

ECONOMY

OF

# ELECTRIC LIGHTING

BY
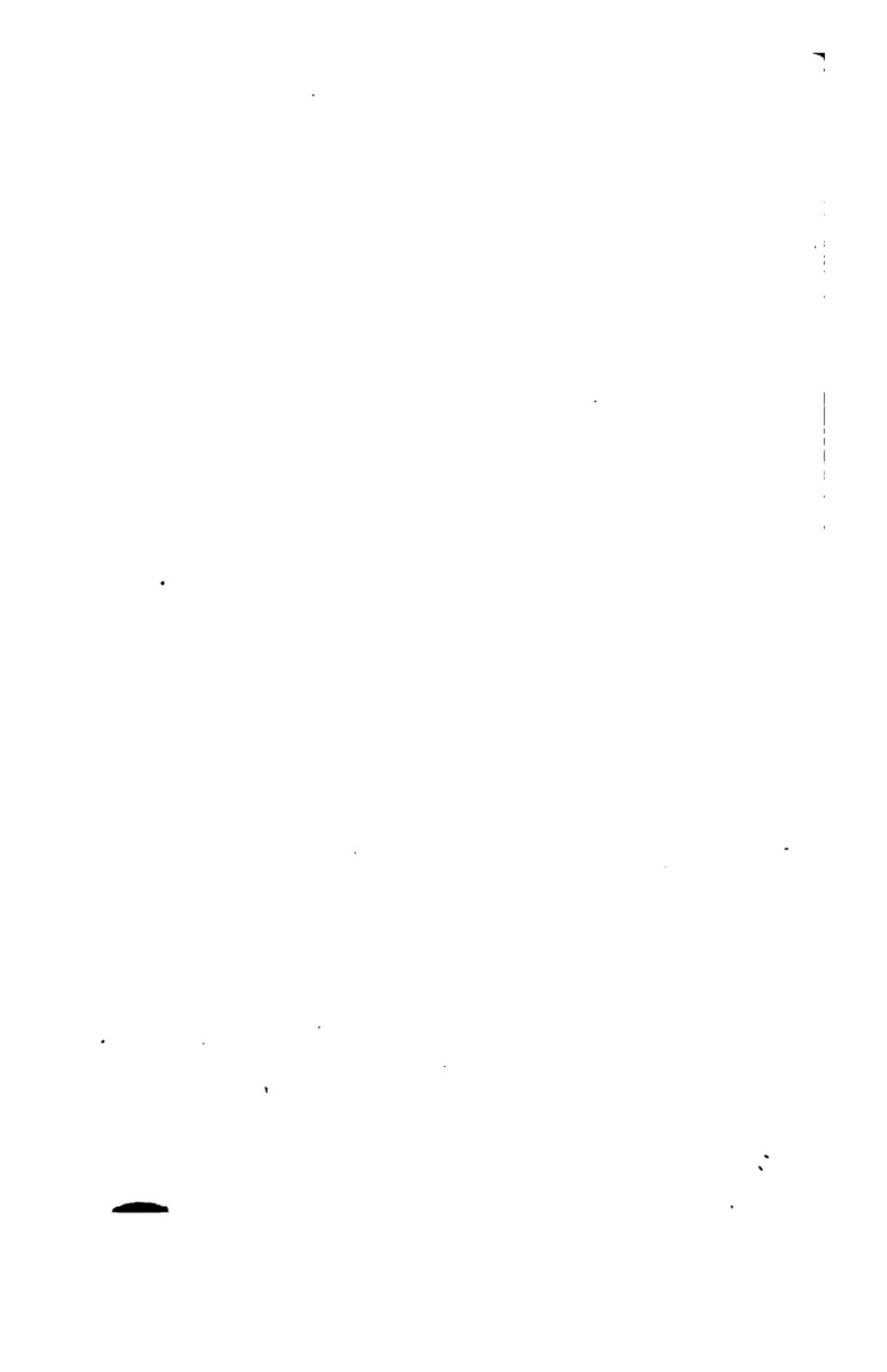
## INCANDESCENCE.

By JOHN W. HOWELL.

STEVENS' INSTITUTE OF TECHNOLOGY.

I.—ECONOMY OF THE GENERATOR.
II.—ECONOMY OF THE CONDUCTOR.
III.—ECONOMY OF THE LAMPS.

# Economy of Electric Lighting by Incandescence.

In writing this thesis I have endeavored to determine as nearly as I was able the cost of electric lighting by incandescence. Owing to the interest attached to the subject, and the lack of data upon which calculations can be based, I have endeavored to consider the subject in all its details, and have taken every precaution that suggested itself to guard against error.

The data given are sufficient to calculate the number of lamps to be obtained from each indicated horse power in a steam engine; beyond this I have not attempted to go, as my experience is insufficient to enable me to make any further determinations.

### EFFICIENCY OF THE GENERATOR.

The generator tested was one of the latest pattern devised by Mr. Edison. It

differs from the generators heretofore in general use, principally in the substitution of bars of copper for wires in the armature, which make the resistance of the armature very low and also economizes space, as the bars have a trapazoidal section, and when in position there is only clearance enough to allow for the insulation between them.

In my experiments the field was excited by a current shunted from the main circuit, the relative resistance of the mains and magnet coils determining the amount of energy expended on the magnets, and consequently the intensity of the magnetization and the electro-motive force of the generator.

### APPARATUS FOR MEASUREMENT OF THE MECHANICALL ENERGY TRANSMITTED TO THE GENERATOR.

In measuring the energy transmitted to the generator, the dynamometer built by the class of '79 was used. This was carefully standardized by supporting the pendulum in a horizontal position at a point
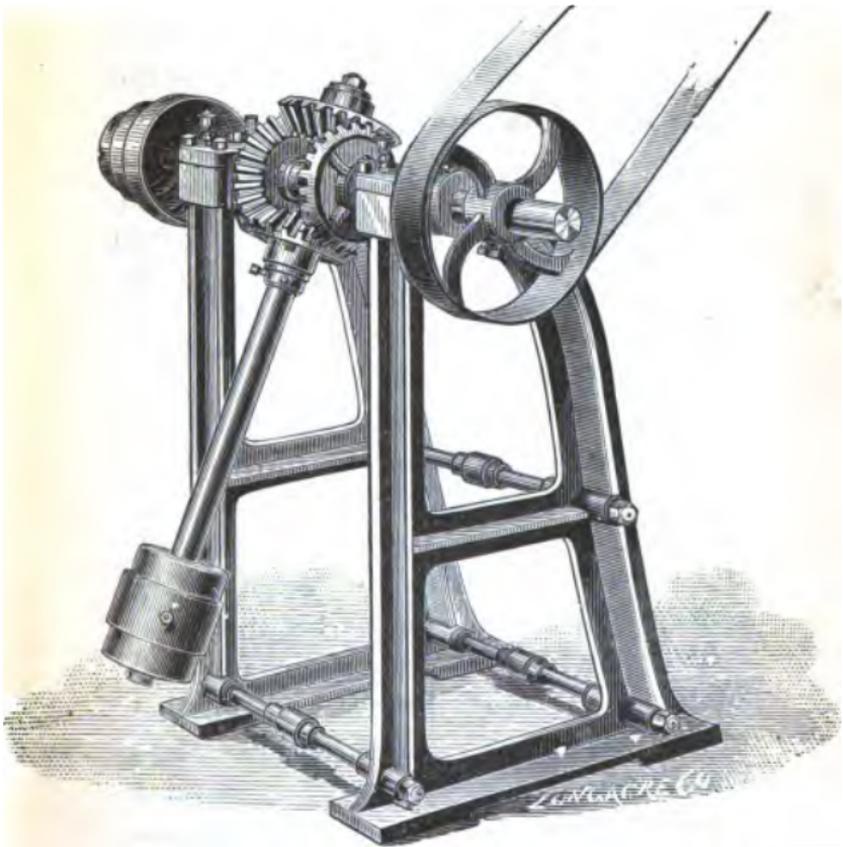
2 feet from the axis of the shaft, and
weighing the pressure of the support upon
a platform scale: the weight of the pen-
dulum and support was 183.25; the weight
of the support was 12.1; the weight of the
pendulum was 171.2 lbs.

This gives us the force acting at the
circumference of a pully of 1 foot radius
by multiplying 171.2 by the sine of the
angle of deflection.  This is a measure of
the force transmitted through the gear at
the top of the pendulum. and includes,
beside the force required to turn the arma-
ture in the field of force, the force neces-
sary to evercome the friction of the dyna-
mometer bearing, and also the friction of
the armature shaft in its bearings.  In
order to determine what part of the trans-
mitted energy was lost in overcoming
friction, a Prony brake was applied
to the pulley of the armature, close
beside the belt, while the generator
was running.  Removing the brushes
to be sure no current was generated,
we tightened the brake until the pen-
dulum showed the same deflection that

A Dynamometer pulley 30".

B Dynamo pulley.

C Prony brake by side of belt on dynamo pulley.

Fig. I.
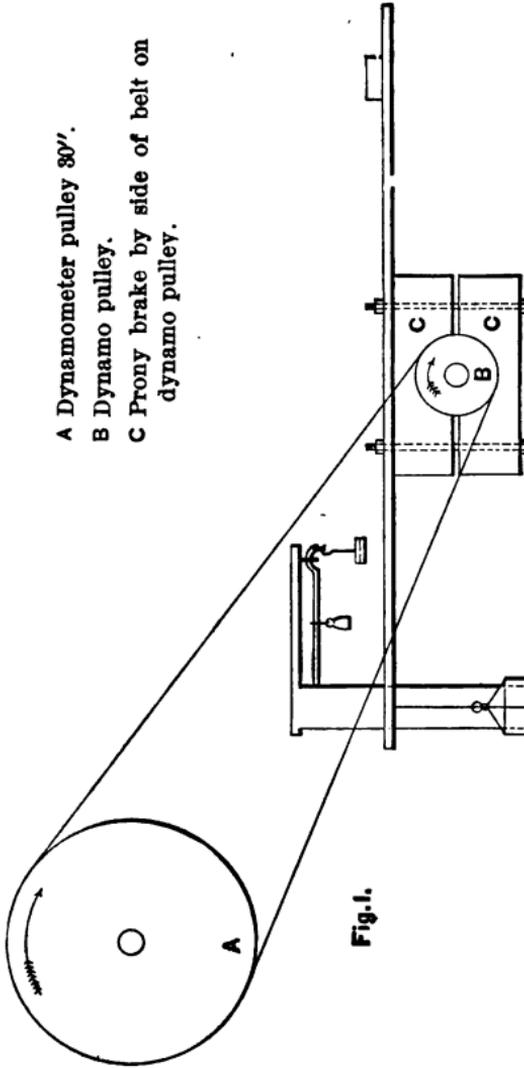
METHOD OF MEASURING USEFUL WORK.

it did during the test; we thus made a direct substitution of the Prony brake for the retarding action of the lines of magnetic force upon the armature when the circuit was closed, and the force exerted by the arm of the brake, upon a platform scale reduced to the radius of the pulley, will be the force required to turn the armature in the field of force. Instead of measuring the pressure exerted by one arm of the brake upon a scale, we measured the lifting effort exerted by the other end upon a weight resting upon the scale. We placed a light counterweight upon the other end of the brake, to make the zero reading more definite, and in getting the zero we raised the counterweighted end, and let it down gently, rapping the center of the brake to prevent sticking.

Several readings fixed the zero between 35½ and 35. Running at about the same speed as in the test, and tightening the brake until we got a deflection of 42°, we made several readings on the scale, which varied from 19 to 20½. Using the highest zero reading and the lowest running read-
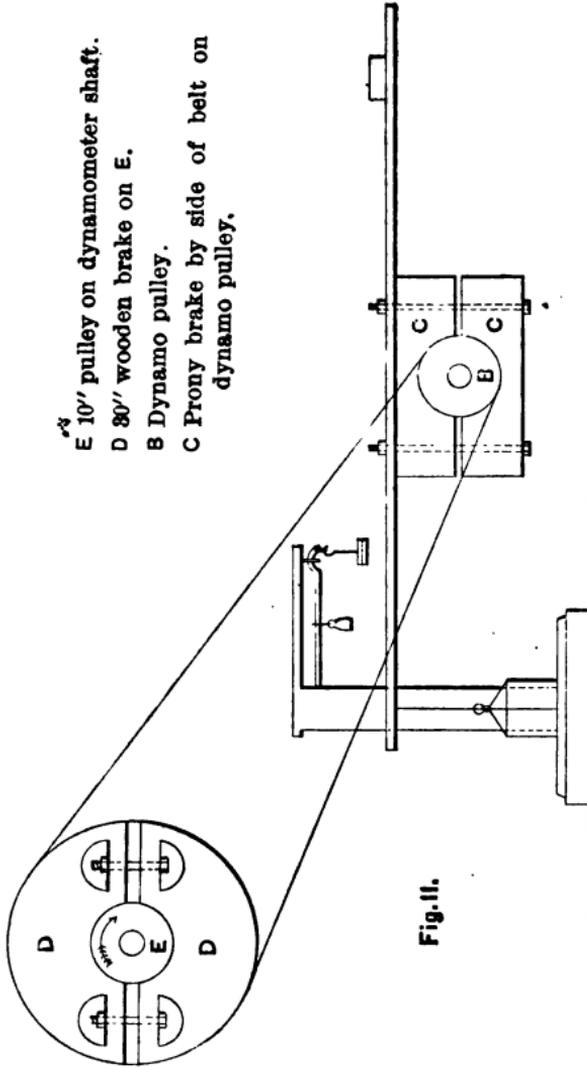
E 10' pulley on dynamometer shaft.

D 30'' wooden brake on E.

B Dynamo pulley.

C Prony brake by side of belt on dynamo pulley.

Fig. II.

METHOD OF MEASURING TOTAL WORK ABSORBED BY DYNAMO.

ing, we get a force of $16\frac{1}{2}$ lbs. acting at a distance of 2 feet from the center of the shaft; this reduced to the radius of the armature pulley gives $16\frac{1}{2} \times \dfrac{24}{5} = 79.2$ for the force acting at the circumference of the armature pulley. If no friction had intervened this force would have been

$$\frac{171.2 \times (\text{sine } 42° = 66.913)}{125} = 91.644 \text{ lbs.,}$$

showing a loss of $91.644 - 79.2 = 12.444$ lbs., or $13\frac{1}{2}$ per cent. of the power transmitted.

This loss of $13\frac{1}{2}$ per cent. is caused by the friction of the dynamometer and the friction of the armature bearings. To get the force actually applied at the circumference of the pulley on the armature shaft, we must determine the friction of the dynamometer bearing alone. To do this we made a wooden brake of the same diameter as the driving pulley on the dynamometer that could run on a 10-inch pulley on the dynamometer shaft, we then clamped the Prony brake upon the dynamo

pulley, and also clamped the belt on the
dynamo pulley and passed it over the
wooden brake. Running under these con-
ditions and tightening the wooden brake
on the 10-inch pulley until the pendulum
showed a deflection of 42°, we measured
the force acting at the circumference of
the dynamo pulley and also at the circum-
ference of the dynamometer pulley by the
lifting effort of the Prony brake upon the
weight on the scale. The object of this
arrangement of brakes was to get the
friction under the same conditions as
those under which we ran the test. To
get the zero reading in this case we
clamped the Prony on the dynamo pulley,
and loosened the wooden brake and coun-
terweighted the other arm of the Prony
brake, until the armature turned in its
bearings ; then letting it come to rest and
rapping the bearings of the dynamo and
dynamometer, we determined the zero
reading to be 33 lbs. Several readings
fixed the readings for 42° at 16 lbs.,
therefore the force acting at the circum-

ference of the dynamo pulley was $(33-16)$

$\times \dfrac{24}{5} = 81.6$, showing a loss of $91.644 - 81.6$

$= 10.044$ lbs., or 10.9 per cent. of the total energy transmitted.

### APPARATUS FOR THE MEASUREMENT OF ELECTRICAL ENERGY.

The resistance over which the generator worked consisted of three strands of iron wire in multiple arc, each of which was .104″ in diameter. These were stretched from one gallery of the shop to the other in the open air.

In measuring the resistance of the different parts of the circuit wires were led from the binding posts of the generator to the Wheatstone bridge, then by breaking the connection with the armature and magnet coils, we could measure the resistance of the line, or by breaking the connections with the line and magnets we could measure the resistance of the armature and leaders, or by breaking the connections with the armature and the line we

could measure the resistance of the magnet coils.

The electrical energy developed in the circuit was determined by three methods:

1st. By a voltameter, or a copper-depositing cell.

2d. By a calorimeter.

. 3d. By measuring the electro-motive force and resistance.

### FIRST METHOD.

The voltameter consisted of a glass jar large enough to hold six plates of copper, $7'' \times 8''$.

These were placed $\frac{1}{2}''$ apart, and held in place by a light wooden frame. They were connected alternately to the positive and negative wires from the generator. This method of arranging the plates brings both sides into action, gives a large area of plate, and makes the resistance of the cell very low and the consequent heating very little. By means of mercury connections the voltameter could be thrown into or out of circuit instantly without

breaking the current, and the leaders were so proportioned that throwing it in and out did not alter the resistance of the circuit.

In calculating the current from the weight of copper carried from one set of plates to the other, the weight gained by the negative plates was considered as the weight carried over, and the constant .32456, given by Sprague (Jenkin gives .324) for the amount of copper in milligrams carried over in one second by a current of one Weber. Before making the test, the current was passed through the voltameter for some time, in a direction opposite to that in which it was passed during the test, to insure that the copper carr'ed over during the test was copper that had been deposited before, otherwise energy may be lost in separating the copper from the positive plate.

### SECOND METHOD.

In determining the electrical energy by the second method, a calorimeter was used which consisted of a cylindrical vessel of

galvanized iron encased in a wooden jacket, and so supported as to leave an air space of about $\frac{1}{2}$ an inch on all sides between the calorimeter and the jacket  This prevented any great conduction of heat from the calorimeter to external objects ; still some heat must be wasted in heating the calorimeter and the surface it rests upon.

To determine the amount of heat thus wasted 55 lbs. of water was put in the calorimeter, and its temperature carefully determined it was 19.85°C.  A large pail of water was then heated to 54.3°C, and 18¾ lbs. were poured into the calorimeter. This made the weight of water in the calorimeter about the same as was used in the test, and the same part of the calorimeter was heated in each case, the final temperature of the water being 28.50°C, the range of temperature used in the test was included in this range.  The heat contained in the water poured into the calorimeter may be represented by $18.75 \times 26.2 = 491.25$.  Of this $55 \times 8.65 = 475.75$ went to raise the temperature of the water in the calorimeter, and the remainder 155

must have been imparted to the calorime-
ter. As the range of temperature in the
calorimeter was 8.65°, 1.78 of these units
were required to raise the temperature 1°,
or the same amount of heat was used in
heating the calorimeter as would be re-
quired to raise 1.78 lbs. of water through
the same range of temperature ; therefore
the proper correction may be applied by
adding 1.78 lbs. to the weight of water in
the calorimeter.

To measure the heating effect of the
current, a coil of copper wire was put into
the calorimeter, the resistance of which
was exactly $\frac{1}{10}$ Ohm, at 74°F. The chief
source of error in a calorimeter test of
this kind is the tendency of the current to
pass from one part of the wire to another
through the water, instead of passing
through the wire. This in itself is not a
source of error if we measure the resist-
ance of the coil in the water, but in so
passing, it may carry metal from one part
of the wire to another, and the energy so
used cannot be calculated, and is lost ; to
obviate this difficulty distilled water was

used, the resistance of which is much higher than ordinary water. The resistance of the coil measured in the water did not differ perceptibly from its resistance in the air, and at the close of the test no evidence of copper having been carried from one part to the other was discernible. To determine the range of temperature during the test, a Fahrenheit thermometer was used that was graduated to fifths of degrees, but the graduation was so plain that twentieths of a degree could easily be read. In order to be certain that the temperature of the water was uniform throughout, a pump was placed in the center of the calorimeter, which consisted simply of a copper tube about $1\frac{3}{4}''$ in diameter, its bottom was $\frac{1}{2}''$ above the bottom of the calorimeter and contained a valve opening downward; the piston also carried a valve opening downward. The water in the calorimeter covered the top of the tube, and by this means the water was taken from the surface when it is warmest, and carried to the bottom, where

it is coldest. The circulation thus obtained was very perfect, as shown by some ink drops put in the pump barrel.

### THIRD METHOD.

In determining the electrical energy by the third method, the electro-motive force was measured between the binding posts of the generator, by means of a Thomson high-resistance galvanometer. As a standard of electro-motive force, Latimer Clark cells were used, four of which were made up new for the purpose. These agreed with each other very closely, and in using them they were connected in series, thus getting their combined effect, and averaging their errors.

In using them they were allowed to charge a condenser, and the condenser was then discharged through the galvanometer.

The deflection produced is an accurate measure of the current flowing through the galvanometer and consequently of the charge held by the condenser, which de-

pends upon the electro-motive force of the terminals connected with the condenser. To connect the condenser alternately with the cells and the galvanometer, a simple switch was used by which the change could be made instantly. In making the test part of the condenser of $\frac{2}{10}$ microfarad capacity wire used and four standard cells in series. The damping magnet of the galvanometer was then adjusted until the discharge of the condenser produced a deflection of 291 divisions, as the electromotive force of the cell is 1,456 volts and four in series were used, the deflection corresponding to one volt was $\frac{291}{1,456 \times 4}$ $=50$. The instrument being standarized in this way, the liability to error was very small; in use, however, $\frac{9}{10}$ of the current was shunted from the galvanometer, only allowing $\frac{1}{10}$ to pass through, thus getting five deflections to a volt.

The ends of all wires dipping into mercury were amalgamated with mercurous nitrate, which made the connections very perfect.

In measuring the resistances of the armature and of the armature and leaders, the Wheatstone's bridge was used, and Thomson's reflecting galvanometer in place of the small galvanometer usually employed. The resistance of the armature mains and leaders was between .17 and .18 Ohm. When the bridge indicated .17 the galvanometer showed a deflection of 29.5 divisions ; when it indicated .18 the galvanometer showed an opposite deflection of 45. From this we get the resistance of the armature mains and leaders, .17395 Ohm.

The main alone measured .14460, leaving for the resistance of the armature and leaders to the binding posts .029 Ohm.

Leading wires being clamped on the commutator the resistance measured in several positions was .16,207. These leaders measured .14,604, leaving for the resistance of the armature alone .016 Ohm.

The resistance of the field magnet coils was 37. Ohms.

### TEST BY VOLTAMETER.

Before making the test the generator was run for some time to allow the circuit to heat up, and the resistance of the line measured from time to time until it was found to remain constant. The voltameter was then introduced into the circuit and allowed to remain fifteen minutes.

During this time the speed of the dynamometer was determined for ten minutes, and the average speed computed.

The deflection of the pendulum was observed every three minutes and the average taken, although the variation was only one degree. At the end of the test the circuit was broken and the resistance again measured, and it was found not to have changed perceptibly.

The plates were then removed, washed in water, then in alcohol, and dried in a gentle heat. They were then weighed carefully.

### DATA OBTAINED FROM THE TEST.

Weight of copper gained by negative plates $= 24,465$ m. g.

Time of test $= 15$ minutes.

Weight gained per second $= 27.183$ m. g.

Average speed of dynamometer $= 400.5$ rev. per min.

Average deflection of pendulum $= 42° \ 20'$.

Resistance of iron wire $= .76$ Ohm.

Resistance of iron wires and magnet coils in multiple arc $= .744$ Ohm.

Total resistance of circuit $= .744 + .029 = .773$ Ohm.

Internal resistance of armature $= .016$ Ohm.

### RESULTS OBTAINED FROM DATA.

Value of current in webers $= \dfrac{27.183}{.32456} = 83.753$.

Electrical energy $(83.753)^2 \times .773 \times 44.24 = 239880.726$ ft. lbs. per minute.

Energy indicated by dynamometer 171.2
$\times$ (sin 42° = .67344) $\times$ 400.5 $\times$ 6.2832
= 290125.54 ft. lbs. per minute.

Friction of dynamometer and generator
290125.54 $\times$ .135 = 39166.9470 ft. lbs.
per minute.

Energy used in turning armature in field
of force 290125.54 $\times$ .865 = 250958.59
ft. lbs. per minute.

Friction of dynamometer alone = 290125.5
$\times$ .109 = 31623.68 ft. lbs. per min-
ute.

Energy actually applied to armature pulley
290125.54 $\times$ .891 = 258501.96 ft. lbs.
per minute.

Of the total electrical energy 239880.7
$\dfrac{.016}{.773}$ = 4965.189 appeared in the armature,

$\dfrac{.744}{.773 \times 49.68} \times 239880.726 = 4647.39$ in the

magnet coils, and 230268.147 ft. lbs. per
minute in the external circuit.

The efficiency of the generator is the
ratio of the energy required to turn the

armature in the magnetic field, to the
total electrical energy developed $=$
$$\frac{239880.726}{250958.59} = .955.$$

The commercial efficiency is the ratio of
the energy required to drive the machine
(including friction) to the electrical energy
which appears in the external circuit

$$= \frac{230268.169}{258501.96} = .8908.$$

### TEST BY MEANS OF THE CALORIMETER.

As in the voltametric test the generator
was first run until the circuit was thor-
oughly heated, and the same care was
taken to determine the speed and deflec-
tion of the dynamometer. When the
calorimeter was thrown into the circuit an
approximately equal resistance was thrown
out so as not to change the total resist-
ance too much. At the end of the test
the resistance of the circuit was measured
carefully as soon as the circuit was broken
and before the wires became cooled.

### DATA OBTAINED FROM THIS TEST.

Water in calorimeter = 77 lbs.

Correction for waste heat = 1.78 lbs.

Range of temperature = 79° − 69.8° = 9.2°F.

Specific heat for this range = 1.0015.

Average speed of dynamometer = 394 rev. per min.

Average deflection of pendulum = 43° 24′ (sin = .68709).

Time of tests = 16 minutes.

Resistance of iron wires and calorimeter coil = .68 Ohm.

This and magnet coil in multiple arc = .667 Ohm.

Total resistance of circuit .667 + .029 = .696.

Resistance of calorimeter coil = .1 Ohm.

### RESULTS OBTAINED FROM THESE DATA.

Energy developed in calorimeter =

$$\frac{78.78 \times 1.0015 \times 9.2 \times 772}{16} = 35022.897 \text{ ft.lbs.}$$

per minute.

Total electrical energy

35022.897 × 6.96 = 243759.36 ft. lbs. per minute.

Energy indicated by dynamometer =

171.2 × .68709 × 394 × 6.2832
= 291201.46 ft. lbs. per min.

Energy used in turning armature in field of force

291201.46 × .865 =
251889.265 ft. lbs. per min.

Energy actually applied to armature pulley

291201.46 × .891 =
259460.5 ft. lbs. per min.

Of the electrical energy

$$243759.36 \times \frac{.016}{.696} = 5603.66$$

appeared in the armature

$$243759.36 \times \frac{.667}{.696 \times 55.41} = 4215.89$$

in the magnet coils; and 233939.81 ft. lbs. per minute appeared outside.

$$\text{Efficiency} = \frac{243759.363}{251889.265} = 967.$$

$$\text{Commercial efficiency} = \frac{233939.81}{259460.5} = .901.$$

### TEST BY MEASUREMENT OF THE ELECTRO-MOTIVE FORCE AND RESISTANCE.

In this test the electro-motive force was measured between the binding posts of the generator, and the external resistance was measured between the same points.

The deflection and speed of the dynamometer were measured at the same time, the electro-motive force was observed and the resistance was measured just before and after these observations and was the same in both cases.

### DATA OBTAINED FROM THIS TEST.

Electro-motive force = 53 volts.

Resistance of circuit (external) .64 Ohm.

Resistance between binding posts .629.

Average speed of dynamometer, 355 rev. per min.

Average deflection, 42°

(nat. sine = .66913).

Total resistance of circuit, .658.

RESULTS OBTAINED FROM THESE DATA.

Energy developed in external circuit and magnets

$$\frac{(53^2)}{.629} \times 44.24 = 197567.43 \text{ ft. lbs. per min.}$$

Total electrical energy

$$197567.43 \times \frac{.658}{.629} = 206673.0295 \text{ ft. lbs. per min.}$$

Energy in armature

$$206673.029 \times \frac{.016}{.658} = 5025.5.$$

Energy in magnet coils

$$\frac{(53^2)}{37} \times 44.24 = 3358.6 \text{ ft. lbs. per min.}$$

Energy in external circuit 198288.8 ft. lbs. per min.

Energy indicated by dynamometer

$$171.2 \times .66913 \times 355 \times 6.2832 = 255519.04 \text{ ft. lbs. per min.}$$

Energy used in turning armature in field of force

$255519.04 \times .865 =$

$221023.97$ ft. lbs. per min

Energy actually applied to armature pulley

$255519.04 \times .891 =$

$227667.47$ ft. lbs. per min.

$$\text{Efficiency} = \frac{206673.0295}{221023.97} = .935.$$

$$\text{Commercial efficiency} = \frac{198288.8}{227667.47} = .87.$$

Average efficiency, .951.

Average commercial efficiency, .887.

### ECONOMY OF THE CONDUCTORS.

The ecomomy of the conductors which convey the electricity from the generator to the lamps may be considered under two heads: first, the efficiency of the material, second, the efficiency of its dimensions.

The efficiency of any material is determined by its price and conductivity as

compared with other materials. The two materials most commonly used for conductors are copper and iron. The present price of copper is about seven times the price of iron and its conductivity is about six times as great; thus the actual cost of a line of copper wire of a given conductivity is one-sixth greater than iron wire of the same conductivity. Copper wire, however, is much more uniform than iron wire; it is free from cinder streaks that are so common to iron wire, and is much more pliable and less bulky, and therefore less difficult to handle. For electric-light mains, which have to be frequently tapped, copper wire seems to be preferable to iron wire.

## 2D. THE EFFICIENCY OF DIMENSIONS.

This is determined by the cost of the conductor and the loss of energy in the conductor. As the energy developed in different parts of the circuit varies directly as the resistance of these parts, some energy must appear in the conductors.

This energy appears as heat, and is lost. The most efficient dimensions of the conductors depend upon the amount of energy to be transmitted and the distance which it is to be transmitted.

To secure maximum efficiency, therefore, we would have to calculate the most efficient size under all conditions as to number of lamps and distances. Knowing, however, the conditions most usually met in practice, we can determine that loss of energy in the conductors, which is usually most efficient, and expressing this loss as a percentage of the total energy transmitted, calculate the size of our conductors upon this basis by making the resistance of the conductors the same percentage of the total resistance of the circuit, as the loss of energy allowed is of the total energy transmitted.

Thus, when we wish to calculate the dimensions of our conductors necessary to convey the current to a given number of lamps a given distance, allowing a loss of $\dfrac{1}{n}$ of the total energy, we must determine

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the resistance of our lamps and make the resistance of our conductors $\dfrac{1}{n-1}$ part of the resistance of the lamps.

Thus we see that the cost of the conductors necessary to carry the current for a given number of lamps a given distance varies inversely as the resistance of the lamps, and although we can make a high or low resistance lamp of the same economy, it will cost less to convey the current to a given number of high-resistance lamps a given distance, than it will to convey the current to the same number of low resistance lamps the same distance.

### ECONOMY OF THE LAMPS.

The economy of the lamps is determined by the energy consumed and the amount of light produced; in determining the energy consumed in the lamps, the electro-motive force was measured between the terminals of the lamps, and also the resistance, and the energy determined in foot

0° 10° 20° 30° 40° 50° 60° 70° 80°

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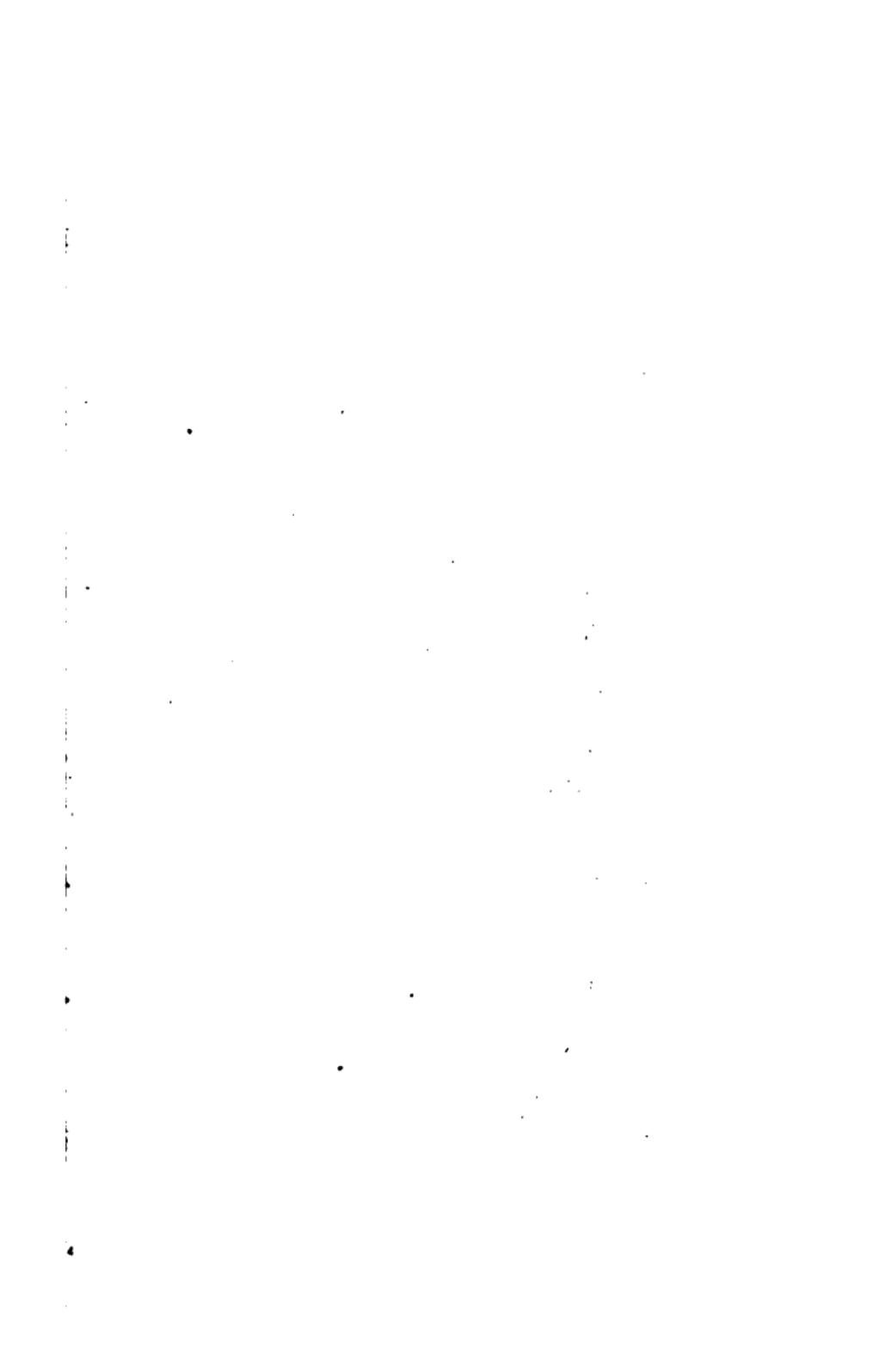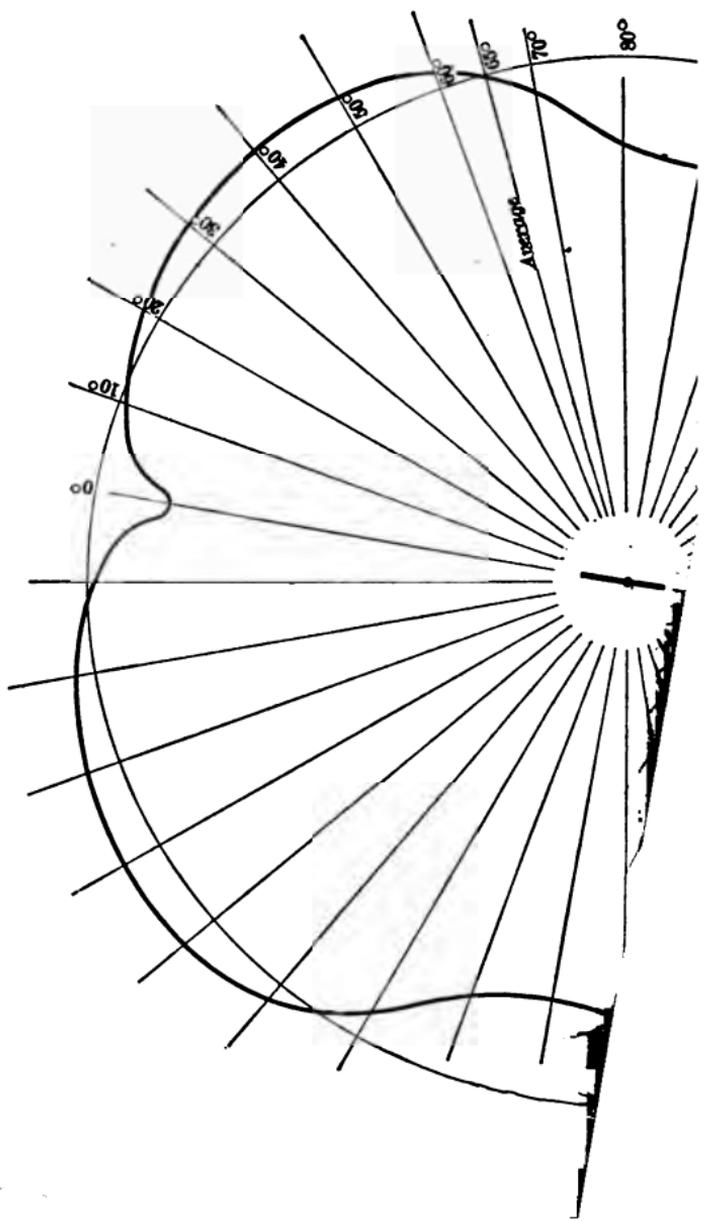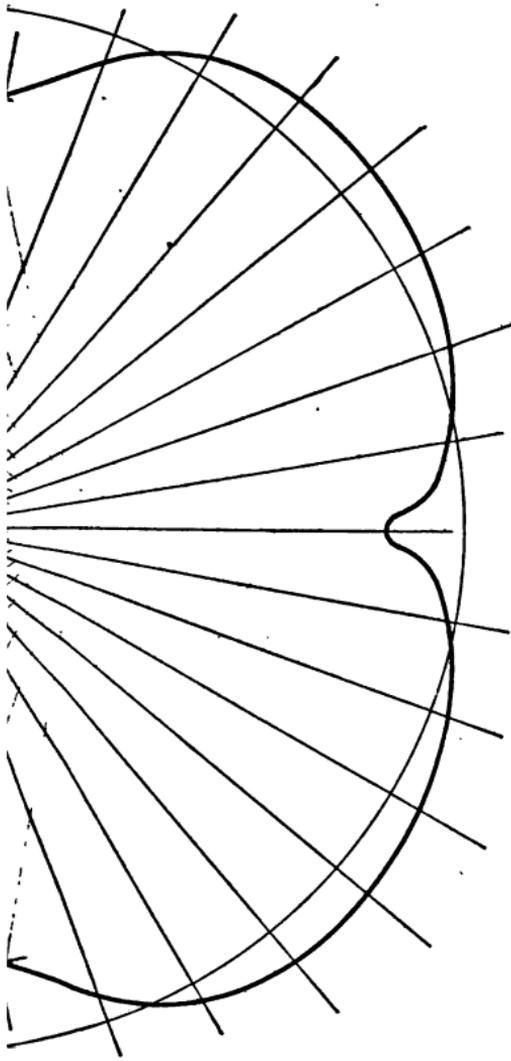
CURVE SHOWING ILLUMINATION OF EDISON'S LAMP IN A HORIZONTAL PLANE.
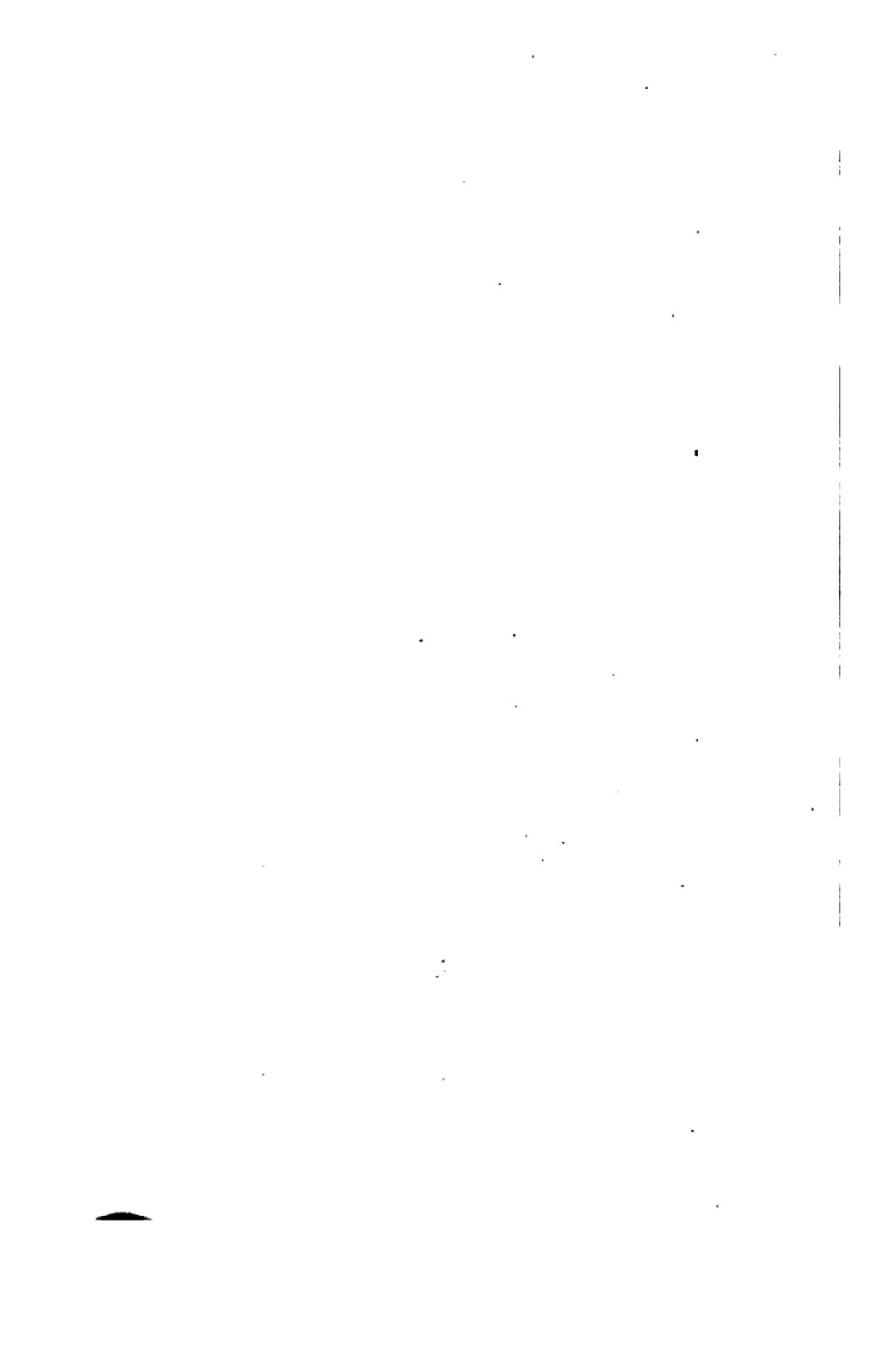
pounds per minute by the formula $\frac{e^2}{R}$ 44.24.

In measuring the electro-motive force the same arrangements were used as in determining the electro-motive force of the generator, but the damping magnet was adjusted to give three units of deflection to a volt instead of five. To measure the resistance of the lamps when burning, the current was divided into two parts, one part was passed through the lamp and the other through a variable resistance, when both were passed through a differential galvanometer, but in opposite directions; when the current was the same in both branches, the needle of the galvanometer would indicate zero. As the electro-motive forces of the two branches were equal, their currents were equal, when their resistances were equal, so by altering the variable resistance until the needle came to zero, and measuring the variable resistance we thus determined the resistance of the lamp while it was burning. This variable resistance was measured each time before it cooled.

As the light given out in a horizontal plane varies at different angles, the angle of average illumination was first determined for the lamp used, which was the Edison lamp. To determine this angle, the candle power was measured every 10° through a quadrant, and the candle power observed laid off on a suitable scale on lines radiated from a point. A curve was drawn through the points thus determined, and the four quadrants being made symmetrical, its area was determined and a circle of equal area drawn about the point from which the lines radiate. The points where this circle cut the curve determine the angle at which the candle power is the same that it would be if the light were evenly distributed.

Having determined the angular position of these points with reference to the plane of the carbon, all measurements were made with the axis of the photometer in this angle.

To insure that the lamp was in this position, it was twisted until the shadow of the carbon fell on the center of the disc and then turned through an angle of 65°,

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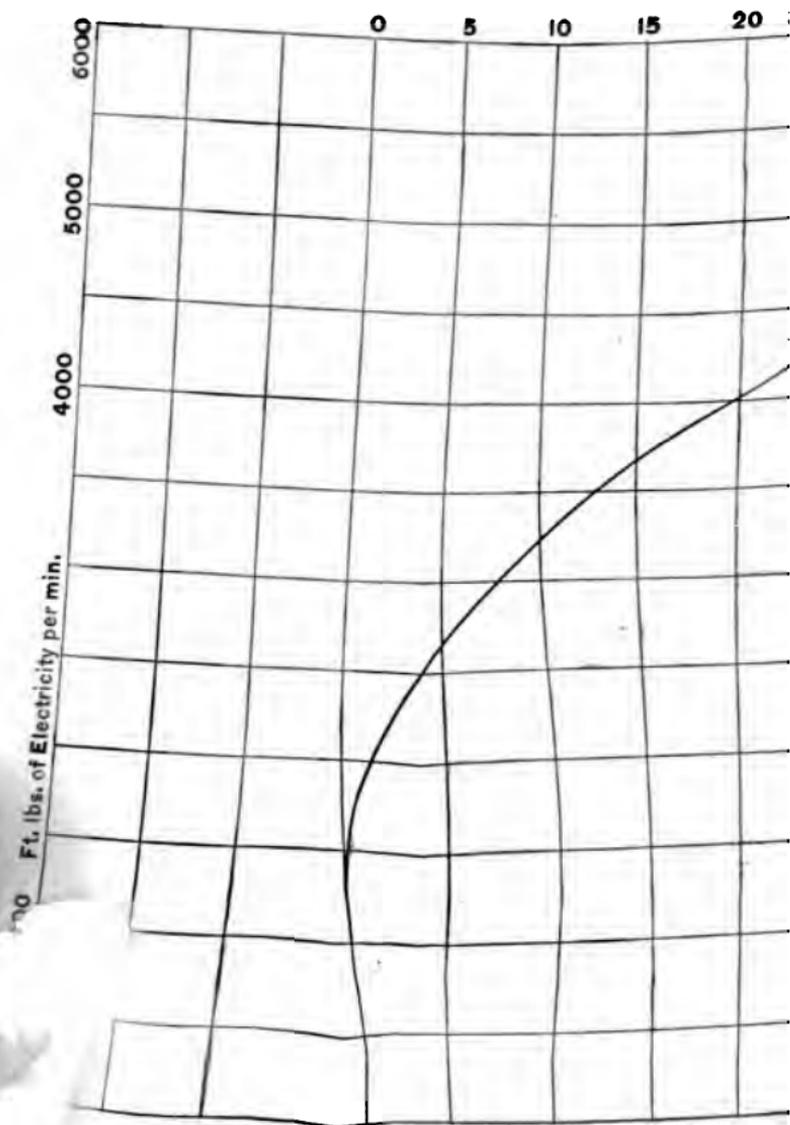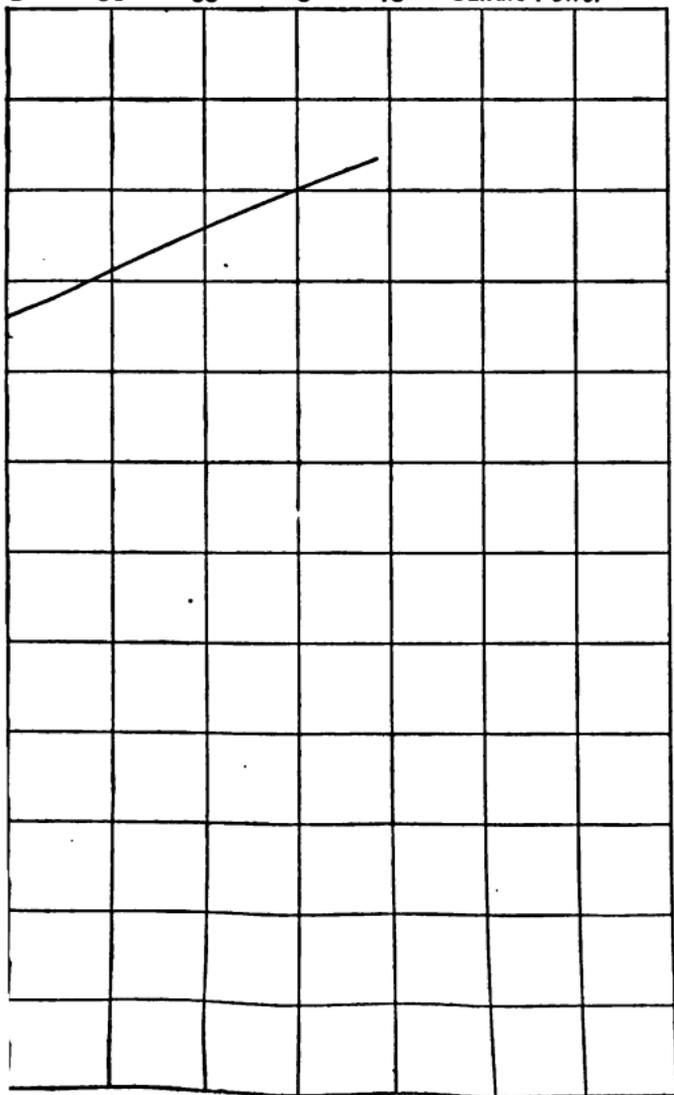
CURVE SHOWING RELATION BETWEEN ECONOMY AND INCANDESCENCE.
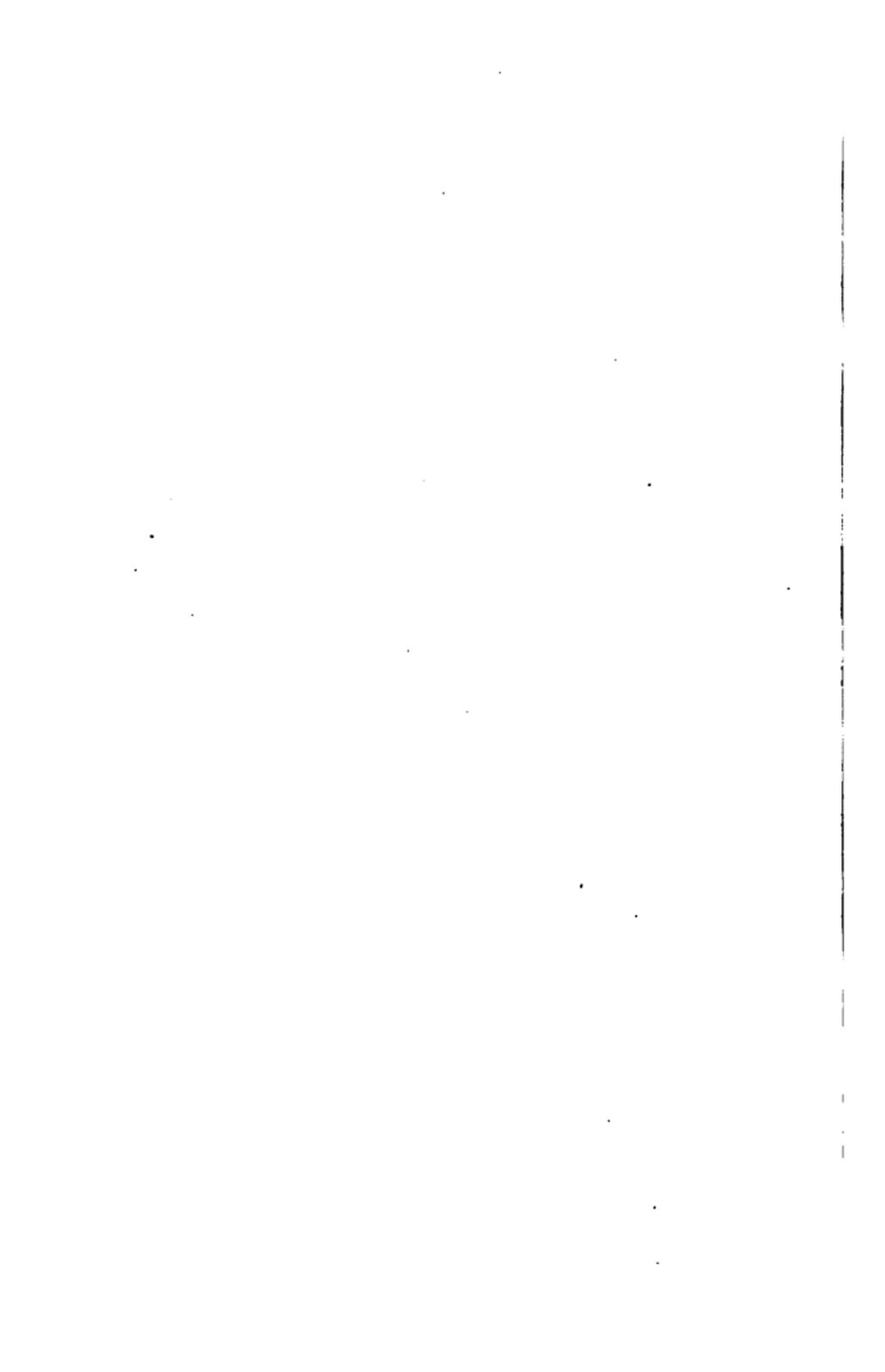
which the curve shows to be the proper angle. All measurements of lamps were made at the angle of equal illumination.

In order to determine the economy of a lamp at different degrees of incandescence, an Edison lamp was measured at intensities ranging foom a dull red to 40 candle power, and the results plotted in a curve show a rapid rise in economy as the candle power increases. While the economy of a lamp increases with incandescence, its life shortens, but as I have had neither time nor opportunities for life tests, I cannot give data for life at various degrees of incandescence.

Mr. Edison's standard of illumination has been 16 candle power, and his aim has been to produce a lamp that will give good economy and a reasonable life at that candle power.

To determine the energy consumed by these lamps when burning at their normal candle power, five lamps, as made at present by Mr. Edison, were tested with the following results:

**TABLE SHOWING ENERGY CONSUMED BY EDISON LAMPS.**

|  | Candle Power. | Volts. | Ohms. | Foot-pounds of Electricity per minute. |
|---|---|---|---|---|
| 1 | 16 | 98.66 | 135.5 | 3178—03 |
| 2 | 16 | 98.66 | 142.5 | 3021—91 |
| 3 | 16 | 99. | 140.5 | 3107—41 |
| 4 | 16 | 98. | 148.5 | 2861—15 |
| 5 | 16 | 99.33 | 131.5 | 3319—32 |

Showing an average of 3,097 — 564 ft. lbs. of electricity per minute, or 10.65 lamps per h. p. of electricity, giving 170 candles per h. p.

Mr. Edison gets 10.65 lamps per horse power of electricity, but as he allows a loss of 10% of the electrical energy used in the lamps upon the conductors, he gets 9.68 lamps for each h. p. of electricity generated. As the average commercial efficiency of this generator is .887, this gives him 6.58 lamps per dynamometrical h. p.

The report of the Board of Commissioners of the Millers' Exhibition, held in

Cincinnati just one year ago, gives the re-
sults of the trial of three modern steam
engines.

These results show an average for the
three engines of .878 of the indicated
power converted into useful work; using
this factor for the conversion of dyna-
mometrical into indicated horse power, we
find that Mr. Edison gets 7.62 lamps per
indicated horse power.

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NOTE.—The Committee to whom was as-
signed the labor of experimenting upon the in-
candescent lights exhibited at the Paris Exposi-
tion, close their report with the conclusion
givenl beow.

The Committee consisted of Wm. Crookes,
Prof Geo. F. Barker and others.

The following conclusions seem to be sus-
tained by the results which have now been
given :

1st.—The maximum efficiency of incandes-
cent lamps in the present state of the subject,
and within the experimental limits of this inves-
tigation, cannot be assumed to exceed 300
candle-lights per horse-power of current.

2d.—The economy of all lamps of this kind
is greater at high than at low incandescence.

3d.—The economy of light-production is greater in high resistance lamps than in those of low resistance, thus agreeing with the economy of distribution.

4th.—The relative efficiency of the four lamps examined, expressed in Carcel burners of 7.4 spermaceti candles each, produced by one horse-power of current is as fellows:—(A). At candles: Edison, 26.5; Swan, 24; Lane-Fox, 23.5; and Maxim, 20.4. (B.) At 32 candles: Edison, 44.5; Lane-Fox, 37.4; Swan, 35.5; and Maxim, 32.4. To double the light given by these lamps, the current energy was increased—for the Maxim and Lane-Fox lamps, 26 per cent.; for the Edison lamp, 28 per cent.; and for the Swan lamp, 37 per cent

ON THE

# DYNAMO-ELECTRIC CURRENT,

AND ON

## CERTAIN MEANS TO IMPROVE ITS STEADINESS.

By C. WILLIAM SIEMENS, D.C.L., F.R.S.

From Philosophical Transactions of the Royal Society.
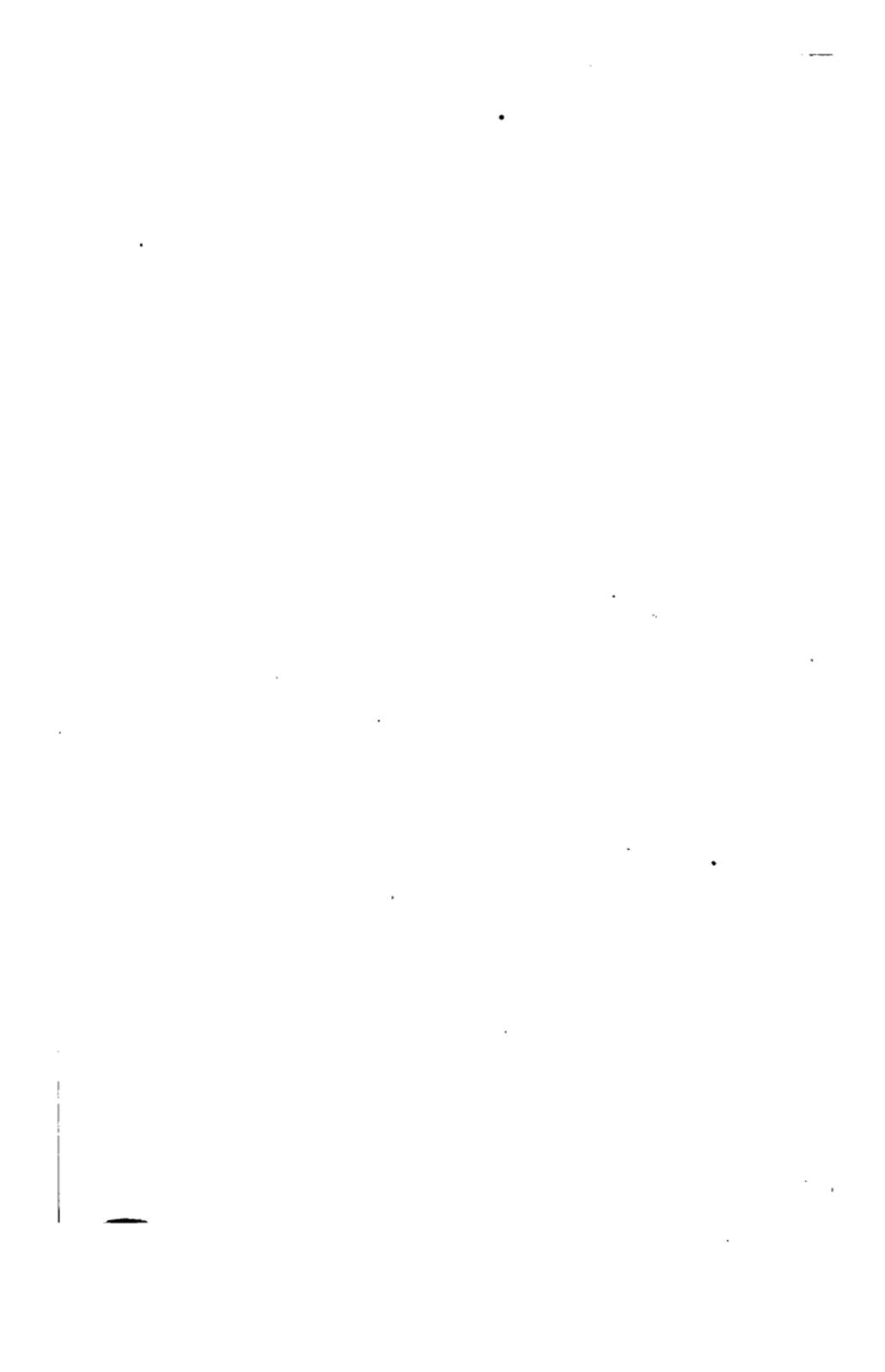
## Steadiness of the Electric Current.

On the 14th of February, 1867, I communicated a short paper to the Royal Society, describing the accumulative or dynamo-electrical principle of action, the conception of which I attributed to my brother, Dr. Werner Siemens. When the paper was read, another paper followed by Sir Charles Wheatstone (sent in on the 24th February) also describing this principle of action, thus showing that the same line of thought had occupied that eminent philosopher.

In illustration of my paper I exhibited a machine of my design, embodying the accumulative principle of action, which furnished abundant evidence of the powerful nature of the current that could be thus produced. It consisted of two horseshoe electro magnets, between the poles of which a Siemens armature could

be made to rotate, the machine being furnished with a handle or pulley for that purpose. A commutator was provided, by which the alternating currents set up in the rotating coil (after a first impulse had been given) were directed through the coils of the stationary electro magnets in a continuous manner, and proceeded thence outward to ignite a platinum wire of some 12″ in length, or to perform other work.

This machine, although the first of its kind, has done good service ever since its construction, having been found very efficacious in exciting powerful permanent magnets at the telegraph works of Siemens Brothers at Woolwich.

Since 1867 the accumulative principle has been employed in the machines of different makers, and one form of dynamo-electric machine, that of M. Gramme, differs very materially from the machine above referred to, and had met very deservedly with extensive recognition. M. Gramme embodied in his machine the principle of Professor Pacinott's mag-

netic ring, which enabled him to produce powerful electric currents without much of the loss of energy caused in previous machines through the heating of the rotating armature.

Another modification of the dynamo-electrical machine is one devised by Mr. Von Heftner Alteneck, an engineer and physicist employed under my brother Werner Siemens, at Berlin. This machine differs from that submitted by myself in several important particulars. Instead of the Werner Siemens armature, Von Heftner Alteneck adopted a rotating coil of iron wire wound with insulated copper wire in more than one direction, the several coils of wire being connected seriatum with the commutator, and through it, with the wire surrounding the soft iron bars, and with the electric lamp or other resistance on the outer circuit.

The advantage claimed for this mode of construction is that all the wire forming the rotating coil or helix is brought into the magnetic field, excepting only those portions crossing from side to side of the

coil; and in order to reduce this unproductive resistance to a minimum, the rotating coil or helix has been made comparatively long, and the number of electro magnets has been increased generally to six or more.

The principal advantage of the dynamo-electrical machine over all other current generators consists in its power of producing currents of great magnitude, and of an intensity up to 100 volts, with a small primary resistance, and therefore with a comparatively small expenditure of mechanical energy. It labors, on the other hand, under the disadvantage that the power of the current depends, at a given velocity, upon the magnetic force developed in the electro magnets. This force depends upon the amount of current passing through the coils of the magnets, which in its turn is dependent in an inverse ratio upon the resistance in the outer circuit. If from some accidental cause the external resistance is increased, the electro-motive force of the machine, instead of rising to overcome the obstruc-

tion, diminishes, and thus aggravates the resulting disturbance. If, on the other hand, the resistance of the outer circuit diminishes, as in the case when the carbons of an electric regulator touch one another, the electro magnets are immediately excited to a maximum, and the electro-motive force of the machine is increased. The power absorbed and its equivalent, the heat generated in the circuit, is equal to the square of the electro-motive force divided by the resistance; hence the work demanded from the engine will be greatly increased, the machine may be dangerously overheated, and powerful sparks may injure the commutator. It is chiefly owing to this instability of the dynamo-electric current that its application to electric illumination has been retarded, and that magneto-electric machines and machines producing alternating currents have been again used, although they are inferior to the dynamo machine in the current energy produced for a given expenditure of mechanical energy.

The properties of dynamo-electric machines have been examined by several observers. Messrs. Houston and Thomson (Franklin Institute) compared the efficiency of the Gramme, Brush, and Wallace Farmer machines. Dr. Hopkinson (Institution of Mechanical Engineers, 25th April, 1879) examined a medium-sized Siemens machine, determined its efficiency, and expressed the electro-motive force as a function of the current. Herrn Mayer and Anerbach (*Wiedmann's Annalen*, November, 1879) and M. Mascart have experimented on the Gramme machine, and Mr. Schwendler on both Gramme and Siemens machines.

The radical defect of the dynamo machine of ordinary construction, may be inferred from the results of these experiments. The remedy has, however, been in our hands from the time of the first announcement of the principle of these machines before the Royal Society, when Sir Charles Wheatstone pointed out that " a very remarkable increase of all the ef-

fects, accompanied by a diminution in the resistance of the machine, is observed when a cross wire is placed so as to divert a great portion of the current from the electro magnet."

Some of the constructors of dynamo machines, namely: Mr. Ladd in this country, and Mr. Brush in the United States of America, have taken advantage of this suggestion, the latter with the avowed object in view of obviating spontaneous changes of polarity in effecting electro precipitation of metals, and without perhaps having realized all of the advantages of which this mode of action is capable; others have refrained from doing so on account of difficulties resulting, as I shall endeavor to show, from an insufficient examination into some important physical conditions that require attention in order to realize economical results.

An ordinary medium-sized Siemens-Alteneck dynamo-electrical machine has wound on its rotating helix insulated copper wire of 2.5 m.m. diameter in 24 sections, representing a resistance of .4014

S. U.* The four electro-magnet coils
connected seriatim are composed of cop-
per wire of 5.5 m.m. diameter, presenting
a total resistance of 0.3065 S. U.

If (as has frequently been done) the
wires of this machine were to be con-
nected as suggested in Sir Charles Wheat-
stone's original paper, thus making the
outer circuit not continuous with but
parallel to the coil circuit, and if the outer
circuit had a resistance of one unit, it
would follow that the total resistance
to the current set up by the rotation of
the armature would be reduced from

$$.4 + .3 + 1. = 1.7 \text{ to } .4 + \frac{.3 \times 1}{1 + .3} = 0.61 \text{ unit,}$$

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\* The resistance coils used in these experiments were
graduated according to the mercury system introduced
by Dr. Werner Siemens, and adopted by the Tele-
graphic Convention at Vienna in 1868. The B. A. unit
was determined in 1874 by Kohlrausch to be 1.0498
S. U., or combined with Lorenz's value of the S. U.
afterwards adopted, $0.9797 \times 10^9$ C.G. S. units—as much
as 2 per cent. below its ascribed theoretical value.
Later determinations by H. F. Weber (Phil. Mag.,
March, 1878) makes the S. U. to be equal to $0.955 \times 10^9$
C. G. S. units, and thus the Ohm to be 0.2 per cent.
higher than its ascribed value; if this latter value is
used, the numerical results must be correspondingly
altered.

causing a great increase of current, the major portion (in the proportion of 10 to 4) would flow through the electro magnets, thus causing a great increase of heating effect. The resistance of the field magnet must therefore be greatly increased, but if it were attempted to increase that resistance simply by reducing the diameter of the wire, and increasing the number of convolutions until the same thickness of coil was obtained, the magnetic excitement and with it the electro-motive force of the current produced at a given velocity of rotation would suffer a material decrease. The current flowing through the helix coil would moreover have to divide itself, and in order to reach the same limit in the outer circuit its intensity in the helix coil would have to be increased, causing it to heat more readily than before. It was necessary, therefore, to raise the effect of the magnet current to the same level as before with as small a proportion of the helix current as possible, in order to leave a maximum proportion of the current for

the outer circuit. In order to effect this, the magnet bars had to be increased in length, and placed further apart so as to provide room for coils of greatly increased weight and dimensions; at the same time the helix wire had to be increased in diameter to give room for the aggregate current, but in reality I found it advantageous to increase the diameter of the same in a much greater proportion.

These general conditions having been determined by preliminary experiment, Mr. Lauckert, electrician engaged at my works, undertook a series of comparative experiments which are given in the appendix attached to this paper, and the results are given numerically and exhibited in curves. On examining the curves it will be remarked:

1. That the electro-motive force instead of diminishing with increased resistance, increases at first rapidly, then more slowly towards an asymptote.

2. That the current in the outer circuit is actually greater for a unit and a-half resistance than for one unit.

3. With an external resistance of one unit, which is about equivalent to an electric arc when 30 or 40 webers are passing through ₁it, 2.44 horse power is expended, of which 1.29 horse power is usefully employed; an efficiency of 53 per cent, as compared with 45 per cent. in the case of the ordinary dynamo machine.

4. That the maximum energy which can be demanded from the engine is 2.6 horse power, so that but a small margin of power is needed to suffice for the greatest possible requirement.

5. That the maximum energy which can be injuriously transferred into heat in the machine itself is 1.3 horse power, so that there is no fear here of destroying the insulation of the helix by excessive heating.

6. That the maximum current is approximately that which would be habitually used, and which the commutator and collecting brushes are quite capable of transmitting.

Hence I conclude that the new machine will give a steadier light than the old one,

with greater average economy of power, that it will be less liable to derangement, and may be driven without variation of speed by a smaller engine; also that the new machine is free from the objection of having its currents reversed when used for the purpose of electro deposition.

The same peculiarity also enables me to effect an important simplification of the regulator to work electric lamps, to dispense with all wheel and clock-work in the arangement, as shown in Fig. 1. The two carbons, being pushed onward by gravity or spring power, are checked laterally by a pointed metallic abutment, situated at such a distance from the arc itself that the heat is only just sufficient to cause the gradual wasting away of the carbon in contact with atmospheric air. The carbon holders are connected with the iron core of a solenoid coil, of a resistance equal to about fifty times that of the arc, the ends of whrch coil are connected with the two electrodes respectively. The weight of the core, which has
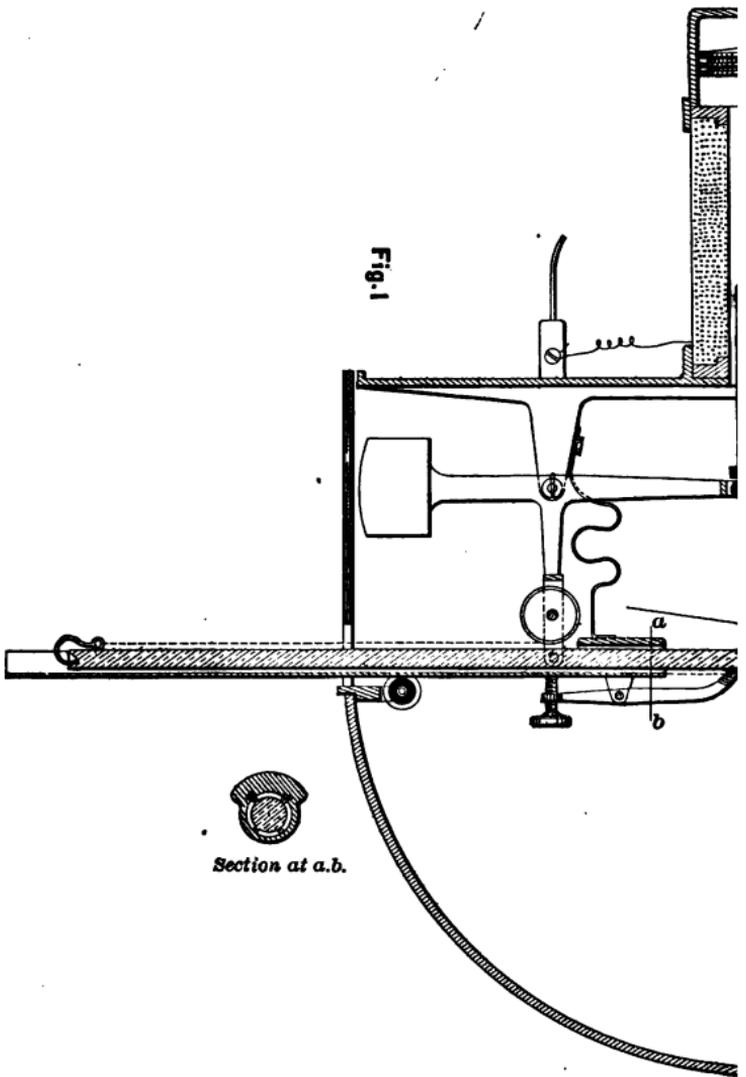
Fig.1

Section at a.b.
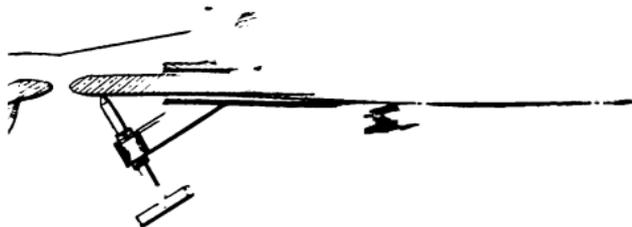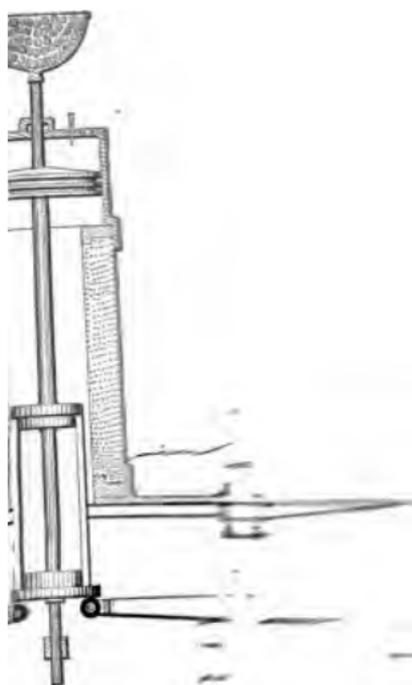
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to be maintained in suspension by the
attractive force produced by the current,
determines the distance between the
electrodes, and hence the electric resist-
ance of the arc. The result is that the
length of the arc is regulated automati-
cally so as to maintain a uniform resist-
ance, signifying a uniform development of
light.

### APPENDIX.

The measurements of the electric cur-
rents were made with an electro dyna-
mometer, the movable part of which con-
sisted of a single turn of 4 m.m. wire, and
the stationary coil of nine turns of the
same.

To be able to reduce the electrical
measurements into absolute power devel-
oped, it was in the first place necessary to
determine the constant of the instrument
in use. This was done in the following
manner: Five copper plates of about
$11'' \times 8''$ were connected as shown in the
sketch.
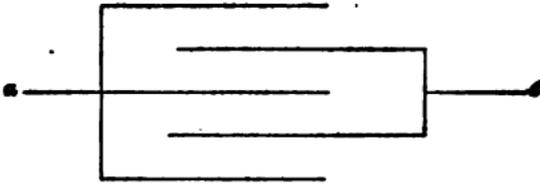
These were carefully weighed and immersed in a solution of sulphate of copper. The machine was previously started, the time of immersion carefully noted, and the readings of the current taken every half minute. The plates were so arranged that the current entering at $a$ and leaving at $z$ deposited the copper on both sides of the plate at $z$. After a certain time the plates were taken out, quickly rinsed in water, and dried in sawdust. The plates were then carefully weighed again and the deposit calculated per degree reading on the instrument per second of time. Six independent measurements were taken with currents varying from 20 to 40 webers, and gave a mean of .000779 gramme of copper per second per degree reading. The differences of these measurements from the mean varied from 0.21

per cent. to 6.6 per cent., the mean of the differences being 1.98 per cent.

According to F. Kohlrausch (Pogg. Ann., Bd. cxlix, 1873) the quantity of silver deposited by the C. G. S. unit of electricity is 0.011363 gramme, and since the quantities vary as the equivalents of the metals deposited, we have

$$\frac{.011363 \times 63.5}{216} = 0.003340$$

gramme of copper.

One weber being $\frac{1}{10}$ C. G. S. unit, we have to divide by 10 the quantity of copper deposited by a current of one weber in one second, that is .000334 gramme, and dividing .000779 by .000334 we get 2.23323 webers for a degree reading of our instrument.

To be able to compare the machines having the new winding (*i. e.*, the wire on the electro magnets connected parallel with the outer circuit) with the ordinary machines, it was necessary to experiment on the relation existing between the power expended and the current produced with

different resistances in circuit and different speeds.

A medium dynamo machine with 24 part commutator was used, the helix being wound with 336 convolutions of 2.5 m.m. wire, having a resistance of .4014 S. U. when measured in the machine. The electro magnets were wound with four layers of 5.5 m.m. wire, each having 32 convolutions, and therefore the four bobbins a total of 512 convolutions with a resistance of .3065 S. U.

The accompanying Tables Nos. 5, 6, 7, 8, and 9 give the details of the experiments made, which are shown graphically in the diagrams similarly numbered. The current in webers was simply calculated by multiplying the square root of the reading on the electro dyamometer with the constant of the instrument, i. e., 2.3323.

To be able to calculate the electromotive force from the current in webers and resistance in Siemens' units, it was necessary to convert the S. U. into C.G.S. units by multiplying the same by .9337 ×

10°. (This figure is given by Lorenz, Pogg. Ann., Bb., cxlix., 1873.) By again multiplying this resistance into the current we get, according to Ohm's law, the electro-motive force in C. G. S. units, and by dividing by $10^{8}$ we get the E. M. F. in volts.

I have further calculated the total amount of work developed in the following manner :

Work done$=E \times C \times t$, or, which is the same, $C^{2} \times R \times t$, where E is E. M. F ; C, current; R, resistance ; $t$, time.

From these calculations $t$ is eliminated as it occurs in all the equations.

1 volt$=10^{8}$ C. G. S. units.

1 weber$=\frac{1}{10}$ C. G. S. unit of current.

1 HP.$=7.46 \times 10^{9}$ C. G. S. units.

Therefore

$$\frac{1 \text{ volt} \times 1 \text{ weber}}{1 \text{ HP.}} = \frac{10^{8} \times 10^{-1}}{7.46 \times 10^{9}} = \frac{1}{746}$$

and if we multiply the E. M. F. in volts by the current in webers, and divide by 746, we have the actual work developed in horse power.

To find the actual work done in the outside resistance we use the formula $C^2 \times R$, of course having to reduce the resistance R into absolute C. G. S. units by multiplying by $.9337 \times 10$.

The machine with the new winding had a helix with 24 part commutator wound with 312 convolutions of 2.8 m.m. wire.

The electro-magnets being lengthened by 2″ to take bobbins $10\frac{1}{2}$″, instead of $8\frac{1}{2}$″ as on the ordinary machines, I had three sets of bobbins made, and had the same wound with different sizes of wire, viz.: 2.5 m.m., 2.8 m.m., and 3 m.m., having a respective resistance of 11.26, 7.563, and 4.46 S. U.

The accompanying Tables Nos. 1, 2, 3, and 4 show the experiments made with this machine with electro-magnets of 11.26 S. U. resistance; Nos. 10, 11, 12, and 13 with electro-magnets of 7.563 S. U.; and Nos. 14 and 15 with electro-magnets of 4.46 S. U. The helix in all cases having been wound with 2.8 m.m. wire with a resistance of .234 S. U. when measured in the machine.

The Tables marked 5, 6, 7, 8, and 9 refer to the dynamo machine wound in the ordinary way.

The Tables marked 16, 17, 18, 19, 20, 21, 22, and 23 show the results obtained with a machine having a helix wound with 288 convolutions of 3 m.m. wire and a resistance of .173 S. units. The electromagnets, as before, had a resistance of 11.26, 7.563, and 4.47 S. U.

No. 1.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .284 S. U. resistance.
Electro-magnets: 8916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance (connected parallel to outer circuit).

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expend E | Total Developed. | Developed in outer circuit. | |
| 500 | 0.0 | .26 | 0.0 | : | : | 1.68 | : | : | .304 | .205 | .00081 | : | : |
| " | .01 | .28 | .5 | : | : | 1.63 | : | : | .3957 | : | .00084 | : | : |
| " | .05 | .28 | 1.0 | : | : | 1.63 | : | : | .6091 | : | .00190 | : | : |
| " | .10 | .34 | 1.5 | 1.0 | : | 2.83 | : | : | .9079 | : | .00848 | : | : |
| " | .25 | .43 | 2.0 | 1.5 | : | 3.86 | 2.88 | : | 1.479 | : | .0654 | : | : |
| " | .50 | .73 | 14.0 | 2.0 | 18 | 8.80 | 8.86 | 8.06 | 5.915 | .714 | .0896 | .0409 | 5.78 |
| " | .75 | .94 | 180.0 | 8.0 | 115 | 26.58 | 8.80 | 25.01 | 28.32 | 1.48 | .881 | .587 | 41.04 |
| " | 1.0 | 1.16 | 180.0 | 8.0 | 145 | 81.30 | 4.04 | 26.08 | 88.90 | 1.88 | 1.422 | .987 | 58.88 |
| " | 1.25 | 1.88 | 145.0 | 8.0 | 125 | 28.08 | 4.04 | 26.07 | 85.65 | : | 1.848 | 1.17 | 68.98 |
| " | 1.5 | 1.56 | 185.0 | 8.0 | 115 | 27.09 | 4.04 | 25.01 | 89.46 | : | 1.488 | 1.068 | 68.98 |
| " | 1.75 | 1.75 | 188.0 | 8.5 | 108 | 26.79 | 4.86 | 23.73 | 48.77 | 1.78 | 1.592 | 1.21 | 66.12 |
| " | 2.0 | 1.94 | 190.0 | 4.0 | 95 | 25.55 | 4.66 | 22.78 | 46.28 | .714 | 1.585 | 1.29 | 69.94 |
| " | ∞ | : | 5.0 | : | 0 | 5.21 | : | : | : | : | : | : | : |

## No. 2.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .234 S. U. resistance. Electro-magnets: 3916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance (connected parallel to outer circuit).

| Revolutions per minute | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 600 | 0.0 | .24 | 0 | | | 2.28 | | | 1.044 | .245 | .0098 | | |
| " | .25 | .48 | 1 | | | 5.21 | | | 8.502 | " | .0244 | | |
| " | .50 | .72 | 5 | | | 26.07 | 8.8 | 25.01 | 22.87 | " | .799 | .587 | 34.24 |
| " | .75 | .94 | 135 | 2.0 | 115 | 34.30 | 8.69 | 30.86 | 37.04 | 1.714 | 1.70 | 1.16 | 47.84 |
| " | 1.25 | 1.16 | 215 | 2.5 | 175 | 32.57 | 4.861 | 28.84 | 41.35 | 2.45 | 1.805 | 1.3 | 53.00 |
| " | 1.50 | 1.38 | 195 | 3.5 | 153 | 31.72 | 4.66 | 27.99 | 46.20 | " | 1.96 | 1.47 | 68.09 |
| " | 1.75 | 1.56 | 185 | 4.0 | 144 | 29.87 | 4.66 | 26.07 | 48.80 | 2.88 | 1.95 | 1.49 | 67.72 |
| " | 2.0 | 1.75 | 164 | 4.0 | 125 | 29.50 | 4.66 | 25.55 | 53.43 | 2.90 | 2.12 | 1.088 | 74.92 |
| " | 8 | 1.94 | 160 | 5.0 | 120 | 5.71 | 5.21 | | 65.66 | 1.10 | .508 | | |
| " | | 11.50 | 6 | | 0 | | | | | | | | |

No. 8.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .234 S. U. resistance.
Electro-magnets: 3918 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance (connected parallel to outer circuit).

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 700 | 0.0 | .24 | .. | .. | .. | 4.66 | .. | .. | 2.078 | .29 | .. | .. | .. |
| " | .25 | .48 | 4 | .. | .. | 7.74 | .. | .. | 5.208 | .. | .0129 | .. | .. |
| " | .5 | .72 | 11 | .5 | .. | 39.87 | .. | .. | 34.56 | .. | .0540 | .. | .. |
| " | .75 | .94 | 285 | 6 | 255 | 42.05 | 5.21 | 37.25 | 46.88 | 2.57 | 1.83 | 1.3 | 55.68 |
| " | 1.0 | 1.18 | 335 | 6 | 280 | 40.40 | 5.71 | 39.08 | 51.8 | 3.47 | 2.61 | 1.9 | 54.75 |
| " | 1.25 | 1.36 | 300 | 6 | 250 | 38.75 | 5.71 | 36.88 | 55.81 | .. | 2.77 | 2.18 | 61.87 |
| " | 1.5 | 1.56 | 276 | 6 | 205 | 35.87 | 5.71 | 38.39 | 57.79 | .. | 2.90 | 2.09 | 60.98 |
| " | 1.75 | 1.75 | 230 | 7 | 170 | 34.2 | 6.17 | 30.41 | 61.95 | .. | 2.74 | 2.08 | 58.50 |
| " | 2.0 | 1.94 | 215 | 10 | 158 | | 7.87 | 29.81 | 68.11 | 8.28 | 2.84 | 2.15 | 65.54 |
| " | 8 | 11.50 | 11 | | 0 | 7.74 | | | | 1.29 | .868 | | .. |

## No. 4.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .284 S. U. resistance.
Electro-magnets: 3916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance (connected parallel to outer circuit).

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 768 | 12.30 | 6.11 | 86 | 9.0 | 9 | 14.88 | 6.99 | 6.99 | 82.08 | 2.78 | 1.58 | .768 | 27.26 |
| 766 | 8.90 | 5.21 | 49 | 8.5 | 14 | 16.32 | 6.77 | 8.88 | 79.38 | 2.98 | 1.74 | .872 | 29.06 |
| 784 | 6.00 | 4.15 | 69 | 8.0 | 28 | 19.37 | 6.99 | 12.84 | 75.06 | 3.0 | 1.96 | 1.14 | 38.00 |
| 768 | 6.00 | 4.15 | 72 | 8.0 | 34 | 19.79 | 6.99 | 13.61 | 76.67 | 3.09 | 2.08 | 1.14 | 38.00 |
| 760 | 4.50 | 3.43 | 85 | 8.0 | 87 | 21.50 | 6.99 | 21.75 | 68.85 | 3.21 | 1.98 | 1.04 | 32.40 |
| 766 | 3.50 | 2.61 | 150 | 7.0 | 107 | 28.56 | 6.17 | 24.12 | 77.59 | 3.60 | 2.97 | 2.17 | 52.07 |
| 760 | 3.00 | 2.01 | 185 | 6.0 | 130 | 31.72 | 5.71 | 26.58 | 77.30 | 3.67 | 3.29 | 2.18 | 56.18 |
| 758 | 2.50 | 2.28 | 204 | 5.0 | 150 | 33.31 | 5.21 | 28.56 | 70.91 | 3.57 | 3.17 | 2.21 | 57.11 |
| 760 | 2.25 | 2.12 | 220 | .. | 157 | 35.37 | .. | 28.56 | 70.01 | 3.83 | 3.32 | 2.30 | 60.01 |
| 760 | 2.00 | 1.94 | 226 | .. | | 35.06 | .. | 29.27 | 63.51 | 3.88 | 2.99 | 2.14 | 55.15 |

No. 4.—*Continued.*

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 755 | 1.75 | 1.75 | 258 | | 180 | 37.08 | | 31.90 | 60.50 | 8.85 | 3.00 | 2.14 | 35.58 |
| 754 | 1.50 | 1.56 | 265 | | 185 | 37.25 | | 31.72 | 54.28 | 8.85 | 2.71 | 1.89 | 49.10 |
| 760 | 1.35 | 1.44 | 305 | | 240 | 41.20 | | 36.14 | 54.71 | 8.78 | 2.99 | 2.21 | 59.41 |
| 755 | 1.25 | 1.36 | 310 | | 245 | 41.06 | | 36.50 | 52.14 | 8.70 | 2.99 | 2.08 | 56.48 |
| 764 | 1.10 | 1.24 | 315 | | 260 | 41.20 | | 37.61 | 47.70 | 8.71 | 2.63 | 1.94 | 51.87 |
| 766 | 1.00 | 1.10 | 315 | | 264 | 40.73 | | 37.89 | 44.68 | 8.59 | 2.46 | 1.80 | 51.01 |
| 760 | .90 | 1.07 | 285 | | 288 | 38.87 | | 37.96 | 39.68 | 8.06 | 2.07 | 1.46 | 50.01 |
| 768 | .80 | .99 | 285 | | 305 | 35.75 | | 35.96 | 33.04 | 2.50 | 1.68 | 1.12 | 47.71 |
| 766 | .75 | .94 | 208 | | 185 | 38.64 | | 35.80 | 29.08 | 2.48 | 1.88 | .98 | 44.80 |
| 760 | .65 | .85 | 98 | | 87 | 28.09 | | 31.80 | 29.52 | 1.08 | .567 | .667 | 37.00 |
| 700 | .60 | .81 | 50 | | 45 | 16.49 | | 21.75 | 18.38 | 1.08 | .275 | .184 | 35.64 |
| 758 | .55 | .78 | 18 | | 25 | 12.77 | | 15.64 | 12.47 | .46 | .155 | .094 | 17.08 |
| : | .40 | .65 | 5 | 12.00 | 10 | 8.07 | | 11.68 | 9.07 | | .089 | .084 | 21.86 |
| : | 8 | 11.50 | 12 | | 4 | 5.21 | 8.07 | 7.87 | 6.38 | | .0221 | .0109 | 7.89 |
| | | | | | : | 8.07 | | 4.66 | 8.16 | | .987 | | 2.87 |
| | | | | | | | | | 86.64 | | | | |

**No. 5.**

Helix: 24 part commutator, 396 convolutions, 2.5 m.m. wire, .4014 S. U. resistance.
Electro-magnets: 512 convolutions, 5.5 m.m. wire, .3065 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dyna-mometer. | Current in webers. | E. M. F. in volts. | Horse power. | | | Percentage of energy turned into useful work. |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | In outer circuit. | Total in circuit. | | | | Expended. | Total developed. | Developed in outer circuit. | |
| 750 | 8.9 | 9.61 | : | 2.88 | 20.90 | .806 | .0058 | .0605 | 19.77 |
| " | 6.0 | 6.71 | 1 | " | 14.59 | " | .0455 | .0408 | 18.88 |
| " | 4.5 | 5.21 | 1 | " | 11.88 | " | .0858 | .0808 | 10.00 |
| 745 | 4.5 | 4.21 | 7 | 6.17 | 84.25 | .804 | .905 | .167 | 54.98 |
| 780 | 8.25 | 8.96 | 16 | 9.88 | 84.46 | .680 | .490 | .858 | 56.90 |
| 708 | 8.0 | 8.71 | 28 | 11.89 | 41.18 | .778 | .656 | .531 | 68.70 |
| 750 | 2.75 | 8.46 | 40 | 14.75 | 47.65 | 1.284 | .942 | .749 | 61.19 |
| 740 | 2.5 | 8.20 | 68 | 18.95 | 56.62 | 1.660 | 1.44 | 1.12 | 67.67 |
| 756 | 2.25 | 2.96 | 85 | 21.50 | 59.49 | 2.16 | 1.71 | 1.80 | 60.12 |
| 774 | 2.0 | 2.71 | 120 | 25.55 | 64.65 | 2.69 | 2.21 | 1.68 | 60.59 |
| 708 | 1.75 | 2.46 | 165 | 29.96 | 68.81 | 8.45 | 2.76 | 1.97 | 57.10 |
| 786 | 1.5 | 2.21 | 215 | 84.20 | 70.57 | 8.90 | 8.28 | 8.20 | 56.41 |
| 710 | 1.25 | 1.96 | 260 | 87.61 | 68.80 | 4.85 | 8.47 | 2.21 | 50.80 |
| 784 | 1.0 | 1.71 | 380 | 42.87 | 67.65 | 5.02 | 8.81 | 2.85 | 44.88 |
| 798 | .9 | 1.61 | 520 | 58.17 | 79.92 | 6.16 | 5.60 | 8.16 | 51.29 |
| " | .8 | 1.51 | 570 | 55.67 | 78.49 | 6.91 | 5.86 | 8.10 | 44.87 |
| " | .75 | 1.46 | 625 | 58.81 | 79.48 | 6.91 | 6.21 | 8.19 | 46.16 |

No. 6.

Helix: 24 part commutator, 336 convolutions, 2.5 m.m. wire, .4014 S. U. resistance.
Electro-magnets: 512 convolutions, 5.5 m.m. wire, .3065 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | Current in webers. | E. M. F. in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | | | | Expended. | Total developed. | Developed in outer circuit. | |
| 500 | 3.5 | 3.71 | 1.5 | 2.86 | 9.90 | .257 | .0879 | .0007 | 7.58 |
| 496 | 3.0 | 3.21 | 2 | 3.29 | 9.86 | .405 | .1484 | .0888 | 6.568 |
| 505 | 2.5 | 2.71 | 9 | 6.99 | 17.08 | .515 | .185 | .128 | 21.07 |
| 516 | 2.0 | 2.46 | 42 | 15.11 | 34.70 | .579 | .708 | .500 | 62.81 |
| 520 | 1.75 | 2.21 | 60 | 18.08 | 37.28 | .796 | .902 | .612 | 51.00 |
| 490 | 1.5 | 1.96 | 120 | 25.55 | 46.75 | 1.20 | 1.61 | 1.08 | 56.04 |
| 496 | 1.25 | 1.71 | 180 | 31.80 | 49.97 | 1.88 | 2.00 | 1.28 | 58.47 |
| 490 | 1.0 | 1.56 | 245 | 38.50 | 53.16 | 1.88 | 2.60 | 1.43 | 50.71 |
| 490 | .85 | 1.46 | 280 | 39.03 | 53.20 | 2.80 | 2.78 | 1.43 | 46.48 |
| 504 | .75 | 1.36 | 330 | 41.72 | 52.97 | 2.80 | 2.96 | 1.41 | 45.79 |
| 502 | .65 | 1.31 | 340 | 43.01 | 52.00 | 3.08 | 3.08 | 1.39 | 38.88 |
| " | .60 | 1.26 | 385 | 43.94 | 51.70 | 3.58 | 3.04 | 1.33 | 38.88 |
| " | .55 | 1.21 | 420 | 45.76 | 51.77 | 3.58 | 3.17 | 1.25 | 37.15 |
| 488 | .50 | 1.16 | 491 | 47.80 | 53.49 | 3.78 | 3.38 | 1.29 | 34.92 |
| " | .45 | 1.11 | 510 | 51.68 | 52.10 | 3.98 | 3.70 | 1.88 | 34.13 |
| " | .40 | 1.06 | 600 | 52.66 | 53.89 | 4.08 | 3.66 | 1.21 | 38.49 |
| " | .35 | 1.01 | 630 | 57.12 | 53.89 | 4.28 | 4.12 | 1.22 | 29.65 |
| " | .30 | .96 | | 58.54 | 52.46 | 4.58 | 4.11 | 1.07 | 28.51 |
| " | .25 | | | | | | | | 23.88 |

No. 7.

Helix: 24 part commutator, 336 convolutions, 2.5 m.m. wire, .4014 S. U. resistance.
Electro-magnets: 512 convolutions, 5.5 m.m. wire, .3065 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dyna-mometer. | Current in webers. | E. M. F. in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | | | | Ex-pended. | Total developed. | Developed in outer circuit. | |
| 608 | 4.5 | 5.21 | ... | ... | ... | .246 | ... | ... | ... |
| " | 8.5 | 4.31 | ... | ... | ... | .491 | ... | ... | 8.872 |
| 580 | 3.0 | 3.71 | 1 | 2.88 | 8.07 | .602 | .0252 | .0203 | 8.81 |
| 602 | 2.5 | 3.21 | 16 | 9.88 | 27.98 | .676 | .849 | .2725 | 40.81 |
| 606 | 2.0 | 2.71 | 60 | 18.08 | 45.69 | 1.118 | 1.108 | .816 | 78.81 |
| 602 | 1.75 | 2.46 | 105 | 23.90 | 54.89 | 1.72 | 1.780 | 1.25 | 72.67 |
| 600 | 1.5 | 2.21 | 140 | 27.59 | 56.98 | 2.20 | 2.110 | 1.439 | 64.95 |
| 580 | 1.25 | 1.96 | 170 | 30.41 | 55.65 | 2.53 | 2.27 | 1.45 | 57.81 |
| 600 | 1.0 | 1.71 | 270 | 38.32 | 61.18 | 3.43 | 3.14 | 1.84 | 53.64 |
| 620 | .85 | 1.56 | 378 | 45.34 | 66.04 | 4.43 | 4.01 | 2.18 | 49.81 |
| " | .75 | 1.46 | 400 | 46.64 | 63.57 | 4.68 | 3.97 | 2.05 | 43.80 |
| " | .60 | 1.31 | 505 | 52.41 | 64.11 | 5.06 | 4.50 | 2.06 | 40.71 |

## No. 8.

Helix: 24 part commutator, 336 convolutions, 2.5 m.m. wire, .4014 S. U. resistance.
Electro-magnets: 512 convolutions, 5.5 m.m. wire, .3065 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | Current in webers. | E. M. F. in volts. | Horse power. | | | Percentage of energy turned into useful work. |
| | In outer circuit. | Total in circuit. | | | | Expended. | Total developed. | Developed in outer circuit. | |
|---|---|---|---|---|---|---|---|---|---|
| 715 | 4.5 | 5.21 | : | : | : | .365 | .114 | .095 | 22.25 |
| 698 | 3.5 | 4.21 | 4 | 4.66 | 18.39 | .427 | .550 | .439 | 30.00 |
| 700 | 3.0 | 3.71 | 21 | 10.69 | 37.03 | 1.48 | 1.00 | .663 | 43.80 |
| 710 | 2.5 | 3.21 | 50 | 16.49 | 49.49 | 1.59 | 1.94 | 1.43 | 54.16 |
| 680 | 2.0 | 2.71 | 105 | 23.91 | 60.50 | 2.64 | 2.76 | 1.98 | 50.25 |
| 680 | 1.75 | 2.46 | 165 | 29.96 | 68.11 | 2.94 | 3.16 | 2.14 | 54.87 |
| 708 | 1.5 | 2.21 | 210 | 33.80 | 69.75 | 3.90 | 3.60 | 2.80 | 51.45 |
| 685 | 1.25 | 1.96 | 270 | 38.32 | 70.18 | 4.47 | 4.48 | 2.59 | 51.99 |
| 688 | 1.0 | 1.71 | 380 | 45.46 | 72.58 | 5.04 | 5.14 | 3.18 | 49.92 |
| 720 | .85 | 1.56 | 550 | 54.69 | 79.66 | 6.46 | 6.16 | 8.16 | 46.74 |
| " | .75 | 1.46 | 680 | 58.07 | 79.16 | 6.76 | 6.07 | 8.16 | 39.43 |
| " | .60 | 1.31 | 680 | 60.88 | 74.41 | 7.05 | | 2.78 | 39.68 |
| " | .50 | 1.21 | 900 | 69.97 | 79.05 | 7.72 | 7.42 | 8.06 | |

No. 9.

Helix: 24 part commutator, 336 convolutions, 2.5 m.m. wire, .4014 S. U. resistance.
Electro-magnets: 512 convolutions, 5.6 m.m. wire, .3065 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | Current in webers. | E. M. F. in volts. | Horse power. | | | Percentage of energy turned into useful work. |
| | In outer circuit. | Total in circuit. | | | | Expended. | Total Developed. | Developed in outer circuit. | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 450 | 1 | 1.71 | 100 | 28.38 | 37.24 | 1.56 | 1.16 | .681 | 48.66 |
| 500 | " | " | 145 | 28.08 | 44.84 | 2.14 | 1.69 | .987 | 46.12 |
| 550 | " | " | 190 | 32.14 | 51.83 | 2.69 | 2.21 | 1.29 | 47.98 |
| 600 | " | " | 235 | 35.75 | 57.08 | 3.43 | 2.73 | 1.60 | 46.65 |
| 650 | " | " | 280 | 39.72 | 63.48 | 4.24 | 3.37 | 1.97 | 46.46 |
| 700 | " | " | 360 | 44.25 | 70.65 | 5.00 | 4.18 | 2.45 | 49.00 |
| 750 | " | " | 420 | 47.80 | 76.32 | 5.81 | 4.80 | 2.88 | 49.28 |
| 800 | " | " | 490 | 51.63 | 82.44 | 6.86 | 5.70 | 3.84 | 48.69 |

## No. 10.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .234 S. U. resistance.
Electro-magnets: 3200 convolutions, 2.8 m.m. wire, 7.568 S. U. resistance.

| Revolutions per minute | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 502 | ∞ | 7.8 | 18 | 18 | .5 | 8.41 | 8.41 | | 61.25 | 1.88 | .69 | | 27.98 |
| 518 | 12.0 | 4.87 | 30 | 18 | 5 | 12.77 | 8.08 | 5.21 | 58.07 | 1.47 | .994 | .409 | 30.12 |
| 517 | 10.0 | 4.54 | 35 | 12 | 7 | 18.80 | 8.08 | 6.17 | 58.50 | 1.88 | 1.082 | .476 | 34.78 |
| 530 | 9.0 | 4.34 | 43 | 10 | 9 | 15.11 | 8.08 | 7.0 | 61.23 | 1.59 | 1.261 | .552 | 35.90 |
| 498 | 7.5 | 3.90 | 40 | 10 | 10 | 14.75 | 7.87 | 7.87 | 54.95 | 1.43 | 1.086 | .510 | 40.00 |
| 501 | 6.0 | 3.51 | 49 | 8 | 15 | 15.11 | 6.60 | 9.03 | 50.36 | 1.58 | 1.020 | .612 | 44.05 |
| 500 | 4.5 | 3.05 | 50 | 7 | 22 | 16.49 | 6.17 | 10.94 | 46.96 | 1.58 | 1.086 | .674 | 47.18 |
| 510 | 3.5 | 2.68 | 75 | 7 | 35 | 20.30 | 5.71 | 18.8 | 49.41 | 1.77 | 1.388 | .884 | 49.85 |
| 508 | 2.8 | 2.08 | 83 | 6 | 43 | 21.12 | 5.71 | 15.11 | 46.88 | 1.74 | 1.389 | .897 | 45.75 |
| 507 | 2.5 | 2.11 | 90 | 6 | 49 | 23.12 | 5.71 | 16.49 | 43.88 | 1.86 | 1.392 | .861 | 56.98 |
| 508 | 2.0 | 1.81 | 130 | 6 | 50 | 25.55 | 5.71 | 21.5 | 49.5 | 1.95 | 1.479 | 1.11 | 58.86 |
| 495 | 1.75 | 1.65 | 140 | 5 | 85 | 27.59 | 5.71 | 22.73 | 42.5 | 1.92 | 1.572 | 1.18 | 55.78 |
| 492 | 1.5 | 1.49 | 160 | 4 | 95 | 29.50 | 5.21 | 24.46 | 40.77 | 2.01 | 1.612 | 1.19 | 55.09 |
| 504 | 1.25 | 1.30 | 190 | 4 | 110 | 32.14 | 4.66 | 27.59 | 39.01 | 2.16 | 1.061 | 1.16 | 51.10 |
| 506 | 1.1 | 1.19 | 205 | 4 | 140 | 33.89 | 4.66 | 29.21 | 37.12 | 2.27 | 1.611 | 1.05 | 50.88 |
| 512 | 1.0 | 1.11 | 200 | 4 | 157 | 33.98 | 4.66 | 29.03 | 34.18 | 2.09 | 1.511 | 1.04 | 58.05 |
| 505 | .85 | .998 | 225 | 4 | 155 | 34.98 | 4.66 | 31.80 | 32.60 | 1.98 | 1.628 | .984 | 49.95 |
| 510 | .75 | .917 | 220 | 4 | 180 | 34.60 | 4.66 | 31.55 | 39.68 | 1.97 | 1.374 | .490 | 33.70 |
| 507 | .6 | .790 | 160 | 8 | 120 | 29.50 | 4.04 | 25.55 | 21.77 | 1.45 | .961 | | |

No. 11.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, 234 S. U. resistance.
Electro-magnets: 3200 convolutions, 2.8 m.m. wire, 7.563 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 596 | .8 | .53 | 8 | 1 | 8 | 4.04 | 2.88 | 4.04 | 1.962 | .24 | .0108 | .00618 | 2.554 |
| 596 | .4 | .61 | 4 | 1 | 8 | 4.66 | 2.88 | 4.04 | 2.655 | .24 | .0108 | .00817 | 8.404 |
| 612" | .5 | .70 | 90 | 1 | 28 | 12.77 | 2.88 | 11.59 | 8.34 | .875 | .148 | .0894 | 28.87 |
| 630 | .6 | .70 | 180 | 2 | 180 | 31.30 | 3.30 | 31.30 | 23.08 | .97 | .968 | .736 | 41.68 |
| 615" | .7 | .79 | 215 | 3 | 240 | 34.90 | 4.04 | 36.14 | 25.83 | 1.77 | 1.16 | 1.14 | 50.44 |
| 600 | .75 | .87 | 280 | 4 | 250 | 39.08 | 4.66 | 36.50 | 31.71 | 2.26 | 1.66 | 1.28 | 51.50 |
| 612" | .85 | .917 | 300 | 4 | 245 | 40.40 | 4.66 | 35.75 | 34.59 | 2.51 | 1.87 | 1.42 | 55.85 |
| 596 | 1.0 | .998 | 290 | 6 | 235 | 39.72 | 5.17 | 33.80 | 37.08 | 2.671 | 1.97 | 1.60 | 55.74 |
| 615 | 1.25 | 1.11 | 305 | 7 | 210 | 39.72 | 6.17 | 33.30 | 42.21 | 2.87 | 2.56 | 1.60 | 62.98 |
| 630 | 1.5 | 1.30 | 290 | 8 | 160 | 36.87 | 6.60 | 29.50 | 43.29 | 2.88 | 2.56 | 1.68 | 68.00 |
| 625" | 2.0 | 1.48 | 290 | 10 | 120 | 36.57 | 7.34 | 25.55 | 46.88 | 2.81 | 2.40 | 1.68 | 56.40 |
| 630 | 3.0 | 1.81 | 195 | 12 | 65 | 26.58 | 8.06 | 18.80 | 55.05 | 2.99 | 2.10 | 1.88 | 50.00 |
| | 4.5 | 2.88 | 105 | 14 | 33 | 21.50 | 8.08 | 13.19 | 59.07 | 2.66 | 1.76 | .98 | 42.61 |
| | 6.0 | 8.05 | 85 | 15 | 22 | 19.51 | 9.08 | 10.94 | 61.28 | 2.80 | 1.71 | .868 | 41.87 |
| 630 | 7.5 | 8.99 | 55 | 16 | 16 | 17.39 | 9.38 | 9.38 | 64.43 | 1.69 | 1.49 | .817 | 42.83 |

## No. 12.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .234 S. U. resistance.
Electro-magnets: 3200 convolutions, 2.8 m.m. wire, 7.563 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 700 | 7.5 | 4.01 | 80 | 18 | 18 | 20.86 | 0.89 | 9.69 | 78.10 | 2.57 | 2.18 | .018 | 85.79 |
| :: | 6.0 | 3.59 | 90 | 17 | 25 | 20.86 | 0.63 | 11.68 | 69.98 | 2.57 | 1.95 | 1.08 | 89.69 |
| 707 | 4.5 | 3.08 | 95 | 16 | 35 | 22.78 | 0.33 | 13.80 | 64.94 | 2.88 | 1.97 | 1.07 | 87.15 |
| 710 | 3.0 | 2.89 | 105 | 14 | 90 | 29.98 | 8.88 | 22.12 | 66.85 | 8.19 | 2.68 | 1.84 | 57.67 |
| 704 | 2.5 | 2.12 | 196 | 12 | 115 | 32.57 | 8.08 | 25.01 | 64.47 | 8.59 | 2.81 | 1.96 | 54.59 |
| 716 | 2.0 | 1.88 | 225 | 9 | 150 | 35.75 | 7.0 | 28.56 | 60.75 | 8.94 | 2.91 | 2.04 | 51.77 |
| 728 | 1.5 | 1.49 | 315 | 7 | 280 | 41.40 | 6.17 | 34.60 | 67.00 | 4.28 | 8.80 | 2.25 | 58.57 |
| 715 | 1.25 | 1.31 | 350 | 6 | 300 | 43.04 | 5.71 | 37.61 | 63.88 | 4.28 | 8.12 | 2.21 | 63.25 |
| 722 | 1.0 | 1.12 | 385 | 5 | 305 | 45.76 | 5.21 | 40.40 | 47.85 | 4.27 | 2.98 | 2.04 | 47.77 |
| 705 | .75 | .92 | 370 | 5 | 270 | 44.86 | 5.21 | 40.73 | 88.58 | 8.45 | 2.81 | 1.56 | 45.31 |
| 708 | .60 | .80 | 300 | 5 | 100 | 40.40 | 5.21 | 38.52 | 80.18 | 8.20 | 1.68 | 1.10 | 46.08 |
| 716 | .50 | .71 | 150 | 4 | | 29.56 | 4.0; | 28.82 | 18.04 | .282 | .725 | .34 | 11.64 |
| 710 | .40 | .63 | 7 | 1 | 7 | 6.17 | 2.38 | 6.17 | 8.571 | .820 | .295 | .019 | 6.562 |

Helix: 24 part commutator, 812 convolutions, 2.8 m.m. wire, .284 S. U. resistance.
Electro-magnets: 8200 convolutions, 2.8 m.m. wire, 7.568 S. U. resistance.

| Revolutions per minute | Resistance in S. U. | | Reading on electro-dynamometer | | | Current in webers | | | E.M.F. in helix in volts | Horse power | | | Percentage of energy turned into useful work |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit | Total in circuit | Helix | Electro-magnet | Outer circuit | Helix | Electro-magnet | Outer circuit | | Expended | Total developed | Developed in outer circuit | |
| 450 | 1.0 | 1.12 | 140 | | 105 | 37.59 | | 28.91 | 28.85 | 1.47 | 1.08 | .715 | 49.68 |
| 500 | " | " | 185 | | 150 | 31.72 | | 28.56 | 33.16 | 1.94 | 1.41 | 1.08 | 55.57 |
| 550 | " | " | 250 | | 195 | 36.86 | | 38.57 | 38.56 | 2.47 | 1.91 | 1.38 | 58.55 |
| 600 | " | " | 335 | | 260 | 42.05 | | 37.61 | 43.97 | 3.08 | 2.48 | 1.77 | 57.84 |
| 650 | " | " | 400 | | 305 | 46.64 | | 40.73 | 48.77 | 3.71 | 3.05 | 2.08 | 56.05 |
| 700 | " | " | 470 | | 350 | 50.56 | | 45.44 | 52.87 | 4.43 | 3.56 | 2.69 | 51.76 |
| 750 | " | " | 580 | | 395 | 55.99 | | 48.66 | 56.14 | 5.30 | 4.36 | 2.89 | 53.28 |
| 800 | " | " | 640 | | 460 | 58.99 | | 50.08 | 61.69 | 5.88 | 4.88 | 3.18 | 54.06 |
| 850 | " | " | 700 | | 510 | 61.89 | | 55.67 | 64.51 | 6.43 | 5.88 | 3.47 | 55.59 |
| 900 | " | " | 735 | | 570 | 65.83 | | 58.41 | 68.31 | 6.48 | 5.87 | 3.44 | 58.56 |
| 850 | " | " | 700 | | 505 | 61.89 | | 52.41 | 64.51 | 5.71 | 5.39 | 3.99 | 51.68 |
| 800 | " | " | 600 | | 440 | 57.12 | | 46.98 | 59.73 | 4.90 | 3.99 | 2.53 | 54.86 |
| 750 | " | " | 510 | | 372 | 52.66 | | 44.98 | 55.07 | 4.14 | 3.85 | 2.35 | 53.88 |
| 700 | " | " | 440 | | 330 | 48.66 | | 43.82 | 51.15 | 3.45 | 2.67 | 1.84 | 53.19 |
| 650 | " | " | 350 | | 270 | 43.64 | | 38.82 | 45.68 | 2.88 | 2.18 | 1.5 | 53.88 |
| 600 | " | " | 295 | | 220 | 39.47 | | 34.60 | 41.27 | 2.24 | 1.87 | 1.38 | 54.91 |
| 550 | " | " | 240 | | 180 | 36.14 | | 31.80 | 37.79 | 1.78 | | .918 | 53.08 |
| 500 | " | " | 180 | | 135 | 31.80 | | 27.09 | 33.73 | 1.28 | 1.08 | .681 | 53.20 |
| 450 | " | " | 135 | | 100 | 27.09 | | 28.82 | 28.88 | | | | |

No. 14.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .294 S. U. resistance.
Electro-magnets: 2240 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. In outer circuit. | Resistance in S. U. Total in circuit. | Reading on electro-dynamometer. Helix. | Reading on electro-dynamometer. Electro-magnet. | Reading on electro-dynamometer. Outer circuit. | Current in webers. Helix. | Current in webers. Electro-magnet. | Current in webers. Outer circuit. | E. M. F. in helix in volts. | Horse power. Expended. | Horse power. Total developed. | Horse power. Developed in outer circuit. | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 505 | 8.0 | 4.70 | 98 | 28 | .. | 11.19 | 11.19 | .99 | 49.01 | 1.84 | .788 | .498 | 24.18 |
| 510 | 7.0 | 2.98 | 55 | .. | 9 | 17.29 | .. | 8.08 | 47.79 | 1.77 | 1.11 | .490 | 28.16 |
| 502 | 6.0 | 2.8 | 60 | 18 | 12 | 18.06 | 9.89 | 8.88 | 47.21 | 1.74 | 1.14 | .498 | 28.88 |
| 508 | 5.0 | 2.48 | 65 | 16 | 14 | 18.80 | 9.88 | 9.82 | 45.64 | 1.74 | 1.16 | .489 | 28.60 |
| 492 | 4.5 | 2.08 | 85 | 15 | 16 | 18.80 | 8.88 | 9.82 | 45.58 | 1.71 | 1.10 | .817 | 28.60 |
| " | 3.0 | 1.84 | 120 | 14 | 40 | 35.55 | .. | 14.75 | 48.48 | 1.71 | 1.08 | .908 | 47.78 |
| 515 | 2.5 | 1.68 | 125 | 10 | 58 | 26.07 | 7.87 | 16.96 | 44.79 | 1.99 | 1.57 | .958 | 45.88 |
| 494 | 2.0 | 1.88 | 145 | .. | 7 | 28.08 | .. | 10.51 | 42.47 | 2.01 | 1.60 | 1.08 | 49.88 |
| " | 1.5 | 1.22 | 180 | 9 | 100 | 31.20 | 6.90 | 28.83 | 89.75 | 2.18 | 1.67 | 1.10 | 50.74 |
| 508 | 1.25 | 1.08 | 210 | .. | 180 | 88.80 | .. | 26.58 | 88.50 | 2.40 | 1.74 | 1.16 | 50.46 |
| 518 | 1.0 | 1.06 | 280 | .. | 170 | 87.61 | 6.17 | 80.41 | 82.78 | 2.41 | 1.65 | 1.28 | 48.88 |
| 515 | 1.0 | 1.0 | 280 | 7 | 180 | 89.08 | .. | 81.80 | 88.65 | 2.87 | 2.02 | 1.25 | 51.08 |
| 506 | .9 | .93 | 280 | .. | 205 | 40.06 | 8.29 | 88.39 | 86.98 | 2.58 | 1.98 | 1.20 | 58.74 |
| 515 | .8 | .84 | 280 | 9 | 220 | 34.60 | 5.81 | 84.60 | 29.72 | 2.58 | 1.88 | 1.05 | 47.61 |
| " | .7 | .58 | 295 | 5 | 228 | 40.06 | .. | 84.75 | 81.49 | 0.71 | 1.69 | .158 | 41.67 |
| 498 | .8 | .77 | 95 | .. | 75 | 22.73 | .. | 20.20 | 11.04 | 2.18 | .880 | .817 | 81.55 |
| 510 | .5 | .69 | 280 | .. | 200 | 30.08 | .. | 82.98 | 26.06 | 2.42 | 1.47 | .715 | 87.48 |
| " | | | 275 | | 210 | 88.08 | | 88.80 | 24.02 | | 1.29 | | 89.54 |

No. 15.

Helix: 24 part commutator, 812 convolutions, 2.8 m.m. wire, .234 S. U. resistance.
Electro-magnets: 2240 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S U | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 700 | .1 | .24 | 2 | ... | ... | 8.29 | ... | ... | 1.044 | .98 | .0046 | ... | ... |
| " | .2 | .34 | 8 | ... | ... | 4.03 | ... | ... | 1.617 | .98 | .0087 | ... | ... |
| 712 | .3 | .43 | 14 | ... | 10 | 8.88 | ... | 7.87 | 4.311 | .98 | .0518 | .0204 | 7.084 |
| 698 | .4 | .52 | 15 | 4 | 12 | 9.08 | 4.66 | 8.07 | 5.143 | .98 | .0622 | .0886 | 11.84 |
| 718 | .5 | .61 | 870 | 6 | 905 | 44.86 | 5.71 | 40.73 | 28.89 | 2.61 | 1.74 | 1.04 | 89.84 |
| 715 | .6 | .69 | 510 | 15 | 870 | 52.66 | 9.08 | 44.25 | 37.86 | 8.50 | 2.67 | 1.51 | 48.14 |
| " | .75 | .77 | 570 | 18 | 380 | 55.67 | 9.89 | 44.86 | 45.74 | 4.08 | 8.41 | 1.88 | 44.86 |
| 720 | 1.0 | .88 | 680 | 21 | 385 | 53.69 | 10.69 | 42.69 | 53.14 | 4.10 | 8.88 | 2.88 | 55.61 |
| 714 | 1.25 | 1.06 | 440 | 25 | 280 | 48.83 | 10.69 | 37.61 | 55.73 | 4.08 | 8.66 | 2.21 | 54.16 |
| 708 | 1.5 | 1.22 | 410 | 32 | 215 | 47.23 | 11.68 | 34.90 | 59.97 | 4.05 | 8.80 | 2.90 | 54.88 |
| 700 | 2.0 | 1.38 | 385 | 32 | 150 | 42.05 | 13.19 | 28.56 | 63.60 | 4.00 | 8.58 | 2.04 | 51.00 |
| 712 | 3.0 | 1.62 | 280 | 50 | 80 | 35.37 | 16.65 | 20.86 | 67.04 | 8.48 | 8.18 | 1.68 | 46.88 |
| " | 8 | 2.08 | ... | ... | ... | ... | ... | ... | ... | 2.47 | ... | ... | ... |

## No. 16.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 3916 convolutions, 2 5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 612 | 0.0 | .418 | : | : | : | : | : | : | : | .25 | .018 | : | : |
| 640 | .25 | .652 | 4 | : | : | 4.68 | : | : | 2.84 | .25 | .379 | : | : |
| 635 | .5 | .876 | 97 | : | : | 22.97 | : | 22.12 | 18.8 | .25 | 1.68 | .46 | 60.6 |
| 620 | .75 | 1.09 | 220 | 2.0 | 90.0 | 34.6 | 3.8 | 32.14 | 35.21 | .76 | 1.08 | 1.29 | 52.88 |
| 630 | 1.0 | 1.29 | 225 | 8.0 | 190.0 | 34.98 | 4.04 | 32.14 | 41.18 | 2.44 | 1.98 | 1.61 | 62.64 |
| 630 | 1.25 | 1.5 | 205 | 8.5 | 190.0 | 33.89 | 4.36 | 32.14 | 46.76 | 2.57 | 2.09 | 1.8 | 68.79 |
| 635 | 1.5 | 1.69 | 185 | 8.5 | 170.0 | 31.72 | 4.36 | 30.41 | 50.05 | 2.59 | 2.13 | 1.73 | 70.88 |
| 636 | 1.75 | 1.87 | 165 | 4.0 | 145.0 | 29.96 | 4.66 | 28.06 | 52.8 | 2.46 | 2.10 | 1.68 | (5.99 |
| 638 | 2.0 | 3.88 | 68 | 6.0 | 120.0 | 19.23 | 5.71 | 25.55 | 60.69 | 2.47 | 1.56 | .98 | 47.86 |
| 628 | 4.5 | 4.29 | 43 | 7.0 | 82.0 | 15.11 | 6.16 | 13.19 | 60.52 | 2.05 | 1.22 | .66 | 34.55 |
| 624 | 6.0 | 5.17 | 33 | 7.5 | 15.0 | 13.19 | 6.39 | 9.08 | 68.67 | 1.91 | 1.18 | .321 | 39.78 |
| 635 | 9.0 | 5.78 | 25 | 7.0 | 8.5 | 11.68 | 6.16 | 9.8 | 62.49 | 1.81 | .96 | .523 | 32.28 |
| 610 | 11.0 | 11.43 | 8 | 8.0 | 7.0 | 6.6 | 6.6 | 6.16 | 70.48 | 1.62 | .028 | | |
| 614 | 8 | | | | : | | | | | 1.25 | | | : |

No. 17.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 3916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 665 | .25 | .43 | 8 | | 8 | 4.04 | | 4.04 | 1.58 | .271 | .0085 | .0051 | 1.58 |
| 670 | .5 | .632 | 80 | | 98 | 12.77 | | 12.84 | 7.74 | .547 | .182 | .095 | 17.87 |
| 665 | .75 | .875 | 245 | 2.0 | 225 | 86.50 | 8.8 | 84.98 | 89.85 | 2.04 | 1.45 | 1.14 | 55.88 |
| 660 | .85 | .963 | 265 | 2.5 | 235 | 87.25 | 8.69 | 85.75 | 83.49 | 2.29 | 1.67 | 1.86 | 59.88 |
| 640 | 1.0 | 1.09 | 290 | 3.0 | 280 | 89.72 | 4.04 | 87.61 | 40.42 | 2.61 | 2.15 | 1.77 | 67.81 |
| 645 | 1.1 | 1.17 | 273 | 3.0 | 290 | 88.47 | 4.04 | 85.37 | 42.02 | 2.63 | 2.17 | 1.72 | 65.40 |
| 650 | 1.25 | 1.33 | 250 | 3.5 | 205 | 86.98 | 4.88 | 83.39 | 44.43 | 2.65 | 2.2 | 1.74 | 65.66 |
| 645 | 1.4 | 1.43 | 235 | 4.0 | 185 | 85.75 | 4.66 | 81.72 | 47.80 | 2.63 | 2.27 | 1.76 | 66.98 |
| 650 | 1.5 | 1.5 | 225 | 4.0 | 180 | 85.22 | 4.66 | 81.3 | 49.88 | 2.58 | 2.28 | 1.84 | 73.01 |
| 660 | 1.75 | 1.69 | 200 | 4.5 | 158 | 82.98 | 4.94 | 28.84 | 53.04 | 2.56 | 2.3 | 1.88 | 71.09 |
| 660 | 2.0 | 1.87 | 190 | 5.0 | 145 | 81.3 | 5.21 | 26.08 | 54.65 | 2.43 | 2.29 | 1.97 | 81.40 |

## No. 18.

Helix · 25 parts commutator, 278 convolutions, 3 m.m. wire, 178 S. U. resistance.
Electro-magnets : 3,916 convolutions, 2.5 m.m. wire, 11 26 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in S.U. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 817 | 1.1 | 1.17 | 495 | | 360 | 48.65 | | 44.25 | 53.15 | 4.67 | 8.47 | 2.60 | 57.6 |
| 812 | 1.0 | 1.09 | 465 | | 385 | 50.29 | | 45.76 | 51.11 | 4.81 | 8.44 | 2.61 | 54.26 |
| 815 | 1.25 | 1.29 | 405 | | 335 | 46.94 | | 42.69 | 56.58 | 4.82 | 8.56 | 2.85 | 59.12 |
| 830 | 1.5 | 1.5 | 870 | 5.0 | 290 | 44.86 | 5.21 | 39.72 | 62.88 | 4.85 | 8.78 | 2.98 | 61.08 |
| 814 | 1.75 | 1.69 | 880 | 5.5 | 250 | 42.37 | 5.47 | 86.88 | 66.85 | 4.82 | 8.8 | 2.98 | 61.65 |
| 812 | 2.0 | 1.87 | 800 | | 220 | 40.40 | | 34.6 | 70.54 | 4.64 | 8.00 | 3.00 | 64.85 |
| 824 | .9 | 1.01 | 800 | | 385 | 49.47 | | 46.00 | 46.65 | 4.71 | 8.09 | 3.08 | 60.10 |
| 830 | .8 | .92 | 450 | | 890 | 49.47 | | 46.00 | 42.56 | 4.85 | 2.82 | 2.12 | 48.78 |
| 808 | .75 | .876 | 450 | | 890 | 48.38 | | 46.00 | 39.55 | 4.12 | 2.56 | 1.99 | 48.30 |
| 840 | .6 | .748 | 320 | | 215 | 34.60 | | 34.2 | 24.00 | 2.4 | 1.11 | .878 | 36.58 |
| 830 | .5 | .652 | | | 100 | | | 23.32 | | 2.37 | | .84 | 14.84 |
| 830 | .5 | .652 | 75 | | 70 | 20.20 | | 19.51 | 12.30 | 2.34 | .388 | .238 | 10.16 |

No. 19.

Helix : 24-part commutator, 288 convolutions, 3 m. m. wire, .173 S. U. resistance.
Electro-magnets : 3916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 480 | 1.0 | 1.091 | 98 | ...... | 85 | 23.09 | ...... | 21.5 | 23.83 | 1.87 | .728 | .578 | 42.19 |
| 530 | " | " | 185 | ...... | 123 | 27.09 | ...... | 25.86 | 27.60 | 1.73 | 1.00 | .887 | 48.88 |
| 602 | " | " | 223 | ...... | 195 | 34.83 | ...... | 32.57 | 35.49 | 2.33 | 1.66 | 1.38 | 57.08 |
| 670 | " | " | 290 | ...... | 250 | 39.72 | ...... | 36.88 | 40.47 | 3.14 | 2.15 | 1.7 | 54.14 |
| 744 | " | " | 390 | ...... | 320 | 46.06 | ...... | 41.72 | 46.98 | 3.95 | 2.89 | 2.18 | 55.19 |
| 800 | " | " | 455 | ...... | 380 | 49.75 | ...... | 45.46 | 50.70 | 4.73 | 3.88 | 2.59 | 54.76 |
| 864 | " | " | 515 | ...... | 430 | 52.98 | ...... | 48.86 | 53.92 | 5.64 | 3.88 | 2.93 | 51.95 |
| 911 | " | " | 585 | ...... | 490 | 56.42 | ...... | 51.68 | 57.49 | 6.32 | 4.35 | 3.34 | 52.85 |

**No. 20.**

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .173 S. U. resistance.
Electro-magnets: 3,200 convolutions, 2.8 m.m. wire, 7,563 S. U. resistance.

| Revolutions per minute. | Resistance in U.S. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 716 | 8 | 7.74 | 26 | 26.0 | | 11.89 | 11.89 | | 85.98 | 2.04 | 1.87 | 2.66 | 73.48 |
| 710 | 2.0 | 1.75 | 300 | 15.0 | 195 | 40.4 | 9.08 | 82.57 | 66.01 | 3.62 | 3.57 | 2.62 | 70.05 |
| 706 | 1.75 | 1.59 | 320 | 18.5 | 220 | 41.72 | 8.57 | 34.6 | 61.98 | 3.74 | 3.46 | 2.61 | 65.91 |
| 718 | 1.5 | 1.42 | 360 | 12.0 | 255 | 44.25 | 8.08 | 37.25 | 58.66 | 3.96 | 3.48 | 2.47 | 60.84 |
| 710 | 1.25 | 1.25 | 385 | 9.0 | 290 | 46.36 | 6.99 | 39.72 | 54.10 | 4.08 | 3.36 | 2.51 | 57.18 |
| 708 | 1.0 | 1.06 | 445 | 7.0 | 340 | 49.21 | 6.16 | 43.01 | 48.70 | 4.04 | 3.21 | 2.88 | 61.47 |
| 714 | .95 | 1.02 | 460 | 6.0 | 360 | 50.08 | 5.71 | 44.25 | 47.65 | 4.04 | 3.2 | 2.27 | 60.53 |
| 706 | .9 | .977 | 460 | | 370 | 50.08 | | 44.86 | 45.64 | 3.79 | 3.19 | 2.07 | 57.18 |
| 710 | .8 | .896 | 400 | 5.0 | 380 | 50.23 | 5.21 | 45.46 | 41.85 | 3.75 | 2.81 | 1.78 | 58.13 |
| 714 | .7 | .814 | 445 | 4.0 | 375 | 49.20 | 4.66 | 45.16 | 37.40 | 3.68 | 2.47 | 1.89 | 50.18 |
| 715 | .6 | .728 | 390 | | 340 | 46.06 | | 43.01 | 31.85 | 3.85 | 1.94 | .875 | |
| 715 | .5 | .642 | | | 230 | | | 35.87 | | 2.77 | | | |
| 710 | .5 | .642 | 205 | | 195 | 38.39 | | 82.57 | 20.02 | 1.8 | .896 | .665 | 51.15 |

No. 21.

Helix: 24 part commutator, 288 convolutions, 8 m.m. wire, .178 S. U. resistance.

Electro-magnets: 3200 convolutions, 2.8 m.m. wire, 7.563 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current on webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 408 | 1.0 | 1.06 | 170 | ... | 180 | 30.41 | ... | 26.58 | 30.10 | 1.84 | 1.23 | .884 | 65.97 |
| 532 | " | " | 235 | ... | 185 | 35.75 | ... | 31.72 | 35.88 | 1.98 | 1.69 | 1.25 | 64.81 |
| 610 | " | " | 310 | ... | 240 | 41.06 | ... | 36.14 | 40.64 | 2.61 | 2.24 | 1.64 | 68.88 |
| 678 | " | " | 365 | ... | 290 | 44.56 | ... | 39.72 | 44.10 | 3.32 | 2.63 | 1.98 | 59.64 |
| 716 | " | " | 430 | ... | 385 | 48.38 | ... | 42.68 | 47.86 | 3.79 | 3.10 | 2.33 | 60.16 |
| 798 | " | " | 510 | ... | 385 | 52.66 | ... | 45.76 | 52.12 | 4.85 | 3.67 | 2.63 | 60.48 |
| 880 | " | " | 620 | ... | 430 | 57.14 | ... | 48.86 | 56.55 | 5.08 | 4.38 | 2.98 | 57.08 |

No. 22.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 2556 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 690 | 8.0 | 4.68 | 46 | 46 | ... | 15.82 | 15.82 | ... | 68.4 | 2.67 | 1.45 | ... | 52.69 |
| 702 | 2.0 | 1.55 | 300 | 24 | 155 | 40.4 | 15.88 | 29.08 | 68.47 | 4.01 | 8.16 | 2.11 | 51.18 |
| 694 | 1.75 | 1.43 | 300 | 22 | 170 | 40.4 | 11.43 | 30.41 | 53.94 | 3.97 | 3.92 | 2.08 | 52.88 |
| 696 | 1.5 | 1.29 | 300 | 20 | 205 | 46.06 | 10.94 | 33.89 | 51.43 | 3.99 | 2.94 | 2.09 | 50.48 |
| 696 | 1.25 | 1.15 | 300 | 18 | 245 | 46.85 | 10.48 | 36.50 | 49.46 | 4.12 | 3.06 | 2.08 | 45.22 |
| 696 | 1.0 | .99 | 300 | 14 | 265 | 46.06 | 9.9 | 37.97 | 49.85 | 3.98 | 2.67 | 1.8 | 50.57 |
| 649 | .9 | .85 | 300 | 9 | 280 | 46.85 | 8.88 | 39.72 | 39.56 | 3.52 | 2.44 | 1.78 | 46.61 |
| 706 | .8 | .78 | 305 | 8 | 280 | 46.06 | 6.9 | 38.72 | 36.88 | 3.89 | 2.22 | 1.88 | 46.61 |
| 706 | .7 | .702 | 300 | 7 | 270 | 45.75 | 6.6 | 38.88 | 32.14 | 3.08 | 1.9 | 1.99 | 49.71 |
| 684 | .6 | .623 | 300 | ... | 245 | 44.25 | ... | 36.50 | 26.08 | 2.65 | 1.88 | 1.0 | 37.78 |
| 684 | .5 | .623 | 290 | ... | 160 | 39.72 | 6.16 | 29.50 | ... | 1.26 | .594 | .544 | 43.18 |
| | .5 | | ...140 | ... | ... | 27.59 | ... | ... | 16.05 | 1.23 | | | |

No. 23.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .173 S. U. resistance.
Electro-magnets, 2556 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E.M.F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 492 | 1 | 99 | 240 | 7.0 | 160 | 36.14 | 6.16 | 29.5 | 38.41 | 2.11 | 1.62 | 1.09 | 51.06 |
| 538 | " | " | 282 | 9.0 | 185 | 39.17 | 6.99 | 31.72 | 31.21 | 2.48 | 1.9 | 1.28 | 50.81 |
| 602 | " | " | 345 | 12.0 | 225 | 43.31 | 8.08 | 35.75 | 40.04 | 3.07 | 2.32 | 1.6 | 52.12 |
| 684 | " | " | 410 | 14.0 | 290 | 47.28 | 8.88 | 39.08 | 43.63 | 3.61 | 2.76 | 1.9 | 52.68 |
| 722 | " | " | 450 | 16.0 | 300 | 49.47 | 9.38 | 40.4 | 45.73 | 4.27 | 3.08 | 2.04 | 47.78 |
| 790 | " | " | 540 | 18.5 | 335 | 54.20 | 10.08 | 42.69 | 50.10 | 5.0 | 8.64 | 2.28 | 45.60 |
| 856 | " | " | 610 | 21.0 | 370 | 57.60 | 10.69 | 44.86 | 53.24 | 5.76 | 4.11 | 2.52 | 48.74 |

3166

No. 14.

Helix: 24 part commutator, 312 convolutions, 2.8 m.m. wire, .334 S. U. resistance.
Electro-magnets: 2240 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 505 | 8.0 | 4.70 | 98 | 28 | 9 | 11.19 | 11.19 | 6.99 | 49.01 | 1.84 | .786 | .408 | 24.18 |
| 510 | 6.0 | 2.98 | 55 | | 12 | 17.29 | | 8.08 | 47.79 | 1.77 | 1.11 | .490 | 28.16 |
| 502 | 5.0 | 2.8 | 60 | 18 | 14 | 18.00 | 9.89 | 8.88 | 47.21 | 1.74 | 1.14 | .498 | 28.80 |
| 503 | 4.5 | 2.6 | 65 | 16 | 16 | 18.80 | 9.08 | 9.88 | 45.64 | 1.74 | 1.10 | .489 | 28.60 |
| 492 | 8.0 | 2.08 | 120 | 15 | 40 | 25.55 | 8.08 | 14.75 | 48.48 | 1.71 | 1.66 | .817 | 47.78 |
| 515 | 2.5 | 1.84 | 125 | 14 | 68 | 26.07 | 8.40 | 16.98 | 44.79 | 1.99 | 1.57 | .902 | 45.88 |
| 494 | 2.0 | 1.68 | 145 | 18 | 100 | 28.08 | 7.87 | 19.51 | 42.47 | 1.91 | 1.60 | .958 | 49.84 |
| | 1.5 | 1.35 | 180 | 10 | 180 | 31.80 | | 28.82 | 39.75 | 2.01 | 1.67 | 1.08 | 50.74 |
| 508 | 1.25 | 1.29 | 210 | | 170 | 38.80 | 6.90 | 28.58 | 39.51 | 1.74 | 1.74 | 1.10 | 50.46 |
| 519 | 1.0 | 1.08 | 290 | 9 | 180 | 37.61 | | 30.41 | 32.78 | 2.40 | 1.65 | 1.16 | 48.88 |
| 515 | 1.0 | 1.00 | 290 | | 205 | 40.06 | 6.17 | 31.80 | 38.65 | 2.41 | 2.08 | 1.28 | 51.08 |
| 505 | .9 | .99 | 285 | 7 | 220 | 34.80 | | 38.89 | 38.98 | 2.37 | 1.98 | 1.30 | 53.74 |
| 515 | .8 | .84 | 280 | | 225 | 40.06 | | 34.00 | 29.72 | 2.58 | 1.88 | 1.05 | 57.61 |
| | .7 | .68 | 295 | 2 | 75 | 22.78 | 8.29 | 34.75 | 31.49 | 2.58 | 1.69 | .158 | 41.67 |
| 498 | .8 | .77 | 95 | 5 | 200 | 30.20 | 5.21 | 20.20 | 11.04 | 0.71 | .880 | .817 | 31.55 |
| 510 | .6 | .69 | 280 | | 210 | 38.08 | | 32.98 | 28.08 | 2.18 | 1.47 | .715 | 37.48 |
| | .5 | | 275 | | | | | 38.80 | 24.98 | 2.42 | 1.28 | | 39.54 |

## No. 15.

Helix: 24 part commutator, 812 convolutions, 2.8 m.m. wire, .234 S. U. resistance.
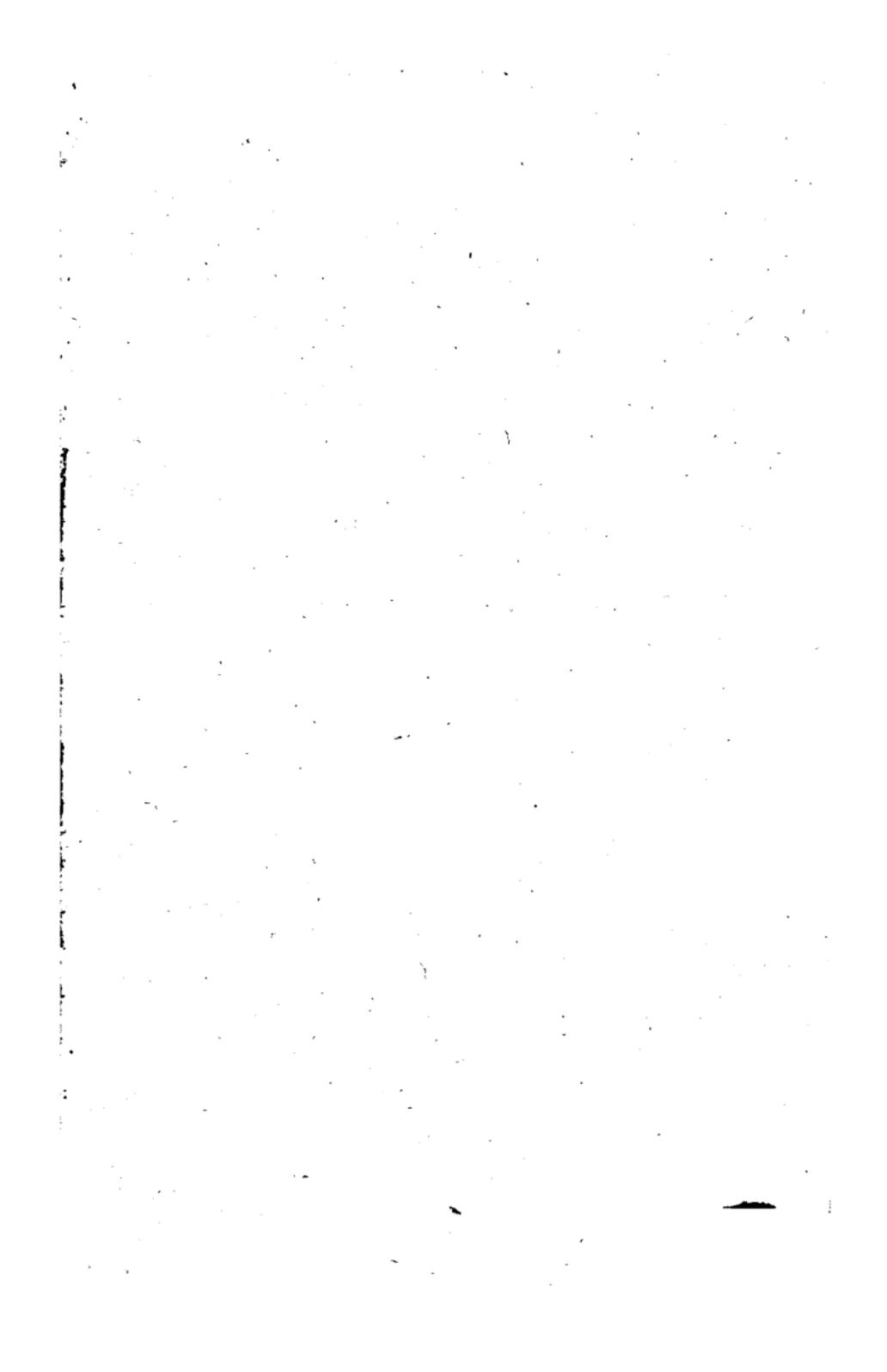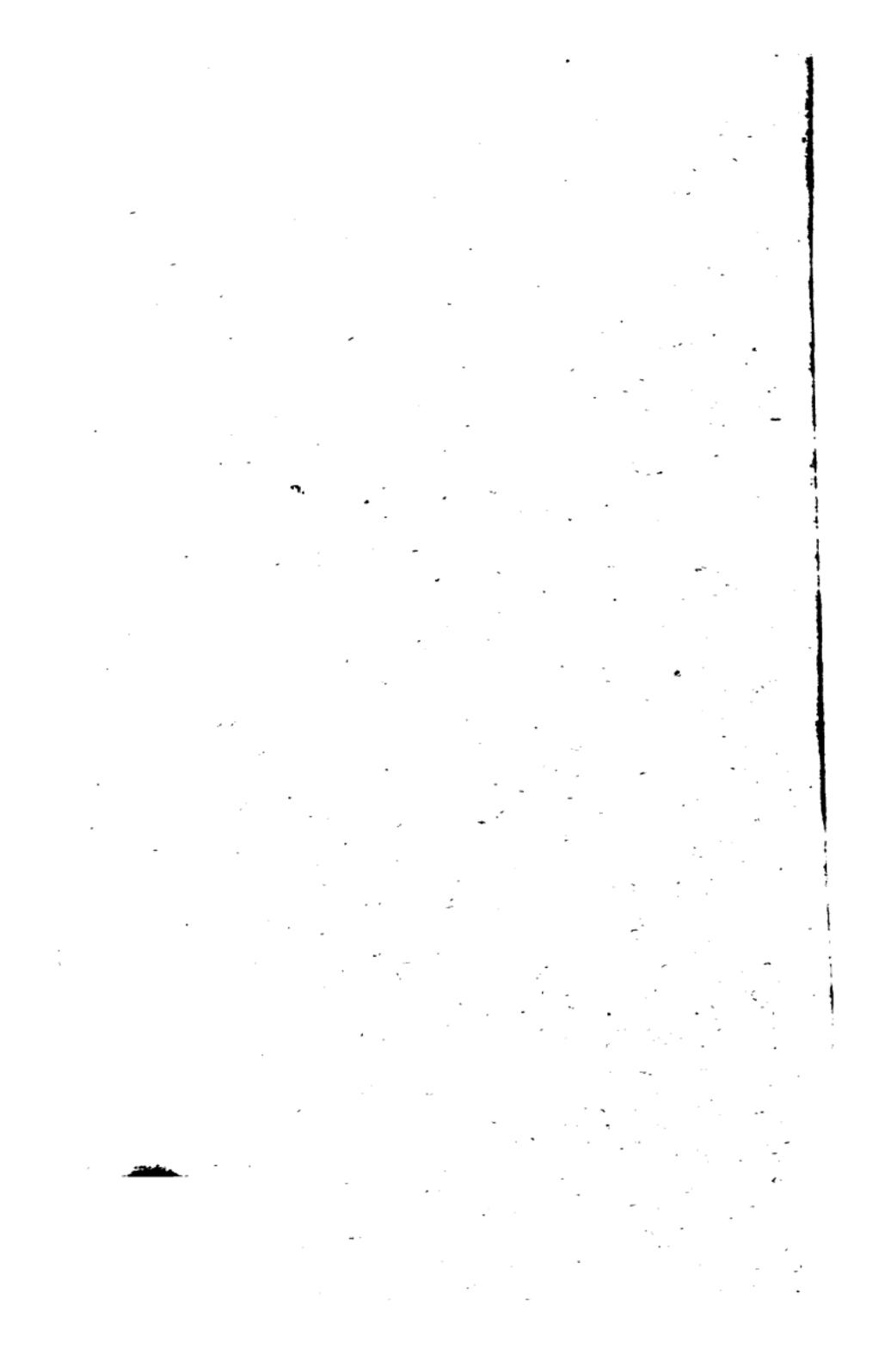Electro-magnets: 2240 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute | Resistance in S U. In outer circuit. | Resistance in S U. Total in circuit. | Reading on electro-dynamometer. Helix. | Reading on electro-dynamometer. Electro-magnet. | Reading on electro-dynamometer. Outer circuit. | Current in webers. Helix. | Current in webers. Electro-magnet. | Current in webers. Outer circuit. | E. M. F. in helix in volts. | Horse power. Expended. | Horse power. Total developed. | Horse power. Developed in outer circuit. | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 700 | .1 | .24 | 2 | | | 3.29 | | | 1.044 | .98 | .0046 | | |
| " | .2 | .34 | 8 | | | 4.03 | | | 1.617 | .98 | .0087 | | |
| 712 | .3 | .43 | 14 | | 10 | 8.88 | | 7.87 | 4.811 | .98 | .0618 | .0204 | 7.084 |
| 698 | .4 | .52 | 15 | 4 | 12 | 9.08 | 4.66 | 8.07 | 5.143 | .98 | .0682 | .0686 | 11.64 |
| 712 | .5 | .61 | 870 | 6 | 305 | 44.86 | 5.71 | 40.73 | 38.89 | 2.61 | 1.74 | 1.04 | 39.84 |
| 715 | .6 | .69 | 510 | 15 | 870 | 52.66 | 9.08 | 44.86 | 37.86 | 2.50 | 2.67 | 1.51 | 43.14 |
| " | .75 | .77 | 570 | 18 | 880 | 55.67 | 9.89 | 44.25 | 45.74 | 4.08 | 3.41 | 1.88 | 44.85 |
| 720 | 1.0 | .88 | 680 | 21 | 885 | 58.69 | 10.69 | 42.69 | 53.14 | 4.10 | 3.88 | 2.88 | 55.61 |
| 714 | 1.25 | 1.06 | 440 | 25 | 290 | 48.88 | 11.68 | 37.61 | 55.78 | 4.08 | 8.66 | 2.21 | 54.16 |
| 708 | 1.5 | 1.22 | 410 | 82 | 215 | 47.28 | 18.19 | 34.90 | 69.97 | 4.05 | 8.80 | 2.80 | 54.88 |
| 700 | 2.0 | 1.38 | 835 | 50 | 150 | 42.05 | 16.65 | 28.56 | 68.60 | 4.00 | 8.60 | 2.04 | 51.00 |
| 712 | 3.0 | 1.68 | 290 | | 80 | 85.87 | | 20.86 | 67.04 | 8.48 | 8.18 | 1.68 | 46.88 |
| " | 8 | 2.08 | | | | | | | | 2.47 | | | |
| | | 4.7 | | | | | | | | | | | |

No. 16.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 3918 convolutions, 2 5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 612 | 0.0 | | | | | | | | | .25 | | | |
| 640 | .25 | .418 | | | | | | | | .25 | .018 | | |
| 685 | .5 | .652 | 4 | | | 4.66 | | | 2.84 | .85 | .579 | .46 | 60.6 |
| 620 | .75 | .876 | 97 | 2.0 | 90.0 | 22.97 | 3.8 | 22.12 | 18.8 | .76 | 1.68 | 1.29 | 52.86 |
| 630 | 1.0 | 1.09 | 220 | 8.5 | 190.0 | 34.6 | 4.04 | 32.14 | 35.21 | 2.44 | 1.93 | 1.61 | 62.64 |
| 680 | 1.25 | 1.29 | 225 | 8.5 | 190.0 | 34.98 | 4.86 | 32.14 | 41.18 | 2.57 | 2.09 | 1.8 | 66.79 |
| 685 | 1.5 | 1.5- | 205 | 8.5 | 170.0 | 38.89 | 4.86 | 30.41 | 46.76 | 2.59 | 2.13 | 1.73 | 70.32 |
| 696 | 1.75 | 1.69 | 185 | 4.0 | 145.0 | 31.72 | 4.66 | 28.08 | 50.06 | 2.46 | 2.09 | 1.68 | (5.99 |
| 698 | 2.0 | 1.87 | 165 | 6.0 | 182.0 | 29.96 | 5.71 | 25.55 | 52.8 | 2.47 | 2.13 | 1.68 | 47.86 |
| 628 | 4.5 | 8.88 | 68 | 7.5 | 15.0 | 19.28 | 6.16 | 18.19 | 60.69 | 2.05 | 2.10 | .98 | 34.55 |
| 624 | 6.5 | 4.29 | 43 | 7.0 | 8.5 | 15.11 | 6.39 | 9.08 | 60.53 | 1.91 | 1.56 | .66 | 28.78 |
| 635 | 9.0 | 5.78 | 32 | 7.0 | 7.0 | 11.68 | 6.16 | 6.16 | 68.67 | 1.81 | 1.22 | .521 | 32.28 |
| 610 | 11.0 | 11.48 | 25 | 8.0 | | | 6.6 | | 62.49 | 1.62 | 1.13 | .622 | |
| 614 | 8 | | 8 | | | 6.6 | | | 70.43 | 1.25 | .98 | | |
| | | | | | | | | | | | .628 | | |

No. 17.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 8916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 665 | .25 | .42 | 3 | .. | 8 | 4.04 | .. | 4.04 | 1.58 | .271 | .0065 | .0051 | 1.88 |
| 670 | .5 | .652 | 80 | .. | 98 | 12.77 | .. | 12.84 | 7.74 | .547 | .188 | .095 | 17.87 |
| 665 | .75 | .875 | 245 | 2.0 | 225 | 36.50 | 3.8 | 34.98 | 29.85 | 2.04 | 1.45 | 1.14 | 55.88 |
| 660 | .85 | .963 | 255 | 2.5 | 235 | 37.25 | 3.69 | 35.75 | 38.49 | 2.29 | 1.67 | 1.86 | 59.88 |
| 640 | 1.0 | 1.09 | 230 | 3.0 | 230 | 39.72 | 4.04 | 37.61 | 40.43 | 2.61 | 2.15 | 1.77 | 67.81 |
| 645 | 1.1 | 1.17 | 272 | 3.5 | 280 | 38.47 | 4.86 | 35.87 | 42.08 | 2.65 | 2.17 | 1.72 | 65.40 |
| 650 | 1.25 | 1.29 | 250 | 4.0 | 205 | 36.88 | 4.66 | 33.39 | 44.43 | 2.9 | 2.2 | 1.74 | 65.66 |
| 645 | 1.4 | 1.42 | 285 | 4.5 | 185 | 35.75 | 4.66 | 31.72 | 47.80 | 2.63 | 2.27 | 1.76 | 66.98 |
| 650 | 1.5 | 1.5 | 228 | 5.0 | 190 | 35.29 | 4.94 | 31.8 | 49.88 | 2.58 | 2.28 | 1.84 | 78.01 |
| 660 | 1.75 | 1.69 | 200 | | 158 | 33.98 | 5.21 | 28.84 | 53.04 | 2.56 | 2.8 | 1.88 | 71.09 |
| 660 | 2.0 | 1.87 | 180 | | 145 | 31.8 | | 28.08 | 54.65 | 2.49 | 2.29 | 1.97 | 81.40 |

No. 18.

Helix · 25 parts commutator, 278 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets : 3,916 convolutions, 2.5 m.m. wire, 11 26 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 817 | 1.1 | 1.17 | 485 | | 360 | 48.65 | | 44.25 | 53.15 | 4.67 | 8.47 | 2.69 | 57.6 |
| 812 | 1.0 | 1.09 | 465 | | 885 | 50.29 | | 45.76 | 51.11 | 4.81 | 8.44 | 2.61 | 54.28 |
| 815 | 1.25 | 1.29 | 405 | 5.0 | 888 | 46.94 | 5.21 | 42.69 | 56.58 | 4.82 | 8.56 | 2.85 | 59.12 |
| 880 | 1.5 | 1.5 | 870 | 5.5 | 280 | 44.86 | 5.47 | 39.72 | 62.88 | 4.85 | 8.78 | 2.98 | 61.08 |
| 814 | 1.75 | 1.69 | 880 | | 250 | 42.37 | | 86.85 | 66.85 | 4.82 | 8.8 | 2.98 | 61.88 |
| 812 | 2.0 | 1.87 | 800 | | 220 | 40.40 | | 34.6 | 70.54 | 4.64 | 8.88 | 8.00 | 64.65 |
| 894 | .9 | 1.01 | 450 | | 885 | 49.47 | | 45.76 | 46.56 | 4.71 | 8.09 | 8.08 | 50.10 |
| 880 | .8 | .98 | 450 | | 800 | 49.47 | | 46.06 | 42.56 | 4.85 | 8.88 | 2.18 | 48.78 |
| 808 | .75 | .876 | 430 | | 800 | 48.38 | | 34.2 | 39.55 | 4.12 | 2.56 | 1.99 | 48.80 |
| 840 | .6 | .748 | 220 | | 215 | 34.60 | | 23.88 | 24.00 | 2.4 | 1.11 | .878 | 36.58 |
| 880 | .5 | .652 | | | 100 | | | 19.51 | | 2.87 | | .84 | 14.84 |
| 830 | .5 | .652 | 75 | | 70 | 20.90 | | 19.51 | 12.30 | 2.94 | .888 | .888 | 10.16 |

## No. 19.

Helix : 24-part commutator, 288 convolutions, 3 m. m. wire, .173 S. U. resistance.
Electro-magnets : 3916 convolutions, 2.5 m.m. wire, 11.26 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 480 | 1.0 | 1.091 | 98 | .... | 85 | 28.09 | .... | 21.5 | 23.53 | 1.87 | .728 | .578 | 42.19 |
| 580 | " | " | 135 | .... | 123 | 27.09 | .... | 25.86 | 27.60 | 1.73 | 1.00 | .887 | 48.88 |
| 608 | " | " | 223 | .... | 195 | 34.83 | .... | 32.57 | 35.49 | 2.38 | 1.66 | 1.38 | 57.08 |
| 670 | " | " | 290 | .... | 250 | 39.72 | .... | 36.88 | 40.47 | 3.14 | 2.15 | 1.7 | 54.14 |
| 744 | " | " | 390 | .... | 330 | 46.06 | .... | 41.72 | 46.93 | 3.95 | 2.80 | 2.18 | 55.19 |
| 800 | " | " | 455 | .... | 380 | 49.75 | .... | 45.46 | 50.70 | 4.73 | 3.38 | 2.59 | 54.76 |
| 864 | " | " | 515 | .... | 430 | 52.92 | .... | 48.36 | 53.92 | 5.64 | 3.88 | 2.93 | 51.95 |
| 911 | " | " | 585 | .... | 490 | 56.42 | .... | 51.68 | 57.49 | 6.52 | 4.35 | 3.34 | 52.85 |

No. 20.

Helix : 24 part commutator, 288 convolutions, 3 m.m. wire, 173 S. U. resistance.
Electro-magnets : 3,200 convolutions, 2.8 m.m. wire, 7,563 S. U. resistance.

| Revolutions per minute. | Resistance in U.S. | | Reading on electro-dynamometer. | | | Current in webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 710 | ∞ | 7.74 | 36 | 26.0 | ... | 11.89 | 11.80 | ... | 85.98 | 2.04 | 1.87 | .66 | 73.48 |
| 710 | 2.0 | 1.75 | 300 | 15.0 | 195 | 40.4 | 9.08 | 32.57 | 66.01 | 3.62 | 3.57 | 2.62 | 70.05 |
| 708 | 1.75 | 1.59 | 380 | 18.5 | 220 | 41.72 | 8.57 | 34.6 | 61.98 | 3.74 | 3.46 | 2.61 | 65.91 |
| 718 | 1.5 | 1.42 | 380 | 12.0 | 255 | 44.85 | 8.08 | 37.25 | 58.66 | 3.96 | 3.48 | 2.47 | 60.84 |
| 710 | 1.25 | 1.25 | 385 | 9.0 | 280 | 46.85 | 6.99 | 39.72 | 54.10 | 4.06 | 3.88 | 2.51 | 57.18 |
| 708 | 1.0 | 1.06 | 445 | 7.0 | 340 | 49.21 | 6.16 | 44.25 | 48.70 | 4.04 | 3.21 | 2.38 | 61.47 |
| 714 | .95 | 1.02 | 460 | 6.0 | 360 | 50.08 | 5.71 | 44.86 | 47.65 | 3.79 | 3.2 | 2.27 | 60.53 |
| 706 | .9 | .977 | 460 | ... | 370 | 50.08 | ... | 45.46 | 45.64 | 3.75 | 3.19 | 2.07 | 57.18 |
| 710 | .8 | .896 | 400 | 5.0 | 390 | 50.23 | 5.21 | 45.16 | 41.85 | 3.62 | 2.81 | 1.78 | 53.13 |
| 714 | .7 | .814 | 445 | 4.0 | 375 | 49.20 | 4.60 | 43.01 | 37.40 | 3.35 | 2.47 | 1.39 | 50.18 |
| 715 | .6 | .728 | 380 | ... | 340 | 46.06 | ... | 35.57 | 31.35 | 2.77 | 1.94 | .875 | |
| 710 | .5 | .642 | | | 230 | | | | | | | .665 | |
| | | .642 | 205 | ... | 195 | 38.39 | ... | 32.57 | 20.02 | 1.3 | .896 | | 51.15 |

No. 21.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.

Electro-magnets: 3200 convolutions, 2.8 m.m. wire, 7.503 S. U. resistance.

| Revolutions per minute. | Resistance in S. U. | | Reading on electro-dynamometer. | | | Current on webers. | | | E. M. F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 468 | 1.0 | 1.06 | 170 | ... | 180 | 30.41 | ... | 26.58 | 30.10 | 1.34 | 1.23 | .884 | 65.97 |
| 532 | " | " | 235 | ... | 185 | 35.75 | ... | 31.72 | 35.88 | 1.96 | 1.69 | 1.28 | 64.21 |
| 610 | " | " | 310 | ... | 240 | 41.06 | ... | 36.14 | 40.64 | 2.61 | 2.24 | 1.64 | 62.88 |
| 678 | " | " | 365 | ... | 290 | 44.56 | ... | 39.72 | 44.10 | 3.32 | 2.63 | 1.98 | 59.64 |
| 718 | " | " | 430 | ... | 335 | 48.36 | ... | 42.68 | 47.88 | 3.79 | 3.10 | 2.28 | 60.16 |
| 788 | " | " | 510 | ... | 385 | 52.66 | ... | 45.76 | 52.12 | 4.35 | 3.67 | 2.63 | 60.46 |
| 880 | " | " | 680 | ... | 430 | 57.14 | ... | 48.36 | 56.55 | 5.08 | 4.38 | 2.98 | 57.68 |

No. 22.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .178 S. U. resistance.
Electro-magnets: 2556 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E.M.F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 690 | 3.0 | 4.63 | 46 | 46 | ... | 15.83 | 15.83 | ... | 68.4 | 2.67 | 1.45 | ... | 53.63 |
| 702 | 2.0 | 1.55 | 300 | 24 | 155 | 40.4 | 11.43 | 29.08 | 58.47 | 4.01 | 3.16 | 2.11 | 51.18 |
| 694 | 1.75 | 1.43 | 300 | 22 | 170 | 40.4 | 10.94 | 30.41 | 53.94 | 3.97 | 2.93 | 2.08 | 53.88 |
| 696 | 1.5 | 1.29 | 335 | 20 | 205 | 43.69 | 10.43 | 33.89 | 51.43 | 3.99 | 2.94 | 2.09 | 50.48 |
| 696 | 1.25 | 1.15 | 390 | 18 | 245 | 46.06 | 9.9 | 36.50 | 49.46 | 4.12 | 3.06 | 2.18 | 45.22 |
| 696 | 1.0 | .99 | 395 | 14 | 265 | 46.85 | 8.88 | 37.97 | 43.85 | 3.98 | 2.67 | 1.8 | 50.57 |
| 690 | .9 | .92 | 390 | 9 | 290 | 46.06 | 6.99 | 39.72 | 39.56 | 3.53 | 2.44 | 1.78 | 46.61 |
| 649 | .8 | .85 | 380 | 8 | 290 | 45.75 | 6.9 | 39.72 | 36.22 | 3.39 | 2.32 | 1.58 | 49.71 |
| 706 | .7 | .78 | 360 | 7 | 270 | 44.25 | 6.16 | 38.50 | 32.14 | 3.02 | 1.9 | 1.32 | 37.73 |
| 694 | .6 | .703 | 245 | ... | 245 | 39.72 | ... | 36.50 | 26.08 | 2.65 | 1.88 | 1.0 | 43.18 |
| 684 | .5 | .628 | 140 | ... | 160 | 27.59 | ... | 29.50 | 16.05 | 1.28 | .594 | .544 | ... |

## No. 28.

Helix: 24 part commutator, 288 convolutions, 3 m.m. wire, .173 S. U. resistance.
Electro-magnets, 2556 convolutions, 3 m.m. wire, 4.46 S. U. resistance.

| Revolutions per minute. | Resistance in S.U. | | Reading on electro-dynamometer. | | | Current in webers. | | | E.M.F. in helix in volts. | Horse power. | | | Percentage of energy turned into useful work. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Outer circuit. | Total in circuit. | Helix. | Electro-magnet. | Outer circuit. | Helix. | Electro-magnet. | Outer circuit. | | Expended. | Total developed. | Developed in outer circuit. | |
| 492 | 1 | 99 | 240 | 7.0 | 100 | 36.14 | 6.16 | 29.5 | 38.41 | 2.11 | 1.08 | 1.08 | 51.06 |
| 528 | " | " | 283 | 9.0 | 145 | 39.17 | 6.99 | 31.72 | 81.21 | 2.48 | 1.9 | 1.26 | 50.81 |
| 602 | " | " | 345 | 12.0 | 235 | 43.31 | 8.08 | 35.75 | 40.04 | 3.07 | 2.38 | 1.6 | 52.12 |
| 684 | " | " | 410 | 14.0 | 280 | 47.23 | 8.88 | 39.08 | 43.63 | 3.61 | 2.76 | 1.9 | 52.68 |
| 722 | " | " | 450 | 16.5 | 300 | 49.47 | 9.33 | 40.4 | 45.73 | 4.27 | 3.04 | 2.04 | 47.78 |
| 790 | " | " | 540 | 18.5 | 335 | 54.20 | 10.08 | 42.69 | 50.10 | 5.0 | 8.04 | 2.28 | 45.60 |
| 856 | " | " | 610 | 21.0 | 370 | 57.00 | 10.69 | 44.86 | 53.24 | 5.76 | 4.11 | 2.52 | 43.74 |