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DYNAMO-ELECTRIC MACHINERY.

By Prof. George Forbes, M.A., F.R.S.E.

[A Lecture delivered at the International Electrical Exhibition of the Franklin Institute, Tuesday, September 16, 1884.]

Mr. W. P. Tatham, president of the Franklin Institute, introduced the lecturer, and spoke as follows:

Ladies and Gentlemen:—It has been the earnest desire of the managers of the Franklin Institute, and particularly of Col. Banes, the chairman of the committee in charge, to give the present exhibition an educational character; and to this object they have arranged a series of lectures to be delivered in this hall on Tuesday and Thursday of each week. The present lecture will be on the subject of "Dynamo-Electric Machinery," and will be delivered by Prof. George Forbes, of London, whom I now have the honor of presenting to you.

Professor Forbes spoke as follows:

Ladies and Gentlemen:—The subject of this evening's lecture is Dynamo-Electric Machinery, and it ought, perhaps, in greater strictness to be defined as dynamo-electric machinery in general, and not dynamo-electric machinery in particular; because in a single lecture it is impossible to go into the whole subject of the differences between various types of machines, and all I can hope to do in the course of this lecture is to give to you a general insight into the theory and principles of construction of dynamo machinery and of the progress which has been made up to the present time in theoretical investigation and practical application.

At the beginning of this century our information about the action of electrical currents was extremely limited indeed, and it was not until a great discovery was made in the year 1820 that the basis was laid for those developments which have culminated in the vast number of machines which you see around you in this exhibition. At the commencement of the century, in fact up to quite a recent date, the current of electricity was developed, not by means of these machines which we see around us in the exhibition, but by means of a chemical apparatus which was called a voltaic battery, such a one as I hold in my hand here, which consists of two dissimilar metals, one of which is zinc and the other may be of carbon, copper or some other metal. When these two metals are dipped into a suitable acid and connected by a wire, a current of electricity is said to pass from the copper through that wire to the zinc. Now, if you ask me what is the current of electricity, I am bound to confess to you that I do not know. All that I can do is to give you some analogy to fix your mind upon while you are thinking about a current of electricity. If I were to take a copper wire and hold one end of it in a hot flame and hold the other end in a block of ice, heat would be absorbed in the end which was in the flame and heat would be given out in the end which was in the ice, and heat would be conducted along the wire. No material substance is conducted along that wire, and I am sure there are very few of you that can form any conception of what is passing along in the wire. But you have a notion, not a physical conception, of heat, and the phenomenon of heat transference through the wire is not unfamiliar to you. I do not say that electricity is the same as this, but it is the general opinion of scientific men that electricity passes through the wire in a somewhat similar manner to heat. It is energy and not matter which passes through the wire. That is not a tangible analogy.

I will try now to give you a clearer but grosser analogy. I allude to the analogy which exists between electricity and the flow of water in pipes. When we have a certain head or pressure of water we have also a flow of water through the pipes, and the greater the head or pressure the greater is the flow of water through the pipes. At the same time we have in the pipes a certain resistance to this flow, a resistance due to the small diameter of the pipe, and the smaller the diameter the greater the resistance to the flow of water. In all these points electricity has an analogue. We are able to get up what we call an electric pressure or electro-motive force which exactly corresponds to the pressure of the head of water. When we have this electromotive force in the wire, we are able to get a current of electricity through the wire. That is to say, a flow of electricity which is exactly analogous to the flow of water in the pipes. But this wire offers a resistance to the passage of electricity just as the pipe offered a resistance to the flow of water, and the larger the wire is, and the greater its sectional area, the greater is the flow of electricity, just as the greater the diameter of the pipe, the greater is the flow of water. Thus, I think you will admit that we have here a tangible analogy between the flow of water and the flow of electricity; and when I speak of the electro-motive force which we have, you will understand that it is

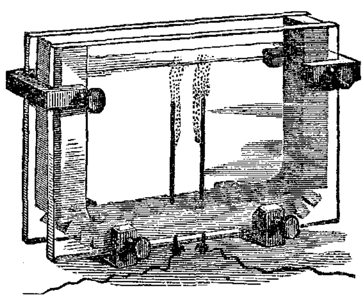

FIG. 1.—Decomposition of water by an electric current. (Cell upright.)

analogous to the pressure of water, and when I speak of the resistance it is analogous to the frictional resistance to the flow of water in the pipe.

Previous to the year 1820 the important facts which were known in connection with the electric currents were these: First, that if two wires coming from a voltaic battery were dipped into a solution of acidulated water, the elements of which the water is composed were separated or decomposed and rose as bubbles to the surface. This experiment I can show to you now by means of the magic lantern. We will lower the lights. We have now a cell which is exhibited on an enormous scale on this screen in an inverted position. (See Fig. 1.) Here is the top, and this is all air below; the cell being inverted the water which is contained in the cell is shown at the top of the picture; and here we have two wires; one is connected with the positive pole of the voltaic battery and the other with the negative pole. If now the wires be connected we shall see bubbles of gas, hydrogen and oxygen, rising to the surface. This shows a decomposition of the water in the cell in a manner such as it would be impossible for me to show to you on the lecture table.

Another fact which was known at the same time and which was one of the few important facts known was this: that if a conductor, made thin enough, were brought in connection with the two poles of the battery it would become red hot or white hot.

I have underneath this table a voltaic battery connected with two wires coming above the table. You will be able to see as soon as I connect them with a thin piece of platinum wire that the wire becomes red hot, and if I diminish the resistance in the circuit by shortening the wire I can make it even hotter than that; I am able to make this wire of a bright red heat.

These two important facts were then known, the decomposition of water, and the heating of a conductor, by the passage of an electric current. There was another fact that was known which I ought not to omit to mention. The discovery of Sir Humphrey Davy, about the year 1811, that the spark which had often been seen on the breaking of the circuit could be intensified by using a large number of cells in a voltaic battery and taking the two ends of the wire and attaching to them two pieces of charcoal; on separating these two pieces of charcoal a brilliant light was seen to pass from one piece of the charcoal to the other. That is the fundamental experiment which led to the discovery of the electric light, that is the arc light, which is so very much used in this country.

I have in the course of the last few years visited each one of the different electrical exhibitions which have been held in Europe. Last year I was at one held in Vienna. After I had wandered about the exhibition and visited the host of applications of electricity rivalling in number those which you see in this Franklin Institute exhibition, the great variety of telegraph instruments, the hosts of different kinds of telephones and the great number of types of dynamos distributed all over the building, I happened to find myself standing in front of a small exhibit which filled me with respect and a feeling akin to awe. This was a small object placed upon velvet and covered with a glass shade, and behind it there was a bust of the illustrious man who had used this apparatus. I looked upon this instrument with respect, because in the discovery made with it I saw the commencement and the dawn of the whole of that science of electricity which had reached such a culmination in the Vienna exhibition. I saw in that one experiment of that famous man the genesis of every one of the telegraph instruments in the exhibition, of every one of those telephones, of all the various applications of electricity, of every one of the types of dynamos in that building. I need hardly say to those acquainted with the history of electricity that I was looking at a small compass needle, and that the bust was that of the late Professor Oersted, of Copenhagen.

For many years people were aware that there was some hidden connection between the compass and electricity, between the power that impelled the compass to point to the north and the lightning in the sky. It had been believed that when lightning had disarranged the

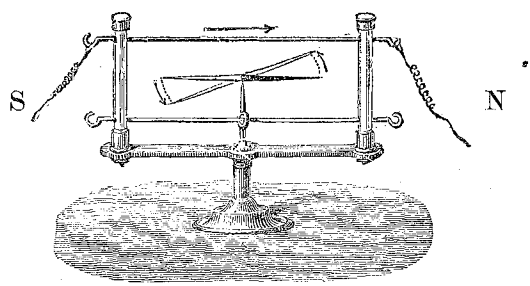

FIG. 2.—Action of an electric current on a compass needle.

compass needle and reversed its polarity it showed that there was some connection between electricity and magnetism, but no one could tell what that connection was. Mathematics were of no avail in the solution of this problem. Oersted happened to be experimenting with a battery and a compass and found the secret of the mystery, and it is from this point that we have to investigate the progress of electricity this evening.

Here we have a compass needle suspended under a wire. (See Fig. 2.) The wire will presently have an electric current passing through it. Oersted found that when the current coming from the copper pole passed over a compass needle from the south to the north, the compass needle moved with its north pole towards the west. That is, the compass needle was moved by the influence of the electric current, an action taking place between the current over it and itself. On this compass needle I have put some pieces of paper that you may be better able to see the experiment. If Mr. Knapp, who is kindly giving me his assistance, will now lower the plates into the battery you will immediately see a declination of the north pole of the compass to the west. On breaking the current the compass needle, as you see, immediately resumes its position from north to south. In other words, when the current is flowing in this direction the north pole of the compass needle goes to your left. That is to say, if I be looking in the direction in which the current is going, the north pole of the compass needle seems to go round the wire in the direction of the hands of a watch. And if I had the compass needle at one side of the current the north pole would

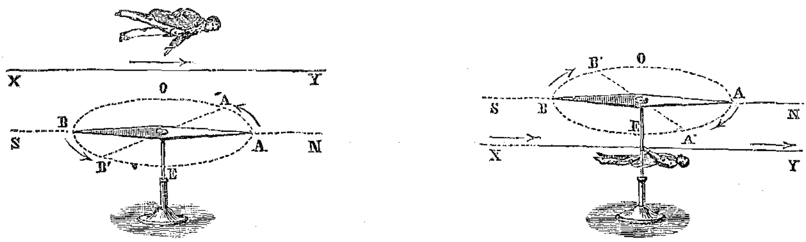

FIG. 2 *a*. FIG. 2 *b*.
Action of an electric current on a compass needle.

still tend to turn round in the direction of the hands of a watch. The south pole tends to go in the opposite direction. Another means has been proposed for indicating the direction of motion of the compass needle. If a man be supposed to be swimming in the direction of the current and facing the compass needle, he will see the north pole going to the left. In this way, looking at Fig. 2 (*a*) and Fig. 2 (*b*), we see that a current going from south to north, if above the compass, deflects it to the west of north, and if below, to the east of north. There are various results which we can see to follow from this principle. Here I have a rough ring to illustrate the direction in which the current is going. (See Fig. 3.) Let the light arrows show the direction of the current. Now, I have found, when I am looking along these the north point appears to go round in the direction of the hands of a watch; so, also, looking at it from another point, the needle would still tend to go round in the direction of the hands of the watch, so that wherever in front of this circle I may hold the north pole of the compass needle it will always tend to go through the circle in that direction if the current is going in the direction of the arrows. Here, we have a method of intensifying what was shown by Oersted. If I hold a compass in front of a coil the north pole will tend to be sucked in, in that direction; and the south pole would be sucked in, in a similar manner if held at the other side of the coil.

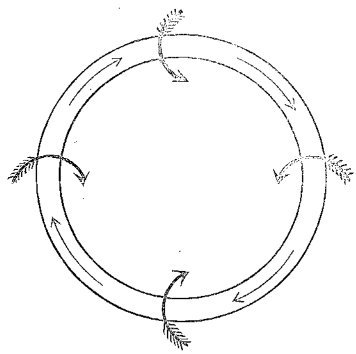

FIG. 3.—A current passing in direction of light arrows moves a north pole in direction of dark arrows.

I will show you next another experiment to illustrate the analogy between the electric current and magnetism, which follows directly from Oersted's experiments. Here I have a mass of iron or sets of bars going directly downwards with iron at their base and coils of copper wire surrounding them through which I can pass an electric current. As soon as I pass such a current through the wire this becomes a powerful magnet capable of attracting iron objects placed in its neighborhood. It will hold a bar of iron like this with enormous intensity. So, if I tumble upon the poles a quantity of nails the magnetic attraction is so great as to give the nails the appearance of cohesion which enables them to stand upright in a bridge; but as soon as I take away the current they fall down, which shows that the magnetism has left the magnet as soon as the current ceases to flow. (See Fig. 4.) In this experiment the north polarity is urged through the iron in the direction indicated by Oersted's experiment.

Having shown you how a magnet can be produced, I will show you the experiment which I described just now. Here I have a coil of wire analogous to the coil which Mr. Knapp was just now holding in his hand, and here I have a bar of iron, and I have said that if I have a north pole under here it will be sucked up if the current is going in the right direction. Now the coil will magnetize this bar. As soon as I have magnetized the bar it has a north pole at the top, which is powerfully sucked in. The intensity of the magnetic effect of this current of electricity is so great that I have considerable difficulty in dealing with this mass of iron which I am holding in my hand.

Now, in this experiment I wish to point out to you the key that exists to the whole of the researches of Faraday which were made some years afterwards. When I have this magnetic needle, which is deflected by the current, or this bar which is sucked into the coil, it is evident to every person of sense here that work is being done. That is to say, that when the needle is moved away from the position which it naturally occupies, work is being done. Where does this work come from? It comes from the interaction of the compass needle and the electric current. It is, therefore, safe to say that when a compass needle is moved in the neighborhood of an electric current it is doing

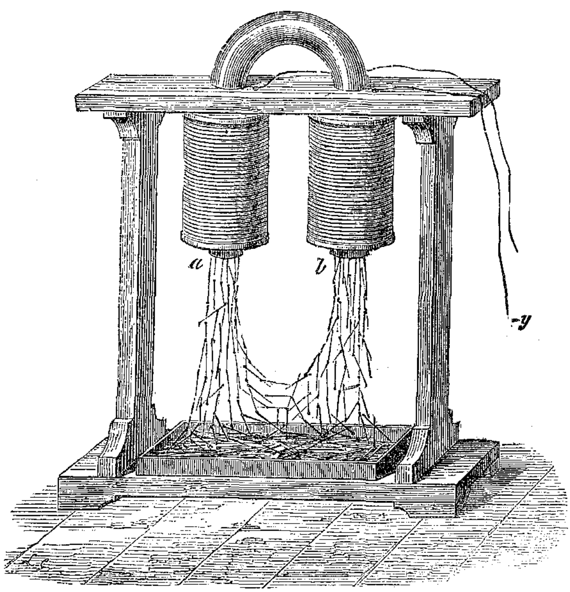

FIG. 4.—Electro-magnet supporting a bridge of nails.

work, and in order to do work it must take away a part of the current from that current which is acting. Now, in order to take away from the current it must have started a feeble opposing current in an opposite direction. And here is the point that I wish you to grasp, that in the movement of the compass needle from one side or the other, an opposing electro-motive force has been created, that is, a force tending to set up a current in the wire in the opposite direction. This I believe was the manner in which Faraday argued the matter out in his mind and that is how he was able to originate the experiments which he made to produce the opposite result, that is, to create a current in the wire.

Hitherto, Oersted had shown that a current could produce motion in a magnet; Faraday conceived the idea that by the motion of the magnet we could produce a current in the wire. This experiment I shall now be able to show you. By moving a magnet pole into a coil you will be able to see a movement of the pointer which I have here and which indicates the strength of currents which are made to flow

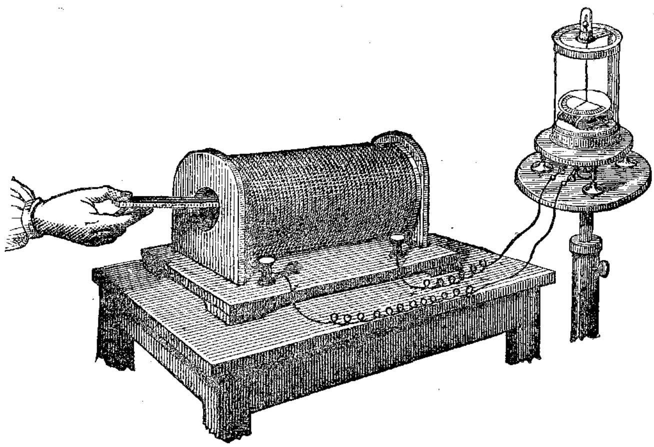

FIG. 5.—Galvanometer showing an induced current while a magnet is moving into a coil of wire.

through wires which are connected with it. This instrument which I have here is a galvanometer, an instrument whose object is to measure the strength of electric currents. You see the index traveling over the scale at the present moment; it now points almost to the middle of the scale. If then, I take an ordinary coil of wire and reverse the experiment which I was talking of a short time ago, that is to say, pass the pole of the magnet into the coil of wire, we shall find that the electro-motive force is started in the coil of wire, and if the circuit of the wire forming the coil be completed through the galvanometer, we shall find that a current is created which will show itself by the deflection of the galvanometer. (See Fig. 5.) Now, in order that this be made distinct, I shall ask Mr. Knapp suddenly to insert the north pole of the magnet into the coil of wire. The movement of the galvanometer will be very slight, but you will be able to see it. I will now ask him to withdraw the pole and the movement will be in the opposite direction. In this manner I get up a sort of swing in the galvanometer which is more visible to you and shows that I can move the galvanometer needle from one side to the other when I put in the north pole of the compass or draw it out. The motion you see is very slight, but I am perfectly able to control it; it moves always to the right when I put the pole in and always to the left when I take the pole out. This movement of the index proves that Faraday's notion was right.

I am anxious now to show you this experiment in another way, for it shows a further development of our notion which will enable you to understand the application of Faraday's principle to the construction of the dynamo machine, which we will be investigating in a few minutes.

Here I have a coil of wire connected up with the galvanometer. In the coil there is a bar of iron. I show you that when I magnetize the bar of iron which goes through it, there will be a deflection of the galvanometer, and when I reverse the magnetism, there will be a deflection in the opposite direction; so that when I have a piece of iron enclosed in the coil of wire all I have to do is to magnetize it by the influence of these neighboring poles. Mr. Knapp will now magnetize the pole by touching the end with a magnet; as soon as it is magnetized there is a movement to the right. Reverse now—there is a movement to the left. This is merely an experiment which assists our comprehension of the construction of the machine, or shows that magnetizing the iron core produces the same effect as the introduction of the magnetic pole into the system.

Now let us see how all these principles, discovered by Faraday, can be applied to the construction of dynamo-electrical machines. You have seen when I have a coil here with the north pole introduced through it that there is then a current of electricity established in it, and that current is established only while the north pole is passing through it. When the magnet is fixed no action is taking place. I have introduced the north pole into the coil and if I withdraw that north pole by the way it went in, I shall of course create a current in the opposite direction. If, on the other hand, I carry the south pole in the same direction in which the north pole has gone, it also will create a current in the opposite direction. After I have passed the north pole through the coil, it is impossible to increase the current in that direction. The further motion of the other pole must produce a current in the opposite direction to the current first produced. However I may act in this way, I am bound to get a motion which gives alternate currents. If I use a bar of iron surrounded by a coil of wire and magnetize it, with the north at one end and the south at the other end

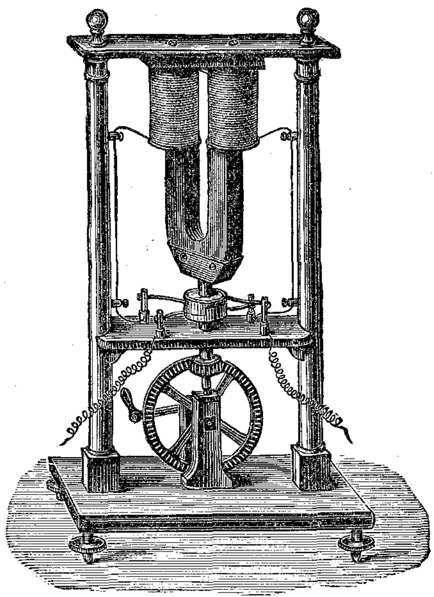

FIG. 6.—Pixii's machine.

I get a current, but it is impossible for me to keep that current going because I cannot get beyond a certain amount of magnetization. If I reverse the magnetization I produce a current in the opposite direction at the moment of reversal.

It would seem then that we have the power of producing currents alternating in direction. This was the only type of machine known for a considerable time; and all of you have seen those instruments in which a handle was turned rapidly while a person held the ends of the wire in his hand and received a succession of severe shocks; that was due to the production of alternate currents by an arrangement which alternately magnetized and demagnetized the iron core inside the coil.

I will now show you some illustrations on the screen which show the construction of machines for producing alternate currents in this manner.

This in one of the alternate current machines, like that of Pixii or Saxton (Fig. 6). Here we have a horse-shoe magnet fixed about an axis to which a rapid rotation can be given. At the top are two coils which remain fixed, and inside these coils there are bars of iron. The consequence of this is that when the magnet is rapidly rotated the

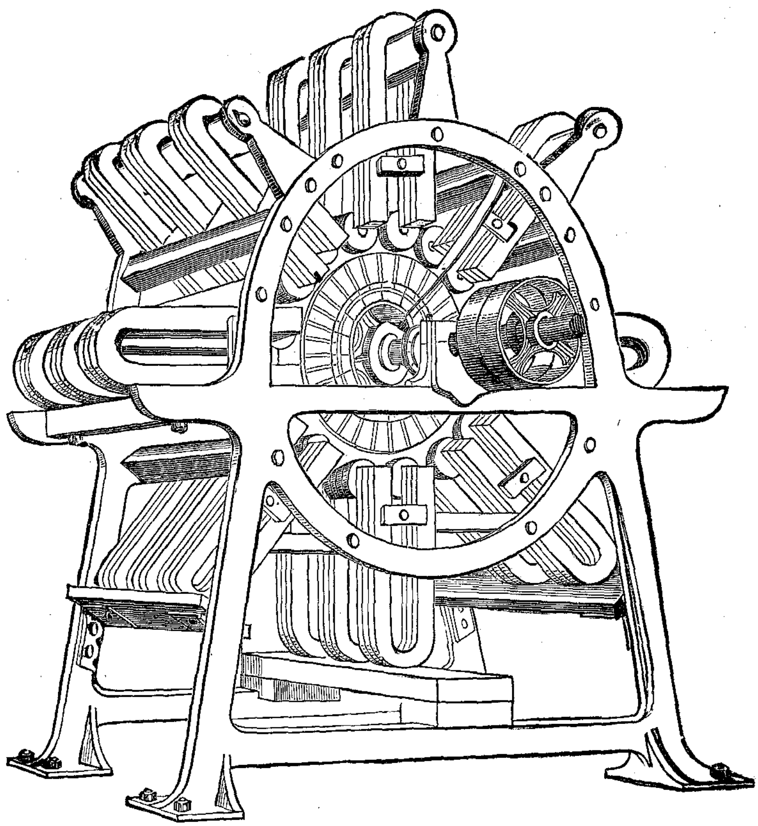

FIG. 7.—The Alliance machine for alternate currents.

north pole and the south pole will be successively presented to the coils, and the result is a continual reversal of the magnetism in those coils; and every time the magnetism is reversed a current is created in one direction or the other; and if the wires in these coils are held in the hand, a succession of violent shocks will be felt by the person holding them. One of the original machines of this type is shown in the historical collection in this exhibition.

I will put into the lantern another slide, showing a different form of machine. Here again is a horse shoe magnet. The magnet does not revolve, but the coils of wire revolve in front of the poles of the magnet. Here are the two coils at the bottom mounted upon a spindle which is horizontal. These two coils are rotated rapidly. Inside the coils are cores of iron. The cores of iron are magnetized in opposite directions as they pass from one pole of the fixed magnet to the other pole, and every time they do so, the current is changed in direction. Here also we are able to receive shocks from the coils by holding the ends of the wire in the hand. In this machine, as constructed, there was an arrangement for changing the direction of the current in the outer circuit at the same time that the magnetism was changed, but of that I will speak later.

In the next slide I shall show you the most practical of all the older machines (Fig. 7). This was the Alliance Machine used for lighthouses in Great Britain and France. It consists of a vast number of horse-shoe magnets. This machine has actually been employed in in our lighthouses in France and England. At the present moment you may see a machine made by De Meritens which is exhibited by James W. Queen & Co., at the far end of this Exhibition and which is constructed on the same principle.

A large number of rows of horse-shoe magnets are about this central axis, around which also there is a ring of coils of wire each with iron enclosed, and all these coils pass in succession the poles of the magnets and so alternate currents are created in the coils which produce a current of great intensity. These powerful currents are generated by means of a steam engine and so we were able to get the powerful spark of the arc lamp like what was seen by Sir Humphrey Davy, in 1811.

I may now pass on rapidly to the greatest improvement which was introduced, and that was the continuous current machine. It was found possible to take these currents from the machine which were alternately in opposite direction and reverse their direction through the circuit, that is to say through an arc lamp or through the hands of the person holding the wires, and thus a continuous current always in the same direction was made. A single reversal, however, did not produce a steady current and it was a long time afterwards before means were devised for creating a steady current which was of real use in producing these continuous currents which we now use in electric lighting, and in this country in telegraphy.

The greatest improvement was introduced by Mr. Gramme about the year 1870, and he did this by means of a machine, a diagram of which you can see on the board here. This is only a rough diagram showing the principle of the machine. (Fig. 8.)

Here is the north pole of the field-magnet, marked "*N*," and here is the south pole, marked "*S*." These are magnetized by coils going around the mass of iron. Here is a ring of iron with coils of wire wound around it. This is the armature. The iron of the ring becomes magnetized by the influence of these north and south poles of the field

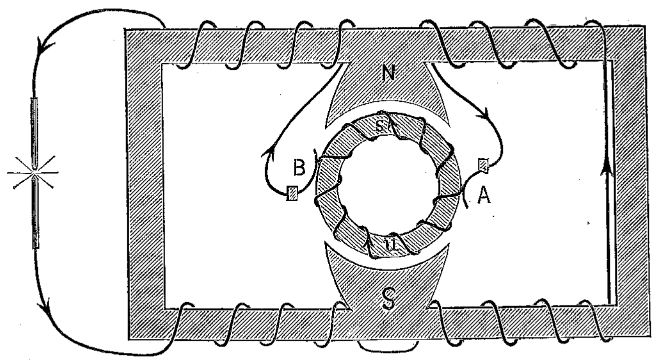

FIG. 8.—Diagram of Gramme machine (series wound), showing field-magnet and pole pieces, ring armature, commutator, and direction of currents. The armature rotates with the hands of a watch.

magnet and the poles in the ring retain the same position in space while the ring revolves. As soon as the ring rotates it follows that these wire coils are continually passing over the pole, or I might say this pole in the iron is continually passing through the coils. In other words, an electric current is being continually developed through successive coils as they pass through here.

If you look at the sketch you will see that there is a south pole in the ring at *s* opposite to the north pole in the field magnet, and a north pole in the ring at *n* opposite to the south pole of the field magnet. If you remember the rule I have given you about the direction of currents you will be able to trace their direction in the machine. Suppose the ring to be revolving in the direction of the hands of a watch, the north pole will be going in the opposite direction through the coils, and if the eye be placed so that the north pole is coming towards it the induced current circulates with the hands of a watch; with a south pole the reverse takes place. Follow this out and you will see that the current flows in the upper semicircle from *A* through *s* to *B*, and in the lower one from *A* through *n* to *B*. But the wire is continuous, and if metallic brushes take up the current at *A* and *B* you see that the current will go out of the armature coils at *B*, through the circuit, and in again at *A*.

Mr. Gramme constructed a commutator with a large number of bars to which the ends of these coils were connected, and he used metal brushes to rub on them, and thus there was a continual series of changes going on as each coil passed those brushes, and thus he was enabled to get a very continuous current of electricity through his machine.

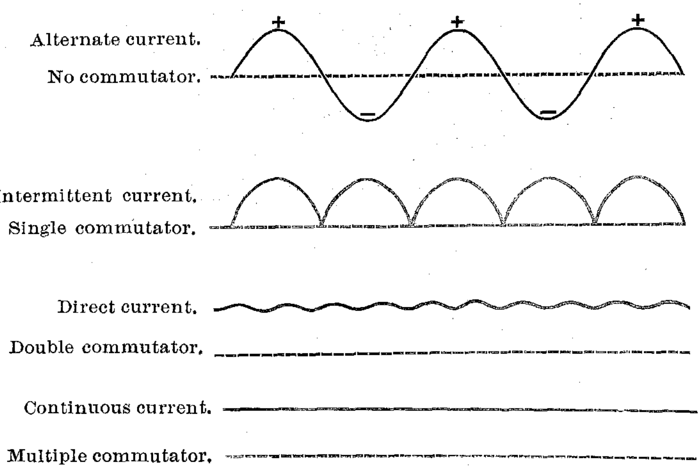

FIG. 9.—Action of commutators.

I have put up here a small diagram to illustrate the action of these commutators. (Fig. 9.) In the old alternate current machine there is a bobbin passing the poles of the magnet; the current increases to a maximum and falls to a minimum then increases to a maximum in the opposite direction when there is no commutator employed. When we put in a single commutator so as to reverse the current in each pole it rises to a maximum and falls to a minimum and we get this interrupted current, but always in the same direction. That was the first kind of continuous current made. Some machines were introduced to give a double commutation that is twice commutated in the course of a revolution, and thus an irregular sort of current was produced; but when Gramme introduced his machine with a vast number of commutations in one revolution he had a vast number of currents and thus there is an almost continuous current produced by the Gramme machine.

In the Gramme machine which I showed you here, the current

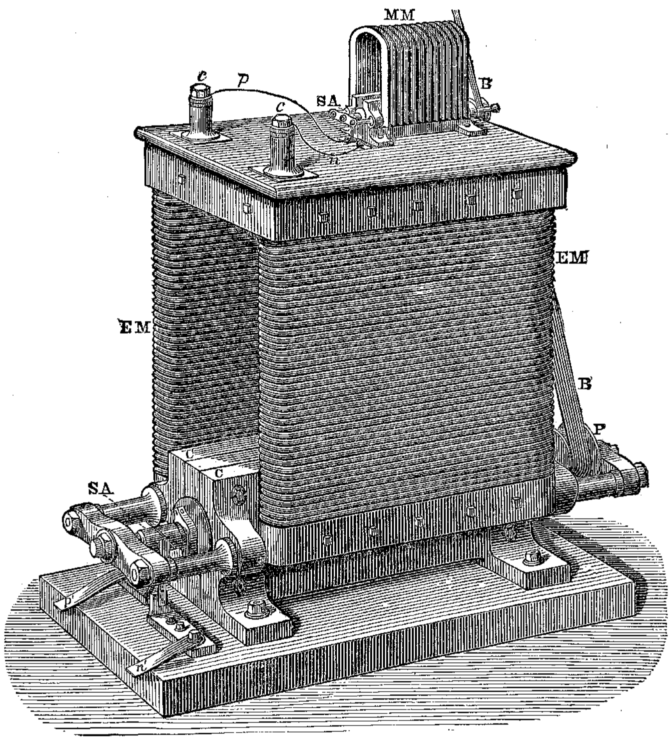

FIG. 10.—Wilde's magneto-electric machine.

itself is used to excite the magnetism in what are called the field magnets, and it passes through this field magnet before going to the lamp circuit. That is what is called winding the field magnets in series. Sometimes the current is taken direct from the revolving portion to the lamp circuit and a second current is taken to the field magnets forming two circuits and thus the field magnets are said to be magnetized in a shunt. The practice of using the current which is induced to produce the magnetism of the field magnet was a completely new thing in 1866, and was invented simultaneously by several people, notably by Wheatstone and Siemens, who produced papers describing it on the same day in the Royal Society of London.

I will now show you on the screen a few more machines of the continuous current nature, including a Gramme machine, and some of the details of the Gramme machine, and I hope when you have seen these diagrams you will be able when going around this exhibition to study the nature of the different machines. It is in the arrangement of the field magnet and armatures in which the machines vary. The whole evening might be given to the variations of the different machines;

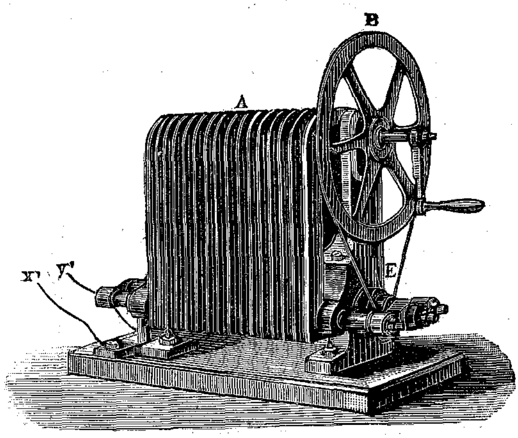

FIG. 11.—Siemens' machine.

in the meantime I can only show you a very few illustrations of the different types of machines.

The first machine which I have to show you here is the machine of Wilde (Fig. 10). Allow me to call your attention to the special parts. *S A* is the axis about which it revolves. In this revolving armature electricity is induced. This is the seat of the electro-motive force; this is the pump which pumps the water and gives it its pressure, and enables it to go through the circuit. *E M* are the magnets, which are composed of soft iron, magnetized by the coils of wire surrounding them. In Wilde's machine, he had a small machine, *M M*, with permanent steel magnets, fixed on top of the larger one. They are not so powerful magnets as these electro-magnets, and he used them to induce a small current of electricity instead of using the larger current to magnetize these electro-magnets. It created a feeble current, which circulated around these field magnets, and gave an intense magnetism to these pole pieces *C C*. These pole pieces being polarized, and the armature revolving, the coils of the armature developed an electric current of

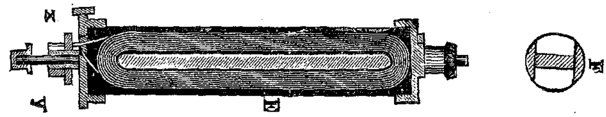

FIG. 12.—Armature of Siemens' machine.

great intensity, far surpassing the current developed by the little machine. Thus he was enabled to get a very great current, sufficient for electric lighting.

This next slide is a Siemens' machine, made also with permanent horse shoe magnets (Fig. 11). You will see the revolving part attached to the driving gear at *E*. That revolving part is of course the armature;

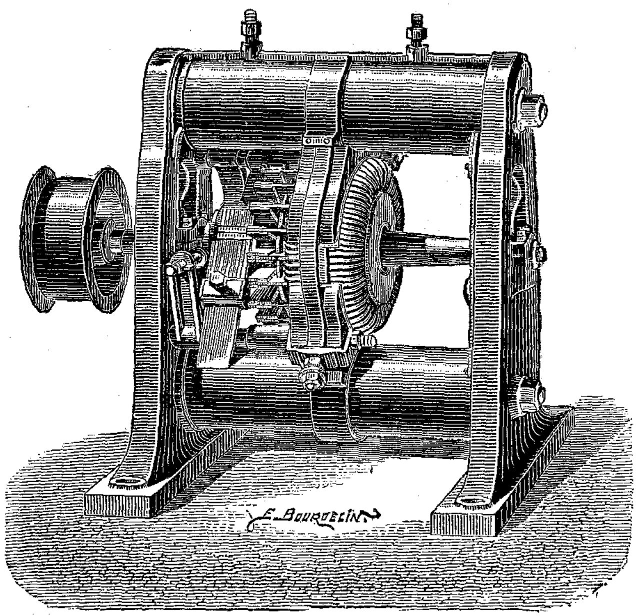

FIG. 13.—A Gramme machine.

the coils of the armature being between the pole pieces. This central part is a mass of iron, and the coils of wire run longitudinally around the core. (Fig. 12.) This machine, as originally constructed, had simply a single commutator, which reversed the current once in each revolution, which sent a continuous but varying current through the circuit.

This slide (Fig. 13) is a Gramme machine, and was introduced to the public shortly after 1870, and this machine has been the basis of nearly all the dynamo machines seen in the world. These round parts at the bottom and top, surrounded by coils of wire, and the pole pieces seen at the top and bottom, are the magnets. There is the Gramme

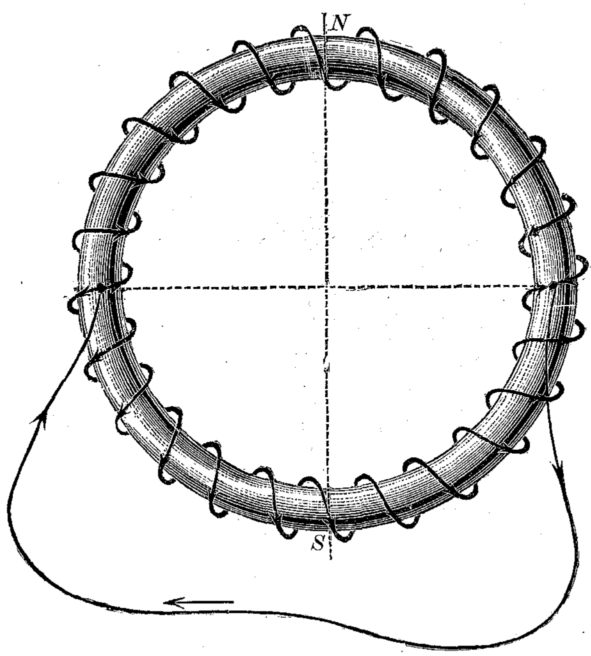

FIG. 14.—Ideal Gramme ring.

armature, which rotates about the horizontal axis, and here is the commutator.

This next picture is an ideal Gramme ring (Fig. 14). Here are are the successive coils. Here is the south and here is the north pole of the ring. You will notice that in each coil, as it passes the pole, an electric current is developed. The current will always be in the same direction, at any part of the ring, and very nearly continuous.

The next picture is a portion of a Gramme ring (Fig. 15). It shows the way it is made up; it consists of a central core of iron wire and coils of insulated wire successively laid upon it. It is cut, showing the ends of the wires projecting.

Here is a small Gramme machine, which can be worked by hand (Fig. 16). In construction it is exactly similar. Here are the poles; there is the revolving ring; the commutator is on the other side, and cannot be seen.

This picture is of a machine of very remarkable historical interest (Fig. 17). This was designed by Pacinotti, and described about the year 1864. It is exactly like a Gramme ring in many points. It revolves around a vertical axis instead of a horizontal axis, and as it revolves the current is picked up by a commutator. This was made on a small scale, and was not used for commercial purposes. It is conclusively proved, however, that Gramme did not know of the work

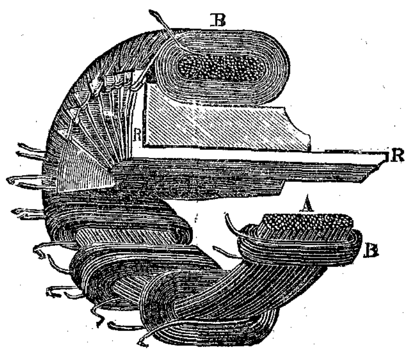

FIG. 15.—Portion of a Gramme ring, showing the mode of construction. A is a section of the iron ring made up of iron wire. B is a coil with the wire ends ready for attachment to commutator bars.

of Pacinotti, but it is incontestible that Pacinotti was the inventor of the type from which all the other machines have been constructed.

An attempt has been made to improve the constancy of the current, and prevent the difference in intensity which is observed when we are using a large or small number of lights. It is found with some kinds of machines that the intensity of the electro-motive force increases when we add lamps to the circuit, and in other kinds we find the opposite is the case. When the field-magnet of a machine is wound as a shunt, as we diminish the number of lamps, the lamps left burning increase in brightness. The machine which illuminates this hall is one with a shunt. It is the large Edison machine. This machine will not show the effect very much, because the armature of that machine is made of very low resistance, and it is only lighting 300 lamps instead of 1,500; and the electro-motive force or pressure is steady, however we vary the number of lamps. Still it is a shunt-wound machine, and there is a slight difference between the intensity of the lights.

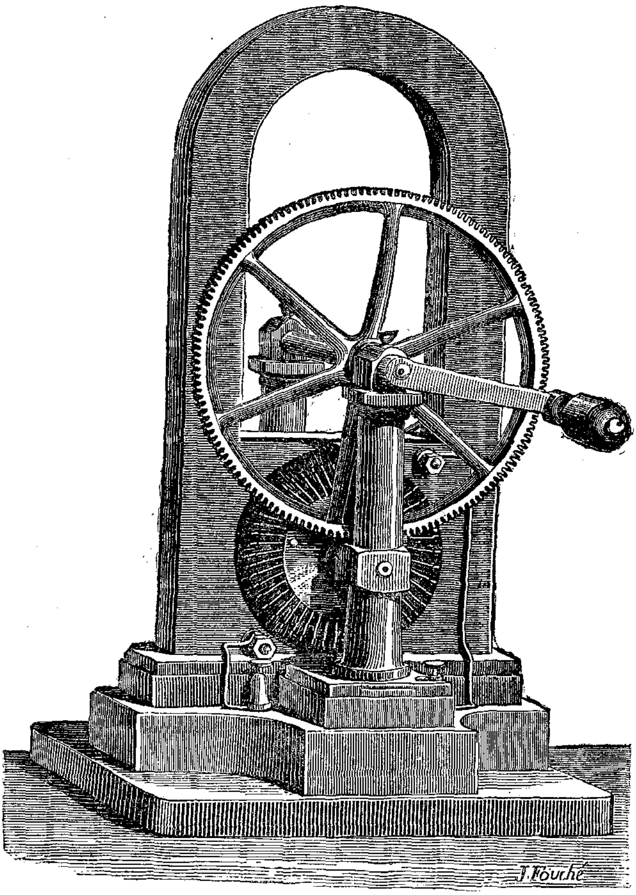

FIG. 16.—Hand Gramme machine.

I will now put out the lights in succession, and leave these two lamps to be last put out. You will notice that there is a slight increase in the brightness of the last two lights; it remains with you to notice that the change is very slight indeed. This illustrates how we can make a machine that will regulate itself; that is, however many lamps we put upon the circuit the electrical pressure is the same and the intensity remains constant.

Now watch these two lights as the others are put out in succession. You see they are decidedly getting brighter. Put them in again and you will see the opposite effect take place. You will see them dimming. Now, this is distinctly dimmer than it was a little ago, though but very little. It is quite evident to you that a machine like the Edison (the machine producing these lights is what is called the Jumbo) does not vary much when we vary the number of lamps up to 300.

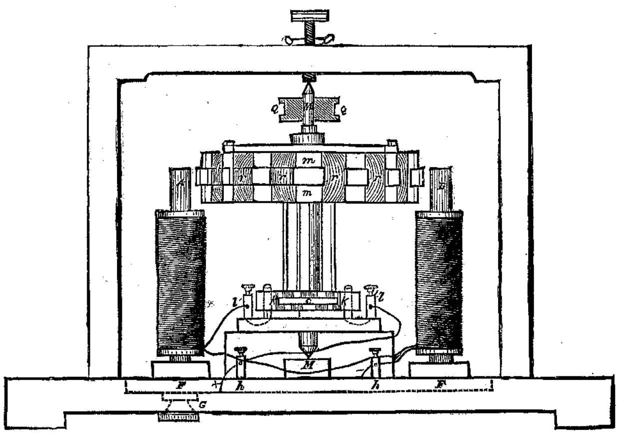

FIG. 17.—Pacinotti's machine.

It is astonishing when we descend to one lamp and show such a small variation in the light. In an ordinary small machine the change of brightness would have been decided. In the shunt wound machine, when we increase the number of lights we diminish the intensity of each. In the series machine the opposite is the fact. I might show you that experiment, but time is passing quickly. That is to say, when we put in one lamp in a series machine it hardly glows at all. The reason is that the current is very feeble with one lamp, because the resistance in the circuit is very great. When the current is feeble the magnetism of the field magnets is feeble, and that is the cause of the low electro-motive force. As I increase the number of lamps I am increasing the means of escape; that is, I am increasing the number of pipes of my hydraulic system, and letting more water flow, and the magnetization is more complete.

Of late years it has been earnestly attempted to produce perfect equality even in the small machines, and without going to the vast dimensions of the large-size Edison machines, by winding the field magnet in a double way, partly as series machine and partly as shunt machine. I have already explained to you that when we have a shunt-wound machine the electro-motive force gradually diminishes as we put in more lamps; and I have shown that in the series machine the electro-motive force gradually increases as we reduce the resistance and put in more lamps. Therefore, taking the mean of these, or summing these two curves together (Fig. 18), by winding these two magnets partly in series and partly in shunt, the electro-motive force does not

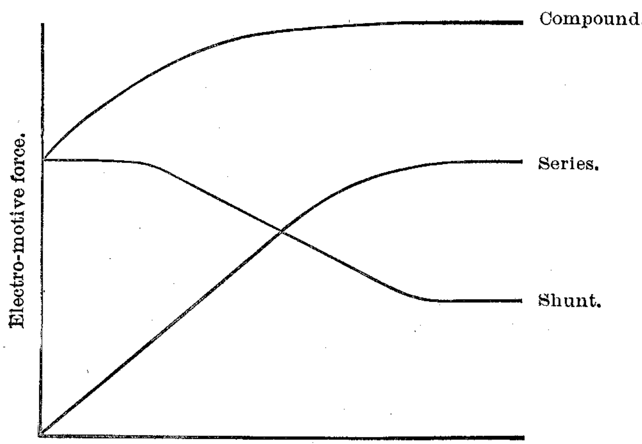

FIG. 18.—Showing relative advantage of compound winding in maintaining the electro-motive force constant when the current is changed.

vary in so great a degree. Thus we are able to get by a proper adjustment a perfect equality or difference of potential between the two parts of the line, and, whether we are dealing with the terminals, at the machine itself, or where the lamps are applied a mile away, by a proper compound winding, partly in series and partly in shunt, we are able to produce a compound machine which gives a constant electro-motive force however many lamps we are using, that is, however many pipes we may have drawing off water from our supply.

I had hoped to have spoken about the effects of alternate current machines, which would have been extremely interesting; but time is passing so rapidly that it is impossible to deal with this subject now.

I will only show you one remarkable experiment by means of the alternate current passed through a coil of wire on one arm of the electro magnet and through an incandescent lamp.

I will show these effects, because they are very remarkable. The effects of the alternate current machines are very difficult to understand at first sight. Perhaps, if I explain to you this one action I may have given some information to some of my audience here, and it may enable them to see some of the difficulties to be met with in alternate current machines, and enable them to avoid making mistakes in their applications in the future. I will pass an alternate current through one coil of the electro-magnet, and also through one incandescent lamp. That lamp glows very feebly indeed. But as soon as I join the terminals of this wire, going round the second coil of the electro-magnet, it immediately glows brightly. (See Fig. 19.)

When I have an alternate current passing through this first core, it

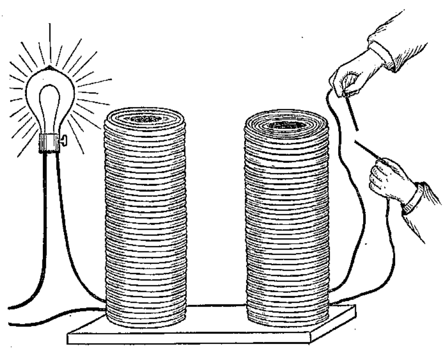

FIG. 19.—An alternate current passing through one arm of an electro-magnet and an incandescent lamp. When the ends of the other coil are separated the lamp is dull; when joined the lamp is bright.

is exercising a large power in magnetizing and demagnetizing that core. That core exercises its influence upon the other core to magnetize and demagnetize it. Thus the iron in these two arms of the magnet is being magnetized and demagnetized with great rapidity, and it is taking away from the current which is feeding this lamp. But so soon as I connect the wires of this other coil I am using up the power and magnetism in this core. I am making it do work in creating currents in this second coil; that is to say, this second coil acts as a drag on the magnetism of the core. So soon, then, as I connect the ends of the wire of this second coil the magnetism cannot change there so suddenly, and the primary current is not able to do so much work in the magnet, and therefore it is more free to exert its own force, and therefore it enables the lamp to glow with greater brightness than it did before.

I must not trespass upon your time longer; I feel that I have already exhausted the limits which I had set myself, and which ought to be set to a lecture of this kind. On the subject of dynamo-electric machines several lectures might advantageously be given. We have, I think, advanced a great distance in the way of theoretical application of the laws of electricity to the dynamo-electric machines; we owe a great deal of this not only to the advance in theory, but also to the advance in the application of theory. There is a great deal still to be done by theory and by practical application. If we look to the past we shall find that there has been too much hesitation on the part of practical men in accepting the results of theory; and if we look with hope to the future we shall see theoretical views put to practice to guide us and direct us in our efforts to arrive at perfection. In fact I may say that I have seen private experiments which lead me to predict remarkable progress in dynamo-electric machinery in the near future.

On a recent occasion Lord Rayleigh, the president of the British Association, at Montreal, and also the very distinguished professor at the University of Cambridge, England, stated that he was astonished to find, considering how well known were the laws of induction in the time of Faraday, and how complete was our knowledge of electrical induction in those years long past, he was astonished to find at how slow a rate the practical applications of those principles long ago published by Faraday had been introduced into every-day work. Lord Rayleigh then stated his opinion that the cause of this slowness to apply the achievements of science was due to want of faith, and I agree with him that this is the true solution of the enigma. Faraday was a man whose mind was taken up with original investigation. Faraday had as complete a mathematical conception of the theory of electricity as any of us who have studied Clerk Maxwell's book could have; although he could not express one word of his ideas in terms of x, y and z. And in this way from the experiment of Oersted he was able to divine in his own mind the consequences of that experiment, and foresee the results of his own experiments in developing electro-magnetic induction; whereas you would have thought it was only by the application of the higher mathematics that this could have been done. He also had this peculiarity, that he knew what his bent was, and in what manner he could be of the most benefit to mankind. He says himself, in one of his writings, as much as this. In speaking of the possible applications, and throwing out a hint as to the manner in which powerful dynamo-electric currents might be created, he makes use of the following language: "But in all my work it has been my endeavor not to seek out applications in practice so much as to arrive at new principles." I speak from memory, but I think these are nearly the words that appear in his "Researches." This was the key to his life. He knew that he had an inherent power to discover new principles, and that if he left the applications to others they would come in time.

In this past history of the applications of electricity we have thus to remember that thirty, forty and even fifty years ago we had the knowledge which was given us by Faraday, which would have enabled us to construct this dynamo-electric machine, and it was only through want of faith in those whose duty it is to deal with the applications of scientific facts that the slowness has been due. And in future let it be hoped that theory and application will work hand in hand, and that, while theorists see that the value of their investigations and the impetus which prompts them are due to their practical application, so others whose duty it is to apply science commercially may see that the rapidity of these applications depends upon the acceptance of the results of theory; and if this exhibition and this course of lectures lead those who apply science to study a little more fully the new ideas which theory is teaching us, and if they lead theorists to see a wider range for the applications of theory, then the managers of this Institute will have had the best reward possible for giving these lectures in knowing that they have been of some avail.

Mr. Joseph M. Wilson:—We are all so very much indebted to Prof. Forbes for his exceedingly interesting lecture, that I feel I am only expressing the sentiments of those present when I move that a vote of thanks be extended him, to be indicated by the audience rising.

The motion was seconded by Dr. William H. Wahl, and was unanimously adopted.

Note.—A number of the illustrations in Prof. Forbes' lecture are from "*Schellen* (*Keith*), *Magneto and Dynamo-Electric Machines*, for the use of which the Journal is indebted to the politeness of the publisher, D. Van Nostrand, New York.