

adjourn immediately, and I think, as we have so much business before us, it would be well to take simply an hour.

It was voted to take a recess for lunch, until 2 P. M.

#### AFTERNOON SESSION.

THE PRESIDENT:—The business of the afternoon is to take up first some very interesting phenomena, which will be brought to our notice by Professor Elihu Thomson, on alternating currents. We all listen to the professor with the utmost interest and pleasure whenever he has an opportunity to address us. I am sure that on the present occasion it will be one of extreme pleasure and profit.

#### NOVEL PHENOMENA OF ALTERNATING CURRENTS.

BY PROFESSOR ELIHU THOMSON.

The actions produced and producible by the agency of alternating currents of considerable energy, are assuming greater importance in the electric arts. I mean, of course, by the term alternating currents, currents of electricity reversed at frequent intervals, so that a positive flow is succeeded by a negative flow, and that again by a positive flow, such reversals occurring many times in a second, so that the curve of current or of electromotive force will, if plotted, be a wave line, the amplitude of which is the arithmetical sum of the positive and negative maxima of current or electromotive force, as the case may be, while a horizontal middle line joins the zero points of current or electromotive force.

It is well known that such a current passing in a coil or conductor laid parallel with, or in inductive relation to a second coil or conductor, will induce in the second conductor, if on open circuit, alternating electromotive forces, and that if its terminals be closed or joined, alternating currents of the same rhythm, period or pitch, will circulate in the second conductor. This is the action occurring in any induction coil whose primary wire is traversed by alternating currents, and whose secondary wire is closed either upon itself directly or through a resistance. What I desire to draw attention to in the present paper, are the mechanical actions of attraction and the repulsion which will be exhibited between the two conductors, and the novel results which may be obtained by modifications in the relative dispositions of the two conductors.

In 1884, while preparing for the International Electrical Exhi-

bition at Philadelphia, we had occasion to construct a large electro-magnet, the cores of which were about six inches in diameter and about twenty inches long. They were made of bundles of iron rod of about  $\frac{5}{16}$  inch diameter. When complete, the magnet was energized by the current of a dynamo giving continuous currents, and it exhibited the usual powerful magnetic effects. It was found also that a disc of sheet copper, of about  $\frac{1}{8}$  inch thickness and 10 inches in diameter, if dropped flat against a pole of the magnet, would settle down softly upon it, being retarded by the development of currents in the disc due to its movement in a strong magnetic field, and which currents were of opposite direction to those in the coils of the magnet. In fact, it was impossible to strike the magnet pole a sharp blow with the disc even when the attempt was made by holding one edge of the disc in

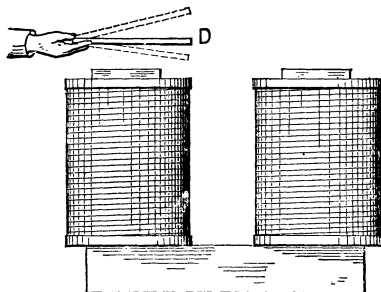


Figure 1.

the hand and bringing it down forcibly towards the magnet. In attempting to raise the disc quickly off the pole, a similar but opposite action of resistance to movement took place, showing the development of currents in the same direction to those in the coils of the magnet, and which currents, of course, would cause attraction as a result.

The experiment was, however, varied, as in figure 1. The disc *D* was held over the magnet pole, as shown, and the current in the magnet coils cut off by shunting them. There was felt an attraction of the disc or a dip toward the pole. The current was then put on by opening the shunting switch and a repulsive action or lift of the disc was felt. The actions just described are what would be expected in such a case, for when attraction took place, currents had been induced in the disc *D* in the same direction as those in the magnet coils beneath it, and when repulsion took

place, the induced current in the disc was of opposite character or direction to that in the coils.

Now let us imagine the current in the magnet coils to be not only cut off, but reversed back and forth. For the reasons just given, we will find that the disc  $D$  is attracted and repelled alternately; for, whenever the currents induced in it are of the same direction with those in the inducing, or magnet coil, attraction will ensue, and when they are opposite in direction, repulsion will be produced. Moreover, the repulsion will be produced when the current in the magnet coil is rising to a maximum in either direction, and attraction will be the result when the current of either direction is falling to zero, since in the former case opposite currents are induced in the disc  $D$  in accordance with well-known laws; and in the latter case currents of the same direction will exist in the disc  $D$  and the magnet coil. The disc might, of course, be replaced by a ring of copper or other good conductor, or by a closed coil of bare or insulated wire, or by a series of discs, rings or coils superposed, and the results would be the same. Thus far, indeed, we have nothing of a particularly novel character, and, doubtless, other experimenters have made very similar experiments and noted similar results to those described.

The account just given of the effects produced by alternating currents, while true, is not the whole truth; and just here we may supplement it by the following statements.

*An alternating current circuit or coil repels and attracts a closed circuit or coil placed in direct or magnetic inductive relation therewith; but the repulsive effect is in excess of the attractive effect.*

*When the closed circuit or coil is so placed, and is of such low resistance metal that a comparatively large current can circulate as an induced current, so as to be subject to a large self-induction, the repulsive far exceeds the attractive effort.*

For want of a better name I shall call this excess of repulsive effect the "electro-inductive repulsion" of the coils or circuit.

This preponderating repulsive effect may be utilized or may show its presence by producing movement or pressure in a given direction, by producing angular deflection as of a pivoted body, or by producing continuous rotation with a properly organized structure. Some of the simple devices realizing the conditions I will now describe.

In Fig. 2,  $C$  is a coil traversed by alternating currents,  $B$  is a

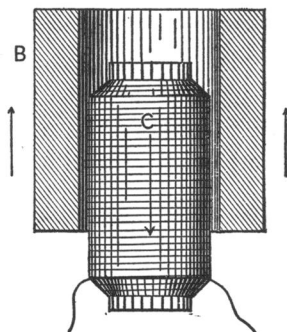


Figure 2.

copper case or tube surrounding it, but not exactly over its centre. The copper tube  $B$  is fairly massive and is the seat of heavy induced currents. There is a preponderance of repulsive action, tending to force the two conductors apart in an axial line. The part  $B$  may be replaced by concentric tubes slid one in the other, or by a pile of flat rings, or by a closed coil of coarse or fine wire insulated, or not. If the coil  $C$ , or primary coil, is provided with an iron core such as a bundle of fine iron wires, the effects are greatly increased in intensity, and the repulsion with a strong primary current may become quite vigorous, many pounds of thrust being producible by apparatus of quite moderate size.

The forms and relations of the two parts,  $C$  and  $B$ , may be greatly modified with the general result of a preponderance of repulsive action when the alternating currents circulate.

Fig. 3 shows the part  $B$  of an internally tapered or coned form, and  $C$  of an externally coned form, wound on an iron wire

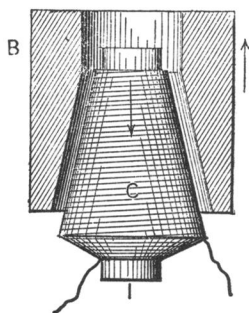


Figure 3.

bundle *I*. The action of Fig. 2 may be said to be analogous to that of a plain solenoid with its core, except that repulsion, and not attraction is produced ; while that of Fig. 3 is more like the action of tapered or conically wound solenoids and taper cores. Of course it is unnecessary that both be tapered. The effect of such shaping is simply to modify the range of action, and the amount of repulsive effort existing at different parts of the range.

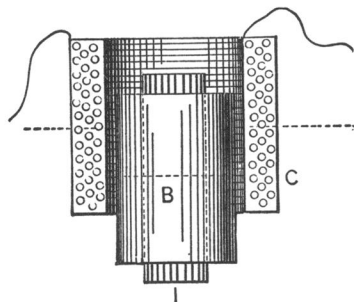


Figure 4.

In Fig. 4, the arrangement is modified so that the coil *C* is outside, and the closed band or circuit *B* inside and around the core *I*. Electro-inductive repulsion is produced as before.

It will be evident that the repulsive actions will not be mechanically manifested by axial movement or effort, when the electrical middles of the coils or circuits are coincident. In cylindrical coils in which the current is uniformly distributed through all parts of the conductor section—what I here term the electrical middle, or the centre of gravity of the ampère turns of the coils, will be the plane at right angles to its axis at its middle ; that of *B* and *C* in Fig. 4 being indicated by a dotted line. To repeat, then, when the centres or centre planes of the conductors, Fig. 4, coincide, no indication of electro-inductive repulsion is given, because it is mutually balanced in all directions ; but when the coils are displaced, a repulsion is manifested, which reaches a maximum at a position depending on the peculiarities of proportion and distribution of current at any time in the two circuits or conductors.

It is not my purpose now to discuss the ways of determining the distribution of currents and mechanical effects, as that would extend the present paper much beyond its intended limit. The forms and relative arrangement of the two conductors may be

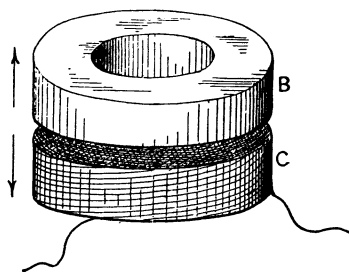


Figure 5.

greatly varied. In Fig. 5, the parts are of equal diameter, one, *B*, being a closed ring, and the other, *C*, being an annular coil placed parallel thereto, and an iron core or wire bundle placed in the common axis of the two coils increases the repulsive action. *B* may be simply a disc or plate of any form, without greatly affecting the nature of the action produced. It may also be composed of a pile of copper washers or a coil of wire, as before indicated.

An arrangement of parts somewhat analogous to that of a horseshoe electro-magnet and armature is shown in Fig. 6. The

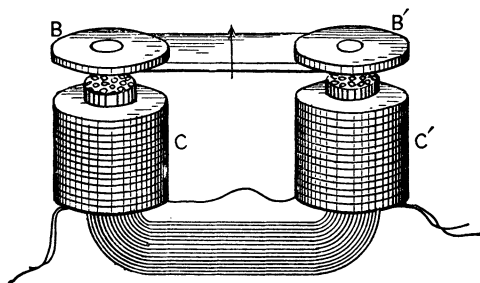


Figure 6.

alternating current coils *C C'* are wound upon an iron wire bundle bent into U-form, and opposite its poles is placed a pair of thick copper discs *B B'*, which are attracted and repelled, but with an excess of repulsion depending on their form, thickness, etc.

If the iron core takes the form of that shown by *II*, Fig. 7, such as a cut ring with the coil *C* wound thereon, the insertion of a heavy copper plate *B* into the slot or divided portion of the ring will be opposed by a repulsive effort when alternating currents pass in *C*. This was the first form of device in which I noticed the phenomenon of repulsive preponderance in question. The tendency is to thrust the plate *B* out of the slot in the ring,

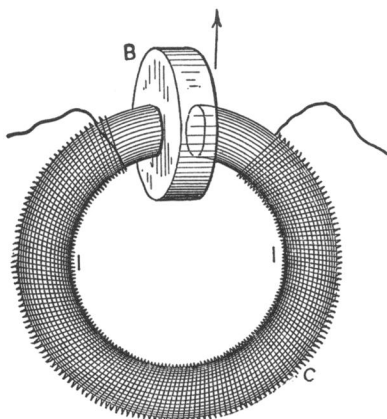


Figure 7.

excepting only when its centre is coincident with the magnetic axis joining the poles of the ring between which *B* is placed.

If the axes of the conductors, Fig. 5, are not coincident but displaced, as in Fig. 8, then, besides a simple repulsion apart,

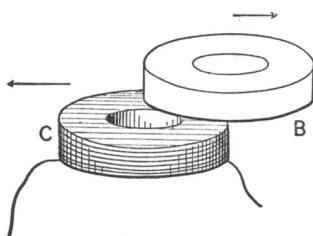


Figure 8.

there is a lateral component or tendency as indicated by the arrows. Akin to this is the experiment illustrated in Fig. 9. Here the closed conductor *B* is placed with its plane at right angles to that of *C*, wound on a wire bundle. The part *B* tends to move

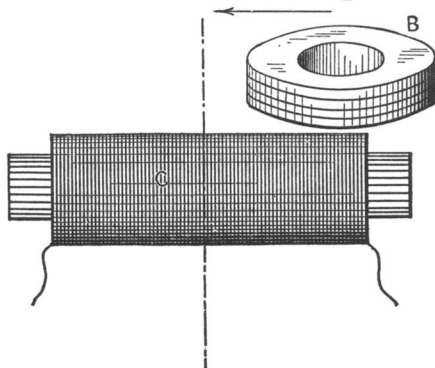


Figure 9.

toward the centre of the coil  $C$ , so that its axis will be in the middle plane of  $C$ , transverse to the core, as indicated by the dotted line. This leads us at once to another class of actions, *i. e.*, deflective action.

When one of the conductors, as  $B$ , Fig. 10, composed of a disc, or better, of a pile of thin copper discs, or of a closed coil of wire, is mounted on an axis  $X$  transverse to the axis of coil  $C$ , through

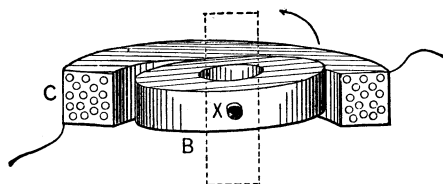


Figure 10.

which coil the alternating current passes, a deflection of  $B$  to the position indicated by dotted lines will take place, unless the plane of  $B$  is at the start exactly coincident with that of  $C$ . If slightly inclined at the start, deflection will be caused as stated. It matters not whether the coil  $C$  incloses the part  $B$  or be inclosed by it, or whether the coil  $C$  be pivoted and  $B$  fixed, or both be pivoted. In Fig. 11 the coil  $C$  surrounds an iron wire core and

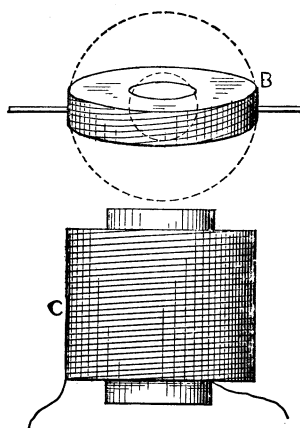


Figure 11.

$B$  is pivoted above it, as shown. It is deflected, as before, to the position indicated in dotted lines.

It is important to remark here that, in cases where deflection is to be obtained, as in Figs. 10 and 11,  $B$  had best be made of a



pile of thin washers or a closed coil of insulated wire instead of a solid ring. This avoids the lessening of effect which would come from the induction of currents in the ring *B* in other directions than parallel to its circumference.

We will now turn our attention to the explanation of the actions exhibited, and afterwards refer to their possible applications. It may be stated as certainly true that were the induced currents in the closed conductor unaffected by any self-induction, the only phenomena exhibited would be alternate equal attractions and repulsions; because currents would be induced in opposite directions to that of the primary current, when the latter current was changing from zero to maximum positive or negative current, so producing repulsion; and would be induced in the same direction when changing from maximum positive or negative value to zero, so producing attraction.

This condition can be illustrated by a diagram, Fig. 12. Here the lines of zero current are the horizontal straight lines. The

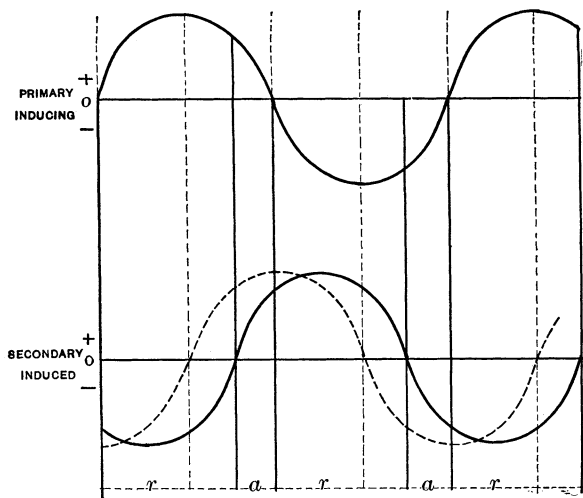


Figure 12.

wavy lines represent the variations of current strength in each conductor, the current in one direction being indicated by that portion of the curve above the zero line, and in the other direction by that portion below it. The vertical dotted lines simply mark off corresponding portions of phase or succession of times.

Here it will be seen that in the positive primary current de-

scending from  $m$ , its maximum, to the zero line, the secondary current has risen from its zero to  $m'$ , its maximum. Attraction will therefore ensue, for the currents are in the same direction in the two conductors. When the primary current increases from zero to its negative maximum  $n$ , the positive current in the secondary closed circuit will be decreasing from  $m'$ , its positive maximum, to zero; but, as the currents are in opposite directions, repulsion will occur. These actions of attraction and repulsion will be reproduced continually, there being a repulsion, then an attraction, then a repulsion, and again an attraction, during one complete wave of the primary current. The letters  $r$ ,  $a$ , at the foot of the diagram, Fig. 12, indicate this succession.

In reality, however, the effects of self induction in causing a lag, shift, or retardation of phase in the secondary current, will considerably modify the results and especially so when the secondary conductor is constructed so as to give to such self induction a large value. In other words, the maxima of the primary or inducing current will no longer be found coincident with the zero points of the secondary currents. The effect will be the same as if the line representing the wave of the secondary current in Fig. 12 had been shifted forward to a greater or less extent. This

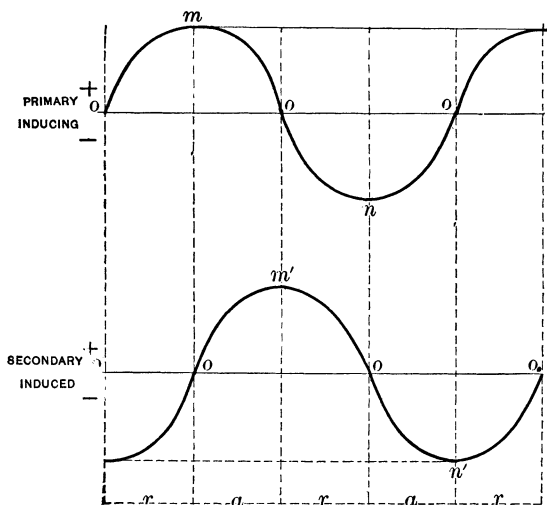


Figure 13.

is indicated in diagram, Fig. 13. It gives doubtless, an exaggerated view of the action, though from the effects of repulsion

which I have produced I should say it is by no means an unrealizable condition.

It will be noticed that the period during which the currents are opposite, and during which repulsion can take place, is lengthened at the expense of the period during which the currents are in the same direction for attractive action. These differing periods are marked  $r$ ,  $a$ , etc., or the period during which *repulsion* exists is from the zero of the primary or inducing current to the succeeding zero of the secondary or induced current; and the period during which *attraction* exists is from the zero of the induced current to the zero of inducing current.

But far more important still, in giving prominence to the repulsive effect than this difference of effective period, is the fact that during the period of repulsion both the inducing and induced currents have their greatest values, while during the period of attraction the currents are of small amounts comparatively. This condition may be otherwise expressed by saying that the period during which repulsion occurs includes all the maxima of current, while the period of attraction includes no maxima. There is then a *repulsion due to the summative effects of strong opposite currents* for a *lengthened period* against an *attraction* due to the summative effects of *weak currents* of the *same direction* during a *shortened period*, the result and effect being a greatly *preponderating* repulsion.

It is now not difficult to understand all the actions before described as obtained with the varied relations of coils, magnetic fields and closed circuits. It will be easily understood, also, that an alternating magnetic field is in all respects the same as an alternating current coil in producing repulsion on the closed conductor, because the repulsion between the two conductors are the result of magnetic repulsions arising from opposing fields produced by the coils when the currents are of opposite directions in them.

Thus far I have applied the repulsion action described in the construction of alternating current indicators, alternating current arc lamps, regulating devices for alternating currents, and to rotary motors for such currents. For current indicators, a pivoted or suspended copper band or ring composed of thin washers piled together and insulated from one another and made to carry a pointer or index, has been placed in the axis of a coil conveying alternating currents whose amount or potential is to be indicated.

Gravity or a spring is used to bring the index to the zero of a divided scale, at which time the plane of the copper ring or band makes an angle of, say 15 degrees to 20 degrees with the plane of the coil. This angle is increased by deflection more or less great, according to the current traversing the coil. The instrument can be calibrated for set conditions of use. Time would not permit of a full description of these arrangements as made up to the present.

In arc lamps, the magnet for forming the arc can be composed of a closed conductor, a coil for the passage of current and an iron wire core. The repulsive action upon the closed conductor lifts and regulates the carbons in much the same manner that electro-magnets do when continuous currents are used. The electro-inductive repulsive action has also been applied to regulating devices for alternating currents, with the details of which I cannot now deal.

For the construction of an alternating current motor which can be started from a state of rest the principle has also been applied, and it may here be remarked, that a number of designs of such motors is practicable.

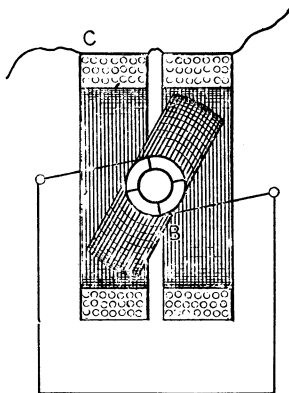


FIG. 14.

One of the simplest is as follows: The coils *C*, Fig. 14, are traversed by an alternating current and are placed over a coil *B*, mounted upon a horizontal axis, transverse to the axis of the coil *C*. The terminals of the coil *B*, which is wound with insulated wire, are carried to a commutator, the brushes being connected by a wire, as indicated. The commutator is so constructed as to

keep the coil *B* on short circuit from the position of coincidence with the plane of *C*, to the position where the plane of *B* is at right angles to that of *C*; and to keep the coil *B* open circuited from the right angled position or thereabouts to the position of parallel or coincident planes. The defective repulsion exhibited by *B* will, when its circuit is completed by the commutator and brushes, as described, act to place its plane at right angles to that of *C*, but being then open-circuited its momentum carries it to the position just past parallelism, at which moment it is again short circuited, and so on. It is capable of very rapid rotation, but its energy is small. I have, however, extended the principle to the construction of more complete apparatus. One form has its revolving portion or armature composed of a number of sheet iron discs, wound as usual with three coils crossing near the shaft. The commutator is arranged to short-circuit, each of these coils in succession, and twice in a revolution, and for a period of 90 degrees of rotation each. The field coils surround the armature and there is a laminated iron field structure completing the magnetic circuit. I may say here that surrounding the armature of a dynamo by the field coils, though very recently put forth as a new departure, was described in various Thomson-Houston patents, and to a certain extent all Thomson-Houston machines embody this feature.

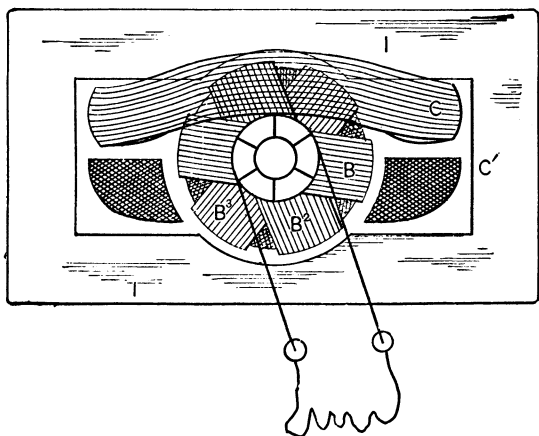


Figure 15.

Figures 15 and 16 will give an idea of the construction of the motor referred to.  $CC^1$  are the field coils or inducing coils which

alone are put into the alternating current circuit. *II* is a mass of laminated iron, in the interior of which the armature revolves,

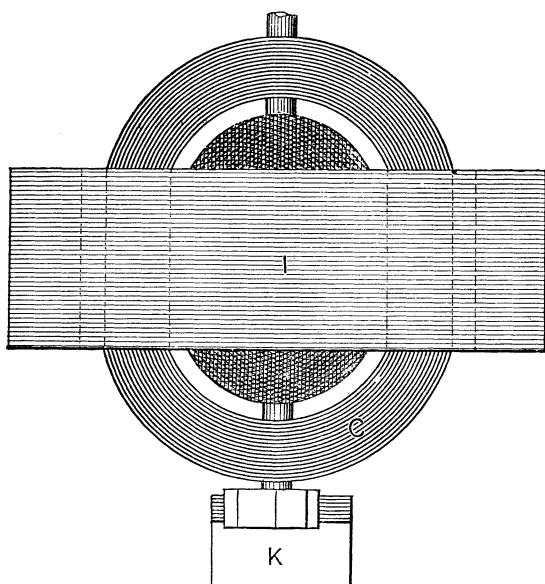


Figure 16.

with its three coils  $B$ ,  $B^2$ ,  $B^3$  wound on a core of sheet-iron discs. The commutator short-circuits the armature coils in succession in the proper positions to utilize the repulsive effect set up by the currents which are induced in them by the alternations in the field coils. The motor has no dead point and will start from a state of rest and give out considerable power, but with what economy is not yet known.

A curious property of the machine is that at a certain speed, depending on the rapidity of the alternations in the coil  $C$ , a continuous current passes from one commutator brush to the other, and it will energize electro-magnet and perform other actions of direct currents. Here we have, then, a means of inducing direct currents from alternating currents. To control the speed and keep it at that required for the purpose, we have only to properly gear the motor to another of the ordinary type for alternating currents, namely, an alternating current dynamo used as a motor. The charging of storage batteries would not be difficult with such a machine, even from an alternating current line, though the losses might be considerable.

## DISCUSSION.

THE PRESIDENT:—I think we have reason to be proud of our distinguished member, and of the interest he takes in us when he presents so valuable a paper at our meeting. It is now open for discussion.

MR. WHEELER:—I was particularly interested in this, because I heard very much the same thing, or the same in its principle features described under the title of an ironclad dynamo. Of course, this is for alternating currents, but the field will be an ironclad field, or nearly so.

MR. MAILLOUX:—I might add to what has just been said by Mr. Wheeler, and also in corroboration of the statement made by Professor Thomson, that I am perfectly aware myself that the ironclad dynamo, as we have heard it called very recently, is another of those things that have been done before. I remember distinctly reading one of Professor Thomson's patents, where the direct magnetizing effect of the coil on the armature itself, is adverted to; and I do not think there can be any dispute as to the fact that it had been brought out before; and I would also state that I myself made experiments with dynamos, in which the same result was accomplished as early as 1879.

There is one interesting point that is mentioned by Professor Thomson. I think it is the phenomenon which he illustrated by means of his first figure, noting the repulsion and the attraction that take place when the current is reversed in an ordinary magnet. I could not help thinking, at the time, of some experiments made some years ago by Professors Elphinstone and Vincent, and about which I once took it into my head to write something. The fact was brought out by Messrs. Elphinstone and Vincent of the importance of the magnetic circuit that we now so well know and use in dynamo-electric machines. I had been very much struck by the statement of Faraday in his "Experimental Researches," where he speaks of lines of force expanding during the action of the beginning of current through a circuit, and of their collapse when the current is discontinued or decreased, and I remember making a note in this article (which you will find somewhere in the London *Electrician*, several years back) of experiments or observations made by me to show that that phenomenon was observable in an ordinary electro-magnet. I have been able by means of a delicately suspended needle or by a very thin piece of iron wire fast to

the pole, so that it might place itself in the lines of force and follow the oscillations of the lines of force, to trace a positive motion in the lines of force which would be exactly corresponding with that just referred to by Professor Thomson; in a word, when the electro-magnet is in process of magnetization, when the current is passing through it,—there is an expansion of the lines of force starting apparently from the yoke, and the effect of the motion of these lines of force re-acting on the disc would be exactly such as would produce repulsion in accordance with the phenomenon of Lenz's Law. On the contrary there is a collapsing process of the lines of force in the process of demagnetization and the action would be again such as to produce attraction or the dragging of the disc with it. Now, with regard to the difference of repulsive and attractive effect, there is another fact which I think Professor Thomson has not taken into consideration and which to some extent increases the difference of repulsive effect. If we assume for a moment that the process of expansion and collapse of lines of force is true, and I have no reason to doubt that it is, then we will readily see that, as our current is put on, we are dealing with quantities. First, the resistance of the diamagnetic medium to the stress that is produced by the current, and second, the amount of energy or the rate at which we supply energy to overcome that elasticity. I might also add, of course, a third quantity, which is reaction produced by self-induction of surrounding metal; but when the collapse takes place we have the action of the pent-up energy that has been stored by the process of contraction. I might explain this by taking a piece of rubber and stretching it. The rapidity with which it is stretched depends upon the rate at which energy is applied to it and on the elasticity; but when I let go, it falls back by virtue of its own elasticity, nothing else. In the case of the secondary coil we can deal with this self-induction, but there are experiments which have been made, I think, by Professor Von Beets, which show very clearly that the impulse of collapse is much more rapid than the impulse of rise. Consequently there would be a difference of current in the inductive circuits, which would tend if we follow them carefully by means of the curves produced by Professor Thomson, to emphasize that difference of action in favor of the repulsive process. I would like to hear the views of other gentlemen, who are well informed on these subjects.

MR. PRESCOTT :—Professor Thomson has so clearly and beauti-



fully described the experiments he has made that he has left hardly anything to be asked. I would say that I am particularly interested in the application to measuring instruments, and I would like to know whether in the application he has discovered, the repulsion is inversely proportional to the square of the distance of the plates, and if so whether he has preferred to make his instruments to measure that distance directly, or whether he has preferred to counterweight or in some way counteract the movement so as to keep it always constant.

He has paid so much attention to this question of alternating currents that I should like to ask him also whether he has made any experiments to determine, for instance, whether a secondary battery, in the circuit of an alternating current machine, would cut off a portion of the electromotive force in one direction which was counter and equal to that of the battery itself, in which case an ordinary current instrument would measure the distance if connected around the poles of the battery.

PROFESSOR THOMSON:—In regard to the measuring instruments, I have used the principle in several ways. The matter has not been carried sufficiently far as yet to determine all the points on the subject, but I have used gravity and a spring as a counterforce device. However, I find there does not seem to be any regular law, perhaps any more than there is with an electro-magnet, for the decrease of the effect by distance, except when the distances become very large. The very fact of a change of position changes the relations of the currents themselves and of the relations between the two currents, so that we can hardly regard the problem as any different from the problem of an electro-magnet attracting its armature. When the armature is placed at a certain distance, there is a certain distribution of magnetism; when it is taken to another distance the distribution is so changed that we could not consider that the centre of gravity, so to speak, of the magnetism, is the same in the two cases, and the redistribution will depend on the length, the diameter of the core and the sizes of the armatures, so that the problem becomes a very complex one. But I have made a very curious application of the principle in this way: I have taken an ordinary fruit jar and put in it a disc of a certain thickness and attached to it a bulb of glass and immersed it in alcohol or water and adjusted it, until the gravitational effect was so overcome by the flotation, that it was almost indifferent as to position, but it would just settle down to the bottom of the jar. I

then put an alternating current coil below it and passed a current of gradually increasing amount. Gradually the disc would begin to lift itself, and at a certain current would float to a certain height, standing in the liquid supported by the repulsion. There we have a very excellent illustration and a means of getting at

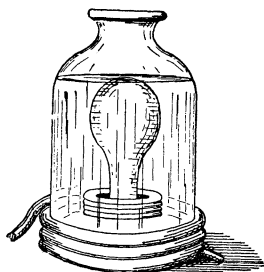


Figure 17.

probably the relative repulsive effort under different conditions.

In regard to the point brought up by Mr. Mailloux, concerning the more rapid drop in the current at the end of a wave, I think that he must have been considering the effect of interrupted currents only, as in the ordinary induction coil—that is, you pass a primary current through the primary coil, as a battery current, and on closing the circuit the counter-electromotive force developed keeps down the current, and it slightly rises to that current which can pass with the electro-motive force present acting over the resistance of the primary circuit. But when you cut off the current, the secondary current is much more vigorous in electromotive force than that on making the circuit of the primary, but does not last as long. In the primary, surrounded by its secondary, when we put on the current or close the circuit, there is an opposing electromotive force; the battery does not get its full amount of current for some time, and during that time the secondary currents will seek to evolve their energy; that is, they have duration without great force. But when we cut the battery current off and do it specially with a condenser which enables us to open the contact without sparking, or in other words, to cheat the current a little and give it another path for the time being, the secondary then gives out considerable electromotive force or energy.

I may mention an interesting experiment in this connection showing the effects of self-induction in magnets—a very curious experiment tried with a large magnet. It has nothing to do with

the repulsive effect; it has to do with self-induction and the curious effects produced by it in lagging or stopping waves and preventing waves from having their full value. We put this magnet into circuit with a dynamo and we make a shunt of carbon points—a shunting switch made with carbon contacts, as they might be placed in an arc light. The current comes through this way through the magnet coils [illustrating on the black-board], when the shunting switch is open, and goes on. We close the carbon switch, and, of course, the current gradually leaves the magnet and gradually it flows in nearly full volume over the carbon points in accordance with their resistance. If their resistance is much less than the magnet coils, nearly all the current will flow through the carbon points as a shunt. Now, on opening the carbons, the arc formed there instead of being a good, strong, full arc, will simply be the tops of the waves of the current, while a steady current will flow through the magnet. That is, you will have a steady current in the magnet, and the tops of the waves will be chopped off and sent through the carbon. There is no self-induction in this carbon branch, and the current there in the magnet branch is steady. In fact, the spark you get here at the carbons or the arc you get here will very closely resemble the spark obtained from the Rhumkorff coil—a thin spark with a considerable aureola, and not very hot. I have drawn them three-quarters of an inch long; playing and sputtering, showing that the waves of the current are having their true effect in provoking undulations of sound, whereas an ammeter put in the magnet circuit or branch shows a current pretty nearly the line current.

There was one other point on which information was asked for. It has just slipped my mind.

MR. PRESCOTT :—In regard to the secondary battery and the alternating current circuit.

PROFESSOR THOMSON :—That is a question that I have not investigated at all, but there would be a current of double volume in one direction and a stoppage in the other direction provided the volts of counter-electromotive force were right. There is a possibility of producing a current of this character by combination of an alternating current machine and a dynamo and a continuous current machine. We may have a current like that (illustrating) produced, which would approximate the current that you were asking about. Whether applications of such currents will ever be made or not I do not know.

MR. PRESCOTT :—The point I wanted to make is a little different. Suppose that an alternating current is passing through that wire (illustrating) and that at this point here we introduce a counter electromotive force, or a certain electromotive force in one direction, and we have a resistance in circuit with it, connected in *here*. Now, suppose this point to be shifted until the difference of potential in one direction of this alternating current is equal to the electromotive force of this opposing battery; then there will be a current of one direction only through this wire, and if that is the case having a known resistance in here you have simply to interpose an electromotive force in one direction and shift its point of contact along until you get no deflection in the galvanometer, then you would have all the data necessary to determine the electromotive force of the alternating current. Something like this was suggested to me by Mr. John Howell, of the Edison company, and he wanted me to try it. It was very recently and I have not yet had an opportunity of doing so.

THE PRESIDENT :—We have with us Mr. Pendleton, President of the New York Electrical Society, who is very much interested in this subject and we should be most happy to hear from him anything he may wish to say.

MR. PENDLETON :—I came here this afternoon more particularly to take a back seat and listen; I am grateful for the hospitality with which you have received me, and thank you for the invitation to speak upon the subject now under discussion. It is, however, not one to which I have given much thought, and it has been so thoroughly demonstrated that I feel that there is but little for me to say. In regard to the secondary battery application that the gentleman has just made, I should fancy the result would be the steady discharge of the battery of whatever charge it might have; and I believe it would be impossible to accumulate chemical energy in the battery under such circumstances. While I was listening to Professor Thomson's interesting account of his experiments, it occurred to me that if the actions are sufficiently delicate, there is a great variety of applications for it, several of which he mentioned, and also that it would be possible, in connection with the telephone, to make a recording instrument, which might at any rate equal the success of the Edison phonograph. In this case it would be a reproduction of the waves of sound in the same manner. I merely make the suggestion in addition to those Professor Thomson made.

MR. MAILLOUX :—I merely wish to ask Professor Thomson to tell us the results, if he has any, in regard to the measurement of electromotive forces of alternating currents, as the subject seems to be receiving some attention in the discussion.

MR. THOMSON :—I would be glad to give way to gentlemen who have tried to get an opportunity to say something.

MR. HERING :—I would like to ask Professor Thomson how the magnetic attraction compares with its induction. If the closed copper disc were to be made of iron, there would be attraction; now, how does that attraction compare with the repulsion in case it is not magnetic. I ask that, in order that we may get some idea of the strength of this repelling force.

PROF. THOMSON :—I have not made any determinations with that object in view—that is, to determine the relation between, as I understand it, electro inductive repulsion and the attraction of the magnet coil for its core. I think we can say, however, that it compares very well, only that the copper band, of course, naturally occupies a greater space and uses energy of current flowing in it. If we have a current flowing in a coil attracting an iron core, and the iron core is thoroughly divided so as to avoid currents in the iron itself, we would get electro-magnetic attraction pure and simple without necessary loss of energy; but in the case of the copper band there is undoubtedly, where large work is being done, a loss of energy, due to the flow of heavy currents in the conductor; but in the case of a disc which is deflected, the disc saves itself that loss by throwing itself more or less at right angles. It is only when you are resisting motion by a counter-weight that the loss amounts to much. Allow the thing to move and it relieves itself of the stress by leaving the point of greatest stress.

MR. POWERS :—I had a very interesting experience in the line of Professor Thomson's address, about the lag of heavy currents, which I wish to bring to your notice, and be somewhat personal about the matter again. At Troy, we are making an alternating current dynamo, producing direct currents from it; in other words, a simple multi-polar dynamo, with this exception, that the armatures are in two layers, the neutral point on one armature corresponding with the maximum point on the other. Those two armatures are connected to a single commutator, there being two bars connected with one armature and the next two bars with the other; the positive of one and the positive of the other, the nega-

tive of one and the negative of the other; in that relation, a brush being put on there of a certain width, we found some curious results. With plating machines of low tension we found we could increase the width of contact to such an extent that we seemed to collect the entire current from both sides of the armature; in other words, the current seemed to be prolonged from each side of the armature so that we were practically collecting the current from both sides. The moment we got the high tension currents we failed. Without apparent lag of the current, whatever that was, the minute we increased the tension of currents up to three or four hundred volts, we failed entirely. But the point I wished to bring to your attention was that we could make that contact of considerable width and apparently get a larger power from the same amount of material in the machine, in low tension work, than we could when we got too high tension, and apparently there existed this feature of lag of heavy currents which Professor Thomson first brought up.

PROFESSOR THOMSON:—I do not think you can say that heavy currents lag any more than light currents. A heavy current is nothing more or less than the flowing around of so many lighter currents. In a closed circuit coil it is the same current going round many times, as compared we may say with many parallel currents in a band, which represent the currents that pass in a fine coil repeated side by side so many times, and the lag ought to be the same in both cases. I find, for example, that it does not matter in these experiments whether I use a copper ring or a closed coil or a finely wound coil; I might use number 36 wire, provided that I could get as much copper into the same space with the number 36 wire as I could get with a heavy mass of copper. That, of course, I cannot do; but if I could, I haven't the slightest doubt that the electromotive force currents, closed on themselves, would have the same lag as heavy currents closed on themselves. In one case there is greater length; in the other there is greater volume, both of which cause lag of the current.

Mr. Powers is probably working with high potentials in one case and quite low potentials in the other. Now, a high potential machine is a ticklish thing to handle anyhow. You must put your brushes on and carry the coil terminals away from them not a moment too late or you will have a flash and short circuit of the commutator from one point to the other. I am speaking of the type of machine to which you refer. The low potential current, how

ever, permits us to have a considerable variation in the point of commutation, without provoking bad sparking and flashing ; you no doubt are able to use an extra over-lap of brushes on the low potential machine bringing coils into action at the moment they begin to be active, or are developing very low electromotive force and taking them out of action when they are developing nearly no electromotive force. That you could not do in a machine of such type with high potentials, because if you keep the coils in beyond their time of possessing electromotive force which could just sustain the circuit, you would have a flash ; there would be an alternation at the slot in the commutator which would cause a reverse current.

MR. POWERS :—The action I was speaking of was not flashing at the commutator, but the curious growling of the machine against itself ; for instance the relation between ten volts and one hundred volts on the same machine if you choose to couple them up directly, and the same brushes, would give you that slowing down and growling effect, while in the other case the brushes worked smoothly and gave good results.

PROFESSOR THOMSON :—I misunderstood the point in question.

MR. PENDLETON :—The subject has brought up a matter which was of considerable interest to me sometime ago. The different action upon the magnetization of a differential magnet in a lamp that I invented some three or four years ago, may be somewhat analogous to the action that is found in the difference between these two makes. It was an unexplained action so far as I could get at it ; but some one may be able to give the reason for the fact. An ordinary differential lamp, extended poles acting upon an armature which governed the carbon rod, I ran for several weeks upon the circuit of the United States Electric Light Company to good advantage. The lamp worked well and the feeding point and polarization of the cores was correct and worked very satisfactorily. I had occasion afterwards to put the same lamp upon a high tension current and found that consequent poles were developed in the iron and the lamp although it worked, yet at the same time was working under great disadvantage. Mr. Field at the time examined the lamp ; and while he spoke well of its mechanism remarked one day, "Pendleton you have got a bug in that lamp." "Well," said I, "I have, but how did you find it out?" "I had the same difficulty some years ago in meeting with consequent poles." I then told my experience with the lamp,—

that with low tension—it ran perfectly well, and then consequent poles were not formed. I remedied it, however, by placing upon each core the two differential magnets—as it were on one spool, the coarse wire and fine wire. Now, in this action spoken of, between the high and low tension currents, I find there may be some similarity of action; and it is a matter that has not been thoroughly ventilated. I have never been able to account for it. I remedied it, but the cause of it I have never been able to ascertain. There are a great many things in the matter of magnetization, simple though it may be, that we are foggy about.

THE PRESIDENT:—We have other items on the programme, and interesting as this subject is, and attractive as it is, I think we shall have to move on. Mr. Shelbourne will you kindly take the chair.

MR. SHELBOURNE took the chair, and MR. MARTIN read the following paper, entitled, “A Few Comparative Statistics of Electrical Railways.”

#### A FEW COMPARATIVE STATISTICS OF ELECTRIC RAILWAYS.

BY T. COMMERFORD MARTIN.

It is not now my intention to present a paper on the general subject of electric railways. That I did at a meeting of the Institute, held last December, when I was enabled to offer a few statistics on the electric railway as compared with horse, cable and other methods of traction for street cars. I have found since then a great desire generally for information as to the status of electric roads in the United States and Europe. Street railway men, investors and others have wished to know whether such a thing as an electric road was really operating anywhere or not, and, if the lines were running, what the cost of construction and operation was. The tables I submit herewith are intended as an answer to those queries. It has been difficult to get at a common basis of estimate and statement. With regard to the European roads, I would say, that I have been greatly indebted for the figures to a most admirable and exhaustive paper, read a few weeks ago by Mr. Anthony Reckenzaun, before the London Society of Arts. In Europe, as here, various systems of transmitting the current and of connecting up the motor with the car axles and wheels are in use, and as yet, no determination as to the best method seems to have been reached.