TORPEDO MANUAL

FOR

HIS MAJESTY'S FLEET.

IN THREE VOLUMES.

VOLUME I.

ELECTRICITY

AND

MAGNETISM, ELECTRIC LIGHTING

AND

MACHINERY.

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TORPEDO MANUAL.

VOL. I.

CHAPTER I.

ELEMENTARY THEORY.

Introductory.—Electricity, like heat and gravity, is one of those natural forces of whose real nature we know very little. We do not know what gravity is, but we have perfect confidence that if we let go a heavy body from a height it will fall. And, having grasped this fact, we can make use of it in many ways. Also we have no more knowledge of what heat really is, but it has been observed that when heat is applied to water, the water eventually turns into steam. A knowledge of this fact, and a careful study of the properties of steam, were what led to the invention of the steam engine.

In the same way, by studying the effects produced by electricity, its energies can be turned to account, and by means of suitable machines, can be made to do useful work.

The study of electricity is generally divided under two heads, namely :—

Electrostatics, which deal with the effects produced by electricity when at rest.

Electromagnetics, which deal with the effects produced by electricity when in motion.

It cannot, however, be too strongly impressed on the student that it is essentially the same electricity that is being studied in each case, and that this division is only made for the sake of convenience.

The first chapter will deal with the subject of electrostatics, which are best studied first, as they were the first effects discovered.

Electrification.—If a stick of sealing-wax, resin, or glass is rubbed with a piece of flannel or silk, it will be found to have acquired a property which it did not previously possess, namely, the power of attracting to itself such light bodies as chaff, bits of paper, or balls of pith. The sealing-wax, glass, or whatever is used, is then said to be "electrified," or "charged with electricity."

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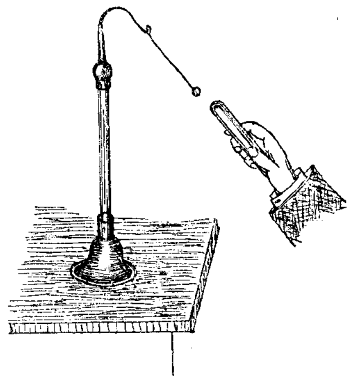
When this experiment is made, it will be noticed that the bits of paper or chaff are first attracted and fly towards the electrified body, but after having touched it, they are immediately repelled and fly away from it. This can best be shown by means of a ball of pith suspended from a silk thread (Fig. 1). If a glass rod

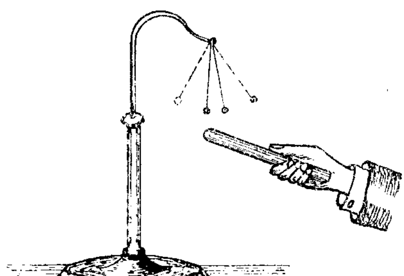
FIG. 1.



which has been rubbed with a piece of silk is brought near the pith ball, this effect will be observed, the ball being first attracted, and as soon as it has touched the glass, being violently repelled. If a non-electrified body, such as the hand, is then brought near the pith ball, it will be seen that it is again attracted; so that the pith ball, by touching an electrified body, has also acquired a property that it did not possess before.

To show this more clearly, two pith balls may be hung side by side by two strings, and both electrified by approaching to them an electrified glass rod and allowing them to touch it. It

FIG. 2.



will then be seen that not only are they repelled by the glass, but also they repel one another, and instead of hanging down side by side, they are pushed apart and hang at an angle (Fig. 2). The conclusion we draw from this is that electrified bodies repel one another.

Electrified bodies do not, however, always repel each other. Suppose we take two pith balls, hung by silk threads from separate supports, and electrify one by allowing it to touch a glass rod that has been rubbed with silk, and the other by allowing it to touch a rod of sealing-wax that has been rubbed with flannel, the following facts will be observed:—

1. The two pith balls attract one another.
2. The ball that was electrified by touching the glass is repelled by the glass but attracted by the sealing-wax.
3. The ball that was electrified by touching the sealing-wax is repelled by the sealing-wax but attracted by the glass.
4. If we hang up the glass and sealing-wax by silk we find that they attract each other.

Two kinds of Electricity. — The conclusions to be drawn from these facts are that there are two kinds of electricity, and that each kind attracts electricity of the other kind while it repels its own kind. These two kinds of electricity have been named positive and negative, that produced when glass is rubbed with silk being called positive, and the other kind negative.

It is found, however, that the kind of electricity that is produced depends not only on the substance rubbed, but also on what it is rubbed with. Thus, although glass yields positive electricity when rubbed with silk, it yields negative when rubbed with catskin, and resin, which gives negative when rubbed with flannel, gives positive when rubbed with a mixture of tin and mercury spread on leather.

It is also found by careful observation that neither kind of electricity is ever produced alone, but always an equal amount of each; one sort appearing on the thing rubbed and an equal amount of the other kind on the rubber. This can be proved in the following manner:—If a piece of sealing-wax is electrified by being rubbed with a piece of flannel, each being held by a glass handle, the amount of charge on each can be measured by means of an insulated pot connected to an instrument called an "electroscope." The electroscope will be described later, and it will suffice to say now that it is an instrument that can be used to detect and measure charges of electricity. If either the sealing-wax or the flannel be inserted alone into the pot, the electroscope at once shows the presence of a charge of electricity, while if both are put in together no effect at all is observed, the two opposite charges exactly neutralising one another.

In the following list the different substances are arranged in such order that if any two are rubbed together the one that stands earlier in the list becomes positively electrified, and the one that comes later becomes negatively electrified:—Fur, wool, ivory, silk, metals, sulphur, indiarubber, guttapercha, celluloid.

Conductors and Insulators.—It was found by early experimenters that there was a class of bodies that could not be readily electrified, namely, metals, and also that damp nearly always prevented the manifestation of any of the effects so far mentioned. It was at first supposed that these substances were not capable of being electrified. After a time, however, it was discovered that metals could be electrified if they were mounted on handles made of glass, ebonite, or some similar substance. Then it was found that nearly all substances could be roughly divided into two classes, those that apparently allow electricity to flow freely through them or over their surface, and those that apparently offer some resistance to the passage of electricity. The former class was given the name of conductors, and the latter the name of insulators. There is no sharp dividing line between them, and indeed there are many substances that cannot be said definitely to belong to either class, but nearly all the substances commonly met with can be classified in this way.

Substances that are very bad conductors are said to offer a great "resistance" to the flow of electricity through them. There is indeed no substance so good a conductor as to offer no resistance at all, and there is no substance of so high a resistance as not to conduct a little. Even silver, which conducts best of all known substances, resists the flow of electricity to a small extent; and, on the other hand, such a non-conducting substance as glass, though its resistance is many million times greater than any metal, does allow a very small quantity of electricity to pass through it. In the following list, the substances named are placed in order, each conducting better than those lower down on the list:—

Silver	Good conductors.
Copper	
Other metals	
Carbon	
Sea-water	Partial conductors.
The human body	
Cotton	
Dry wood	
Marble	
Paper	
Oils	Non-conductors or insulators.
Porcelain	
Wool	
Silk	
Resin	
Guttapercha	
Shellac	
Ebonite	
Paraffin	
Glass	
Quartz (fused)	
Air	

When the charge of electricity is removed from a charged body, the body is said to be discharged. Good conductors of electricity are immediately discharged if touched by the hand or any conductor in contact with the ground, the charge being thus provided with a means of escaping to earth or the surrounding walls. A body composed of some insulating substance, however, is not discharged merely by touching it, since, as before explained, electricity does not seem to be able to move about on insulators, but seems to be somehow bound to the surface.

Manifestations of Electricity.—The presence of electricity is not manifested only by attraction and repulsion, which we have hitherto taken to be the tests of electrification. It is also observed that sparks and flashes of light can be obtained from highly electrified bodies at the moment that they are discharged. Such sparks are accompanied by a crackling sound suggestive, on a small scale, of the thunder accompanying the lightning spark.

Causes of Electrification.—It must be remembered that friction is not the only means of producing electrification. It is true that friction between two different substances always produces electrification whatever the substances are, and generally the substance becomes negatively electrified whose particles are more easily removed by friction. There are, however, many other ways of producing electrification which will be mentioned later. The quantity of electricity produced when two different substances are rubbed together seems to depend rather on the nature of the substances than the amount of friction used. Hence it appears doubtful whether friction is actually the cause of electrification. It seems likely that the only function of the friction is to bring the surfaces into intimate contact. Certainly it is found that when the surfaces of two different bodies have been brought into contact they are charged with electricity when drawn apart, and though a certain amount of friction between them may increase this charge, no amount of friction will increase it beyond a certain point.

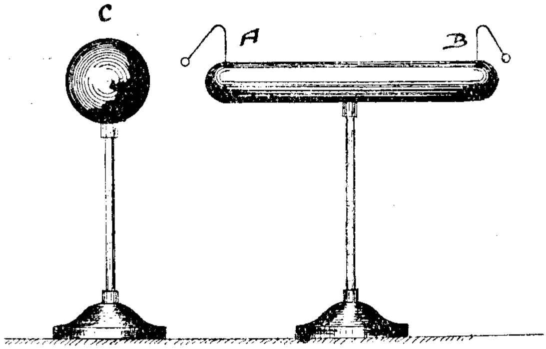
Unit Quantity.—In consequence of the attraction and repulsion that charges of electricity exert on one another, it is found most convenient to make them the basis of measurement of the amount of electricity present in a given charge. The unit quantity of electricity is therefore defined as follows:—"One unit "of electricity is that quantity which, when placed at a distance "of one centimetre in air from a similar and equal quantity, "repels it with a force of one dyne." A dyne is the unit of force in what is called the C.G.S. system. If instead of air some other substance such as oil or mica occupies the space between the charges, the repulsion will be less.

The force of attraction or repulsion that one charge of electricity exerts on another is called "electric force," and any space in which such force exists is called an "electric field."

Electrification by Influence.

It has been said above that it is the charges of electricity on electrified bodies, and not the bodies themselves, that attract and repel one another, and we will now describe some experiments that support this view.

FIG. 3.



Suppose we electrify positively a ball C, shown in Fig. 3, and place it near to a long sausage-shaped piece of metal held upon a glass support. This conductor, so-called because it is made of metal, which allows electricity to pass freely through it or over its surface, is supported on a glass rod to prevent the escape of electricity to earth. The positive charge on the ball C will be found to induce electrification on the conductor, which, although it has not been rubbed itself, will be found to behave at its ends as an electrified body. The ends of the conductor will attract little bits of paper, and if pith balls are hung to the ends they will be repelled. It is found, however, that the middle portion of the conductor exhibits no sign of electrification at all. Further examination will show that the two electrifications on the ends of the conductor are of opposite kinds, the end nearest to the ball being negatively electrified and the further end positively electrified. When the ball C is removed, both the charges disappear and leave no trace behind. This action is spoken of as "electrification by influence," and we can explain this phenomena in the following way. If we suppose that on every body when not electrified there always exists a certain amount of each kind of electricity, in exactly equal quantities—if the two kinds of electricity are equally distributed over the surface of the body, each will exactly neutralise the other, and no sign of electrification will be apparent. When, however, a positively electrified body is brought near, it will attract the negative electricity on the first body and draw it all as near as possible and repel the positive, according to the laws of electric attraction and repulsion stated on page 3. The effect will be that the non-electrified body will show a negative charge at the end nearest to the electrified body, and a positive charge at the end furthest away. When the electrified body is withdrawn, the attraction between the two opposite charges will cause them to rush together and neutralise one another once more, so that the body will again show no signs of electrification. It will be seen that the ordinary phenomena of electrification can also be explained by this theory. That is to say, we may imagine the glass rod and the silk in the first experiment described, each to have an equal amount of each sort of electricity before being rubbed together, and when they come into contact, a certain amount of positive electricity to be transferred from the silk to the glass, and an equal amount of negative electricity from the glass to the silk. This will leave the glass with more positive electricity than negative, and therefore with a positive charge, while the silk in a similar manner has acquired a negative charge.

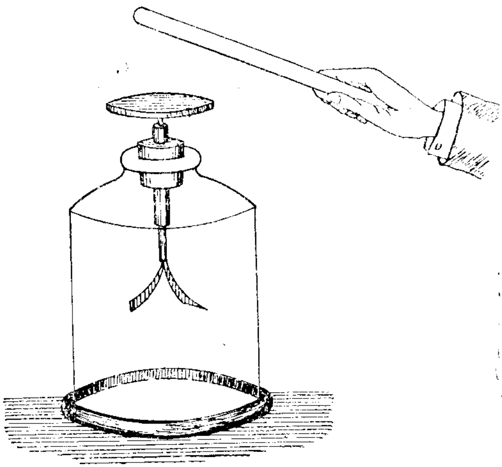
If a conductor be made in two parts, which, while under the influence of an electrified body, can be separated, then on the removal of the electrified body the two charges can no longer return to neutralise one another, but remain each on its own portion of the conductor. In the same way, if a conductor while under the influence of an electrified body be touched by the hand, or otherwise momentarily put in connection with the earth, the positive charge, instead of merely being repelled to the other end of the conductor, is repelled right away to the earth, and when the electrified body is removed the conductor is found to be left with a negative charge.

Amount of Influence Charge.—The quantity of the two charges thus separated by influence on such a conductor in the presence of a charge of electricity, depends on the amount of the charge, and on the distance of the charged body from the conductor. A highly electrified glass rod will exert a greater influence than a less highly electrified one; and it produces a greater effect as it is brought nearer and nearer. The utmost it can do is to induce a negative charge equal in amount to its own positive charge, and a similar amount of positive electrification at the other end; but usually before the electrified body can be brought near enough to do this, something else occurs which entirely alters the condition of affairs. As the electrified body is brought nearer and nearer the charge of opposite sign on the two opposed surfaces attract one another more and more strongly and accumulate more and more densely, until, as the electrified body approaches very near, a spark is seen to jump across, the two charges thus rushing together to neutralise one another, leaving the induced charge of positive electricity, which was formerly repelled, as a permanent charge after the electrified body is removed. If oil instead of air is the medium between the two bodies, not only is the attraction between the two charges very much less than before, as was stated above; but even if the charges are increased until the attraction is the same as before, the oil is found to stand a much greater strain than air, and the bodies must be brought much closer before it breaks down and allows a spark to pass.

THE ELECTROSCOPE.

The electroscope is an instrument for detecting and roughly measuring charges of electricity. The most common form is known as the "gold leaf" electroscope (Fig. 4), which consists of two very thin strips of gold leaf suspended from a metal rod which

FIG. 4.



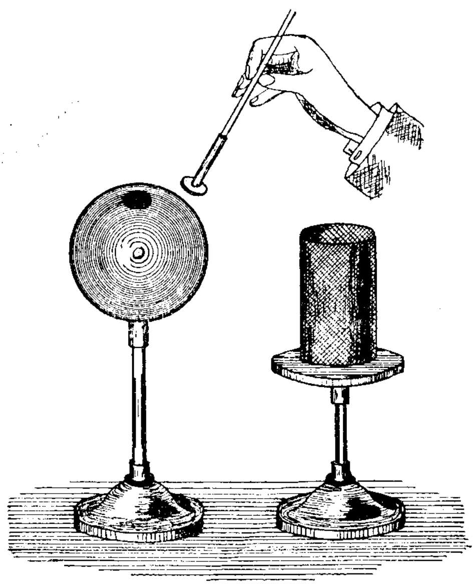
passes through the stopper of a glass jar. The jar serves both to shield the leaves from draughts and to insulate them from the earth. To the upper end of the metal rod is fixed either a flat plate or a metal knob. When a charge is imparted to the knob or plate, it immediately distributes itself all over the metal and gold leaves, and the leaves repel each other and fly apart, as did the two pith balls described in the first experiment. The greater is the charge, the greater is the angle at which the leaves stand out from one another, and so, by observing this angle, the amount of a charge can be roughly measured.

Distribution of Charge on Bodies.

If electrification is produced at one point of a non-conducting body it remains at that point and does not flow over the surface, or at most flows very slowly. Thus if a glass tube is rubbed at one end, that end only is electrified. The case is however quite different with conductors placed on insulating supports. For if a charge of electricity is imparted to any part of a conducting body it immediately distributes itself all over the surface, though not in general uniformly over the whole surface. We can investigate the distribution of the charge by means of a small disc of metal mounted on an insulating handle, called a proof plane, and an electroscope. If the proof plane is put in contact with any part of an electrified body, part of the charge on the body will be imparted to it, the amount of such imparted charge being proportional to the density of the electricity at the point touched. If the proof plane is then put in contact with the electroscope, the electricity on the proof plane will be imparted to the electroscope and will cause the leaves to diverge.

Charge resides on the outside of Conductors.—A charge of electricity is found to reside only on the outside surface of a conductor, and this fact can be proved in the following way. It is found that it is immaterial what the interior of a conductor is made of; it may be solid metal, or hollow, or even consist of wood or ebonite covered with tinfoil or gilt, but, if the shape be the same, the charge will distribute itself precisely in the same manner over the surface. Also this important fact can be proved by direct experiment. Suppose we take a hollow metal ball with a hole in the top, and set it on an insulating stand, as in Fig. 5, and

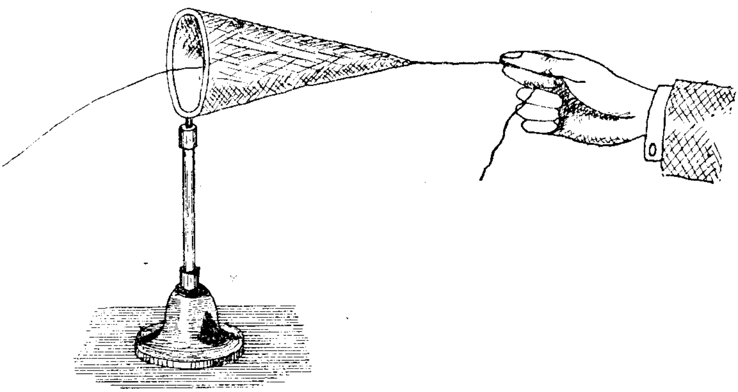
FIG. 5.



charge it with electricity. If the proof plane be applied to the outside of the ball and then touched on the knob of the electroscope, the leaves will diverge, thus showing that there is electricity on the outside of the ball. But if the proof plane be applied to the inside of the ball by putting it through the hole, care being taken that it does not touch the edge in passing it through, there will be no divergence of the leaves on touching the electroscope, thus showing that there is no electricity on the inside of the ball. An electrified pewter mug will show the same result, and so will a cylinder of wire gauze.

Doubtless the explanation of this behaviour of electricity is to be found in the property already noticed, as possessed by either kind of electricity, namely, that of repelling itself; hence it retreats as far as it can from the centre and remains on the surface. Faraday constructed a conical bag of linen gauze, supported as in Fig. 6 upon an insulating stand, and to which

FIG. 6.

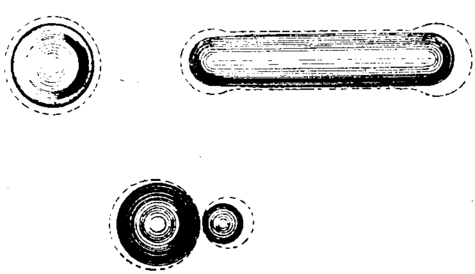


silk strings were attached, by which it could be turned inside out. It was charged, and the charge was shown by the proof plane and electroscope to be on the outside of the bag. On turning it inside-out the electricity was once more found to be all outside.

Distribution of Charge.—A charge of electricity is not usually distributed uniformly over the surface of an electrified body, as was said above. Experiment shows that there is more electricity on the edges and corners of bodies than on their flatter parts. The term "electric density" is used to signify the amount of electricity at any point of a surface, and may be defined a follows:—The electric density at a point is the number of units of electricity per unit of area (*i.e.*, per square inch, or per square centimetre), the distribution being supposed uniform over this small surface

Sphere.—The distribution of a charge over an insulated sphere of conducting material is uniform, provided the sphere is

FIG. 7.



isolated, that is to say, is remote from the presence of other conductors and all other electrified bodies. The density is uniform all over it. This is symbolised by the dotted line round the sphere in Fig. 7, which is an equal distance from the sphere all round, suggesting an equal thickness of charge at every point of the surface. It must be remembered, however, that the charge is not really of any thickness at all; it resides at or on the surface, but cannot be said to form a layer on it.

Cylinder with Rounded Ends.—Upon such a conductor as shown in Fig. 7 the density is greatest at the ends where the curvature is greatest.

Two Spheres in Contact. — If two spheres in contact be insulated and charged, it is found that the density is greatest at the parts farthest from the point of contact and least in the crevice between them. If the spheres are of unequal sizes the density is greater on the smaller sphere, which has the surface more curved.

Cone.—The density is greatest at the apex, and if the cone terminates in a sharp point, the density there is much greater than anywhere else.

Effect of Points.—At a point, indeed, the density of the collected electricity may be so great as to electrify the neighbouring particles of air, which are then repelled, causing what is known as an "electric wind," and thus producing a continual loss of charge. This effect is also called a "silent" or "brush discharge."

Redistribution of Change.—If any portion of the charge of an insulated conductor be removed, the remainder of the charge will immediately redistribute itself over the surface in the same manner as the original charge, provided it also is isolated, *i.e.* that no other conductors or charged bodies are near enough to disturb the distribution by their influence.

If a conductor be charged with any quantity of electricity, and another conductor of the same size and shape, but uncharged, be brought into contact with it for an instant and then separated, it will be found that the charge has divided itself equally between them. In the same way a charge may be divided equally into three or more parts by being distributed simultaneously over three or more equal and similar conductors brought into contact and symmetrically placed.

If two equal metal balls, suspended by silk strings, charged with unequal quantities of electricity, are brought for an instant into contact and then separated, it will be found that the charge has redistributed itself fairly, the charge on each ball being now half the sum of the two original charges. This may even be extended to the case of charges of opposite signs. For, suppose two similar conductors to be electrified, one with a positive charge of five units and the other with a negative charge of three units, when they are made to touch and separated, each will have a positive charge of one unit; for the three negative units will neutralise three of the positive units, leaving two positive units to be shared by the two conductors. Another way of stating, this, is to say that the algebraic sum of $+5$ and -3 is $+2$, which, shared between the two equal conductors, leaves $+1$ for each.

Capacity and Potential.

If the conductors be unequal in size, or unlike in form, the shares taken by each in this redistribution will not be equal, but will be proportional to the electric "capacities" of the conductors.

Two insulated conductors of the same form but of different sizes differ in their electrical capacity; for the larger one must have a larger amount of electricity imparted to it in order to electrify its surface to the same degree. The term "potential" is employed in this connection in the following way:—A given quantity of electricity will electrify an isolated body up to a certain "potential" (or power of doing electrical work), depending on its "capacity." A large *quantity* of electricity, imparted to a conductor of small *capacity*, will electrify it up to a very high *potential;* just as a large quantity of water poured into a vessel of narrow section will raise the surface of the water to a very high level.

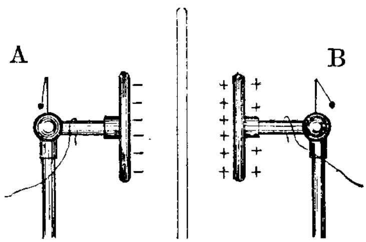
It will be found convenient to refer to a positively electrified body as one electrified to a *positive or high potential;* while a negatively electrified body may be regarded as one elecrified to a *negative or low potential.* And just as we take the level of the sea as a zero level, and measure the heights of mountains above it, and the depth of sea below it, so we take the potential of the earth's surface (for the earth is always electrified to a certain degree) as zero potential, and use it as a convenient point of reference from which to measure differences of electric potential.

The Leyden Jar and other Condensers.

It has been shown that opposite charges of electricity attract one another; and that electricity cannot flow through glass; and that electricity can act across glass by influence. Two suspended pith balls, one electrified positively and the other negatively, will attract one another across the intervening air. If a plate of glass be put between them they will still attract one another, though neither they nor the electric charges on them can pass through the glass. If a pane of glass be taken, and a piece of tinfoil be stuck upon the middle of each face of the pane, and one piece of the tinfoil be charged positively and the other negatively, the two charges will attract one another across the glass. If the pane be set up on edge so that neither piece of tinfoil touches the table, it will be found that hardly any electricity can be got by merely touching either of the foils, for each charge is "bound," so to speak, by the attraction of the other. In fact it will be found that these two pieces of tinfoil may be, in this manner, charged a great deal more strongly than either of them could possibly be if it were stuck to a piece of glass alone and then electrified. In other words, *the capacity of a conductor is greatly increased when it is placed near to another conductor electrified with the opposite kind of charge.* If its capacity is increased, a greater quantity of electricity may be put into it before it is charged to an equal degree of potential. Hence, such an arrangement for holding a large quantity of electricity is called a "condenser" of electricity.

Next, suppose that we have two brass discs, A and B (Fig. 8), set upon insulating stands, and that a glass plate is

FIG. 8.



placed between them. Let B be connected by a wire to an electric machine, which is a machine for giving any amount of electricity, while A is joined by a wire to earth. The + charge on B will act inductively across the glass plate on A, and will repel its positive electricity into earth, leaving the nearest face of A negatively electrified. This — charge on A will attract the + charge on B to the side nearest the glass, and a fresh supply of electricity will come from the machine. Thus this arrangement will become a condenser. If the two brass discs are pushed close up to the brass plate there will be a still stronger attraction between the + and — charges, because they are now nearer one another, and the inductive action will be greater, hence a still larger quantity can be accumulated in the plates. We see therefore that the capacity of a condenser is increased by bringing the plates nearer together. If now while the discs are strongly charged, the wires are removed and the discs are drawn backwards from one another, the two charges will not hold one another "bound" so strongly, and there will be more "free" electrification than before over their surfaces. This would be rendered evident by the little pith balls fixed to them (*see* the figure), which would fly out as the brass discs were moved apart. We have put no further charge on the disc B, and yet, from the indications of the pith ball, we should conclude that by being moved away from the disc A it had become electrified to a higher degree. The fact is, that while the conductor B was near the — charge of A, the *capacity* of B was greatly increased, but on moving it away from A its capacity has diminished, and hence the same quantity of electricity now electrifies it to a higher potential than before. The presence therefore of an earth-connected plate near an insulated conductor increases its capacity, and permits it to accumulate a greater charge by attracting and *condensing* the electricity upon the face of the nearest earth plate, the electrical density on this face being very great; hence the appropriateness of the term condenser as applied to this arrangement.

Dielectric Coefficient.

As before stated on page 5, if the medium between the plates is oil, glass, mica, or some similar substance, the force of attraction between the two charges is less than if the plates are in air. It follows, therefore, that in order to electrify them to the same potential as if they were in air, that is to say, until the attraction is the same, a larger quantity of electricity is required. In other words, their capacity depends in some way on the nature of the medium between them. It is said to vary according to a property of the medium, which is called its "specific inductive capacity," or "dielectric coefficient." The dielectric coefficient of air is taken as 1, while those of all other substances are greater than 1. To give an example of this, suppose the two plates were separated by a layer of paraffin wax, whose dielectric coefficient is 2, it would require twice as much electricity to produce the same difference of potential between them as when they are separated by air. Another way of looking at this is to say that the same difference of potential will force twice as much electricity into the plates when separated by paraffin as when separated by air. Or, in other words, their capacity is increased by the substitution of paraffin for air as the medium between them.

Capacity of a Condenser.

It appears then that the capacity of a condenser will depend on—

(1) The size and form of the metal plates or coatings;
(2) The thinness of the layer of insulating material between them;
(3) The dielectric coefficient of the material.

Condensers.—Condensers for practical use are built up of alternate layers of tinfoil and paraffined paper; or in larger ones, thin sheets of mica are used as the dielectric instead of the paper. Two insulated brass pieces on the top of the box containing these sheets are connected respectively with the two series of *alternate* sheets of tinfoil.

Leyden Jar.—A Leyden jar is merely a simple form of condenser. It consists of a glass jar coated up to a certain height on the inside and outside with tinfoil. A brass knob fixed on the end of a stout wire passes down through a lid or top which may be made of ebonite, and communicates by a loose length of brass chain or wire with the inner coating of tinfoil. To charge the jar the knob is held to the conductor of an electrical machine, the outer coating of the jar being held in the hand. When a $+^{ve}$ charge of electricity is imparted from the machine to the inner coating, it acts inductively on the outer coating, attracting a $-^{ve}$ charge into the face of the outer coating nearest the glass, and repelling a $+^{ve}$ charge to the outside of the outer coating, and thence through the hand to earth.

If the jar is dry and free from dust, it will retain its charge for many hours. It can be discharged by connecting the knob with the outer coating of tinfoil, when a spark will be seen. This should not be done by hand, or a painful shock will be experienced, which might be dangerous.

Storage of Energy.—In all cases of charging jars or condensers we are storing up energy, and it is this stored energy which reappears in the discharge.

A large Leyden jar will give a more powerful shock than a small one, for a larger charge can be put into it. Its capacity is larger, since the plates of tinfoil are larger. A Leyden jar made of thin glass has a greater capacity as a condenser than a thick one of the same size; but if it is too thin it will be destroyed, when powerfully charged, by a spark actually piercing the glass.

Leyden Battery.—If it is desired to accumulate a very large charge of electricity, a number of jars must be employed, all their inner coatings being connected together, and all their outer coatings united. This arrangement will be equivalent to one large jar, but of more convenient form, and will so have a very much larger capacity than one single jar. It is called a battery of Leyden jars. When charged it produces very powerful effects, and every care must be taken to avoid a shock from it passing through the person, as it might be fatal.

Other Methods of producing Electrification.

It has been remarked that there are other methods of producing electrification than those of friction and influence so far described. Some of the others will now be named.

1. *Percussion.*—A violent blow struck by one substance upon another produces opposite electrical states on the two substances.

2. *Vibration.*—Vibrations set up within a rod of metal coated with sulphur or other insulating substance, produces a separation of electricities at the surface separating the metal from the non-conductor.

3. *Cleavage.*—If a card is torn asunder in the dark, sparks are seen, and the two halves are found to be oppositely electrified. Many substances, among them linen, mica, and others, show this effect.

4. *Evaporation.*—The evaporation of liquids is often accompanied by electrification, the liquid and the vapour assuming opposite states, though apparently only when the surface is in agitation.

5. *Atmospheric Electricity.*—The atmosphere is always found to be electrified relatively to the earth; this is due possibly to evaporation going on over the oceans.

6. *Contact of Dissimilar Metals.*—The contact of two dissimilar metals in air produces opposite kinds of electrification, one becoming positively, and the other negatively electrified. This can be proved by means of a delicate electroscope. Metals can be arranged in a series as below, in such a way that each one enumerated becomes positively electrified when placed in contact in air with one that comes below it in the series:—

Sodium.	Copper.
Magnesium.	Silver.
Zinc.	Gold.
Lead.	Platinum.
Tin.	Carbon.
Iron.	

Carbon is included, as, although it is not a metal, yet it is a conductor and exhibits the same properties in this connection.

7. *Other Contact Actions.*—A difference of potential is also produced by the contact of two dissimilar liquids with one another.

A liquid and a metal in contact with one another also exhibit a difference of potential, and, if the metal tends to dissolve into the liquid, the metal will be negatively, and the liquid positively, electrified.

ELECTROMAGNETICS.

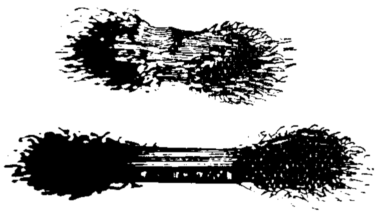
We have hitherto dealt only with charges of electricity at rest, and the effects produced by them under those conditions. When we come to study electric charges flowing along conductors in the form of "currents," we find that a totally new set of effects are manifested. These effects, which are exhibited by currents of electricity, but not by charges at rest, are called magnetic effects, and are generally studied under the name of electromagnetics. Before proceeding to the study of electromagnetics, however, it is more convenient to examine the nature and properties of magnets as we know them.

Natural Magnets or Lodestones.—The name "magnet" was given by the ancients to certain hard black stones found in various parts of the world, notably at Magnesia in Asia Minor, which possessed the property of attracting to themselves small pieces of iron and steel. It was also found that the stones had the property of pointing north and south when hung up by a thread. This property was turned to account in navigation, and the magnet received the name of "lodestone" (or "leading-stone").

Artificial Magnets.—If a piece of iron or, better still, a piece of hard steel, be rubbed with a lodestone, it will be found to have also acquired the characteristic properties of the magnet;

it will attract light bits of iron, and if hung up by a thread it will point north and south. Fig. 9 represents a natural lodestone

FIG. 9.



and an artificial magnet, which have been dipped into iron filings; the filings are attracted and adhere in tufts.

It will be observed that the attractive power of a magnet appears to reside at two regions, and in a long-shaped magnet these two regions, or poles, are usually at the ends (*see* Fig. 9). The portion of the magnet that lies between the two poles is apparently less magnetic, and does not attract the iron filings so strongly; and all round the magnet, halfway between the poles, there is no attraction at all. This region is called the "equator" of the magnet, and the imaginary line joining the poles is called the "axis."

Magnetic Needle.—To investigate more fully the properties of magnets and magnetic forces a "magnetic needle" is employed. This consists of a light needle cut out of steel, and fitted with a little cap, by means of which it can be hung on a sharp point, so as to turn with very little friction. It is made into a magnet by being rubbed upon a magnet, and when thus magnetised it will turn into the north and south position.

Magnetic Attractions and Repulsions.—If we take a magnet (either natural or artificial) in the hand, and present the two poles of it successively to the north-pointing end of a magnetic needle, we shall observe that one pole of the magnet attracts it, while the other repels it. If we repeat the experiment with the south-pointing end of the needle, we find that the end that attracted the north-pointing end repels the south-pointing end, and *vice versâ*.

If we try a similar experiment on the magnetic needle, using instead of the magnet a second magnetic needle which has been previously suspended, and has had its north-pointing end marked to distinguish it from its south-pointing end, we shall find that the N.-pointing pole repels the N.-pointing pole, and the S.-pointing repels the S.-pointing pole; but that a N.-pointing pole attracts and is attracted by a S.-pointing pole.

There would, therefore, appear to be two opposite kinds of magnetic poles, which attract and repel each other very much in the same way as do the two opposite kinds of electricity. It is convenient to have some simple name to distinguish the two different sorts of poles from one another, so in future the N.-pointing end or pole of a magnet will be referred to as the Red pole, and the S.-pointing pole as the Blue pole, as that is the way they are generally painted by the makers. We have seen then that a red pole attracts a blue pole but repels a red pole, and that a blue pole attracts a red pole but repels a blue pole. We may therefore sum up our observations as follows: — "*Like magnetic poles repel one another, and unlike magnetic poles attract one another.*" This is the first law of magnetism.

Two Poles Inseparable.—It is impossible to obtain a magnet with only one pole. If we magnetise a piece of steel or iron, by whatever method we like, we shall find that it always has two poles, one N.-seeking and the other S.-seeking. And if we try to separate the two poles by breaking the magnet into two parts, we shall still find that each half has a red pole at one end and a blue pole at the other. This breaking may be repeated as many times as we like, and each small piece will be found to have two poles as had the original magnet.

Magnetic Force.—The force with which a magnet attracts or repels another magnet, or any piece of iron or steel, is called "magnetic force."

The force exerted by a magnet on a bit of iron or on another magnet is not the same at all distances, being greater when the magnet is near and less when the magnet is farther off. In fact, it is said to "vary inversely as the square of the distance" between the two things on which it is exerted. That is to say, if two magnets exert a certain force on one another at a distance of one inch, if the distance is doubled and made two inches, the force between them will be one quarter of what it was before. And if the distance is made three inches the force will be reduced to one ninth of what it was at one inch. This is called the "Law of Inverse Squares," and is the second law of magnetism.

Attraction across Bodies.—If a piece of glass, wood, paper, or any substance except iron or steel, be interposed between the magnet and the piece of iron or steel that it is attracting, it will still attract it as if nothing were interposed. Across water, vacuum, and all known substances, the magnetic forces will act; with a single exception, namely, that magnetic force will not act across a screen of magnetic substance. The reason of this will be explained later.

Magnetic Substances.—A distinction must be made between magnets and magnetic substances. A magnet attracts only at its poles, and they possess opposite properties. But a lump of iron will attract either pole of a magnet, no matter what part of the lump be presented to the magnet. It has no distinguishable fixed poles, and no magnetic equator. A true magnet has poles, one of which is repelled by the pole of another magnet. The only known magnetic substances are iron and steel, with the exception of nickel cobalt and a few other metals, which exhibit magnetic qualities to a very slight degree.

The Earth a Magnet.—The earth itself is a great magnet, whose poles coincide nearly, but not quite, with the geographical north and south poles, and that is why it causes a freely suspended magnet to turn into a north and south position. It is evident from the first law of magnetism that the north pole of the earth must be a blue pole, since it attracts the red poles of suspended magnets, and the south pole of the earth a red pole.

Magnetic Induction.—Magnetism may be communicated to a bar of iron without actual contact with a magnet. If a short, thin, unmagnetised bar of iron is placed near some filings, and a magnet is brought near the bar, the presence of the magnet will induce magnetism in the iron bar, and it will behave as a magnet and attract the iron filings (Fig. 10). This inductive

FIG. 10.

action is very similar to that observed when an electrified body is brought near a non-electrified body, and it is found that the iron bar thus magnetised by induction has two poles; the nearest to the pole of the inducing magnet being of the opposite kind, while the pole at the farther end of the bar is of the same kind as the inducing pole. Magnetism can, however, only be induced in those bodies which we have enumerated as magnetic substances, and these bodies in which a magnetising force produces a high degree of magnetisation are said to have a high "coefficient of permeability."

We can now see why a magnet should attract a piece of magnetic substance which has not previously been magnetised. It first magnetises it by induction and then attracts it; for the nearest end of the piece of magnetic substance will have the opposite kind of magnetism induced in it, and will be attracted. The other end of the magnetic substance is at the same time repelled, but as it is at a greater distance from the pole of the inducing magnet, the force of repulsion is less than that of attraction, in accordance with the law of inverse squares stated above, and the attraction predominates. It must be understood, however, that induction precedes attraction.

Retention of Magnetisation.—Not all magnetic substances can become permanent magnets. Cast-iron and impure qualities of wrought-iron retain magnetism imperfectly, but steel retains nearly all the magnetism imparted to it almost permanently. Pure soft iron, however, is almost incapable of retaining any magnetism at all, and loses nearly all its magnetism as soon as the magnetising force is removed. The following experiment illustrates this:—Let a few pieces of soft iron be taken. If one of these is placed in contact with the pole of a permanent magnet, it is attracted to it and becomes itself a temporary magnet. Another bit of iron may then be hung to it, and another, until a chain of four or five pieces is built up. But if the steel magnet is removed from the top of the chain, all the rest drop off, and are found to be no longer magnetic. A similar chain of steel needles may be formed, but they will be found to retain their magnetism permanently.

It will be found, however, that a steel needle is more difficult to magnetise than an iron needle of the same dimensions. It is harder to get the magnetism either into or out of steel than iron; for the steel retains the magnetism once put into it. This power of resisting magnetisation or demagnetisation is called "coercive force." The coercive force of hard steel is very great, while that of soft iron is very small; the harder the steel the greater is its coercive force.

Methods of making Magnets.—The simplest way of making a bar of steel into a magnet is to rub it with a magnet. This can be done in several ways, either with one magnet or two, but in no case can a bar be magnetised beyond a certain intensity in this way. Another way of magnetising a bar is to place it in a magnetic field and strike it several blows with a hammer. If no magnets are available to provide the magnetic field, the field of the earth's magnetism may be used. A bar placed in the position that a magnetic needle takes up when freely suspended, and struck with a hammer, is found to be magnetised, having a red pole at the end that was pointing towards the north.

A current of electricity carried in a spiral wire round a bar of iron or steel will magnetise it far more strongly than any of the foregoing methods. In the case of a soft iron bar, it is only a magnet while the current continues to flow, and is then called an "electro-magnet." This arrangement will be fully described later.

Forms of Magnets.—Natural magnets are usually of irregular form, and so are not convenient for experimental purposes. Artificial magnets are generally made in the form of bars, but sometimes the horseshoe shape is preferred. In the horseshoe form the poles are bent round so as to approach one another, the advantage being that both poles can attract one piece of iron. A horseshoe magnet is generally supplied with an "armature" or "keeper," which is a small piece of soft iron that can be placed across the poles. The keeper is itself rendered a magnet by induction when it is placed across the poles, and hence when both poles magnetise it the force with which it is attracted to the magnet is greater than if it were magnetised by one pole only.

Magnetic Saturation.—A magnet to which as powerful a degree of magnetisation as it can attain to has been given, is said to be "saturated." A recently magnetised magnet will sometimes appear to be "super-saturated," possessing after the application of the magnetising force has ceased an even higher degree of magnetism than it is able to retain permanently. Thus a horse-shoe shaped magnet will support a greater weight just after being magnetised than it will after its keeper has been once removed from its poles. Even soft iron after being magnetised retains a small amount of magnetism when its "temporary magnetism" has disappeared. This small remaining amount of magnetism is called "residual magnetism."

Strength of a Magnet.—The strength of a magnet is measured by the magnetic force which it exerts at a distance on other magnets. Thus, suppose there are two magnets, A and B, whose strength we wish to compare. We can do this by making each of them act on the red pole of a third magnet, C. If the red pole of A repels C with twice as much force as that with which the red pole of B repels C, when placed at the same distance, then we should say that the strength of A was twice that of B.

Unit Pole.—A unit magnetic pole is defined in this way, very much as the unit charge of electricity was defined, as follows:—A unit magnetic pole is such that, when unacted on by other forces, if placed at a distance of one centimetre from a similar and equal magnetic pole in air, it repels it with a force of one dyne.

This definition is important, as it is the basis, not only of all measurements of magnets, but also of all measurements of electric currents, as will be seen later.

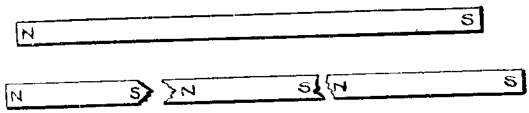
Destruction of Magnetisation.—A steel magnet loses most of its magnetisation if hit or knocked about, or otherwise subjected to rough usage, and also if heated to red heat.

Distribution of Magnetism.—The space all round a magnet pervaded by the magnetic forces is called the "field" of that magnet. It is most intense near the pole of the magnet, and is weaker and weaker at greater distances away from it. At every point in a magnetic field the force has a particular strength, and the magnetic induction acts in a particular direction or line. In a horse-shoe magnet the field is most intense between the two poles, and the lines of magnetic induction are curves which pass from one pole to the other across the field. A practical way of investigating the distribution of the lines of magnetic induction in a magnetic field will be described later under the head of "Magnetic Figures." When the armature is placed on the poles of a horse-shoe magnet, the force of the magnet on all the external regions is weakened, for the induction now goes on through the iron of the keeper, and not through the surrounding space. In fact, a closed system of magnets—such as that made by placing four bar magnets along the sides of a square, the north pole of one touching the south pole of the next—has scarcely any external field of force. A ring of steel may be thus magnetised so to have neither external field nor poles; or rather any point in it may be regarded as a north pole and a south pole, so close together that they neutralise one another's forces.

That poles of opposite name do neutralise one another may be shown by hanging a small object, such as a bit of iron, to the red pole of a bar magnet. If now the blue pole of another magnet is made to touch the first, the two poles will neutralise each other's force, and the piece of iron will fall.

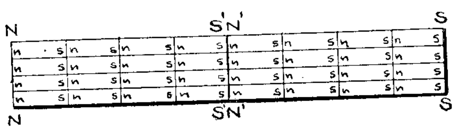
It has already been stated that when a magnet is broken into two or more pieces, each piece is a complete magnet possessing poles, and each is nearly as strong as the original magnet. Fig. 11 shows this. If the broken parts were closely joined, these

FIG. 11.



adjacent poles would neutralise one another as before and disappear, leaving only the poles at the ends as at first. If a magnet is ground to powder each fragment still acts as a little magnet and exhibits polarity. A magnet may therefore be regarded as composed of many little magnets put together, so that their like poles all face one way. Such an arrangement is indicated in Fig. 12,

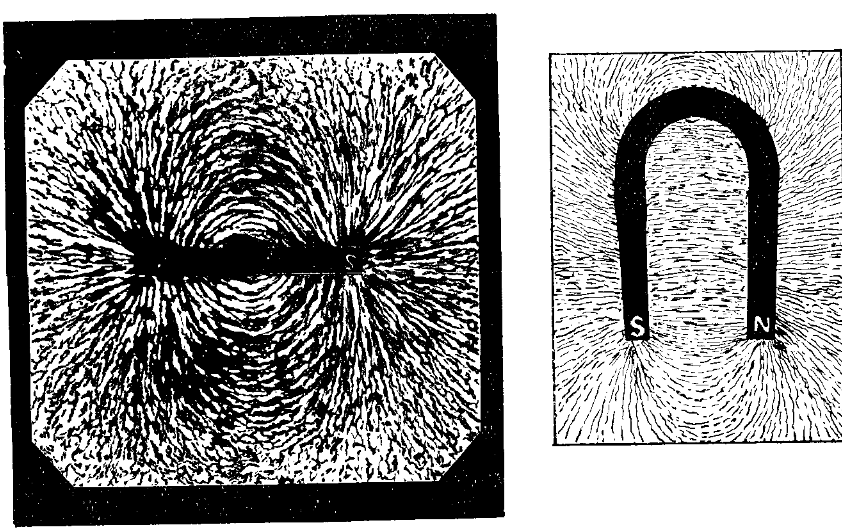
FIG. 12.



from which it will be seen that if the magnet is broken asunder at any part, one face of the fracture will present only north poles, and the other only south poles. This will be true however small are the individual particles.

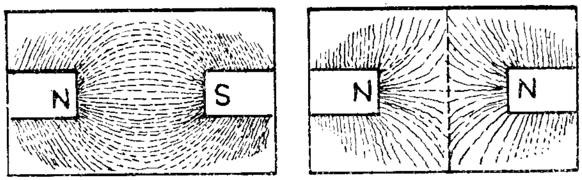
Magnetic Figures.—If a sheet of paper or card be placed over a magnet, and iron filings are dusted over the paper, they

FIG. 13.



figures obtained in the fields between the poles in the two cases, as shown in Fig. 15. In the first case the poles are of opposite

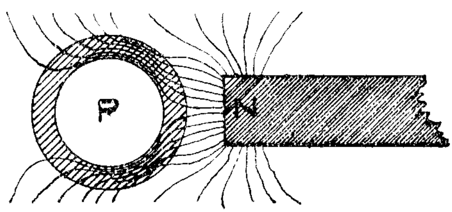
FIG. 15.



kinds, and the lines of force curve across out of one pole into the other ; in the second case, which represents the action of two similar poles, the lines of force curve away as if repelling each other, and turn away at right angles.

Magnetic Screen.—It has been stated above that the magnetic force will not act across a screen of magnetic substance. The magnetic figure shown in Fig. 16 illustrates this and shows the

FIG. 16.



reason of it. If a cylinder of iron or steel is placed close to the pole of a magnet it will be seen that the lines of force follow the path of the iron as far as possible and seem to be all drawn into the iron, leaving the space inside quite clear, so that a magnetic needle placed there is not affected.

Unit Magnetic Field.—A unit magnetic pole has already been defined as that pole which, when placed at a distance of one centimetre from a similar like magnetic pole in air, repels it with a force of one dyne.

A unit magnetic field is the field existing at a distance of one centimetre in air from a unit magnetic pole.

Another definition, which comes to the same thing, is:—A unit magnetic field is a field of such strength that a unit pole, when placed in it, is acted on with a force of one dyne.

THEORIES OF MAGNETISM.

There have been many theories put forward to explain the phenomena of magnetism. The most convincing of these was enunciated by Professor Ewing, and is known as "Ewing's Theory of Molecular Magnetism."

Before explaining this theory it is necessary to give a short account of the general theory of the composition of matter.

We must imagine every substance to be built up of very small particles of the substance itself, called molecules; hence we imagine copper to be simply built up of an enormous quantity of molecules of copper; wood, of molecules of wood; water, of molecules of water; and we also imagine that by mere cutting, or breaking, or grinding, or any purely mechanical force, we cannot break up a molecule into anything smaller. So that when we saw or file a bar of copper we simply tear little portions of copper away from the whole bar, breaking each piece away where the molecules touch one another, but never breaking up a molecule itself. The same with cutting wood—we force the thin wedge-shaped blade of a knife between the molecules of the wood, separate them so far that their attraction for one another is practically nothing, and the wood falls into two pieces.

All these molecules in the case of iron or other magnetic substance are supposed to be magnetic, and to be able, under the influence of magnetic force, to turn round so that their like poles all point the same way. When the iron is not magnetised, all the little magnetic molecules are supposed to be turned in all sorts of directions so that they are all neutralising one another and there is no external field. It was at first supposed that some sort of friction prevented the molecules when once magnetised from turning back into their original positions, but Professor Ewing showed that a complete explanation was offered by their mutual attractions. He constructed a model consisting of a large number of pivoted magnetic needles in one layer. When these needles were simply agitated and allowed to come to rest, they settled down in miscellaneous groups, all neutralising one another and producing practically no outside field. He also showed that there were several different ways in which they could do this, all of which were stable positions. But when they were acted on by a gradually increasing magnetic force they turned round, the operation showing three complete stages:—

(1) With a very small magnetising force the needles merely turned through a small angle.

(2) When a certain force was applied the groupings became unstable, some of the needles suddenly swinging round to new positions, with the result that, after a short time the majority of the needles point nearly, but not quite, along the direction of the force.

(3) A further increase of the magnetising force cannot produce much more effect; it can only pull the needles a little more perfectly into line.

All these things correspond perfectly to what is observed in the gradual magnetisation of iron or steel as described on pages 56 and 57.

CHAPTER II.

ELEMENTARY THEORY—*continued.*

Flow of Currents.

WE have already described how electricity flows away from a charged body through any conducting substance such as a wire or a wet string. If, by any arrangement, electricity could be supplied to a body just as fast as it flowed away, a continuous *current* would be produced. Such a current always flows through a wire if the ends are kept at different electric potentials, in the same manner as a current of heat flows along a rod of metal if the ends are kept at different temperatures, the flow being always from the higher temperature to the lower. No exact evidence exists as to the direction in which the electric current really flows, but it is convenient to regard the electricity as flowing from positive to negative; or, in other words, to consider the flow of electricity to be from the high potential to the low.

It seems probable from recent researches that a current generally consists of a flow of positive electricity in one direction and a simultaneous flow of negative electricity in the other, but this is by no means certain; and the usual convention of supposing the flow to be from high potential to low will be found useful and sufficient.

It is obvious that such a flow will tend to bring both to one level of potential, and in order that a continuous flow may be kept up, there must be a "circuit" provided.

Measurement of Current.—The quantity of electricity conveyed by a current is proportional to the magnitude of the current and to the time it continues to flow. The practical unit of electric quantity used in electromagnetics is called the "Coulomb," and is equal to three thousand millions of the units of electric quantity defined in Chapter I. The reason why such a much larger unit is adopted in electromagnetics than in electrostatics is that in the former we are dealing with very large quantities compared with the latter, and, if we measured these quantities in the electrostatic units, we should have to use numbers so large as to be unwieldy. The electromagnetic units, as will be seen later, are derived from the magnetic effects produced by the electric current.

The practical unit of electric current is called the "Ampere," and is the current that conveys a quantity of one coulomb per second past any given point in the circuit. Consequently, if a current of one ampere flows for one second, we know that a quantity of one coulomb has passed; or if it flows for one minute, sixty coulombs have passed, and so on.

Currents are called *continuous* or *direct* if they flow always in one direction. They are called *alternating* if they continually reverse in direction in a regular periodic manner, flowing first in one direction round the circuit and then in the other.

Continuous currents of electricity, such as we have described above, are produced by *voltaic cells*, or by *dynamos* driven by power, though there are other sources of currents which will be described later.

Alternating currents are at present only used in the Service in connection with wireless telegraphy and will not be dealt with in this volume.

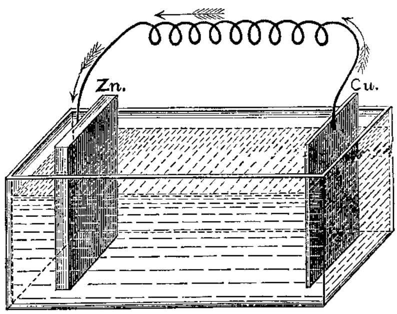
Discovery of Electric Current.—It was discovered by Galvani, a physician of Bologna in 1786, that the electric shocks from a Leyden jar or an electric machine produced convulsive motions in a frog's leg. He also found that these convulsive motions were also produced in the frog's leg when two dissimilar metals such as iron and copper, for example, were placed in contact with a nerve and a muscle respectively, and then brought into contact with each other. He supposed this action to be due to electricity generated by the frog's leg itself, but it was shown by Volta, an Italian professor, that the electricity arose not from the muscle or nerve, but from the contact of dissimilar metals. When two metals are placed in contact with one another in air, as we saw in Chapter I., one of them becomes positively and the other negatively charged, though the charges are very feeble. Volta proved their reality in the following way:—

Voltaic Pile.—He constructed what has since been called the "Voltaic Pile," which consisted of several pairs of discs of zinc and copper in contact with one another, each pair of discs being separated from the next by a piece of flannel moistened with brine. This pile gave quite enough electricity to give a perceptible shock when the top and bottom discs were touched simultaneously with moist fingers. When a single pair of metals are placed in contact, one becomes positively electrified to a small extent and the other negatively electrified, or, in other words, there is a certain difference of electrical potential (*see* Chapter I.) between them. But when a number are thus set in series, with moist conductors between the successive pairs, all the small differences of potential are added together, and the difference of potential between the first zinc and the last copper disc is increased in proportion to the number of pairs. The electrical action of these combinations is best understood by studying the action of a single "voltaic cell."

Voltaic Cell.

Place in a glass jar some water having a little sulphuric or other acid added to it. Place in it separately two clean strips, one of zinc (Zn) and one of copper (Cu). This cell will be capable of supplying a continuous flow of electricity through a wire whose ends are brought into contact with the two strips. When the current flows the zinc strip is observed to waste away; its consumption in fact furnishes the energy required to drive the current through the cell and connecting wire. The cell may therefore be regarded as a sort of chemical furnace in which fuel is consumed to drive the current.

Fig. 17.



The zinc is trying to dissolve and drive a current across to the copper; while the copper is trying (less powerfully) to dissolve and throw a current the other way. The zinc is at about 1·86 volts (*see* page 32) higher potential than the liquid, while the copper is only about ·81 volt higher, having a less tendency to become dissolved. There is then a net difference of potential of about 1·05 volts between the zinc and the copper, but this produces no current as long as there is no conducting circuit. If the strips are made to touch, or joined by a wire, immediately there is a rush of electricity through the acid from the zinc to the copper, as indicated by the arrows in Fig. 17, the current returning by the metal circuit from the copper to the zinc. A small quantity of the zinc is at the same time dissolved away. The copper strip from which the current starts on its journey through the external circuit is called the positive pole, and the zinc strip is called the negative pole of the cell.

Chemical Action.—In order to understand what goes on in a cell when it is used as a source of current, it is necessary to know something about "chemical action."

As was said in discussing the theory of magnetism, all matter is believed to be built up of small particles which we have called molecules.

Now, although we cannot break into these molecules by mere mechanical force and tools, we can do so by using other agents, such as heat, light, electricity, and by means of chemical affinity.

The only one of these agencies which we need consider at present is chemical affinity.

Chemistry is the science which deals with the composition of bodies, and *affinity* is a term used to express a kind of *liking* that bodies have for one another; so that *chemical affinity* may be looked on as a *liking* that some bodies have for combining with others. Some substances have a much greater *affinity* or *liking* for some particular body than for others.

Supposing, then, that by some of these agencies we can break up and pry into the constitution of a molecule, what shall we find? We find at once that one great difference exists between the molecules of different substances; we find that one class, such as copper, iron, silver, carbon, &c., are made of nothing but copper, iron, silver, carbon, &c.; each molecule, so to speak, is made up of nothing but itself; and another sort, such as india-rubber, water, &c. are made up of two or more totally different substances present in the molecule, in different proportions; for instance, india-rubber molecules are built up of carbon and hydrogen, water molecules of two substances called oxygen and hydrogen. Nor are these substances present in the same proportion; they vary largely in the way they are combined in different substances. The little particles that go to build up the little molecule are called atoms, so that we should say that the molecule of water is composed of atoms of hydrogen and oxygen; but since they are not present in the same proportion (there being double the number of hydrogen atoms in each molecule that there are oxygen atoms) we say that the molecule of water is built up of one atom of oxygen and two atoms of hydrogen, or, for shortness sake, we write the molecule of water H_2O, H and O being the symbols used by chemists to express hydrogen and oxygen respectively.

These two different classes of bodies—the one whose molecule is only made of one sort of atom, and the other whose molecule is made of more than one sort of atom, are called respectively *simple* and *compound* bodies, and any substance formed of one sort of atom only is called an *element*, because by no means that we know can it further be divided up into simpler substances.

Elements.—A list of the elements most usually met with is given below. In reality there are over eighty different elements known; but only those are tabulated which are ordinarily met with. Opposite to them are their abbreviated symbols, which are used instead of writing their names in full:—

Aluminium	Al.	Mercury	Hg.
Calcium	Ca.	Nickel	Ni.
Carbon	C.	Nitrogen	N.
Chlorine	Cl.	Oxygen	O.
Copper	Cu.	Phosphorus	P.
Gold	Au.	Platinum	Pt.
Hydrogen	H.	Potassium	K.
Iridium	Ir.	Silver	Ag.
Iron	Fe.	Sodium	Na.
Lead	Pb.	Sulphur	S.
Magnesium	Mg.	Tin	Sn.
Manganese	Mn.	Zinc	Zn.

We may therefore say that what determines the material of which a body is made is the nature, number, and grouping of the *atoms in each molecule*, while the size, &c. of the substance is determined by the *number of molecules*.

Chemical Action.—If we can employ some agency to break into a molecule and set all the atoms free, it is quite possible that they would be able to group themselves differently and form new molecules different in composition to one another and to the original molecule, and as these new molecules rearrange themselves we should be able to get a new substance different in every way to the original body; or again, if we bring two substances into very close contact with one another, so that the molecules of one are within the influence of the molecules of the other, it often happens that some of the atoms in the molecule of one substance have a greater affinity for particular atoms in the molecule of the other substance than they have for their own mates; then, under certain conditions the two molecules may break up, or form into different combination of atoms, so forming new molecules which in their turn build up new and entirely different substances.

To take a simple example, *zinc* is an element, and therefore each of its molecules is composed of atoms of zinc only. *Sulphuric acid* is composed of sulphur, hydrogen, and oxygen in the proportions $H_2S_1O_4$, or as it is usually written H_2SO_4. Now, if molecules of zinc are placed close to molecules of sulphuric acid a rearrangement takes place under certain conditions, and two new substances H_2, hydrogen, and $ZnSO_4$, zinc sulphate, are formed, each of them absolutely different to the original acid.

The process of this rearrangement is usually called chemical action.

From the above short description we ought to have obtained a rough idea of how two substances in close proximity may under certain conditions break up and form two absolutely different substances. This process may be seen going on daily. Coal, when heat is applied, combines with the oxygen of the air, the gases formed go up the chimney, and the ash is left behind. Iron exposed to damp air *rusts;* that is, the oxygen and the iron form little molecules of their own, and these molecules build up the red structure we call *rust.* In fact, all substances that *decay;* leaves, wood, &c., are examples of a slow chemical action going on where molecules of substances break up and combine with those of other substances, forming entirely new ones. In doing so a certain amount of energy is liberated, which may in certain cases manifest itself in the form of electrical energy.

Energy.—Energy may be briefly defined as the power of doing work, which means to say that if we want to *do* anything, or *move* anything, we must employ some form of energy.

As regards human beings, if we want to do any mechanical work, we must pull, push, lift, or exert some power to effect the work, and in this way we expend energy.

Connection between Energy and Heat.—Now, between *energy* and *heat* there is a very close connection. In fact, *heat* is but a form in which *energy* manifests itself. It is impossible in this book to do more than briefly mention that such is the case. The reader's attention is, however, directed to the following two common occurrences which are examples of this important fact :—

(1) A ship is driven ahead by the engines, which are worked by steam, the steam being obtained by *heating* water by means of the fires in the furnaces. Without the *heat* derived from the coal the engines would not move.

(2) A grindstone or any revolving mass, if stopped by hand or by brake, *heats* the hand or brake. The fact of stopping the mass, or, in other words, robbing it of the *energy* it possesses, causes that energy to be given up in heat.

So without going more fully into the matter we must be prepared to find that energy may often appear in the form of [illegible] given out in the voltaic cell from the con[illegible] appears in the form of electrical energy, *i.e.*, [illegible] current propelled by an electromotive [illegible], and not as heat. Any heat in a cell is so much energy wasted.

Effects produced by a Current.

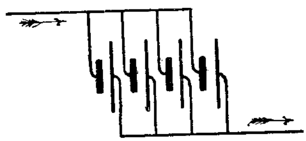
The current itself cannot be seen to flow through the wire circuit; hence to prove that any particular cell or combination of cells produces a current, requires a knowledge of some of the effects that currents can produce. These are of various kinds. A current flowing through a thin wire will heat it; flowing near a magnetic needle will cause it to turn aside; flowing through water and other liquids it decomposes them; and, lastly, flowing through the living body or any sensitive portion of it, produces certain sensations. These effects, thermal, magnetic, chemical, and physiological, will be considered separately.

Voltaic Battery.—If a number of simple cells are joined in a series, the zinc plate of one joined to the copper plate of the next, and so on, a greater difference of potentials will be produced between the copper "pole" at one end of the series and the zinc "pole" at the other end. For since the copper pole of the second is joined to the zinc of the first they must be at the same potential; and then, since there is a difference of potential of ·81 volt between the copper and zinc of the first, and the same amount between the copper and zinc of the second, the total difference of potential between the copper of the first and the zinc of the second will be double ·81 volt, that is, 1·62 volts. In the same way, three cells joined in this manner will give three times the difference of potential of one cell; and so on for any number. Such an arrangement is called a "Voltaic Battery." There are many ways of joining up a battery of cells, but two only will be mentioned now. If the cells are joined in one row, as in Fig. 18, they are said to be in "series." Cells are generally represented in diagrams by a symbol in which a short thick line stands for the negative pole, and a longer thin line stands for the positive pole. Thus Fig. 18 represents four cells joined in series.

FIG. 18.

The other chief way of grouping cells is to join all their positive poles together and all their negative poles together; and they are then said to be joined in "parallel" or "quantity." In this case, all their positive poles, being joined together, are at the same potential, and so are all their negative poles. So that there is no greater difference of potential than in the case of a single cell. The coppers act like one big copper and the zincs like one big zinc. Fig. 19 shows four cells joined in parallel. The

FIG. 19.



relative merits of these two methods of grouping cells will be discussed later.

Electromotive Force.

The term "electromotive force" is used to denote that which moves or tends to move electricity from one place to another. For brevity it is generally written E.M.F. Just as in waterpipes a difference of level produces a pressure, and the pressure produces a flow as soon as the tap is turned on, so a difference of potential produces electromotive force, and electromotive force sets up a current as soon as the circuit is completed for the electricity to flow through. Electromotive force may therefore be conveniently expressed as a difference of potential, and the unit in which difference of potential is measured is called the "volt." The terms "pressure" and "voltage" are sometimes used for difference of potential or electromotive force.

Hitherto we have only spoken of zinc and copper as the materials for a cell; but cells may be made of any two metals, or carbon may be used for one of the plates. The effective E.M.F. of the cell depends on the materials of which it is made. If the same metal were used for both plates of a cell it would give no current, for each plate would be trying to dissolve and send a current across to the other with equal tendency. That cell will have the greatest E.M.F. in which these materials are used which have the greatest difference in their tendency to combine chemically with the acid, or whatever liquid is used in the cell, or are furthest apart in the "contact series" given in Chapter I. Zinc and copper are convenient in this respect, but for more powerful batteries a zinc-platinum or zinc-carbon combination is preferable. That plate or piece of metal by which the current enters the cell is sometimes called the "anode," and the other plate the "kathode," while the liquid is called the "electrolyte." The kathode is not dissolved, and in some cases receives a deposit on its surface.

Resistance.

The same electromotive force does not always produce a current of the same strength. The amount of the current depends not only on the force tending to drive electricity round the circuit, but also on the "resistance" which it has to encounter and overcome in its flow. If the cells be partially choked with sand or sawdust, or if the wire provided to complete the circuit be long and thin, the action will be partly stopped, and the current will be weaker owing to the resistance being greater, although the E.M.F. may be unchanged. The analogy of the waterpipe will again help us. The pressure which forces the water through the pipes depends on the difference of level between the cistern from which the water flows and the tap to which it flows; but the amount of water that runs through will depend not on the pressure alone, but on the resistance it meets with, for if the pipe be a very thin one, or choked with sand or sawdust, the water will run through very slowly.

Now the metals in general conduct well; their resistance is small; but metal wires must not be too thin or too long, or they will resist too much, and permit only a feeble current to flow through them. The liquids in the cell do not conduct nearly so well as the metals, and different liquids have different resistances. Pure water will hardly conduct at all, and is, for the feeble electromotive force of the voltaic cell, almost a perfect insulator; but any impurities in water lower its resistance enormously. Salt and saltpetre dissolved in water are good conductors, and so are acids diluted with water, through strong acids are bad conductors. The resistance of the liquids in the cells may be reduced, if desired, by using larger plates of metal and putting them nearer together. Gases are bad conductors; hence the bubbles of hydrogen gas, which are given off at the positive plate during the action of the cell, and stick to the surface of the positive plate, increase the internal resistance of the cell by diminishing the effective surface of the plate.

Laws of Resistance.—The following are the laws of resistance:—

(1) *The resistance of a conducting wire is proportional to its length*—that is to say, if the resistance of a mile of wire is 17 ohms, the resistance of 50 miles of the same wire will be $17 \times 50 = 850$ ohms.

(2) *The resistance of a conducting wire is inversely proportional to the area of its cross-section.* If one wire is

twice as thick as another, the area of its cross-section will be four times as great, so that it will only have one quarter of the resistance of the first. That is to say, it will conduct four times as well.

(3) *The resistance of a conducting wire of given length and thickness depends upon the material of which it is made,* that is to say, on the *specific resistance* of the material. The "specific resistance" of any material is defined as the resistance between the two opposite faces of a unit cube of the material, that is, a cube each of whose edges is one centimetre in length. This provides a convenient method of comparing the relative resistances of different substances.

Effect of Heat on Resistance.—Changes of temperature affect the conducting power of nearly all substances. In the case of metals, their resistance rises as they get hot, and falls when they are cooled. The resistance of carbon on the other hand diminishes on heating. The filament of a glow lamp has little more than half the resistance when glowing that it has when cold. Certain alloys of metals, such as German silver and manganin, show little if any change of resistance on heating, and are therefore used for making standard resistance coils.

Unit of Resistance.—Resistance is measured in units to which the name of "ohms" has been given. One ohm is that the resistance of a conductor in which an electromotive force of one volt will produce a current of one ampere. The actual magnitude of the ohm is the resistance of a column of mercury, 106·3 centimetres long, and one square millimetre in cross-section, when at the temperature of melting ice.

Chemical Actions in the Cell.—The production of an electric current by a voltaic cell is *always* accompanied by chemical actions in the cell. One of the metals at least must be capable of being acted on by the liquid in the cell. A piece of pure zinc when dipped alone into sulphuric acid is not acted upon by the liquid. But the ordinary commercial zinc is not pure, and when plunged into dilute sulphuric acid dissolves away, a large number of bubbles of hydrogen gas being given off at the surface of the metal. Sulphuric acid, as explained before, is a complex substance in which every molecule is made up of a group of atoms—2 of hydrogen, 1 of sulphur, and 4 of oxygen; or in symbols, H_2SO_4. When chemical action takes place between sulphuric acid and zinc, the sulphur and oxygen enter into combination with the zinc, forming zinc sulphate, $ZnSO_4$, and the hydrogen is set free. This action is represented symbolically by means of a "chemical equation," as follows:—

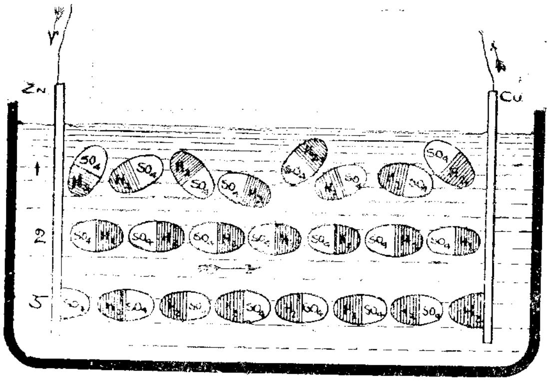
$$Zn \quad + \quad H_2SO_4 \quad = \quad ZnSO_4 \quad + \quad H_2$$

Zinc and *sulphuric acid* produce *zinc sulphate* and *hydrogen.* The zinc sulphate produced in this action remains dissolved in the acid.

Now, when a plate of pure zinc and a plate of some metal less easily acted on—copper or platinum or, best of all, hard carbon—are put side by side into a cell containing dilute acid, no appreciable action takes place until the circuit is completed by joining the plates with a wire or making them touch one another. Directly the circuit is completed a current flows and the chemical actions begin, the zinc dissolving in the acid, and the acid giving up its hydrogen in streams of bubbles. But it will be noticed that these bubbles of hydrogen are given off, not at the zinc plate, nor throughout the liquid, but at the surface of the positive plate (copper or carbon, whichever is employed). This apparent transfer of the hydrogen gas through the liquid from the surface of the zinc plate to the surface of the copper plate is very remarkable.

Grotthus' Theory.—The ingenious theory framed by Grotthus to account for it is as follows:—He supposes that, when two metal plates at different potentials are placed in a cell, the first effect is that the molecules of the liquid themselves in innumerable chains, in which every molecule has its constituent atoms pointing in a certain direction; in this case the hydrogen in the molecule is attracted towards the copper plate and the sulphur and oxygen, SO_4, towards the zinc. The action that is then supposed to take place is that an interchange of partners goes on between the separate atoms all along the line, each H_2 group uniting with an SO_4 group from the next molecule, leaving one SO_4 group at the zinc plate which combines with the zinc to form zinc sulphate, and a hydrogen group at the other end which is set free, and appears at the positive plate. The molecules then all face round and the same thing happens again. Fig. 20 shows

FIG. 20.



this; in the first row the atoms are distributed at random, in the second they have formed themselves into a chain as described, and in the third the interchange has taken place.

These chemical actions go on as long as the current passes. The quantity of zinc used up in each cell is proportional to the amount of electricity which flows round the circuit while the battery is at work, and so is the amount of hydrogen gas evolved; in other words, they are proportional to the current.

Local Action.—When the circuit is not closed the current cannot flow, and there should be no chemical action so long as the battery is producing no current. The impure zinc of commerce, however, does not remain quiescent in the acid, but is continually dissolving and giving off hydrogen bubbles. This *local action*, as it is called, is explained in the following manner: The impurities in the zinc consists of particles of iron, arsenic, and other metals. Suppose a particle of iron to be on the surface anywhere and in contact with the acid. It will behave like the copper plate of a battery toward the zinc particles in its neighbourhood, for a local difference of potential will be set up at the point where there is metallic contact, causing a local current to run from the particles of zinc through the acid to the particles of iron, and so there will be a continual wasting of the zinc, both when the battery circuit is closed and when it is open.

Amalgamation of Zinc.—To avoid this local action the zinc plate is "amalgamated" with mercury. This is done as follows: the surface to be amalgamated is cleaned by being dipped into acid, and then a few drops of mercury poured over it and rubbed in with a bit of linen rag. The mercury mixes with the zinc and forms a pasty mixture called an "amalgam." The iron particles do not dissolve in the mercury, but float up to the surface, whence the hydrogen bubbles that form speedily carry them off. As the zinc in this pasty amalgam dissolves into the acid, the film of mercury mixes with fresh portions of the zinc, and so always presents a clean bright surface to the liquid.

Polarization.—The bubbles of hydrogen gas liberated at the surface of the positive plate stick to it in great numbers, and form a film over its surface; hence the effective amount of surface of the positive plate is seriously reduced in a short time. When a simple cell, or a battery of such cells, is set to produce a current, it is found that the current after a few minutes, or even seconds, falls off very greatly, and may be even stopped. This immediate falling off in the current is almost entirely due to the film of hydrogen bubbles sticking to the positive plate. A battery in this condition is said to be "polarized."

Effect of Polarization.—The film of hydrogen gas affects the strength of the current in the cell in two ways.

Firstly, it weakens the current by the increased resistance that it offers to the flow, for the bubbles of gas are very bad conductors; and

Secondly, it weakens the current by setting up an opposing electromotive force. For hydrogen is nearly as electropositive as zinc, and so tries to send a current through the liquid back to the zinc.

It is therefore a very important matter to abolish this polarization, as otherwise the current given by cells would not be constant. This is generally done by introducing some substance into the cell which has a great affinity for hydrogen, and so combines with it before it can reach the positive plate. The various methods of overcoming polarization will be described at the same time that the different forms of cell in use in the Service are described.

Ohm's Law.—We have seen that a permanent difference of potential set up between the two ends of a conductor will produce an electric current in that conductor, and the strength of that current will depend on the difference of potential and also on the resistance of the conductor. The laws which determine the strength or quantity of the current in a circuit were first enunciated by Dr. G. S. Ohm, who stated them in the following law:—

Ohm's Law.—The current varies directly as the electromotive force, and inversely as the resistance of the circuit: or, in other words, anything that makes the E.M.F. of cell greater will increase the current, while anything that increases the resistance (either the internal resistance of the cells themselves, or the external resistance of the circuit) will diminish the current.

In symbols this may be written—

$$C = \frac{E}{R},$$

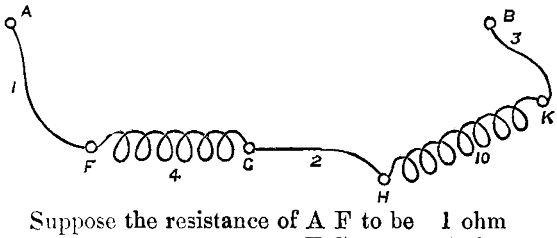
where C is the number of amperes of current, E the number of volts of difference of potential or E.M.F., and R is the number of ohms of resistance in the circuit.

Another way of stating Ohm's Law is:—*The number of amperes of current flowing through a circuit is equal to the number of volts of electromotive force divided by the number of ohms of resistance.*

The application of the law is not quite so simple as its statement. If we apply it to the whole circuit we must consider both the total E and the total R. For if a number of cells are used and the circuit is made up of a number of different parts, through all of which the current must flow, we have to take into account, not only the E.M.F. of the cells, but also their resistances, as well as the resistances of the other parts of the circuit.

Take a simple circuit, as shown.

Fig. 21.



Suppose the resistance of			A F	to be	1 ohm
,,	,,	,,	F G	,,	4 ohms
,,	,,	,,	G H	,,	2 ,,
,,	,,	,,	H K	,,	10 ,,
,,	,,	,,	K B	,,	3 ,,

then the total resistance of the circuit A B is 20 ohms.

The current that we shall get through A B will depend on the D.P. between A and B. Suppose the latter to be 60 volts, then the current in every part of the circuit will be $\frac{60}{20} = 3$ amperes.

Note this carefully.—Whatever the resistance of any portion of a *simple* circuit may be, the current running through it will be the same as in any other portion of the circuit.

Now let us trace how the differences of potential are divided up in the different portions of the circuit.

Take the D.P. between A and F. We have a resistance of 1 ohm, and through this we have to force a current of 3 amperes; the D.P. required to do this will be $C \times R$ or $3 \times 1 = 3$ volts; between F and G we have a resistance of 4 ohms and still the same current of 3 amperes, therefore the D.P. required will be $3 \times 4 = 12$ volts; between G and H the resistance is 2 ohms, the current the same, namely, 3 amperes, therefore the D.P. required will be $3 \times 2 = 6$ volts; between H and K the resistance is 10 ohms, the current 3 amperes, therefore the D.P. required is $3 \times 10 = 30$ volts; and between K and B the resistance is 3, the current 3 amperes, therefore the D.P. is 3×3, or 9 volts.

Adding these together, $3 + 12 + 6 + 30 + 9 = 60$ volts.

In other words, the D.P. of 60 volts between A and B is divided as follows:—

3	volts	forcing	the current	from		A to F,
12	,,	,,	,,	,,	,,	F to G,
6	,,	,,	,,	,,	,,	G to H,
30	,,	,,	,,	,,	,,	H to K,
9	,,	,,	,,	,,	,,	K to B.

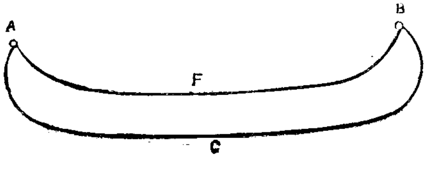
The D.P. between A and G is $3 + 12 = 15$ volts,
,, ,, ,, A and H is $3 + 12 + 6 = 21$ volts,
&c., and similarly,
The D.P. between B and H is $9 + 30 = 39$ volts,
,, ,, ,, B and G is $9 + 30 + 6 = 45$ volts,
&c., and whatever two points in the circuit we take we find that the equation $C = \frac{E}{R}$ will hold good.

The above is the simplest form of circuit when all the conductors are joined together one after the other, or as it is called in *series*, so that the same current traverses each.

Parallel or Divided Circuits.—We will now take a circuit where the conductors are joined *abreast* or in *parallel*, so that the current has two or more roads by which it can travel.

Suppose Fig. 22 to show such a circuit.

FIG. 22.



Here, if A and B are at a D.P. the current will have two paths to travel by, one A F B, the other A G B. What this really means is, that instead of only having the path A F B we have given it another, or, in other words, really given it a *larger* conductor to travel by, and therefore reduced the resistance of the circuit. For suppose A F B, A G B to be two identically similar wires, then as far as the resistance in the circuit is concerned it would be the same if we brought the two wires close together and practically squeezed them into one and so made one wire of double the cross-section of one of the previous wires; but by doubling the cross-section of a wire we double its conductivity and, therefore, halve its resistance, hence by giving two precisely similar roads to the current to travel by instead of one, we have halved the resistance of the whole circuit.

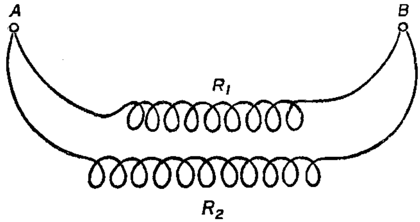
Let us take figures. Suppose each of the wires A F B, A G B to have a resistance of 10 ohms, and suppose A and B to be at a D.P. of 100 volts. If there was only one wire, A F B, the current flowing between A and B would be $\frac{100}{10} = 10$ amperes.

Now add the other wire, A G B. Between its ends also there is a D.P. of 100 volts, therefore the current flowing along it is $\frac{100}{10}$, or 10 amperes. So that the total current flowing between A and B by the two wires is $10 + 10 = 20$ amperes.

But if 20 amperes flow between A and B when A and B are at a D.P. of 100 volts, the resistance of the whole circuit R is $= \frac{E}{C}$ or $\frac{100}{20} = 5$ ohms, or half the resistance of each of the original wires. The resistance of two such wires in parallel is called the *joint* resistance of the wires, and must evidently, whatever the resistance of the wires may be, be less than the resistance of either wire considered by itself.

This is simple enough when we consider the two wires as exactly similar, and therefore each of the same resistance. Suppose now they are of unequal resistances, as in Fig. 23.

FIG. 23.



Here one has any resistance R_1 and the other any resistance R_2. Suppose A and B to be at a D.P. of E volts—

$$\text{Then the current in } R_1 = \frac{E}{R}.$$

$$\text{,, \quad ,, \quad ,, } R = \frac{E}{R_2}.$$

Therefore the total current flowing between A and B is the sum of these two currents, or is equal to $\frac{E}{R_1} + \frac{E}{R_2}$.

Now let R be the joint resistance of these two wires. Then since E is the D.P. between A and B, $C = \frac{E}{R}$.

But this current has been shown equal to $\frac{E}{R_1} + \frac{E}{R_2}$.

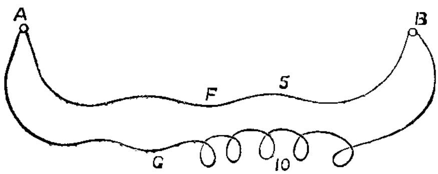
$$\therefore \quad \frac{E}{R} = \frac{E}{R_1} + \frac{E}{R_2},$$

$$\text{or,} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \quad \text{or,} \quad R = \frac{R_1 \times R_2}{R_1 + R_2},$$

or, *the joint resistance of any two circuits joined in parallel is found by multiplying the resistance of each circuit together, and dividing this by the sum of the resistances of the circuits.*

Taking a numerical example: Suppose, as in Fig. 24, a D.P. between A and B of 60 volts, and

FIG. 24.



the resistance A F B to be 5 ohms, and of A G B to be 10 ohms.

If A F B were alone connecting A to B, the current flowing between A and B would be $\frac{60}{5} = 12$ amperes.

If A G B were there alone it would be $\frac{60}{10} = 6$ amperes.

Therefore the total current will be, if A F B and A G B be both in use, $12 + 6 = 18$ amperes.

Now, looking at this from the other point of view, viz., of A F B, A G B having a *joint* resistance, the D.P. between A and B is the same, but the joint resistance of A F B, A G B is $\frac{5 \times 10}{5 + 10} = \frac{50}{15}$ or $= \frac{10}{3}$.

The current, therefore, running between A and B is $\frac{E}{R}$ or $\frac{\frac{60}{1}}{\frac{10}{3}} = 18$ amperes.

NOTE.—The same method of argument may be applied to cases where more than two conductors are joined in divided circuit. A simple way of working at the case is as follows:—

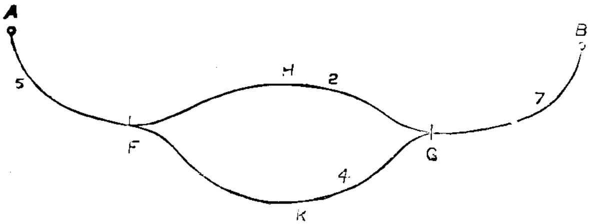
The conductivity of the circuit = sum of the conductivity of the branch circuits, or if L_1, L_2, L_3, L_4, &c. be the conductivity of the branches whose resistances are R_1, R_2, R_3, R_4, &c., and if L be the conductivity of the whole circuit whose resistance is R,

$$\text{Then } L = L_1 + L_2 + L_3 + L_4 + \text{\&c.},$$

$$\therefore \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{\&c.}$$

We will now consider a case of a circuit which is a combination of resistances in series and resistances in parallel, as in Fig. 25, where A to F is a single circuit, then from F to G there are two

FIG. 25.



roads, F H G, F K G, and from G to B one circuit, that is, the current leaving A flows towards F, where the current divides, part flowing through F H G, part flowing through F K G, joining again at G, and all the current flowing by G B to B.

The total resistance this circuit offers to the current is, first, the resistance of A F; next, the *joint* resistance of F H G, F K G; and next, the resistance of G B.

Suppose	A F	to have a	resistance	of	5 ohms.
,,	F H G	,,	,,	,,	2 ohms.
,,	F K G	,,	,,	,,	4 ohms.
,,	G B	,,	,,	,,	7 ohms.

The joint resistance of F H G, F K G will be—

$$\frac{2 \times 4}{2 + 4} = \frac{8}{6} = \frac{4}{3} \text{ ohms.}$$

The total resistance will therefore be $5 + \frac{4}{3} + 7$ ohms,

or $= \frac{40}{3} = 13\frac{1}{3}$ ohms.

If now a D.P. of 80 volts exists between A and B, the current in the whole circuit will be $\dfrac{80}{\frac{40}{3}} = 6$ amperes.

Now, how does the current divide on reaching F; that is to say, which circuit takes the most current, and in what proportion do the currents divide?

The case is exactly the same as the previous one. We will trace it out.

Let E be the D.P. between F and G.
C_1 be the current running through F H G.
C_2 be the current running through F K G.

Let the resistance of F H G, F K G, be respectively R_1 and R_2.

We know then that $C_1 = \frac{E}{R_1}$,

" " " $C_2 = \frac{E}{R_2}$; or $\frac{C_1}{C_2} = \frac{R_2}{R_1}$,

or the current C_1 will bear the same proportion to the current C_2 that the resistance of R_2 does to the resistance of R_1. Now, considering this in relation to C the total current running in the circuit, we see that $C = C_1 + C_2 = \frac{E}{R_1} + \frac{E}{R_2}$.

Current Method.—Therefore the ratio of C_1 to C is found by dividing one by the other, or—

$$\frac{C_1}{C} = \frac{\frac{E}{R_1}}{\frac{E}{R_1} + \frac{E}{R_2}} \text{ or } \frac{\frac{1}{R}}{\frac{1}{R_1} + \frac{1}{R_2}}$$

$$C_1 = C \times \frac{1}{R_1} \div \frac{R_2 + R_1}{R_1 \times R_2} = C \times \frac{1}{R_1} \times \frac{R_1 \times R_2}{R_1 + R_2}$$

$$\text{or } C_1 = \frac{R_2}{R_1 + R_2} \times C.$$

Similarly, $C_2 = \frac{R_1}{R_1 + R_2} \times C.$

That is, the current through each branch is found by multiplying the total current by a fraction, namely, the resistance of the other branch divided by the sum of the two resistances.

Substituting the resistances shown in the diagram (Fig. 25) we have—

$$C_1 = \frac{4}{2 + 4} \times C.$$

$$C_2 = \frac{2}{2 + 4} \times C.$$

Potential Method.—A simpler way perhaps of looking at this is that the resistance of the total circuit as before stated is $5 + \frac{2 \times 4}{2 + 4} + 7 = 13\frac{1}{3}$ ohms. Now since 80 volts is expended in overcoming this we can calculate the pressure lost, or fall of potential between F and G.

We have:

Fall between A B : Fall between F G. : : Total R : Resistance between F G. Or, $80 : V :: 13\frac{1}{3} : 1\frac{1}{3}$.

Hence D.P. between F G (V) = 8 volts.

Consequently the current through F H G $= \frac{8}{2} = 4$ amperes,

and current through F K G $= \frac{8}{4} = 2$ amperes.

It will be found by adopting this *potential method* that the long quadratic equations often arising from the direct current method may be avoided.

In the above examples conductors of different resistances have been grouped and dealt with; it is perfectly immaterial whether such conductors be wires, resistances, lamps, or, in fact, any substance which conducts electricity. The above examples will, therefore, apply to whatever form of electrical appliance we happen to be using, and a close acquaintance with the few preceding cases will enable a beginner to solve some of the numerical electrical problems he will come across.

Resistance and Grouping of Cells.—We are now in a position to consider the relative advantages and disadvantages of the various methods of grouping cells in a battery. If we take a cell, and join its outside terminals with a wire which is so short and thick that its resistance is small enough to be negligible, the only resistance in the circuit will then be the internal resistance of the cell. Suppose that this internal resistance is one ohm, and that the cell has an E.M.F. of 2 volts. Then the current in this case with the terminals short-circuited will be 2 amperes, by Ohm's law, and this is the greatest current that can be got out of the cell. If there is any resistance in the external circuit the current will of course be less, and if it is required to increase the current, more cells, must be added so as to form a battery. Whether they should be added in series or in parallel with the first cell, depends on the magnitude of the external resistance.

Let us suppose in the first case that the external resistance is large in comparison with the internal resistance of the cell, say 100 ohms. Then with one cell the total resistance will be $100 + 1 = 101$ ohms, and the current will be $\frac{2}{101} = \cdot 02$ amperes, roughly. Now if another cell is added in parallel with the first, the internal resistance will be reduced to one half what it was before, that is $\cdot 5$ ohm, and the total resistance will be $100 \cdot 5$ ohms while the E.M.F. is the same as before, that is 2 volts. So that the current will be $\frac{2}{100 \cdot 5}$, or almost exactly the same as it was before. But if the second cell is put in series with the first, instead of in parallel, though the internal resistance is doubled and the total resistance becomes 102 ohms, yet the E.M.F. is also double and is now 4 volts. So that the current is now $\frac{4}{102} = \cdot 04$ amperes, roughly, that is, practically double what it was at first. So that, if the resistance of the outside circuit is large in comparison with the resistance of the cell, the extra cells should be put in *series* with the first in order to increase the current.

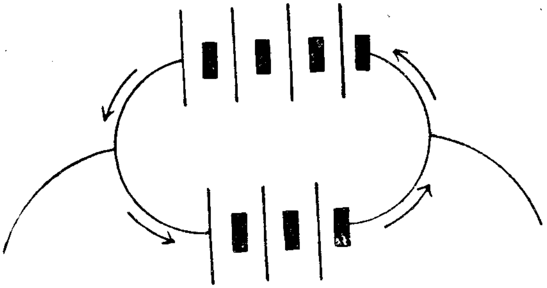
Now let us consider the case in which the external resistance is small compared with the internal resistance, say ·01 ohm. Then the total resistance will be 1·01 ohms, and, the E.M.F. being 2 volts, the current will be $\frac{2}{1 \cdot 01}$ = 2 amperes very nearly. Now if we add another cell in series with the first, the E.M.F. will be doubled, but the internal resistance will also be doubled, and the total resistance will be 2·01 ohms. The current will then be practically the same as before, that is very nearly 2 amperes. If, however the second cell is put in parallel with the first, although the E.M.F. remains the same, yet the internal resistance is halved, and the total resistance is reduced to ·51 ohms, the current will now be $\frac{2}{\cdot 51}$ = 4 amperes very nearly, or double what it was at first. So that, when the external resistance is small, cells should be grouped in ***parallel*** in order to get the greatest amount of current in the outside circuit.

In nearly all cases in the service in which cells are used as a source of electricity, the external resistances that we have to deal with are large in comparison with the internal resistances of the cells, so that nearly all service batteries are formed of cells joined in series.

Best Grouping of Cells.—In order to get the greatest possible current from a given number of cells in conjunction with a given circuit the cells should be grouped so that the internal resistance of the battery is as nearly as possible equal to the resistance of the outside circuit.

In grouping cells in any arrangement which includes both the series and parallel methods, it is most important that two unequal series of cells should not be put in parallel with one another

FIG. 26.



For example, a series of three cells should not be paralleled with four cells in series, as in Fig. 26; for, if there were no outside circuit, there would still be a current flowing through the battery. If the cells each have an E.M.F. of 2 volts the four in series would have a total E.M.F. of 8 volts, while the three in series would have an E.M.F. of 6 volts, so that the four would send a current round the wrong way through the three, and would run themselves down until they were only the same E.M.F. as the three.

CHAPTER III.

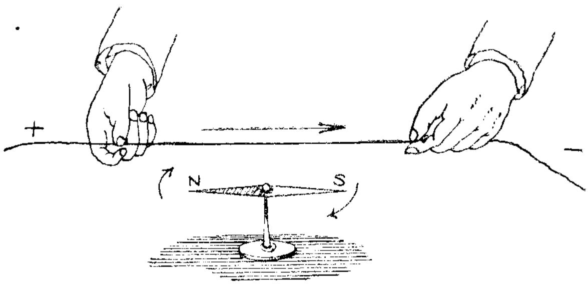
ELEMENTARY THEORY—*continued.*

Magnetic Action of the Electric Current.

A CONNECTION of some kind between magnetism and electricity has long been suspected, but it was only in 1819 that the nature of this connection was discovered. In that year Oersted, of Copenhagen, showed that a magnetic needle, freely suspended, tends to set itself at right angles to a wire carrying an electric current. He also found that the way the needle turns, whether to the right or left of its usual position, depends on the position of the wire—whether it is above or below the needle—and on the direction in which the current flows through the wire.

This can be easily shown as follows:—Let a magnetic needle be suspended on a pointed pivot, as in Fig. 27. Above

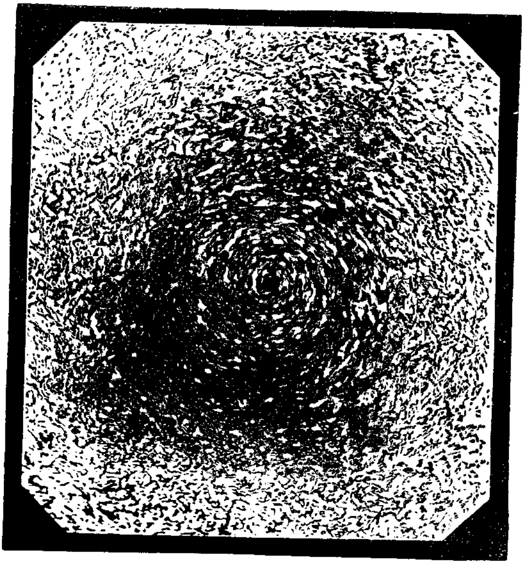
FIG. 27.



it, and parallel to it, is held a stout wire, one end of which is joined to one pole of a battery of one or two cells. The other end of the wire is then brought into contact with the other pole of the battery. As soon as the circuit is completed the current flows through the wire and the needle turns briskly aside. If the current is flowing along the wire above the needle in the direction from north to south, it will cause the N.-seeking end of the needle to turn towards the east, and if the current flows from south to north in the wire the N.-seeking end of the needle will be deflected westwards. If the wire is held underneath the needle, however, these effects will be reversed, and a current flowing from north to south will cause the N.-seeking end of the needle to turn to the westward.

The fact that these effects are produced by a wire carrying an electric current on a magnetic needle suggests that the wire may have "lines of force" in its vicinity as has a magnet, and that this is so can be proved by means of a magnetic figure made with iron filings (Fig. 28).

Fig. 28.



If a wire carrying a current is passed through a hole in a piece of paper, and iron filings are dusted on to the paper, the filings will arrange themselves in circles round the wire as shown in the figure. The circles map out the lines of magnetic force as do the lines in the magnetic figures obtained from a magnet. The direction in which the lines of force are considered to run is best remembered by the "corkscrew rule" suggested by Professor Maxwell. This rule is as follows: *The direction of the current and the resulting magnetic force are related to one another, as are the forward motion and the rotation of an ordinary right-handed corkscrew.*

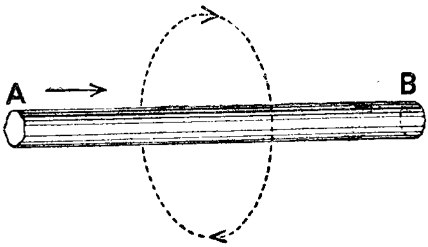
This may be otherwise stated as follows: If the longitudinal direction in which the screw moves either *into* or *out of* a cork be taken to represent the direction of a positive current, then the direction of the lines of force will be that in which the corkscrew handle rotates.

The direction of the lines of force of course means the direction in which a free N.-seeking magnetic pole would tend to move.

In Fig. 29, if the arrow represents the direction of the current along a straight wire, the circle will represent the direction of the resulting magnetic force around it.

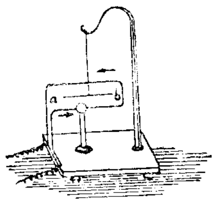
We can now see why a magnetic needle is affected in the way described at the beginning of this chapter. For the small arrows on the circle in Fig. 29 show the direction in which a N.-seeking magnetic pole is urged when under the influence of the magnetic force, and a S.-seeking pole is, of course, urged in the opposite direction. A little consideration will show that if

FIG. 29.



a current is carried below a needle in one direction, and then back in the opposite direction above the needle, by bending the wire round, as in Fig. 30, the force exerted on the needle by

FIG. 30.



both portions of the current will be in the same direction. For, let *a* be the N.-seeking, and *b* the S.-seeking, pole of the suspended needle, then the tendency of the current in the lower part of the wire will be to turn the needle so that *a* comes towards the observer, while *b* retreats; while the current flowing above, which deflects the N.-seeking pole to its left, will equally urge *a* towards the observer, and *b* away from him.

The angle at which the needle will stand out from its normal position in line with the wire depends on the strength of the current flowing in the wire. The directive force of the earth's magnetism is tending to make the needle point north and south, and the magnetic force due to the current in the wire is acting on the needle and tending to make it set itself east and west. If these two are equal the needle will of course set itself half way between the two positions, but if one is stronger than the other, the needle will stand at another angle, being nearer to the north and south line if the current is weak, or nearer to the east and west line if the current is strong. This arrangement can, therefore, be used to measure the strength of electric currents, and it is on this principle that nearly all "galvanometers" and measuring instruments are constructed.

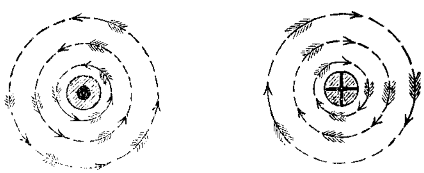
The arrangement as described would not of course be very sensitive, but it can be made more so in two ways. Either the effective action of the current can be increased by carrying the wire more than once round the needle, or the opposing directive force of the earth's magnetism can be lessened by some compensating device. The first of these methods is generally adopted in all galvanometers and sometimes the second as well.

Let us consider the magnetic field due to a current flowing in a wire which is bent into the form of a spiral or helix, as in the galvanometer mentioned above. It is convenient to have some means of representing the direction of the current in a conductor which is shown in section, and the following convention has been adopted:—

Imagine an arrow shot point blank at you, you would see the tip, so in order to express the idea that the positive current is coming towards you, in the centre of the circle showing the conductor we will put a dot.

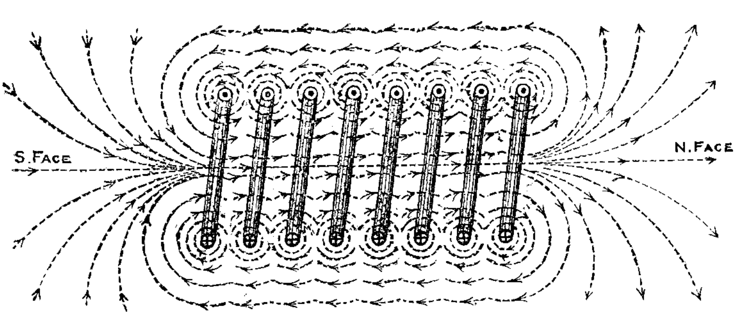
Imagine the arrow shot point blank away from you, you would see the cross of the feathers. So for positive currents running away we will put a cross in the circle showing the conductor. Making use of the above symbols, we can now draw a conductor with a current running and show the direction of the lines of force, that is, the direction in which a "free" north pole would revolve.

Fig. 31.



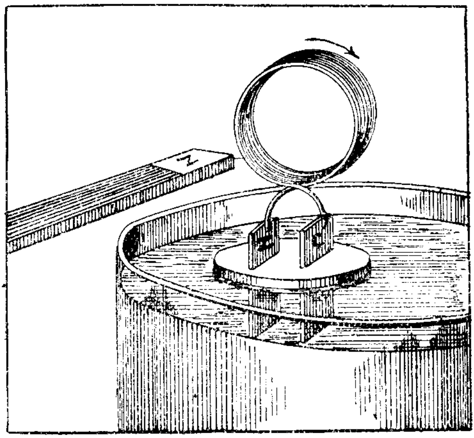
In Fig. 32 the magnetic field due to each part of the wire is shown by the dotted lines, and the direction of the current in the wire is shown as above.

Fig. 32.



It will be seen that all the lines of force inside the spiral run in the same direction, and consequently all join together. At the ends they spread out rather, and curve round so as to enter the opposite end. A similarity between this magnetic figure and that obtained from an ordinary bar magnet will at once be noticed, and it might be supposed that a spiral wire of this sort, with an electric current flowing through it, would behave in very much the same way as a magnet. This is found to be the case, and a spiral of this sort, when a current is flowing in it, behaves in all respects as does a bar magnet; it turns towards the north if freely suspended, and it apparently has two poles which exercise the same attractions and repulsions on magnets as do the poles of an ordinary bar magnet. This can be shown experimentally as follows:—A plate

FIG. 33.



of zinc and one of copper (*see* Fig. 33) are fixed side by side in a large cork, and connected by a coil of several turns of insulated wire. This is floated on a dish containing dilute sulphuric acid. If left to itself it will turn so that the axis of the coil lies in the north and south line. If one pole of a bar magnet is held towards the coil, it will be attracted or repelled according to the pole employed. If the S.-seeking pole of the magnet is presented to that face of the coil that acts as a S.-seeking pole (namely, that face round which the current is flowing in a clock-wise direction), it will repel it. If the pole be thrust right into the ring, and then held still, the coil will be strongly repelled, will draw itself off, float away, and turn round so as to present to the S.-seeking pole of the magnet its own N.-seeking face. It will then be attracted up and will thread itself on to the magnet up to the middle, in which position as many lines of force as possible cross the area of the coil.

It can be shown that two circuits traversed by currents attract and repel one another just as two magnets do. They attract one another if their currents are flowing in the same direction, and repel one another if their currents are flowing in opposite directions.

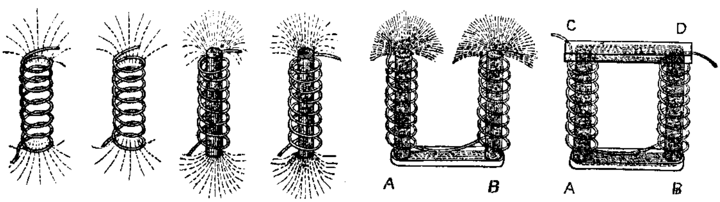
Maxwell's Rule.—Professor Clerk Maxwell propounded the following rule for determining how a circuit carrying an electric current moves when acted upon by a magnetic field: *Every portion of a circuit carrying an electric current, and under the influence of a magnetic field, is acted upon by a force urging it in such a direction as to make it enclose within its embrace the greatest possible number of lines of force.* This rule also applies in the opposite sense; that is to say if the coil is fixed, and the magnet producing the field is free to move, then the force acting on the magnet will also be such as to tend to make the number of lines of force that pass through the circuit a maximum.

It will be seen that this rule accounts for all the motions of the floating coil, and also of the magnet pivoted in the centre of the coil of wire in the galvanometer. And although all these motions can be explained by the laws of ordinary magnetic attraction and repulsion, yet this rule provides a ready means of quickly determining how a coil of wire will move when acted on by a magnet, or *vice versâ*.

Electro-magnets.

Effect of Iron Core on Helix.—A coil such as that shown in Fig. 32 may have its field very much increased by merely inserting an iron core. This may be easily tried experimentally by holding such a helix near a magnetic needle and then inserting a core of soft iron, when it will be seen that the needle is far more strongly affected. The effect of putting soft iron into a magnetic circuit is to reduce its total reluctance and therefore to *create* lines of force, or, in other words, increase the magnetic flux. There is at first always a difficulty in understanding how, by merely putting iron into a magnetic circuit, lines of force are created. The reason is that we are apt to forget that our lines of force do not exist in the field in *reality;* we have only used them to depict the strength and direction of the field of the magnet. For the same magnetising force, by reducing the magnetic reluctance of the circuit we increase the strength of the field. This is shown (Fig. 34) in our diagram by drawing

Fig. 34.



more lines of force, therefore we may say that by adding iron, *i.e.*, by decreasing the magnetic reluctance, we increase the magnetic flux.

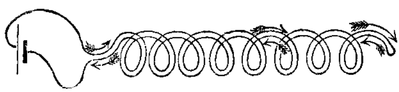
This may be shown by actually building up by degrees an electro-magnet in the form of a horse shoe, measuring the increase in strength of field on the addition of each separate piece of iron.

With the wire coils alone a certain magnetic field is produced, but only a comparatively weak one. On introducing the iron cores of the magnet the field is greatly increased in strength; by adding the yoke the magnetic reluctance between A and B is again greatly reduced, and therefore the strength of the magnet largely increased. If, again, an armature C D be added, the reluctance between C and D is reduced to very little, and all the circuit being now of soft iron, a very large number of lines of force are present in the iron, although, of course, no external magnetic field is produced from an arrangement of this sort, except by leakage of lines of force away from the iron and bobbins. This is called a closed magnetic circuit.

Strength of Field varies as Ampere Turns.—The magnetising force in an electro-magnet is caused by the current running in the helix, and may be considered as directly proportioned to the number of *ampere turns*, that is, the number of turns of wire multiplied by the current in amperes. Hence, broadly speaking, 100 turns, carrying 100 amperes of current, would have the same magnetising force as 1,000 turns carrying 10 amperes, or 10,000 turns carrying 1 ampere: so that we can magnetise cores either by a few turns carrying a large current or with a large number of turns carrying a small current. The application of this will be seen when discussing field magnets.

Non-inductive Coils.—If a wire be wound on the bight so that in each coil the currents in the two wires run in opposite directions, then the circles of force produced by each current run in opposite directions, and consequently neutralize one another's field. This is a device made use of in winding resistance coils, or when leading wires near compasses, where the wires are either twisted round one another or laid close together side by side.

FIG. 35.



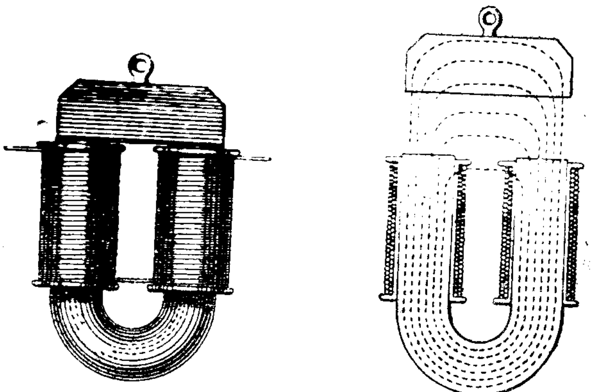
Permeability.—The capability of any substance for conducting magnetic lines of force is known as its *permeability*. The permeability of air may be taken as a standard, and all other substances compared with it. Suppose a piece of steel to be placed in a magnetic field, the lines of force near it are bent out of their previous shape and converge into the steel (*see* Fig. 16). More lines of force, therefore, pass through the space now occupied by the steel than previously; clearly, then, steel is more permeable than air.

The most permeable material known is *pure soft iron*, and it is found by experiment that as the hardness and impurity of iron increase, so its permeability decreases. Permeability is more fully explained below.

Magnetising Force.—We have already stated that the magnetising force in an electro-magnet is proportional to the number of ampere turns; we will now consider this more closely.

Suppose we desire to make an electro-magnet (Fig. 36) as effective as possible.

FIG. 36.



The object is to attract the "armature" as strongly as possible; that is, to urge through it as many lines of force as we can.

Analogy between Electric Current and Magnetic Flux.—Now, in the calculation of the strength of a current of electricity in a circuit we take into account the D.P. urging the current along and the resistance opposing its passage, getting the equation:—

$$\text{Current strength} = \frac{\text{D.P.}}{\text{Resistance.}}$$

In a somewhat similar way we may consider the path round which we wish to urge the magnetic lines of force as a *magnetic circuit*, and taking into account the *reluctance* opposing the magnetic flux we may say:—

$$\begin{array}{c}\text{Total number of lines of force,}\\ \text{or magnetic flux.}\end{array} = \frac{\text{magneto-motive force}}{\text{magnetic reluctance.}}$$

Total Reluctance of a Magnetic Circuit.—The magneto-motive force tending to set up a flux is due to the number of ampere turns used. The reluctance is *directly* proportional to the length of the magnetic circuit, and *inversely* proportional to the sectional area and the permeability of the substances of which the magnetic circuit is composed. In calculating the *total* reluctance of the whole magnetic circuit in the case of the horse-shoe magnet and its armature, we say that the *total reluctance* is the *sum of all the reluctances;* that is, the reluctance due (i) to the iron horse-shoe, (ii) to the armature, (iii) to the two small air gaps between the poles and the armature. In this calculation, if the armature is ever so small a distance from the pole pieces of the horse-shoe magnet, a large increase in the reluctance would take place, because the permeability of air is so small. In other words, the permeability of air being small, less lines of force would pass from the poles through the air space to the armature, and in consequence the armature would be less powerfully attracted. In actual practice the calculation of the number of lines of force is not quite so simple as it would here appear. A knowledge of C.G.S. units is involved, and a further complication sets in because some of the lines of force in practice "leak" out through the iron and do not pass completely round the desired path, and the "leakage" is greatly increased if the air gaps mentioned are of any size, many of the lines of force passing across the air space *between the two magnet poles* and not going through the armature at all.

In calculating the density of the magnetic flux in the case of the horse-shoe magnet, allowance has also to be made for the fact that if there are a large number of turns of wire round the poles, the outer turns will be considerably further from the magnet cores than the inner ones: and consequently their resistance will be greater than those inside them, because each outer coil will contain a greater length of wire.

There are other considerations involved, but enough has been said here to give a general idea of the laws of magnetic circuits.

To return to the horse-shoe magnet, it is clear that it is advantageous to make the reluctance of the magnetic circuit as low as practicable, in order to obtain the greatest number of lines of force for a given magneto-motive force. Consequently the three factors, length, sectional area, and permeability, must be considered.

If lightness and compactness are essential the core should be made of annealed wrought iron. This is not, however, done in the case of the massive cores of the field magnets of a dynamo. Cast iron is not only cheaper, but the material may be cast into such a shape that it requires much less "machining up" than wrought iron. Mild steel which can be cast into moulds is also used, but if cast iron or cast steel are used it will be necessary, owing to their greater reluctance, to increase their sectional area to obtain the same results as with soft iron.

Symbol H.—Now, in considering electro-magnets it is sometimes convenient to speak of the *intensity of the magnetising force at any point*, instead of the magneto-motive force or *total* magnetising force. The value of this intensity is generally denoted by the letter H. The value of H, of course, varies. In a straight, evenly wound helix without any core, for instance, H would be practically uniform inside it along the whole length except just at the ends. If more turns of wire were wound on a helix of the same length, the value of H would increase, and *vice versâ.*

Symbol B.—Again, we sometimes wish to specify the *density of the lines of force at any point;* this density is denoted by the letter B. The value of B also will vary in different parts of the magnetic circuit. B is the resulting number of lines of force per unit area due to the magnetising force H.

Note.—The unit of area taken in magnetic problems is the square centimetre; and the unit of flux is one line of force, or the C.G.S. unit of magnetism. The density of magnetic flux at any point is the number of lines passing through one square centimetre at that point and is denoted by the symbol B.

Permeability.—The precise notion now attached to this word is that of a numerical coefficient. Suppose a magnetising force —due, let us say, to the circulation of an electric current in a surrounding coil—were to act on a space occupied by air, there would result a certain number of magnetic lines of force in that space. In fact, the intensity of the magnetic force, symbolised by the letter H, is often expressed by saying that it would produce H magnetic lines per square centimetre in air. Now, owing to the superior magnetic power of iron, if the space subjected to this magnetic force were filled with iron instead of air, there would be produced a larger number of magnetic lines per square centimetre. This larger number expresses the degree of magnetisation or "flux density" in the iron; it is symbolised by the letter B. The ratio of B to H expresses the permeability of the material, and the usual symbol for permeability is the Greek μ. So we may say that the flux density B is equal to μ times the magnetic force H, or, since $\mu = B/H$, therefore $B = \mu\, H$.

For example, a certain piece of iron, when subjected to a magnetic force capable of creating, in air, 50 magnetic lines per square centimetre, was found to be permeated by no fewer than 16,062 magnetic lines per square centimetre. Dividing the latter figure by the former gives the value of the permeability at this stage of the magnetisation as 321, which means that the permeability of iron is 321 times that of air.

The permeability of empty space, air, and all non-magnetic materials is practically 1.

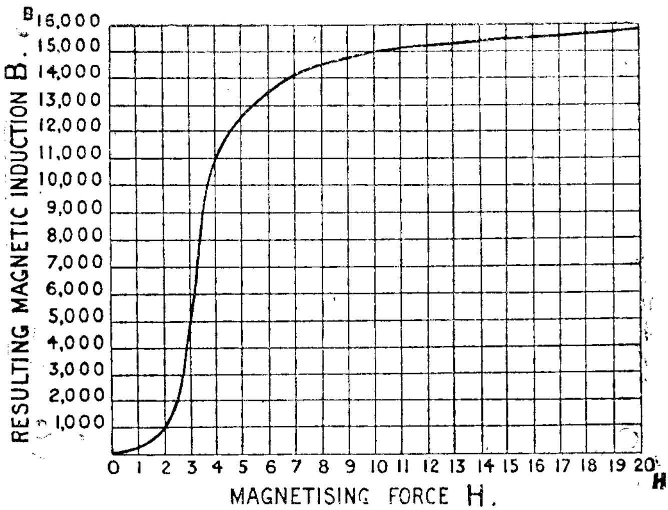
Saturation.—Before the dimensions of the core of an electro-magnet can be determined we must know the permeability of the metal to be used, and as the permeability of either iron or steel *varies* with the value of B, it is also necessary to decide upon the maximum flux density at which the core is to be worked. If we start with a piece of unmagnetised iron and magnetise it by suitable means, it will be found that the effect of projecting the first few lines of force though it will be to increase its permeability; but after a certain number of lines have been urged through, the permeability rapidly diminishes, and beyond a certain point a considerable increase of the magnetising force H makes but little difference in the value of B. The magnet is then said to be *saturated.*

In practice we are content when the metal is approaching the saturation point with a value of B, which is approximately

16,000 to 17,000 lines per square centimetre for the best wrought iron.

In the figure, the line O H has been divided off to represent units of magnetising force and the line O B to represent magnetic

Fig. 37.



density, 1,000 lines for each division; and the curve is the result of plotting the results of a series of experiments in which the magnetising force has been gradually increased. It will be seen that the permeability of the iron rapidly increased after a few lines of force had been passed through it, but that later, when the magnetising force H had risen to between 4 and 5 units from O, and the density had risen to between 11,000 and 12,000 lines, the iron was becoming saturated and a large increase in H was only giving a very small increase in B.

This shows clearly that it is uneconomical to work an iron core above a certain density, and that in the construction of field magnets a sufficient quantity of iron should be used to prevent saturation.

Magnetic Properties of Soft Iron and Steel.—Soft iron has not only high permeability but low *retentivity*, which is another valuable property when it is used for electro-magnets, as in most cases these magnets are required to develop as dense a field as possible as long as the current is flowing, and to lose it on its cessation, leaving but little *residual* magnetism.

Steel behaves in exactly the opposite way, and is consequently largely used for *permanent* magnets. The magnetisation in good "magnet steel" is practically only skin deep, which can be proved by immersing it in some strong acid, when it will be found that as soon as the surface has dissolved away the remaining steel will have lost all traces of magnetisation. For this reason thin strips are magnetised separately and then built up one on top of the other, forming what is termed a *laminated* bar, when a strong permanent magnet is required.

Magnets lose their magnetisation by being set in vibration. This can be done by heating or hammering, consequently permanent magnets should never be dropped or thrown down. Making a steel magnet red hot will cause it to lose its magnetism entirely, but when it has cooled it can be again re-magnetised.

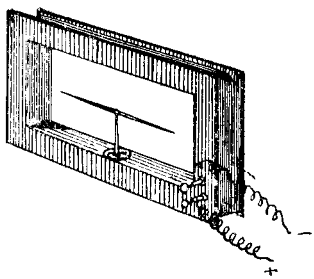
Steel magnets which have developed "consequent poles," or which are found to be getting weak, should be heated to a *cherry red*, dipped in cold water with a layer of oil on the surface, and then re-magnetised.

Soft iron which has become hard should be similarly heated, and then set aside to cool very slowly in sawdust or charcoal.

Galvanometers.

The simplest form of galvanometer is that shown in Fig. 38, It consists of a small magnetic needle on a pivot, and round it a

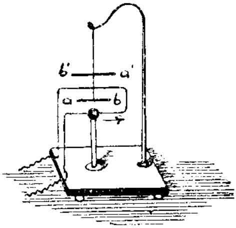
FIG. 38.



coil of many turns of wire wound on a former made of some insulating material, the ends of the wire being brought out to two terminals on the outside. The strength of the current flowing in the wire can be gauged by the angle to which the needle stands out. Before using a galvanometer of this form, it must be placed with the coils pointing north and south, so that the needle will stand in line with the coils before switching on the current. In order to make it more easy to observe the angle at which the needle stands when the current is flowing, the spindle of the needle is generally continued up through the coils and carries a pointer, which moves over a scale placed on top of the instrument; this scale is graduated in degrees, so that it can be seen at a glance what the angle is.

Astatic Pair.—A more sensitive form of galvanometer than this is made by using an "astatic pair" of magnetic needles instead of a single needle. If two magnetic needles of exactly equal strength are mounted on the same spindle, parallel to one another, but with the N.-seeking pole of one pointing in the same direction as the S.-seeking pole of the other, the force tending to make one of them point north and south is exactly counterbalanced by the force that acts on the other. Consequently this pair of needles will remain in any position in which it is set, and is independent of the earth's magnetism. Such a combination is known as an "astatic pair." Such an astatic pair is, however, readily deflected by a current flowing in a wire coiled round one of the needles, as in Fig. 39. For, since the upper needle in

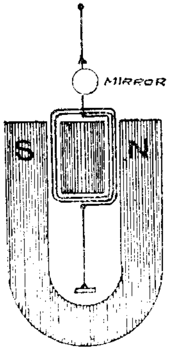
FIG. 39.



above the coil, and pointing in the opposite direction to the lower needle, the current in the upper part of the coil tends to turn both needles in the same direction. It is almost impossible to get two magnetic needles of exactly the same strength, and one of them is nearly always found to be slightly stronger than the other, so that there is a very small directive force on the needles tending to set them in the north and south line. But in any case this directive force is so weak as to make the instrument very sensitive indeed.

Moving Coil Galvanometer.—Instead of having the coil of wire fixed and the magnet free to move, as in those galvanometers already described, it is possible to reverse their positions, and to have the magnet fixed and the coil of wire moving between its poles, as in Fig. 40. The current is led into and from the coil by

FIG. 40.



the suspending wires, and within the coil is a piece of soft iron, filling the space inside but leaving the coil free to move, of which the function is to concentrate the lines of force and make the field in which the coil moves as uniform as possible. The coil is wound on a light frame, which is usually made of metal. This, for a reason that will be explained later, makes these instruments very "dead-beat," which means that the coil moves straight to the position in which it finally rests when current is flowing through it, and does not swing about for some time before settling down, as does a suspended magnet. Generally a pointer moving over a graduated scale is attached to the moving coil, but sometimes a small mirror is used, which reflects a spot of light from a lamp on to a scale, and the motion of the coil is seen by the deflection of the spot of light. Such an instrument is called a "mirror galvanometer." Most indicating instruments, ammeters, voltmeters, and wattmeters, are now made on this principle, namely, a coil moving between the poles of a magnet, which may be either an electro-magnet or an ordinary permanent magnet. Those galvanometers and indicating instruments that are in use in the Service will be described later.

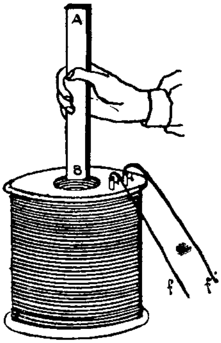
Induction of Currents.

In 1831 Faraday discovered that currents could be induced in a closed circuit by moving magnets near it, or by moving the circuit in a magnetic field; and he followed up this discovery by finding that a current whose strength is altering may induce a secondary current in a closed circuit near it. Such currents, induced by changing magnetic fields, whether these fields are produced by magnets or by other electric currents, are called "induction currents." And the action of a magnet or current in producing such induced currents is termed "electromagnetic induction," or simply "induction." It is most important that this electromagnetic induction should not be confused with the electrostatic induction of one stationary electric charge upon bodies near it; this has nothing to do with currents, and the two should not be in any way confused. It is on this principle of electromagnetic induction that all dynamos, induction coils, and alternating current transformers are made.

The following experiments will illustrate this action. If a coil of insulated wire is connected in circuit with a sufficiently sensitive galvanometer, and a magnet is inserted rapidly into the hollow in the middle of the coil, as in Fig. 41, a momentary current is observed to flow round the circuit while the magnet is being moved into the coil. So long as the magnet lies motionless in the coil it induces no currents, but if it is rapidly pulled out of the coil another momentary current will be observed to flow in the opposite direction to the former. The induced current caused by inserting the magnet into the coil is an "inverse current," that is to say, it is in the opposite direction to that which would magnetise the magnet with its existing polarity. The induced current caused by withdrawing the magnet is a "direct" current, in the same direction as that which would magnetise the magnet with its existing polarity.

Exactly the same effect is produced if the coil is moved towards the magnet as if the magnet is moved towards the coil. The more rapid the motion is, the stronger are the induced currents, though of course they last for a shorter time. As a matter of fact, precisely the same quantity of electricity is set in

FIG. 41.



motion each time that the magnet is inserted into, or withdrawn from, the coil, but if the motion is rapid it all has to move in a shorter time, so that the strength of the current, for the time that it lasts, is of course greater than if the same quantity takes a longer time to move.

The magnet does not grow any weaker by being so used, for the real source of the electrical energy generated is the mechanical energy spent in motion.

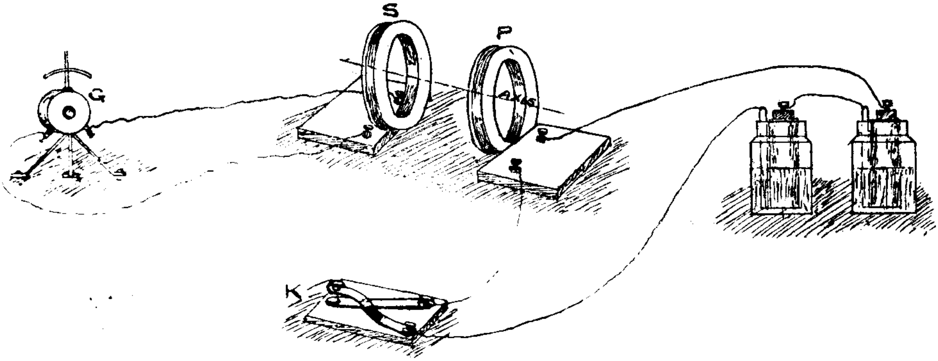
If the circuit is not closed, no currents are produced; but the relative motion of the coil and magnet will set up an electromotive force, *tending* to produce currents.

It was discovered by Faraday that these effects are connected with the magnetic field surrounding the magnet. He showed that no effect was produced unless the circuit cut across the invisible lines of force of the magnet.

Faraday also showed that the approach or recession of a current might induce a current in a closed circuit near it. This may be conveniently shown as an experiment by the apparatus of Fig. 42.

A coil of insulated wire P is connected with a battery B of two or three cells, and a key K to turn the current on or off. A second coil of insulated wire S, entirely unconnected with the first, is joined up with wires to a sensitive galvanometer G. We have seen that a coil of wire in which a current is flowing acts like a magnet. And we find that if while the current is flowing in P, the coil is suddenly moved up towards S, a momentary current will be induced in S. If P is suddenly moved away from S, another momentary current will be observed in the second circuit. The first of these two momentary currents is an "inverse" one, *i.e.*, in the opposite direction to the current in P, while the second is a direct current. The coil P we will call the *primary* coil, and the current in it the *primary* current; the other coil S we will call the *secondary* coil, and the momentary currents induced in it *secondary* currents.

FIG. 42.



Let P now be placed close to S, with no current flowing in either coil. Then on pressing the key K to turn on the primary current, it will be noticed that while the current in P is growing, there will be a transient inverse current in S. The effect of turning on the current in P is just the same as if the current had been turned on while P was far away, and then P suddenly brought close up to S. *Breaking* the battery circuit while the primary coil is close to the secondary coil produces the same effect as if the primary coil were suddenly removed to a great distance. *Making* the battery circuit while the primary coil is close to the secondary produces the same effect as bringing it up suddenly from a great distance.

So long as a steady current is flowing in the primary coil there are no induced currents in the secondary circuit; but moving the secondary coil towards the primary has just the same effect as moving the primary towards the secondary, and *vice versâ*.

We may arrange these results in the form of a table as follows:—

By means of	Momentary Inverse Currents are induced in the Secondary Circuit	Momentary Direct Currents are induced in the Secondary Circuit
Magnet - -	While *approaching* -	While *receding*.
Current - -	While *approaching* or *beginning* or *increasing* in strength.	While *receding* or *ending* or *decreasing* in strength.

Fundamental Laws of Induction.

The facts enumerated above may be summed up in the following laws, remembering that a "direct" current means a current that would produce lines of force in the same direction as those that are being considered, and an "inverse" current means a current in the opposite direction.

(1) *A decrease in the number of lines of force which pass through a circuit induces a direct current in the circuit; while an increase in the number of lines of force which pass through the circuit produces an inverse current in the circuit.*

(2) *The total induced electromotive force acting round a closed circuit is equal to the rate of decrease in the number of lines of force which pass through the circuit.*

Suppose that at first the number of lines of force passing through the circuit to be N_1, and that after a small interval of time t the number becomes N_2, then the change in the number of lines will be $N_1 - N_2$, and the rate of change will be $\frac{N_1 - N_2}{t}$. The electromotive force, E, is therefore $E = \frac{N_1 - N_2}{t}$. And by Ohm's Law $C = E \div R$. Therefore $C = \frac{N_1 - N_2}{Rt}$. If N_2 is greater than N_1, and there is an increase in the number of lines of force, then $N_1 - N_2$ will be a negative quantity, and C will have a negative sign, showing that the E.M.F. is an inverse one.

To induce an E.M.F. equal to that of a single Daniel cell would require that the rate of change in the number of lines passing through the circuit should be 110,000,000 per second. As such large numbers are inconvenient, the unit of E.M.F., the *volt*, has been chosen so that it corresponds to the E.M.F. produced when the rate of change is 100,000,000 lines per second.

As an example of this, suppose the number of lines of force through a circuit to diminish from 800,000 to 0 in the $\frac{1}{50}$ part of a second. The rate of diminution of lines of force will then be $800,000 \times 5 = 40,000,000$ lines per second. And since the volt is taken as the E.M.F. produced by a rate of change of 100,000,000 lines per second, the average E.M.F. in the circuit while the magnetic field is changing will be $0 \cdot 4$ of a volt.

It is important to note that all these inductive experiments are really magnetic. In the experiment with the two coils P and S it is the magnetic lines of force of the coil P which pass through S and set up the induced E.M.F. This is proved by the following further experiment. Take a bar of iron, or better still a bundle of iron wires, and lay it along the dotted line in Fig. 38 so that its ends pass through P and S. It will, by its great magnetic permeability, help to conduct the lines of force from P through S, and when it is so placed it will be found greatly to intensify the inductive actions. In fact, if P is many inches away from S and the iron core is present, the inductive effects of turning the current on and off may be as great as if, in the absence of the core, P were pushed close up to S.

Direction of the Induced E.M.F.—The direction of the induced E.M.F. is given by what is known as "Lenz's Law," which is as follows:—

In all cases of electro-magnetic induction the induced currents have such a direction that their action tends to stop the motion, or other change, that produces them.

The truth of this law will be evident if the table on page 61, giving examples of electromagnetic induction, is studied. For instance, a magnet when approaching a circuit produces a momentary inverse current, and an inverse current repels the magnet, and tends to stop its approach. Also a momentary inverse current is produced in the secondary coil while the current is increasing in the primary coil, and this inverse current produces lines of force in the opposite direction to those of the current in the primary coil. It therefore tends to reduce the total magnetic field, thus opposing the tendency of the changing current, which in increasing is tending to increase the magnetic field. All the other examples will also be found to conform to Lenz's Law.

Self-induction.

We have seen than an E.M.F. is set up in a circuit whenever there is any change in the number of lines of force that pass through its embrace, whether these lines of force are produced by a magnet or by a current in another circuit in the vicinity. It is therefore reasonable to suppose that any alteration in the lines of force through the circuit that are due to a current in the coil itself would produce the same effect. This is, indeed, found to be the case. When the current in a circuit is increasing the lines of force due to the current are also increasing, and consequently an E.M.F. is set up in the coil. This E.M.F., by Lenz's Law, tends to oppose the change that produces it, and is consequently in the opposite direction to that E.M.F. which is causing the current to increase. It therefore makes the current increase more slowly than it otherwise would, if this effect were absent.

Similarly when the current in a coil is decreasing, there is an E.M.F. set up which tends to keep the current at its original value, and consequently again makes the change slower than it would otherwise be.

This action, which has the effect of slowing down all changes in the magnitude of the current in a circuit, is known as "self-induction" or "inductance."

The intensity of the self-inductive action depends to a great extent on the form of the circuit. This will be easily seen from the following explanation. In the case of the two coils P and S when they were close together and nearly all of the lines of force due to the coil P passed through S, the inductive action between them was very much greater than when they were farther apart. In the case of a single coil, or circuit of any form, the number of lines of force, due to the current in the circuit itself, that are embraced by the circuit depends on how the circuit is arranged. If it is in the form of a long flat loop, with the two sides of the loop very close together, as in Fig. 43, there will be very few lines of force embraced by the circuit, when a current of a certain strength, say one ampere, is switched on in it.

If, however, we take the same piece of wire shown in Fig. 43, and bend it into the form of a circle, as in Fig. 44, a far greater

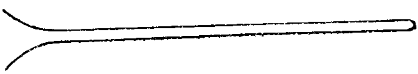


Fig. 43.

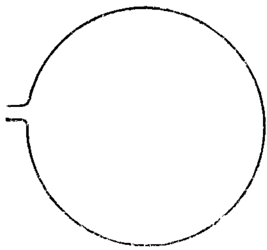


Fig. 44.

number of lines of force will be embraced by it when the same current is flowing. The effect of switching on the current in the first case will be the same as that of thrusting a very weak magnet into the embrace of the coil, while in the second case it is similar to the effect of a much stronger magnet. The inductive effect is therefore very much greater in the second case than in the first. We can still further increase the self-induction of a circuit, however, by adding another circular loop of wire, in series with the first, and placed close to it with the current flowing the same way round each. Then each coil, besides embracing the lines of force due to its own current, also embraces the lines of force due to the current in the other loop, and the self-induction of each loop is double that of the single loop. And since the two loops are in series, their E.M.F.'s of self-induction are added together, and the self-induction of the whole circuit is four times that of the single loop by itself. In the same way we can go on increasing the self-induction of the circuit by adding more loops in series with the first two, and arranging them so that they form a flat spiral or solenoid.

The inductance of a circuit can also be largely increased in another way, namely, by putting an iron core into the solenoid. We have seen that, in the case of the two coils, the inductive effect was very much increased by the use of an iron core, since the same current in the coil produces many more lines of force in iron than in air, owing to the much greater magnetic permeability of the iron. And in the same way the self-induction of a circuit is also increased.

The unit of inductance is called the "henry," and a circuit is said to have an inductance of one henry when, by an alteration of the current flowing it by one ampere per second, an E.M.F. of self-induction of one volt is produced.

Since the volt has been defined as the E.M.F. that is produced in a circuit when the magnetic flux through it is altered at the rate of 100,000,000 lines of force per second, therefore, in a circuit whose inductance is one henry, an alteration of the current of one ampere produces an alteration of 100,000,000 lines of force in the magnetic flux.

In the same way that the letter E is generally used to denote the E.M.F., and the letter R for resistance, and C for current, so inductance is generally denoted by the letter L.

The effects of inductance, when it is fairly large, can easily be observed in many cases. For instance, the field magnet coils of a motor, whose inductance is very great, both because they consist of many turns and also because they are wound on an iron core, afford a very good illustration. When the current is switched on to them, it is observed to rise in value very slowly indeed, as can be seen by watching an ammeter placed in the circuit. Also, if when the current is flowing the circuit is suddenly broken, the effect of the inductance is to set up an E.M.F. that tends to keep the current flowing, and this E.M.F. may, and generally does, reach a very high value owing to the large number of lines of force that are destroyed in a very short space of time, making the *rate of diminution* very great. This E.M.F., since it tends to keep the current flowing, is sometimes enough to spark across the switch, or even puncture the insulation of the coils, if no protecting device is fitted.

Examples of Electro-magnetic Induction.—We are now in a position to explain why, in a moving coil galvanometer or other measuring instrument, the metal frame on which the coil is wound makes the instrument deadbeat, as was mentioned on page 59. The metal frame in the instrument in Fig. 40 forms a closed circuit, and consequently when it moves in the field of the magnet the number of lines of force passing through it is altered, and currents are induced in it. The effect of these currents is, by Lenz's Law, to stop the motion that produces them, and consequently the coil moves slowly and does not swing about after reaching its final position.

Another application of this principle is to be found in the "brake disc" that is used in Kilroy's Stoking Indicator and other instruments. It consists of a disc of copper which is made to revolve in the field of a magnet. The currents induced by its motion with regard to the magnetic field all tend to stop the motion that produces them, and so the disc revolves slowly and acts as a brake, and the stronger is the magnet that produces the field, the larger will be the induced currents and the greater the braking effect.

Faraday's Ring: Principle of Transformation.—Amongst Faraday's earliest experiments he took an iron ring about 8 inches in diameter (Fig. 45) and wound upon it two insulated coils of wire P and S, each of many turns. If P was connected to a battery circuit, and S to a galvanometer, he found that whenever the current was switched on or off in the coil P, secondary currents were generated in the coil S. In fact the currents in P magnetised the iron ring, and the lines of force created by P passed through S, setting up induction currents. If S is used

FIG. 45.

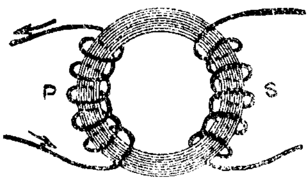
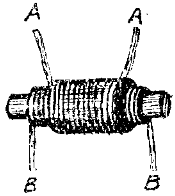


FIG. 46.



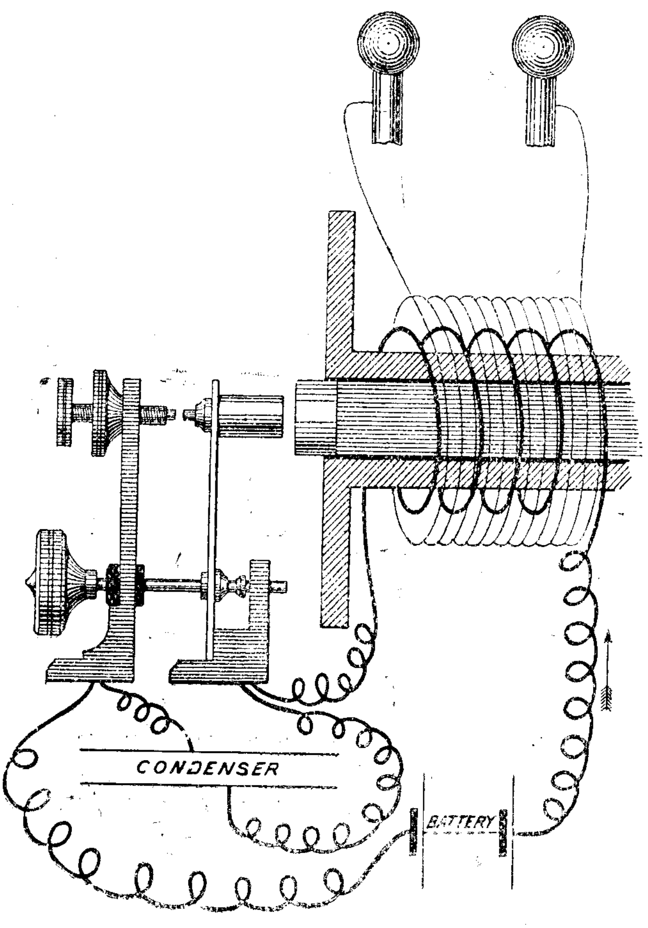
as the primary, then P will act as the secondary; and in fact the induction between P and S is mutual. The Faraday Ring, with its two coils wound upon a closed circuit of iron, may be regarded as the original type of all transformers and induction coils. Faraday also employed some induction coils in which the two coils A and B (Fig. 46) were wound cylindrically outside on another upon a straight core of iron C.

In all transformers the E.M.F.'s generated in the secondary circuit are to those in the primary circuit very nearly in the same proportion as the relative numbers of turns in the two coils. This will be evident from the consideration of a simple example. Suppose the primary coil consists of one turn of wire and the secondary coil of two turns of wire round the core. When the current is switched on in the primary all the lines of force due to it will cut each turn of the secondary, and since the two turns are in series, their E.M.F.'s will be added together, and the total E.M.F. will be double that of the primary.

By choosing the proper number of turns for the two coils, the E.M.F. may be transformed up or down as much or little as is required.

The Induction Coil.—In order to generate very high electromotive forces that shall be able to send sparks across air spaces that ordinary machines or batteries could not possibly pierce, advantage is taken of the transformer principle. The apparatus used is shown in Fig. 47, and is known as an "induction coil." It consists of a cylindrical bobbin having a central iron core surrounded by a short inner, or primary coil of stout wire, and an outer secondary coil, consisting of many thousand turns of very fine wire, very carefully insulated between its separate parts. The primary circuit is joined to an ordinary source of electricity, such as a battery or dynamo, and in it are also included an interrupter, or "make and break," and a key. The function of the interrupter is to make and break the primary circuit in rapid succession. The result of this is that at every "make" a momentary inverse current is induced in the secondary circuit, and at every break a powerful momentary direct current. The actual number of lines of force that pass through the secondary circuit on the make is of course the same as the number destroyed on the break, but as the current takes longer to grow to its full value on switching on than it does to die away on switching off,

FIG. 47.



the rate of change of magnetic flux is much greater in the latter case than in the former. Consequently the E.M.F. generated on breaking the current is very much greater than that generated on the make, and it is only on the break that the spark takes place.

The primary coil is made of stout wire, that it may carry strong magnetising currents, and its inductance be not too great. The central iron core is for the purpose of increasing, by its great permeability, the number of lines of force that pass through the coils; it is usually made of a bundle of fine wires to avoid the induced currents that would otherwise be set up in it if it were a solid bar. The secondary coil is made with many turns in order that the ratio of transformation may be large; and as the induced electromotive force will be many thousands of volts, the resistance of this coil will be immaterial, and it may be wound of the thinnest wire that is convenient.

Induction coils are used in the Service for wireless telegraphy, and detailed descriptions of them and their gear will be found in the Manual of Wireless Telegraphy, page 145.

Heating Effect of an Electric Current.

It has been already mentioned that an electric current flowing in a circuit heats that circuit. The amount of heat that is produced by a current is proportional to the resistance of the circuit and also to the square of the strength of the current, or, in mathematical language, is proportional to C^2R. This means, firstly, that if there are two circuits with the same current flowing in each, but one is double the resistance of the other, the heat developed in the circuit of high resistance will be double that developed in the other. And secondly, if there are two circuits whose resistances are the same, but one has twice as much current flowing in it as the other, four times as much heat will be developed in the one carrying the higher current as in the other. Or if the current is three times as great, the amount of heat will be nine times as great, and so on.

If the wire is not too small and the current not too large, this heat that is developed is all dissipated by conduction and radiation, and the wire does not rise in temperature very much, but in the case of a small wire carrying a fairly large current, the heat has not time to be conducted away and the wire becomes warm, then hot, and finally melts. This is made use of in the construction of fuses and detonators for firing explosives.

In the case of ordinary circuits, which must not be allowed to get hot, care is taken that the wire is of such a size that the heat generated by the current is dissipated as quickly as it is produced.

Chemical Actions of the Electric Current.

In addition to the chemical actions inside the voltaic cell, which always accompany the production of a current, there are also chemical actions produced outside the battery when the current is caused to pass through certain liquids. Liquids may be divided into three classes:—(1) Those that do not conduct at all, such as paraffin and many oils; (2) those that conduct without decomposition, such as mercury and other molten metals which conduct just as solid metals do; (3) those that are decomposed when they conduct current, such as dilute acids and solutions of metallic salts.

Water, when *absolutely pure*, is a non-conductor, but the slightest impurity causes it to conduct more or less, and it is for this reason that sea water is generally classed as a conductor. When an electric current is passed through water that has been rendered conductive by the addition of some other substance, the water is decomposed into two gases, hydrogen and oxygen, the oxygen appearing where the current enters the liquid, and the hydrogen at the point where the current leaves.

This process is called "electrolysis," and the liquid that is subjected to it is called the "electrolyte." The conductor by which the current enters the liquid is called the "anode," and that by which it leaves is called the "cathode." It is found that whenever hydrogen is one of the substances liberated when a liquid is electrolysed, it is given off at the cathode; and that any metal precipitated from a liquid by electrolysis is also deposited on the cathode.

Physiological Effects of the Electric Current.

Currents of electricity passed through the limbs affect the nerves with certain painful sensations, and cause the muscle to undergo involuntary contractions. The violence of these unpleasant sensations, or "electric shocks," as they are called, depends on the amount of current that passes through the system, and this, of course, depends partly on the E.M.F. that produces it, and partly on the electrical resistance of the body. The resistance of the human body depends mainly on the dryness or otherwise of the skin. It may vary from 60,000 ohms when the skin is dry to less than 300 ohms if it is quite moist. A current of ·02 of an ampere causes terrible muscular contraction, while two amperes traversing any vital part of the body is almost certain to be fatal. The effect of the current is twofold; in the first place it acts on the nerves, causing spasms, and contracting the muscles, and secondly it destroys the tissue either by burning or electrolysis, the blood becoming coagulated. To restore a person who has been rendered insensible by an electric shock the same restoratives should be used as for a person drowned. It is most important to remember, that when the skin is wet, and so in a condition to make a good electrical contact, it may be dangerous to take a shock even from so low a voltage as 100 volts, and consequently, when dealing with electrical machinery, the hands should be kept as dry as possible.

Power of an Electric Current.

The power of an electric current to perform useful work, whether in lighting, heating, or producing mechanical movement, is proportional both to the strength of the current and to the E.M.F. that drives it.

In other words, it is proportional to the amperes and volts jointly. In the same way, the power of a steam-engine is proportional, not only to the amount of steam that it uses, but also to the pressure at which the steam is supplied.

The unit of electrical power will therefore be the power exerted by a current of one ampere driven by an E.M.F. of one volt. This unit is called the *watt*, and 746 watts are equal to one horse-power.

The power of any electric current then, measured in watts, is equal to the number of amperes multiplied by the number of volts.

A current of one ampere driven by 10 volts is exerting power at the rate of 10 watts, and a current of 10 amperes driven by one volt is also exerting power at the rate of 10 watts. If the work we want done requires a certain amount of power, it may be convenient to get that power by means of a small current and a high voltage, or *vice versâ*, depending on what sources of supply are available.

The watt, being $\frac{1}{746}$ of a horse-power, is too small a unit for the practical purposes of naming the power of dynamos, &c., so the "*kilowatt*," which is equal to 1,000 watts, is more generally used. For instance, a dynamo capable of supplying a current of 400 amperes with an available E.M.F. of 100 volts is said to be a "40 kilowatt" machine. The kilowatt is about $1\frac{1}{3}$ horse-power.

Connection between Power and Heating Effect.—Suppose we have a wire of resistance R, to whose ends an E.M.F. E is applied. The current C in the wire will be given by Ohm's Law, $C = \frac{E}{R}$. Now if this wire and its surroundings are stationary, the only work that is being done by the current will be the heating of the wire. Now the power of the current, as we have said above, is $E \times C$ watts. But E, in this case, is equal to $C \times R$, by Ohm's Law.

Therefore the power $= C \times C \times R$, or as it may be written C^2R.

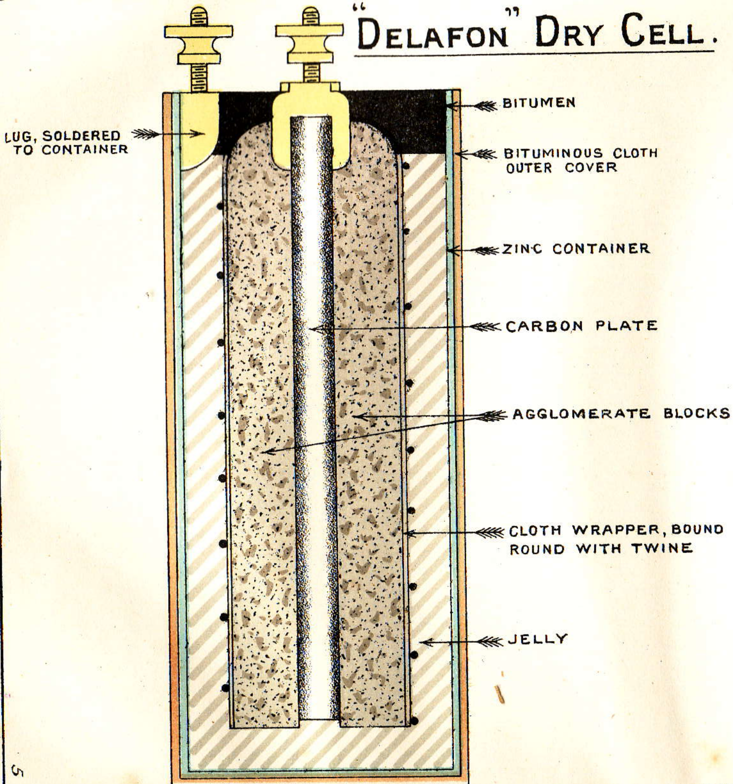
This is the power that is being used in heating the wire, and this will be recognised as the formula that was given when the heating effect of the electric current was being discussed.

The case of the power of an electric current that is doing mechanical work besides heating the wires will be discussed later on, in the chapter on "Motors."

To face page 71.

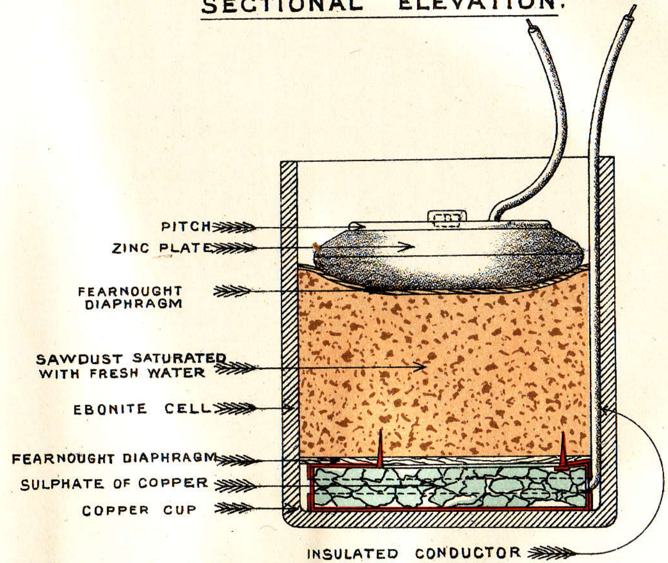
Plate I.

"Delafon" Dry Cell.



Menotti-Daniel Cell.

Sectional Elevation.



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CHAPTER IV.

PRIMARY BATTERIES.

PRIMARY batteries, as distinguished from secondary batteries which will be dealt with later, are those voltaic cells which are used as a primary source of electric current. They are used in the Service for the following purposes:—Testing, and making electrical measurements, firing guns and torpedoes, and working telephones. In later ships the many isolated small batteries for these two last named purposes are being replaced by a central source of power in the shape of a small motor-driven dynamo, but various primary batteries still exist in the Service, and will be described in turn.

Test Batteries.

There are two forms of test battery in common use in H.M. Navy, viz.:—(1) The single-cell Menotti test battery; (2) The 6-cell test battery.

The Menotti cell is a variation of the Daniell cell. As it is used for testing, and has to be portable, the liquids are held in absorbent material, namely sawdust, to prevent them spilling. This sawdust has a very high resistance, but this is no disadvantage as will be pointed out later.

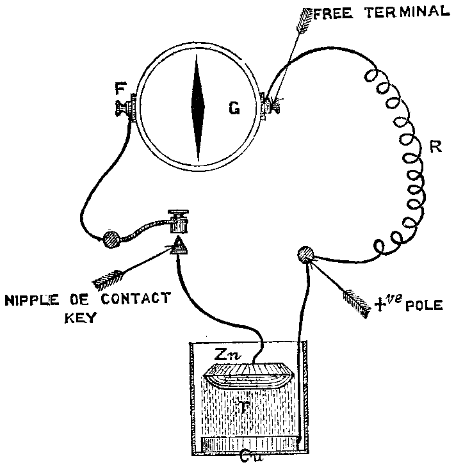
Menotti-Daniell.—Plate I. shows a section of a Menotti cell.

The positive plate consists of a copper cup, containing crystals of copper sulphate, which is placed at the bottom of an ebonite container, and has a lead of insulated wire soldered to it, and passing up through the cell. Over the copper cup is a fearnought diaphragm, and over this a layer of sawdust about three inches thick. On top of this is another fearnought diaphragm, and on this is laid a slab of zinc, which forms the negative plate.

The exciting liquid is ordinary fresh water held in suspension in sawdust. The sulphate of copper is put in the cell in the form of crystals, some of which dissolve and are kept in solution on the under side of the lower diaphragm. The action is as follows:— The Zn is attacked by the water H_2O, forming ZnO, and the H released travels through the lower diaphragm and attacks the $CuSO_4$, forming H_2SO_4 and depositing Cu. The ZnO is insoluble in water, and were it not for the fact of sulphuric acid H_2SO_4 being formed, it would stick to and insulate the zinc plate; however, as the action continues, the H_2SO_4 that is made creeps up through the sawdust, and in reality the cell is formed of dilute acid instead of water. This keeps the zinc plate clean (since H_2SO_4 dissolves ZnO) and also slightly reduces the internal resistance.

Single-Cell Test Battery.—The single-cell Menotti test battery consists of a cell with a galvanometer and contact key permanently in circuit. Fig. 48 shows a diagrammatic view of the connections.

FIG. 48.



It will be seen that the zinc or negative pole is joined to the nipple of the contact key, the bar of the key to one terminal of the galvanometer, the other terminal being left free for the circuit that is to be tested to be joined up to. The copper cup is joined to a terminal called the $+^{ve}$ pole.

The zinc in a Menotti cell is not amalgamated. When the cell is built it is placed on short circuit; the result of this is that firstly zinc oxide is formed, and then sulphuric acid, which in its turn produces zinc sulphate ($ZnSO_4$).

If a conductor R is joined to the two latter terminals when the key is pressed the current will passed from the positive pole through the conductor R, through the galvanometer deflecting the needle, through the contact key to the nipple, and thence to the zinc.

To fire a fuse a certain amount of current is required; this is approximately $\frac{1}{3}$ of an ampere. Now it is absolutely essential that a test battery, even if joined up wrongly, should never be able to give enough current to fire such a fuse. A large internal resistance is therefore arranged for in the cell by using three inches of damp sawdust as the excitant. The sawdust breaks up the continuity of the liquid, interposing small fragments of wood which is a non-conductor, and so considerably reduces the conductivity between the two plates. The internal resistance of such a cell is about 30 ohms, and the total D.P. 1 volt, so that the largest current that could possibly be obtained by joining the $+^{ve}$ pole and F would be

$$C = \frac{1}{30} \text{ ampere.}$$

In addition to this the galvanometer has a resistance of 20 ohms, so that when joined up properly the largest current that could be obtained would be

$$C = \frac{1}{30 + 20} = \frac{1}{50} \text{ ampere.}$$

This particular form of galvanometer should detect a current flowing through an external resistance of between 2,000 or 3,000 ohms, if the cell is in good condition.

6-Cell Test Battery.—The 6-cell test battery is used when testing insulation for very small leaks. By a suitable form of commutator any number of cells up to six can be put into circuit in series. With a very large external resistance the current obtained through an external resistance R, and therefore through the galvanometer, will be

"With one cell $C = \dfrac{E}{R + r + G} = \dfrac{1}{R + 30 + 1000}$.

With six cells $C = \dfrac{6\,E}{R + 6\,r + G} = \dfrac{6}{R + 6 \times 30 + 1000}$

or very nearly six times the current will be obtained by using the six cells in series. The maximum current, however, that can be obtained from the 6-cell test battery is only $\frac{6}{1180}$, or less than one-third of that from a single-cell test battery."

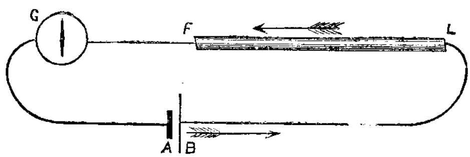
Again, the galvanometer used with this form of battery is far more sensitive, and will detect far smaller currents flowing through it. So the whole arrangement is one well suited to test for high insulation, that is, for very small leakage.

The cells used in the 6-cell test batteries are exactly the same as the single-cell Menotti as to their internal construction, but they are rectangular in shape, instead of cylindrical, and somewhat smaller.

Use of the Test Batteries.

Test for Continuity.—The principle of *testing* is to join a battery of some convenient form with a galvanometer in circuit,

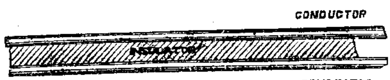
Fig. 49.



to the two ends of the circuit to be tested. If the circuit be a conductor it is called testing for continuity (Fig. 49), where the battery A B is joined in series with the galvanometer G and the conductor F L. If the circuit is complete, that is, if there is no break anywhere, a current will flow through the circuit deflecting the needle of G, and showing thereby that there is *continuity* in the whole circuit. If, on the other hand, there is a break in the circuit, evidence of the fact is at once obtained from the failure of the galvanometer needle to swing on the key being depressed.

Test for Non-contact.—The other use of a test battery is to test the insulating properties of the insulator. There are two cases in this class of testing. One when two conductors run side by side with an insulator between them (Fig. 50); when the two

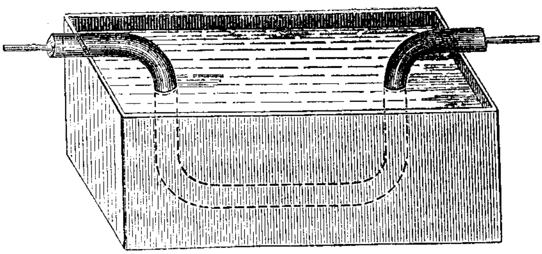
FIG. 50.



wires of the test battery are joined one to each conductor, no current should flow in the circuit since the circuit should be broken by the insulator, and therefore the needle should not deflect. If, however, there is bad insulation there will be a road for the current to pass from one conductor to the other, and the needle will deflect. This is called testing for *non-contact* between the two wires. The test for insulation is exactly the same as the previous case except that the water takes the place of one of the conductors.

Test for Insulation.—Fig. 51 shows a conductor surrounded by an insulator and the insulation surrounded with water; the

FIG. 51.



portion to be tested is the insulator, to see that no current can pass through it. As before, one wire is joined to each conductor, that is, one to the copper conductor, the other to the water, by means of a large plate called an earth plate; and no current should pass. If there is a leak whereby the water can creep through the insulator and touch the copper, a circuit will be established and a current will pass through the galvanometer. In the above example (which refers more especially to cables under water), water is taken as the conducting medium to which the current in the wire may leak, if its insulation is bad. It is *not the only medium* however; for example, the electric light circuit in a ship, are tested for insulation from the iron of the ship. Details as to the routine of testing will be found in the drill book.

Nearly all the other cells in use in the Service are Leclanché cells of some sort, and they only differ from one another in the details of their manufacture.

The Leclanché is a zinc and carbon cell, the carbon being the positive pole and the zinc the negative, and the exciting liquid is a saturated solution of sal-ammoniac in water. In this the zinc dissolves, forming chloride of zinc, while the ammonia gas and hydrogen are liberated at the carbon plate. The depolariser is peroxide of manganese, fragments of which are formed into an "agglomerate block" with powdered carbon, and these blocks are attached to the carbon plate.

The function of the peroxide of manganese is to provide oxygen, with which the liberated hydrogen can combine; this forms water, and tends gradually to weaken the solution. This is counterbalanced by putting more powdered sal-ammoniac in the cell than the liquid can take up; this will not be dissolved at first, because the solution has already dissolved as much as it can; as fast as water is formed in the cell it dissolves some of this powdered sal-ammoniac, thereby keeping the liquid always saturated.

The chemical action of the Leclanché cell may be described as follows, using symbols as before:—

Sal-ammoniac = (H_4NCl), also called ammonic chloride.

Peroxide of manganese = (MnO_2) also called manganic dioxide.

One atom of zinc combines with two atoms of chlorine and forms chloride of zinc = ($ZnCl_2$).

The corresponding two molecules of H_4N, or ammonium, break up into two molecules of (H_3N), or ammoniacal gas, and two atoms of hydrogen.

These latter take one atom of oxygen from two molecules of peroxide of manganese, forming water, and converting them into two molecules of (Mn_2O_3), which is called sesqui-oxide of manganese.

The equation will be: $(Zn) + 2\,(NH_4Cl) + 2\,(MnO_2) = (ZnCl_2) + 2\,(NH_3) + (H_2O) + (Mn_2O_3)$.

The final result therefore is:—The zinc, as in all batteries, is consumed, ammoniacal gas is given off, water is formed, which is prevented from weakening the solution by dissolving fresh crystals of sal-ammoniac, and the peroxide of manganese is used up by being converted into sesqui-oxide. Fresh solution of crystals of sal-ammoniac can be added to the cell at any time to make up for waste, but when the peroxide of manganese is used up the whole battery must be taken to pieces and re-packed.

The peroxide of manganese being in the form of a solid, gives up its oxygen only slowly to the hydrogen, so that if put on short-circuit the battery acts almost as a simple cell, and becomes quickly polarised. Under these circumstances also, other salts, called oxychloride of zinc and zinc-ammonic chloride, are formed on the surface of the zinc; these are not soluble in the liquid, and therefore tend to insulate the zinc plate. The carbon also has the property of absorbing and retaining a considerable quantity of hydrogen, so that if the battery is put on short-circuit for a considerable time there is not only a great waste of its materials, but it takes a long time to recover, and probably never regains its full strength.

This cell cannot, therefore, be called constant, but if properly used, and only for the purpose for which it was intended, it will last a long time with no appreciable fall in D.P.

The E.M.F. of a Leclanché cell is about 1·5 volts, and the internal resistance varies in different patterns.

Cells Patt. 1453.—Each cell is built up of an ebonite container, in which are the zinc element and the carbon element, surrounded by six agglomerate blocks, in a solution of sal-ammoniac (*see* Plate II.). The zinc element is rectangular in shape and rests on three strips of vulcanised india-rubber, cemented across the bottom of the container. It is made of the purest commercial rolled sheet zinc well amalgamated with re-distilled mercury, and has a projecting strip to which a terminal is attached. The carbon element is made of gas retort carbon. Three holes are drilled through the top of this plate, and the top is well soaked in paraffin wax; a brass screw is then secured through one of these holes by two nuts, the long end of the screw projects on the side away from the zinc strip, and is fitted to form the terminal of the carbon plate. Finally, a lead cap is cast on to the top of the carbon element. The agglomerate blocks are made as previously described; they each have a recessed side which is placed next the carbon plate, three of the blocks being on each side of it and secured by means of two vulcanised india-rubber bands. When built up, with three ounces of dry sal-ammoniac in place, the upper part of the cell is covered in with a sealing composition made of two parts of bitumen to one part of plaster of Paris; two holes being left in this covering, one to act as a vent tube for the escape of gas, and fitted with a cane plug; and the other made large enough to permit the cell being charged with solution, and supplied with a cork. The whole of the lead cap or bridge of the carbon plate is completely above the sealing, to prevent as much as possible the "creeping" of the sal-ammoniac, which was formerly a frequent cause of high resistance between the carbon plate and lead bridge. Connected to the terminal on the zinc plate is a short piece of insulated wire; this replaces the copper strip which was soldered to the zinc plate in the older pattern cells.

Preparation.—The cells are prepared for service by pouring in about a pint of a saturated solution of sal-ammoniac. The

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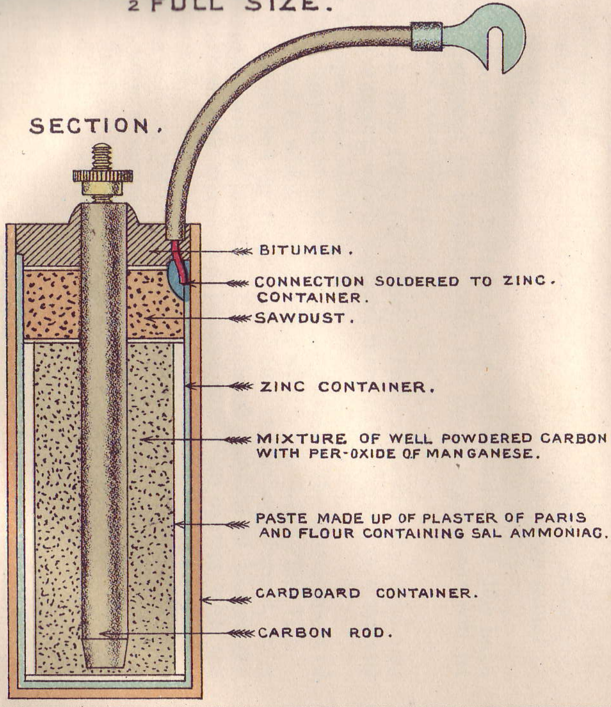
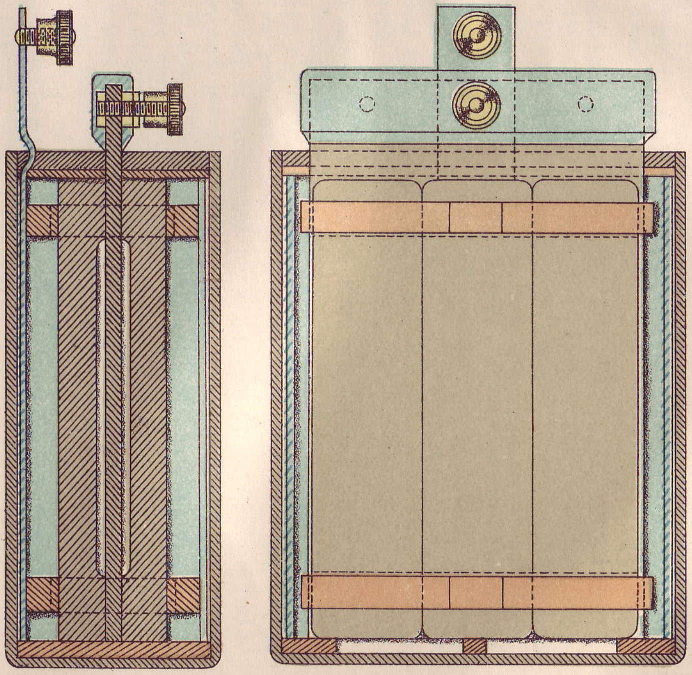
OBACH CELL. Q. TYPE.

½ FULL SIZE.



PATT, 1453. CELL.

SCALE 3/8.



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liquid should not be less than three inches from the top of the cell. Their internal resistance is about ·2 of an ohm.

Leclanché Cell Patt. 1451.—A smaller type of Leclanché, called Patt. 1451, differs from the above in the following points only. The plates are much smaller, and there are only four agglomerate blocks, two placed each side of the carbon plate, which is then bound round with canvas wrapping, and the whole secured together by two india-rubber bands. Their internal resistance is about ·25 of an ohm. No more Patt. 1451 cells are being manufactured, but the existing stock will be used until exhausted.

Transport Cells.—These cells are smaller than the Patt. 1453, being $4\frac{11}{16}$ inches high, exclusive of terminals, and each side $1\frac{15}{16}$ inches wide. The container is of zinc, and forms the negative pole, and the positive pole is a carbon rod. The carbon rod is surrounded by a mixture of peroxide of manganese, and powdered carbon contained in a cylindrical canvas bag. Before charging there is an air space between the zinc container and the canvas bag. The charging hole, which is fitted with a watertight screw cap, communicates with this space by a rubber tube. On top of the canvas bag is a rubber cap which fits watertight round the carbon rod, rubber tube, and the sides of the cell. The top of the cell is closed in by pitch, and the space between this and the rubber cap is ventilated by two fine glass tubes passing through the pitch. Outside the zinc there is a casing of waterproofed cardboard.

These cells are stored empty, and when they are required for use, they are filled in the same manner as the Patt. 1453, with a saturated solution of sal-ammoniac. Their internal resistance, when in good order, is about ·25 of an ohm. They are manufactured by Messrs. Siemens.

No more of these cells are being manufactured, as they have been superseded by Delafon cells, but the existing stock will be issued until exhausted.

Obach Dry Cells (*Q Type*).—These cells are the same size as the Transport, which replaced them, but a larger size, known as the M type, used also to be supplied.

They consist of a zinc container forming the zinc element of the cell, and to which a connecting wire is attached (Plate II.).

A carbon rod in the centre forms the other element, it is surrounded with a mixture of powdered peroxide of manganese and carbon well mixed and pressed into close contact with the carbon rod.

The exciting paste is composed of plaster of Paris and flour mixed with sal-ammonic. In the upper part of the cell is a space filled with sawdust, this space is to hold the gases given off and to contain water. The top of the cell is sealed with bitumen.

It should be remembered that these cells are always active, and care should be taken to see that the wire joined to the zinc plate is prevented from touching the terminal. If this is allowed to occur, the cell will polarise in a few minutes.

No more of these cells are being purchased, as it has been found that they deteriorate after being stored for some time in hot climates, but the existing stock will be exhausted.

Their internal resistance is about ·2 of an ohm when in good condition.

Delafon Cells.—These cells, Plate I., are the same size as the Transport cells, but different in their construction. Instead of being filled with liquid, the exciting substance is sal-ammoniac solution held in a sort of jelly, which is composed of some sort of vaseline mixed with a small amount of sawdust. They cannot be spilt, as there is no liquid, and also they are not adversely affected by high temperature. The usual effect of heat on a cell is to dry it up somewhat and so increase its internal resistance, but in the case of the Delafon, the internal resistance is lowered by heat, probably owing to the jelly being softened. The depolarisers are agglomerate blocks placed round the carbon rod, and secured to it by a cloth wrapper wound round with twine. The top is sealed with a layer of pitch, a small vent hole being left. No filling hole is required, as the cell is stored as supplied, ready for use. Their internal resistance is from ·16 to ·2 of an ohm.

Future Cells.—Any cells introduced into the Service in the future will probably be of the same dimensions as the transport cell.

Batteries.—Cells as used in the Service are generally made up into batteries, and these batteries are usually contained in boxes for the sake of convenience. Most of the battery boxes in the Service were originally designed for Patt. 1453 cells, but they have been adapted to take the latter patterns where necessary.

Patt. 1453 cells are used in batteries for various purposes as shown below:—

3-cell battery for firing guns and torpedoes.

6-cell battery for firing turret guns and submerged torpedo tubes.

10-cell battery for mining and general torpedo work.

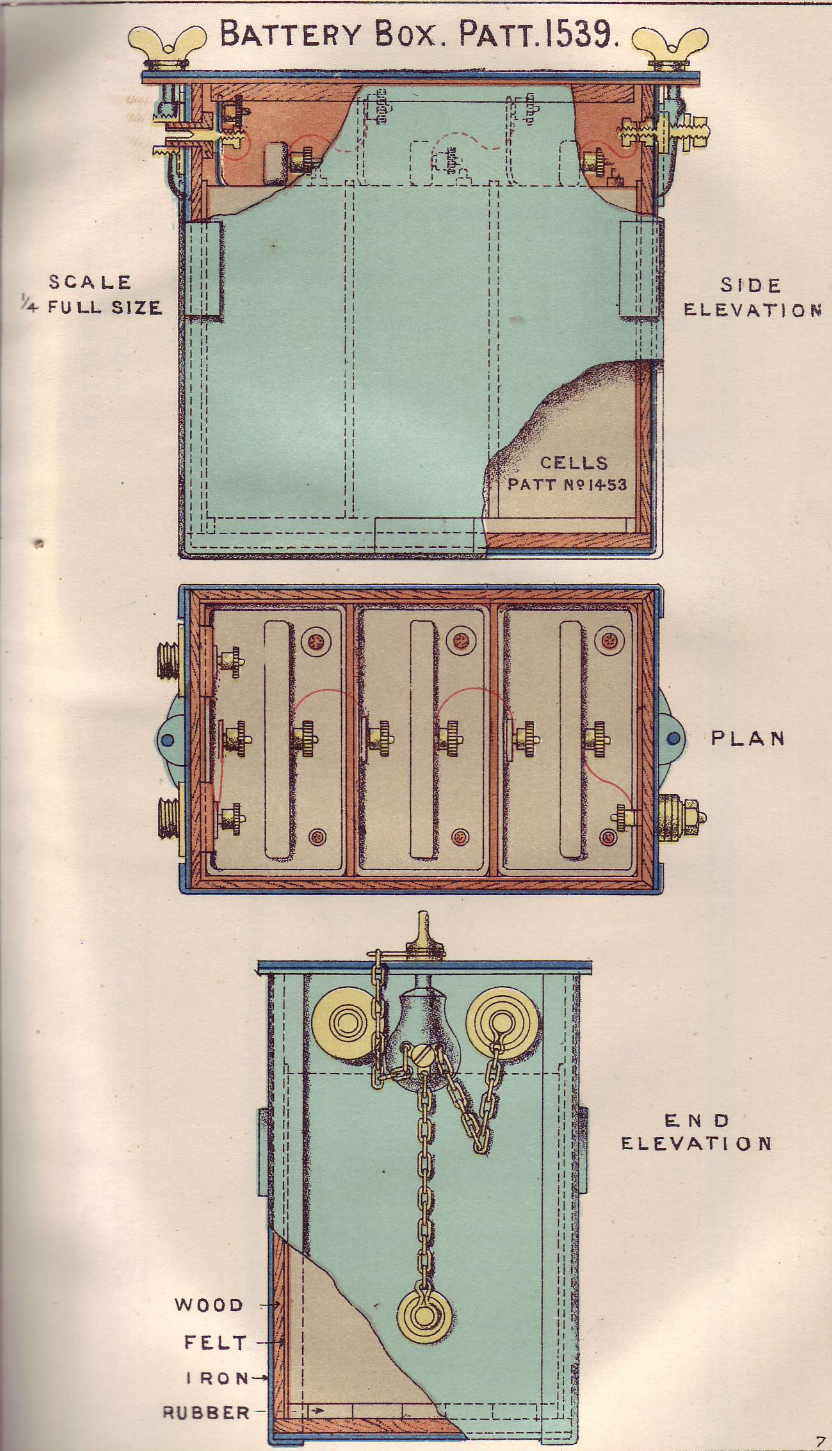
30-cell battery for alternative to dynamo firing.

The 3-cell batteries are contained in a steel water-tight box known as Patt. 1539, which is shown in Plate III. This battery box is used for all electrically-fired guns except turret guns, and for all electrically-fired torpedo tubes where the battery is carried on the tube.

The box has two terminals at one end which are connected to C contacts on the outside of the box, one for the gun circuit and the other for the night sight circuit, and at the other end it has a single terminal connected to a terminal on the outside for the earth connection. The cells in it are joined in series.

In some cases Delafon or Transport cells are used for firing batteries instead of Patt. 1453, the numbers being either

BATTERY BOX. PATT. 1539.



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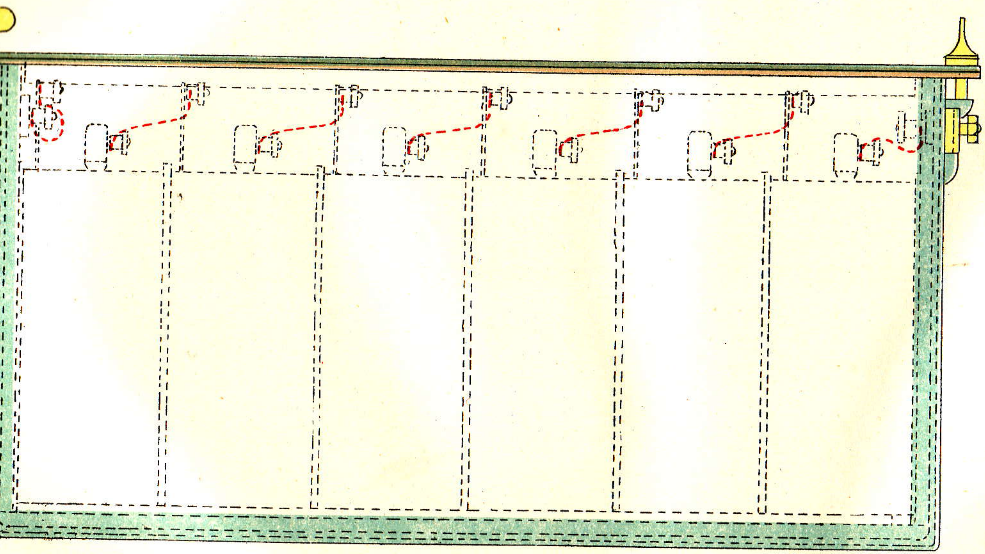
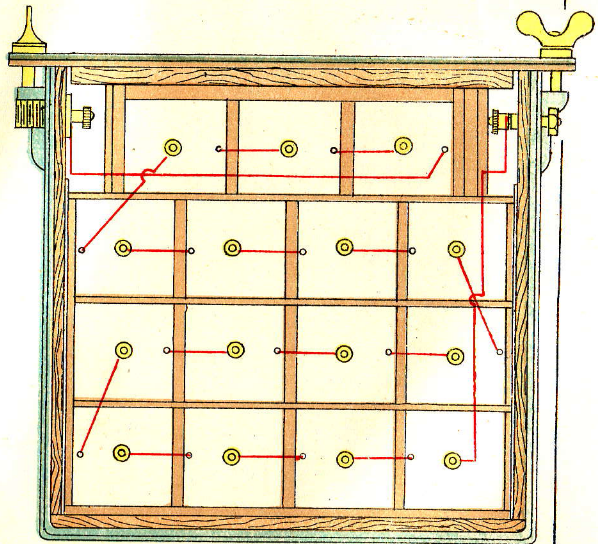
Battery Box. Patt. No. 1701.

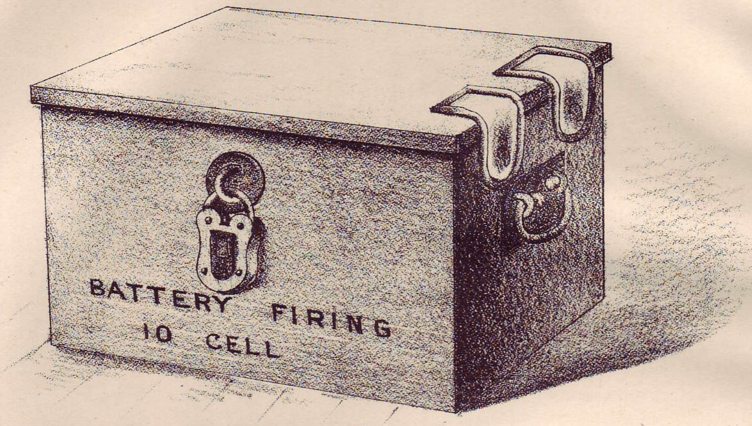


Battery Box. Patt. No. 1539 fitted with Delafon or Transport Cells.

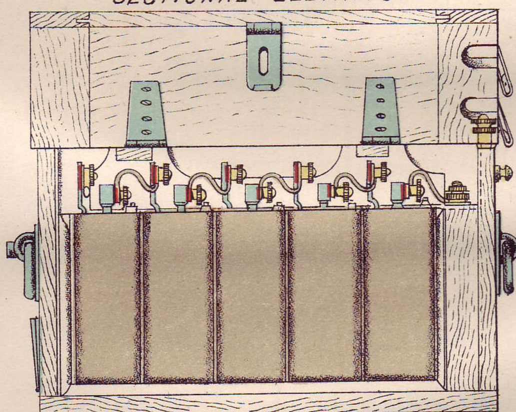


10 CELL BATTERY.

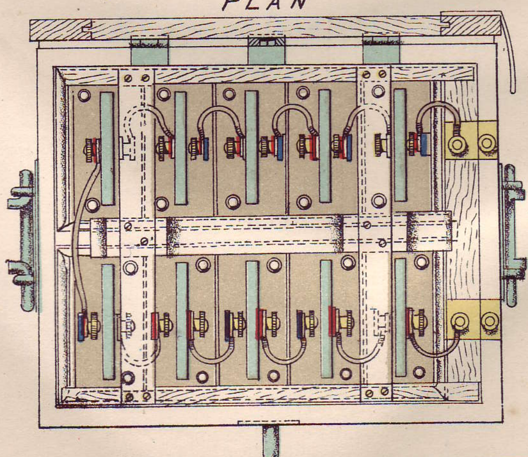
OUTSIDE ELEVATION.



SECTIONAL ELEVATION



PLAN



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15 Delafon or 12 Transport cells. They are stowed in a battery box, Patt. 1539, as shown in Plate IV., the upper row of three cells being left out when Transport cells are used. These batteries are also used for burning night sights, the 15-volt night sight lamp being fitted.

The 6-cell batteries are contained in watertight steel boxes which are very similar to the Patt. 1539. That for the 6-cell firing batteries is known as the Patt. 1701, and is similar in all respects to the Patt. 1539, except that it is of such a length as to take six cells instead of three. It is shown in Plate IV.

The box used for 6-cell batteries for working bells and telephones is Patt. 1704. It is the same size as the Patt. 1701, but differs from it in the following particulars. The lid instead of being removable and secured by two nuts, is hinged, and kept closed by four hinged butterflies, and instead of the terminals passing through the ends of the box, there is a watertight gland at each end for leading in the wires.

The 10-cell batteries for mining and general torpedo work are carried in the wooden box known as the Patt. 145, or 10-cell boat's battery, shown in Plate V. The cells are joined in series and the two poles of the battery joined to two terminals at the end of the box. Recesses are cut in the lid of the box to allow these terminals to be got at without opening the box, and two leather flaps are fitted which cover up these recesses and protect the terminals when the box is in use. Handles are fitted at the ends of the box to facilitate transport, and the lid is secured with a padlock.

The 30-cell battery is contained in a steel watertight box, fitted in very much the same way as the Patt. 1539, with the exception of the terminals. It is of such a size as to hold the 30 cells in three rows of ten cells each, and is known as Patt. 2275. The cells are joined ten in series and three in parallel, the positive pole of the battery being joined to a terminal inside the box at one end, which is in connection with the metal of the box, and so with earth, and the negative pole of the battery to an insulated terminal inside the box at the other. At this end is a watertight gland through which is led the lead of wire from the switchboard for the gun circuits.

In ships that are supplied with Patt. 1451 cells for telegraphy, the cells are contained in a wooden box, Patt. 1335, which contains ten cells, in two rows of five each.

In later ships, the telegraph instruments are supplied in a slightly larger box, which also contains the battery. The instruments are fixed to the front of the box, which opens outwards and lies flat, and the battery, which consists of 14 Transport or Delafon cells, is secured behind a partition at the lower part of the back of the box. As many cells are joined in series as are required for the telegraph line that is being used.

Care and Management of Firing Cells.

The Leclanché's cells, especially in the smaller types, are liable to failure from several causes, and require a great deal of care and attention. They are to be tested the first week in each month, and always before practice, and, at the same time that they are tested, they should be examined to see that the liquid is up to its proper height, that all connections are clean and screwed up, and that no liquid has been spilled or allowed to creep up to the upper part of the cell. All watertight battery boxes should be opened for at least half-an-hour every week, and always after use, so as to allow the gases generated by the cell to escape.

Should a cell at any time fail to fulfil its test, it should be examined to see if the connections are good, and the liquid the right height. If more liquid is required a saturated solution of sal-ammoniac should be added, a supply of this solution being always kept mixed in the store room for this purpose. The use of water for bringing up the level of the liquid uses up the reserve of sal-ammoniac supplied in the cell and weakens the liquid, but in the service cells, which are sealed up, it is frequently desirable to add fresh water only as the reserve of sal-ammonia is very large, and the cells are very tightly packed. If the cause of failure is not evident, the D.P. and Internal Resistance of the cell should be determined when time allows, a new cell being charged to replace the one defective.

Loss in D.P.:—

Cause may be—	Remedy is—
Too little liquid.	Add solution, or water.
Solution weak.	Add sal-ammoniac.
Polarisation.	Allow cell to stand for a few days, with its plugs out, and in fresh air.

Increase of I.R.:—

Cause may be—	Remedy is—
Insulation of lead bridge by chloride of lead.	Balance between terminal and carbon plate itself. If high, drive a brass rivet through lead bridge and carbon plate or cast on a new bridge. In the latter case, the carbon plate must be dipped in molten paraffin for one inch from the top before running on the bridge.
Too little solution.	Add more.

If the cell still remains weak it must be opened and treated as described in Torpedo Drill book, page 30, marine glue being supplied for the purpose of re-sealing.

If none of these remedies restore the cell it shows that the agglomerate blocks are worn out, and the cell should be condemned.

A Leclanché cell must never be left on short-circuit, or run through a resistance of less than 1,000 ohms, as otherwise it quickly becomes polarised. Hence, Mance's method described on p. 385, is not applicable where the exact internal resistance of a Leclanché cell is required, but by unplugging 1,000 ohms in each arm a rough balance can be obtained without much risk to the cell. Should a cell be stripped at any time, particular care must be taken to replace the agglomerate blocks with their recessed sides next to the carbon plates, as it is found that by not doing so the efficiency and endurance of the cell is much impaired.

CHAPTER V.

Measuring Instruments.

Galvanometers.

20-ohm Galvanometer.—The 20-ohm galvanometer is the instrument used with the single-cell Menotti test battery. It is an example of the single form of galvanometer first described in Chapter II., and is shown in Plate VI.

It consists essentially of two coils of fine wire wound on bobbins and placed parallel to one another. Between the coils, and free to swing in a horizontal plane through the centre of the bobbins, a magnetic needle is pivoted, with an ivory needle painted black, fixed to the same pivot, but revolving above the face plate to act as an indicator of the position of the lower or magnetised needle. One jewelled pivot hole is on a bridge across the lower part of the two coils, the other in a bridge stretching across the whole width of the dial. The coils are joined in series, and their free ends permanently connected to the insides of two terminal connections, which are insulated from the brass case with ebonite. The face is marked in degrees from 0° to 90° in each quadrant; these marks are merely as guides to measure the deflection of the needle from zero.

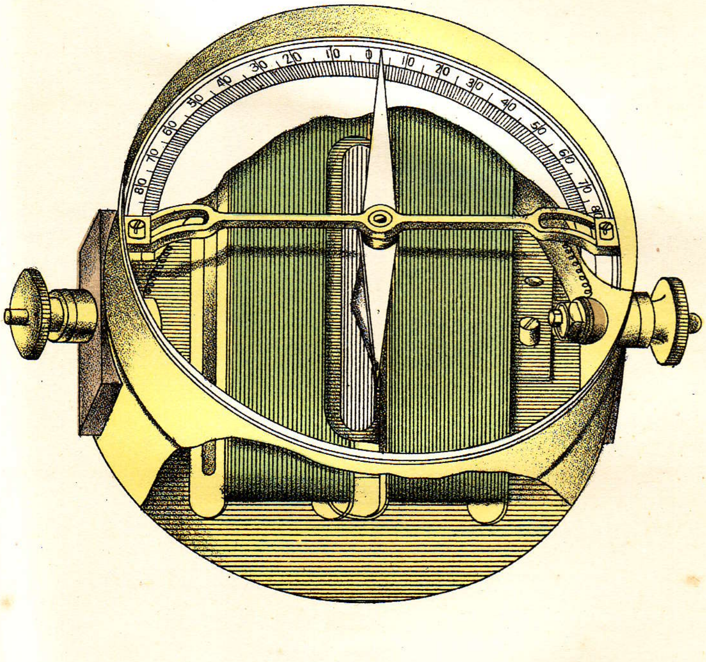
This form of galvanometer is used to *detect* currents only, not to *measure* them.

The following precautions should be observed in using it:—Always start with the upper needle pointing to zero; never have a larger D.P. than 1 volt between the terminals, as otherwise the coils and pivots will be injured. Should the spindle be jarred out of the pivot holes, it may be replaced by removing the glass front, raising the securing screws of the top bridge, and replacing the pivots; but great care should be taken to bring no pressure on the fine pivots in replacing.

1,000-ohm Galvanometer, Pattern 934.—This instrument is used with the older forms of six-cell test battery and Wheatstone's bridge. It differs from the 20-ohm galvanometer in having an "astatic pair" of needles, as described in Chapter II., and is consequently very much more sensitive. It is also made more sensitive to small currents by the large number of coils of wire on the bobbins. In appearance it is almost exactly like the 20-ohm instrument.

1,000-ohm Galvanometer, Pattern 1499.—This galvanometer (Plate VII.) is of the latest Post Office pattern, and will replace Patt. 934. It has a coil of 1,000 ohms resistance, a very light single needle with a locking arrangement and a mirror to prevent parallax error.

20 Ohm Galvanometer.



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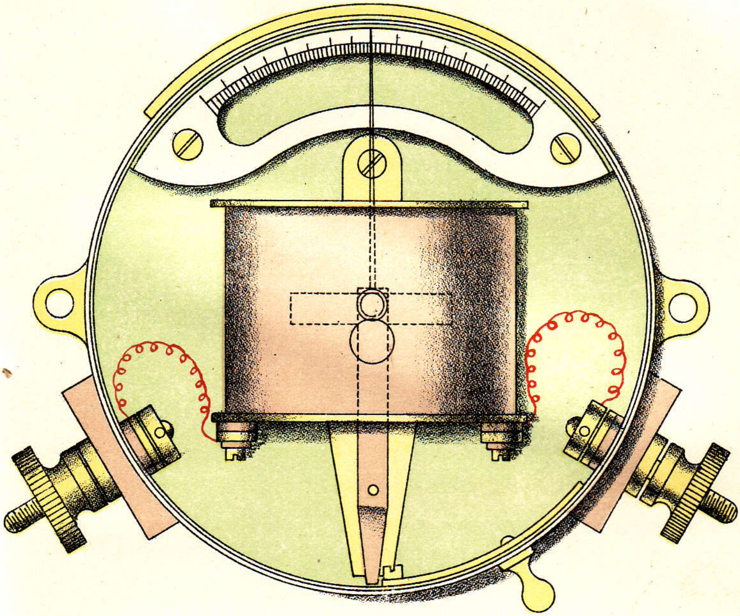
1000 Ohm Galvanometer. Patt. No. 1499.

Plan

¾ Full Size.

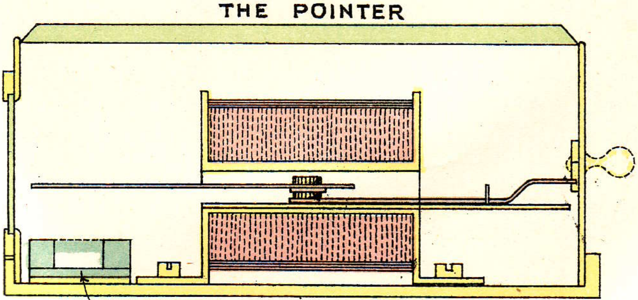
A



B

Section thro' A.B.

Showing arrangement for locking the pointer



Mirror

Magnet for use with the galvanometer.

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SULLIVAN'S UNIVERSAL MARINE GALVANOMETER.

$\frac{1}{3}$ FULL SIZE

FIG. 1.

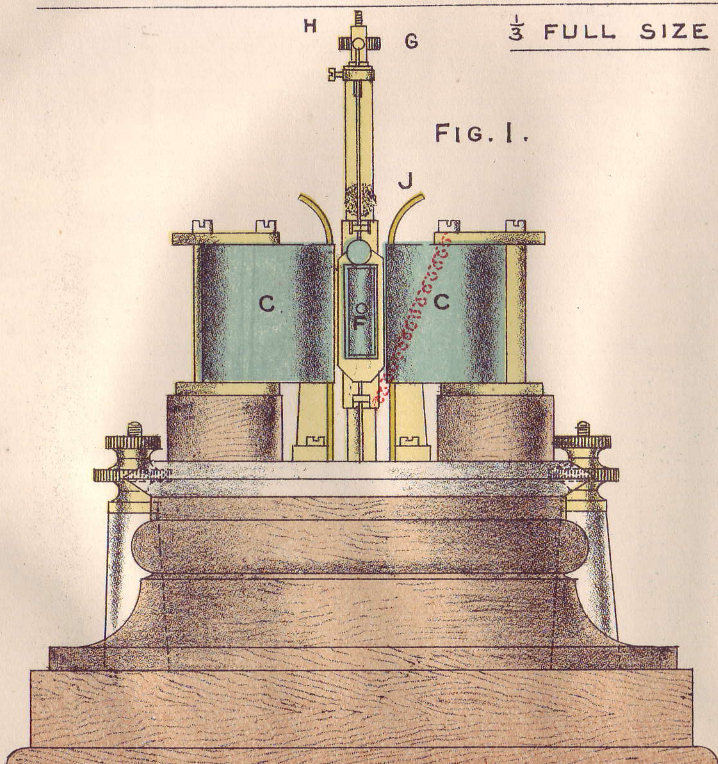
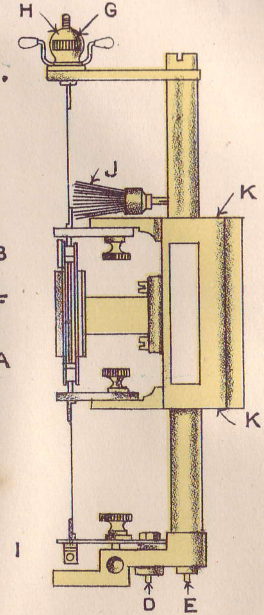


FIG. 2.



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It is used with the later forms of six-cell test battery and dial bridge.

The terminals are placed 120° apart.

When balancing or testing with this galvanometer, the magnet supplied with it should be laid across the face of the glass, and moved so as to bring the needle to zero.

Sullivan's Galvanometer.

This instrument (Plate VIII.) is supplied for making very delicate electrical measurements, and also for submarine telegraphy. It is of the suspended coil type described in Chapter II.

The general principle is as follows :—An open coil of very fine wire is wound on a light rectangular frame, and the current led to and from the coil by its suspending wires. This coil is hung close to and immediately between the two poles of a strong permanent magnet. Inside the coil, and clear of it, is a soft iron core which serves to concentrate the magnetic field; so that the vertical parts of the coil are hanging free in two gaps, where the magnetic field is very dense.

On a current being sent through the coil, the force tending to turn it will be proportional to—

(i) Number of windings on the coil;
(ii) Intensity of field;
(iii) Current.

Since the two former are constant, the deflections should be absolutely proportional to the currents.

The elasticity of the suspending wires controls the position of the coil and tends to bring it back to its original position.

A reflecting mirror is attached to the coil.

This instrument is not only remarkably "dead beat," but it is independent of the earth's magnetic field, and is not affected by magnets in their neighbourhood. There is, however, a limit to its resistance, which is governed practically by the amount of fine wire that can be wound on the coil.

The galvanometer is shown in Plate VIII. It consists of a fixed permanent magnet C, of circular form, between the poles of which is suspended the moving coil A, which is wound on an aluminium sheath and carries the mirror B; the two ends of the coil are connected to the suspending wires, which are of flat phosphor bronze ribbon; the upper suspending wire is connected to the suspension frame and platinised stud E, the lower wire is soldered to the lower torsion head I, and the circuit led through the spring to the insulated contact stud D.

A core of soft iron F is fixed to the suspension frame, and the coil moves freely round it, without contact.

The upper suspending wire is tautened by the mill-headed screw G, and torsion removed from the wires by the plain nut H, to which is attached an ebonite handle.

J is a camel's hair brush, which, if advanced so as to embrace the suspending wire, *damps* the throw of the coil, and reduces the deflections on the scale; its principal use is to reduce the deflection and sharpen the signals when the galvanometer is joined up as a telegraph receiver.

The complete suspension frame can be removed by raising it off a brass spindle, which fits into a guide in its back at K (Fig. II.); when the frame is replaced the studs D and E make contact on two springs, each of which is connected to one of the two galvanometer terminals. The resistance of the coil is marked inside the box, and is generally about 1,500 ohms. In order to prevent any electrostatic effect when testing with high voltages, one side of the moving coil is connected by a short lead of wire to the steel body of the magnet, &c. The whole instrument is mounted on a slab of ebonite to prevent any leakage to earth. In the latest instruments small ivory screw-studs are provided on the lower part of the frames, so as to allow of their being accurately centred in the magnet gap.

Three slides are supplied with each galvanometer, two for balancing and one for submarine telegraphy.

The two slides marked "Testing" are for ordinary testing work, the suspension strip is ·001 inch thick, and ·015 inch wide.

The slide marked "Mirror speaking" differs from the others in having two camel's hair brushes, the suspension strip is ·002 inch thick and ·043 inch wide, and the aluminium frame is cut through at its upper end, and bridged by a fine platinum wire. The frame is cut in order to reduce the electro-magnetic damping effect, and thereby increase the speed of the swing of the coil when signalling.

In addition to these three slides, torpedo depôts and torpedo schools have a special slide for practising, marked "Practice," submarine telegraphy. In this case the suspension strip is ·001 inch thick and ·007 inch wide, and only one camel's hair brush is used, the frame is made of an alloy of lower resistance, and is not cut through. Cable depôts are supplied with a "highly sensitive" slide for measuring the insulation resistance of cables which may be out of the range of the ordinary slide.

It is marked for shore use.

The lower suspension wire is done away with, and a light spiral connection used instead. When using this slide the galvanometer must be perfectly level, and should if possible be mounted on a solid foundation.

A speaking shunt, reversing key (Cottrell's pattern) and reversing double plug (Plate IX.) are also supplied with the galvanometer for Submarine Telegraphy.

General Instructions for Mounting, Balancing, and Resuspending Sullivan's Universal Galvanometer.

1. Hold the suspension frame horizontally in the hand, and *very slowly and very carefully* tighten the suspension by turning the milled-headed nut in the upper torsion head until the coil does

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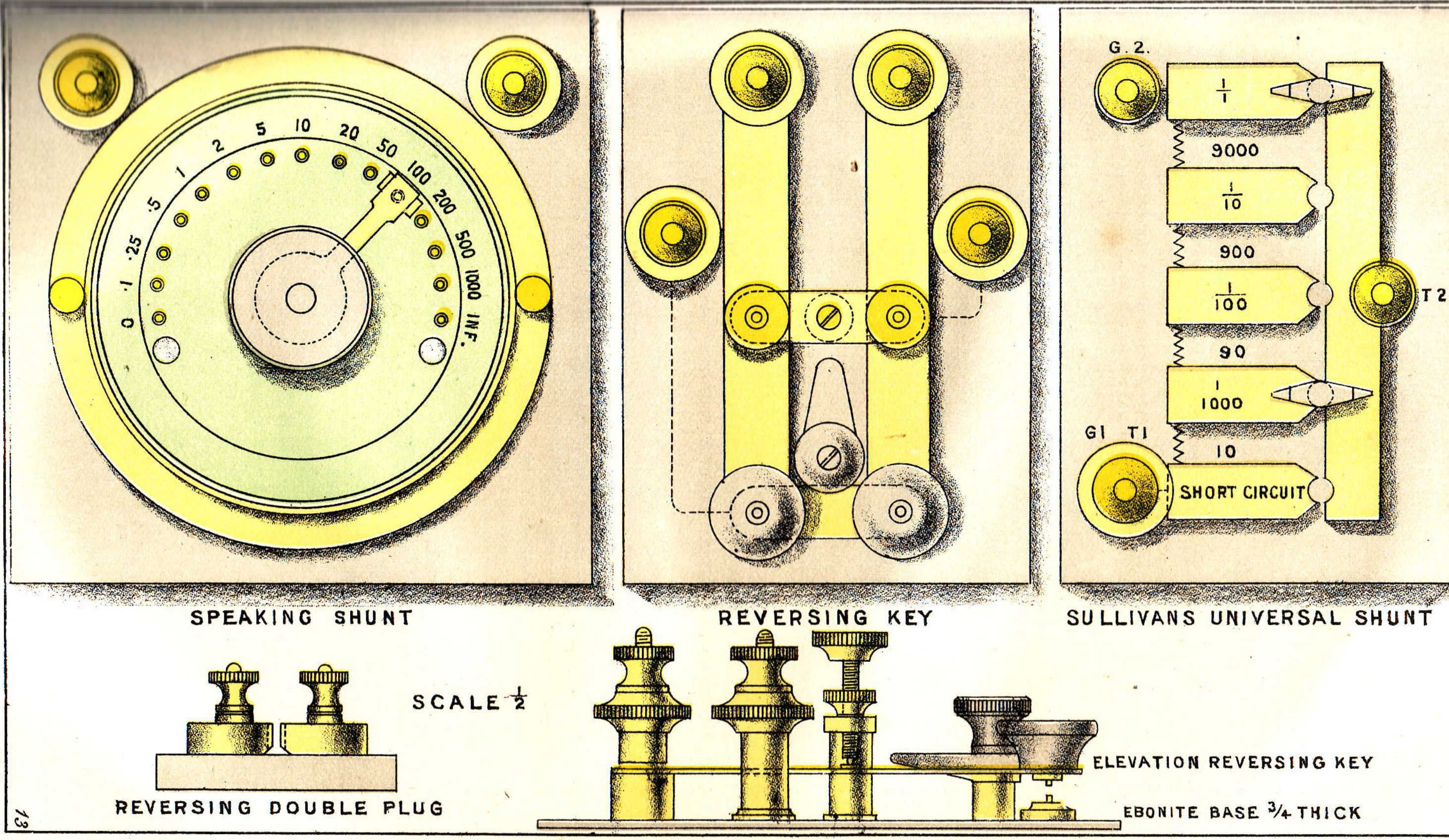

SPEAKING SHUNT

REVERSING KEY

SULLIVANS UNIVERSAL SHUNT

REVERSING DOUBLE PLUG

Plate IX.

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not sag perceptibly downward, as judged by the position of the rigid rods in the adjustable ebonite eyelets through which they pass.

2. Remove any twist from the suspension wires by means of the lever in the top torsion head, and insert the frame in the instrument.

3. The two brass guide plates screwed on to the magnet are so adjusted that the coil has no lateral play, and it hangs centrally and perpendicularly in the gap. *See also* that the coil is equidistant all round from the soft iron core. These adjustments may be assisted by very slightly *forcing* the suspension arms to right or left. In later pattern instruments the coil can be centralised by means of the small ivory screws in the lower suspension arm.

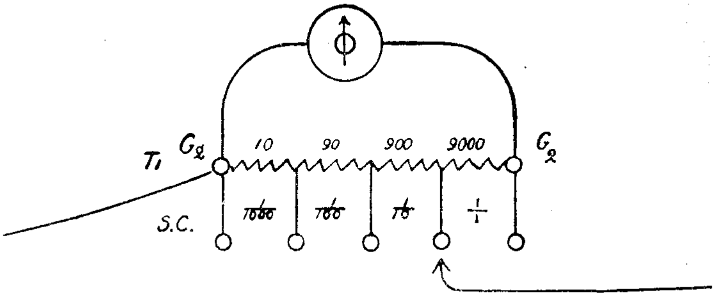
4. Set up the scale, taking care that it is at the *exact focal distance* from the mirror, which will be found recorded in the box. Light the lamp, place it behind the scale, and move it until the light falls through the slot on to the mirror; or an 80-volt lamp may be used. If the spot of light reflected from the mirror is not now visible on the scale it may be caught on a piece of paper at one side, above, or below the scale, by lowering or raising the latter and turning the lever fixed to the upper torsion head. The spot should then be brought accurately to zero on the scale.

5. The "*constant*" of each galvanometer is recorded on a label in the box. It is the degree of sensitiveness possessed by that particular instrument; that is to say, it is the amount of current required to produce a deflection of one division on the scale with the latter at correct focal distance from the mirror. As this amount of current is very small (generally less than a millionth part of an ampere), it is difficult to verify it on board ship, owing to the absence of a sufficiently high resistance. For this reason in measuring the insulation resistance of a cable by the method described in Chapter XXII., we *compare* the unknown resistance with a known resistance of 12,000 ohms.

Galvanometer Shunts.—In case the current that it is necessary to have flowing in the circuit for testing is greater than the current that can with safety be allowed to flow through the galvanometer, a "shunt" or alternative path for the current must be provided. In the case of the Sullivan's galvanometer, this takes the form of a "Sullivan's Universal Shunt Box," which is shown in Plate IX. The figures between the blocks represent the resistance in ohms of the coils that are joined between the blocks. The galvanometer is joined up to the two terminals marked G_1 and G_2, and the other part of the circuit between the terminals marked T_1 and T_2. Two plugs are shown, that can be put into any of the holes provided for them, but only one of them is used as a rule. The circuit of a galvanometer joined up to a universal shunt is shown diagrammatically in Fig. 52.

If the plug is put into the hole marked $\frac{1}{1}$, it will be equivalent to joining the circuit to the right hand terminal in the diagram, and it will be seen that the shunt or alternative path for the current, is of 10,000 ohms resistance. If it is put into the hole

FIG. 52.



marked $\frac{1}{10}$ the shunt is 1,000 ohms and there is 9,000 ohms in series with the galvanometer. The $\frac{1}{100}$ gives a shunt of 100 ohms and 9,900 in series with the galvanometer, and the $\frac{1}{1000}$ position gives a shunt of 10 and 9,990 in series with the galvanometer. The short-circuit position of course short-circuits the galvanometer altogether.

The explanation of the term "Universal Shunt" lies in the fact that this type of shunt can be used with any galvanometer slide, the resistance of the slide not affecting the multiplying power of the shunt as long as the current in the main circuit remains the same. But it must always be remembered that altering the shunt does alter the current in the main circuit a certain amount, the amount depending of course on the other resistances in circuit at the time. Thus if the other resistances in the main circuit are very large, an alteration in the joint resistance of galvanometer and shunt will not have much effect, but if, on the other hand, they are small, the variation in the main current may be considerable.

This is best explained by the following reasoning, and assuming that the other resistances are so large that the main current is not affected by altering the combined resistance of galvanometer and shunt.

Let G = Resistance of galvanometer.
C_g = Current in galvanometer.
C_s = Current in shunt.
C = Current in main circuit.

Then $C = C_g + C_s$.

$$\text{With } \frac{1}{1} \text{ plugged } \frac{C_s}{C_g} = \frac{G}{10000}.$$

$$\therefore \frac{C_g + C_s}{C_g} = \frac{10000 + G}{10000} \text{ or } \frac{C}{C_g} = \frac{10000 + G}{10000}.$$

$$\text{With } \frac{1}{10} \text{ plugged } \frac{C_s}{C_g} = \frac{9000 + G}{1000}.$$

$$\therefore \frac{C_g + C_s}{C_g} = \frac{1000 + 9000 + G}{1000} \text{ or } \frac{C}{C_g} = \frac{10000 + G}{1000}.$$

$$\text{With } \frac{1}{100} \text{ plugged } \frac{C_s}{C_g} = \frac{9900 + G}{100}.$$

$$\therefore \frac{C_g + C_s}{C_g} = \frac{100 + 9900 + G}{100} \text{ or } \frac{C}{C_g} = \frac{10000 + G}{100}.$$

$$\text{With } \frac{1}{1000} \text{ plugged } \frac{C_s}{C_g} = \frac{9990 + G}{10}.$$

$$\therefore \frac{C_g + C_s}{C_g} = \frac{10 + 9990 + G}{10} \text{ or } \frac{C}{C_g} = \frac{10000 + G}{10}.$$

It will therefore be seen that the proportion of the current flowing in the galvanometer, to that flowing in the main circuit, has in each case been reduced in the proportions marked on the shunt box, and also that this reduction is unaffected by the galvanometer resistance.

The *joint resistance* of galvanometer and shunt necessarily varies with the resistance of the shunt, thus *altering the current flowing in the main circuit*, unless the outside resistance is so large that the resistance of the galvanometer and shunt may be neglected in comparison with it.

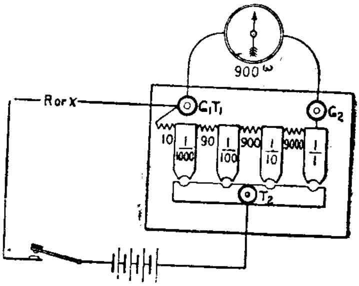
Suppose, for example, the galvanometer resistance be 900 ohms, the joint resistance of galvanometer and shunt with $\frac{1}{1}$, $\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1,000}$ plugged in will vary as follows, and the total resistance of—and current flowing in—the main circuit will be correspondingly altered. Thus the joint resistance of galvo and shunt

$$\text{With } \frac{1}{1} \text{ plugged is } \frac{900 \times 10000}{900 + 10000} = 826\omega.$$

$$\text{,, } \frac{1}{10} \text{ ,, } \frac{9900 \times 1000}{9900 + 1000} = 908\omega.$$

$$\text{,, } \frac{1}{100} \text{ ,, } \frac{10800 \times 100}{10800 + 100} = 99 \cdot 1\omega.$$

$$\text{,, } \frac{1}{1000} \text{ ,, } \frac{10890 \times 10}{10890 + 10} = 9 \cdot 99\omega.$$



Consequently, in measuring resistances by the direct deflection, or substitution method, if x, the unknown resistance, is very much larger than R (the standard resistance with which it is compared), thus necessitating the employment of shunts of different multiplying powers, the joint resistance of the galvanometer and shunts used must be taken into consideration in working out the value of x.

Thus, if the same battery power be used in both cases, and

R = standard resistance,
D = deflection obtained with R in circuit,
d = " " x "
M = multiplying power of shunt used for D,
m = " " " d,
J = joint resistance of galvanometer and shunt used for D,
J_1 = " " " " " d,
r = internal resistance of battery,

theoretically $(x + J_1 + r)dm = (R + J + r)DM$.

But in the case of high insulation resistances where x is expressed in megohms, $J_1 + r$ may be neglected in the expression $(x + J_1 + r)$, as they do not practically affect the result,

Hence $x = \dfrac{(R + J + r)\,(DM)}{dm}$, or, if r is very small, $\dfrac{(R + J)\,DM}{dm}$.

When balancing resistances of less than 100,000 ohms, join the galvanometer to the terminals G_1 and G_2, also join T_1 and T_2 to the Wheatstone's bridge.

When measuring high insulation resistances—above a megohm —Wheatstone's bridge cannot be employed, and the method described in Chapter XXII. should be used, joining galvanometer to G_1 and G_2, the battery to T_2, and the cable or high resistance to T_1.

When used for submarine telegraph work through long cables two camel's hair brushes and a broader suspending ribbon are essential to overcome the hitherto troublesome effect caused by imperfect definition and wandering of the spot. The brushes must then be advanced until they more closely envelope the suspension, according to the length and retardation of the cable, the best adjustment of the brushes must be found by trial.

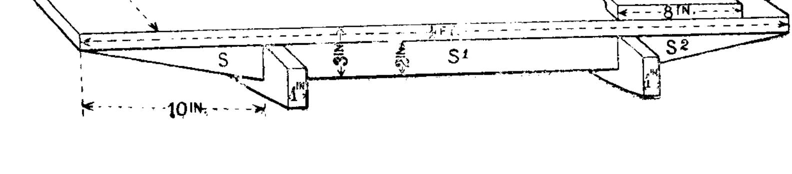
Detailed instructions for testing with this instrument will be found in the chapter on "Electrical Measurements."

Adjusting the Balance of the Coil.

In the case of a galvanometer which is much out of adjustment it may become necessary to readjust the coil as follows:—

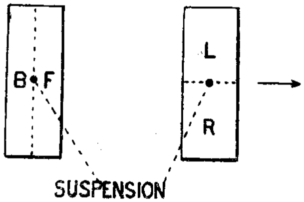
1. Remove the cover, mount the instrument and scale upon a cradle board, *see* Fig. 53, the galvanometer end representing, say, the stern, and the scale end the bow of a ship.

FIG. 53.



2. In order that the "spot" shall not move with rolling and pitching motion, the front part of the coil (F) must equal the back part (B) in weight, while the left-hand side (L) must equal the right-hand side (R). *See* Fig. 54, in which the coil is shown as viewed from above (in plan).

FIG. 54.



3. *To balance for rolling i.e.*, inequality between F and B.—If upon rocking the board, say to the left, looking towards the scale, the spot also travels to left, then the coil is *too heavy in front*, and to secure equilibrium the free leaden arm or arms soldered in front and behind to the coil frame must be bent sufficiently *backward*, and *vice versâ.*

4. *To balance for pitching*, *i.e.*, inequality between L and R. —If upon elevating, say, the *scale* end of the board the spot travels to left, then the coil is too heavy on *the left-hand side*, and the leaden arm or arms must be bent over towards the *right*, and *vice versâ.* In short, whether inclined for rolling or pitching, the coil will always fall down or deflect on its heavier side.

5. To make the adjustments, simply raise the suspension frame half-way up on its cylindrical upright, and holding the coil lightly from behind with one hand, move the balancing arms with the other hand, or by means of the brass burnishers (*see* box of accessories), the final touches being more conveniently given to the *front* arm.

6. Throughout the adjustments *never slacken nor vary the tension of the suspension wire.* This is all-important.

7. Under tension the suspension sometimes stretches slightly, the effect being to disturb the balance between F and B (but not between L and R) causing the coil to appear too heavy in front. Therefore, when the coil has been suspended, and the initial balance obtained to any angle of lift or tilt, set aside the galvanometer for a few hours, without slackening the suspension, and then, if necessary, re-touch the adjustment, after which no further alterations will be necessary other than those small and inevitable ones due to thermal and atmospheric changes. *Then carefully note the constant. In setting up the instrument afresh the tension must be so regulated as to give this constant* under the same conditions.

8. Obviously, where the galvanometer is mounted *athwartships* operations (3) and (4) are reversed.

Fig. 53 shows the dimensions of the cradle board required, which could be made on board if necessary.

Re-suspending the Coil.

1. Lay the suspension frame horizontally in the recess provided for that purpose in the box for accessories.

2. In order to ensure the suspensions being of the exact length required, and to prevent the coil shifting, wedge it up gently with small wooden wedges, so that it is equidistant above and below from the soft iron core.

3. If re-suspending the coil disturbs the balance to any extent, *restore it approximately before re-adjusting the leaden arms, by very slightly bending the end of one or other of the rod parts projecting from the coil.* In doing this, hold the rod close to its brass collar with small pliers, and bend it towards the *heavier* side by means of the brass key. N.B.—The suspension must first be slackened back to avoid risk of accident.

Box of Accessories for Sullivan's Universal Galvanometer.

Contents as supplied with each instrument.

4 mirrors, $\frac{5}{16}$-inch diameter.
1 small soldering iron.
1 brass burnisher (for balancing the coil).
1 pair small scissors.
Ordinary soft solder (for re-suspending the coil, or for re-soldering leaden balancing-arms to coil).
Leaden wire for balancing coils (Nos. 18 and 20 S.W.G.).
4 feet phosphor bronze flat strip (A size).
4 feet „ „ „ (B size).
2 small wooden wedges, for wedging coil in position when re-suspending it.
1 pair small pliers } For roughly adjusting balance after
1 brass key } repairing suspension.

Ammeters and Voltmeters.

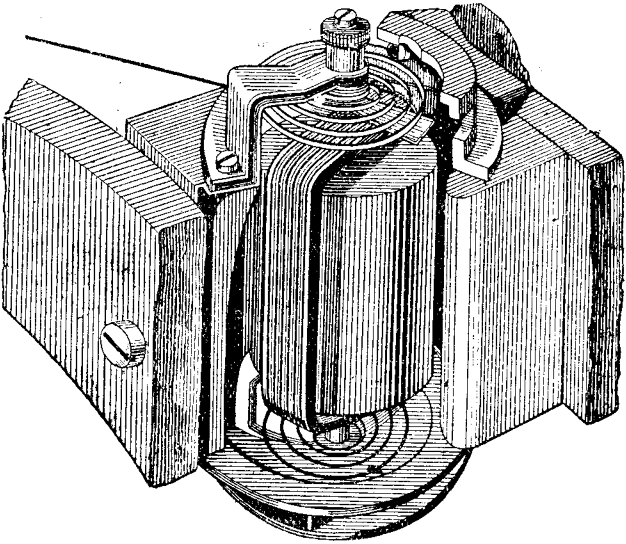
Those ammeters and voltmeters now in use in the Service are nearly all of the "moving coil" type, and are constructed on the same principle as the Sullivan's galvanometer. We will first describe one of these that is designed to measure very small voltages, and then show how it can be used either as an ammeter or as a voltmeter.

The instrument consists essentially of a coil pivoted between the poles of a magnet as in the Sullivan galvanometer, but instead of the coil being suspended by strips, it is generally on a pivot which is held in jewelled bearings. The coil is held in the zero position by two coiled springs, which have their outer ends fixed to the standing part of the instrument and their inner ends to the pivot of the coil. These springs, besides controlling the movement of the coil, in some cases have their ends insulated and are used to lead the current to and from the coil. In other instruments the current is led in and out by two other flexible connections, distinct from the springs. There is generally a fixed core of iron filling up the space inside the moving coil, and the coil itself carries a light pointer which moves over a fixed scale.

When there is a current in the coil, it will of course tend to turn itself round so that its own lines of force coincide with those of the permanent magnet. The springs mentioned above tend to keep the coil in its original position, and the angle through which it moves against these springs depends on the amount of force between the permanent magnet and the coil. This of course will depend directly on the current in the coil. So that the movement of the pointer over the scale is a direct measure of the current that is flowing in the coil. These instruments are very dead-beat, as the moving coil is wound on a metal frame.

Fig. 55 shows the coil and pole pieces of one of these instruments, with part of one of the pole pieces and part of the upper support of the pivot removed, so that the construction can be seen more clearly.

FIG. 55.



Since the coil has to be made as small and light as possible, so as to keep the size and weight of the instrument within reasonable bounds, only very small currents can be allowed to flow through the instrument, or the coil would run the risk of being fused or burnt out. Consequently the instrument as it stands can only be used for measuring very small voltages or currents, but by the use of suitable arrangements it can be made to measure voltages or currents of any size.

Use as a Voltmeter.—If it is required to use it as a voltmeter—that is, to measure the D.P. between any two points—it must of course be connected directly across those two points. The current through the instrument will then, by Ohm's Law, depend directly on the D.P. between them, and so therefore will the movement of the pointer. The dial over which the pointer moves can therefore be so graduated that the D.P. is read off directly.

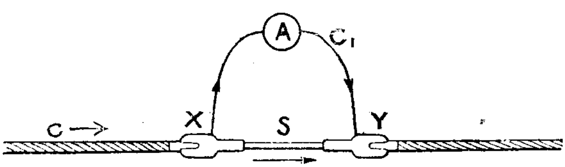
If the maximum voltage to be measured is such as to produce a larger current than is sufficient to make the pointer move over the whole of the scale, then an extra resistance must be put in series with the instrument. Suppose this resistance to be four times the resistance of the instrument. Then when the instrument and resistance in series are joined across the two points whose D.P. is required, four-fifths of the D.P. will be used up in driving current through the resistance and one-fifth in driving it through the voltmeter. So that the voltmeter will only show one-fifth of the whole D.P., and the total D.P. can be at once found by multiplying the voltmeter by five.

It is more usual, however, so to graduate the dial that the total D.P. is read off directly, and this is done in most instruments, the series resistance being contained in the case of the instrument, and the dial graduated for that resistance.

Use as an Ammeter.—If it is required to use the instrument as an ammeter to measure current, it must, of course, be joined in series with the circuit whose current is to be measured, and the dial can be graduated so that the current flowing in the moving coil is read off directly. If the current to be measured, however, is greater than the current that is sufficient to make the pointer move over the whole of the scale, the instrument must be "shunted," like the Sullivan galvanometer—that is, a second path of low resistance for the current must be provided in parallel with the ammeter.

Fig. 56 shows this—

FIG. 56.



Let C be the current in the outside circuit, which it is desired to measure; let C_1 be the current in the ammeter and A its resistance; let S be the resistance of the shunt, and let E be the D.P. between the ends of the shunt, X and Y. Then by Ohm's Law—

$$E = C_1A \text{ and } E = C\,\frac{A \times S}{A + S}. \quad (\textit{See} \text{ "divided circuits."})$$

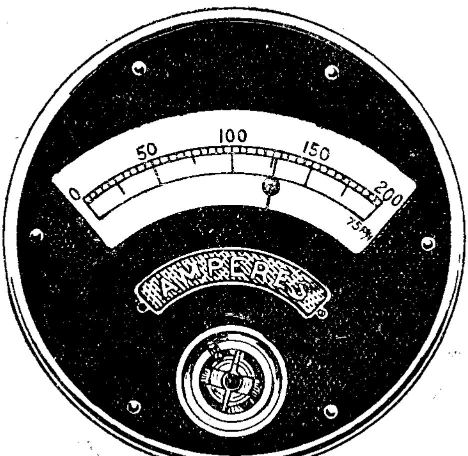
$$\therefore C_1A = C\,\frac{A \times S}{A + S}$$

$$\text{or } \frac{C_1}{C} = \frac{S}{A + S}.$$

But S is so small compared with A that $\frac{S}{A + S}$ is practically equal to $\frac{S}{A}$. That is to say, the current through the ammeter bears the same relation to the current in the circuit that the resistance of the shunt bears to the resistance of the ammeter. So that, if the shunt is one-hundredth of the resistance of the ammeter, only one-hundredth of the whole current will pass through the ammeter, and the total current can be at once found by multiplying the ammeter reading by one hundred. As in the case of the voltmeter, however, it is more usual so to graduate the dial that the current is read off direct. Each shunt is supplied with its own ammeter, which is calibrated for it, and consequently an ammeter must always be used with its own shunt. It is also most necessary that the leads supplied with the instrument for connecting the ammeter to the ends of the shunt should always be used, and not altered in any way. The instrument is calibrated for these leads, and, since the resistance of the shunt is so small, any slight alteration in the resistance of the ammeter circuit would seriously diminish the accuracy of the instrument.

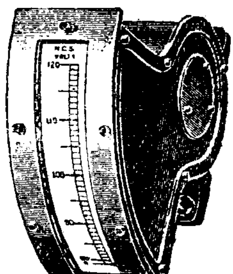
Types of Instruments.—These instruments, ammeters and voltmeters are sometimes arranged with a flat dial, showing

FIG. 57.



Instrument in Circular Case.

FIG. 58.



Edgewise Pattern Instrument.

through an aperture in the face of the instrument (Fig. 57), and sometimes they are of what is known as the "edgewise" pattern, shown in Fig. 58, but they are all constructed on the same principle.

Century Test Set.

This instrument is supplied to certain ships in lieu of spare ammeters and voltmeters. It consists of a small moving coil milliammeter connected to a two-way double-pole switch, by means of which it can be joined to either side of the box. On the left side of the box are several resistances of different values, any of which can be put in series with the instrument by means of a plug on the end of a wandering lead which can be put into various holes. On the right side of the box are two different shunts, by means of which the instrument can be used as an ammeter when the switch is put over to the right. The figures by each hole represent the values of the current or voltage causing a deflection of the needle over the full scale when the plug is in that hole. Two other ammeter shunts are supplied in a separate box, corresponding to full-scale readings of 150 and 600 amperes respectively.

The instrument is shown in Plate X.

When measuring unknown pressures, and in fact at all times as a matter of safety routine, the plug should always be put into the 750 hole first, and worked down until a suitable readable deflection is obtained.

To measure currents of 0 to 1·5 amperes, connect circuit to terminals W and Z and put right hand wanderer in Z^1.

To measure currents of 1·5 to 15 amperes, connect circuit to terminals W and Q and put the right hand wanderer in Q^1.

When measuring currents above 15 amperes with one of the separate shunts, the leads from the shunt in use are in all cases to be connected to the terminals X and Y.

The leads supplied in the box with the instrument are in all cases to be used.

Combined Testing Set.

This instrument is supplied to some ships for the same purposes as the century test set. It contains two moving coil instruments, one at each end of the box, whose pointers move over two dials which are close together and are seen through a glass plate in the top of the box. The field magnets for the two instruments are as shown in Plate XI.

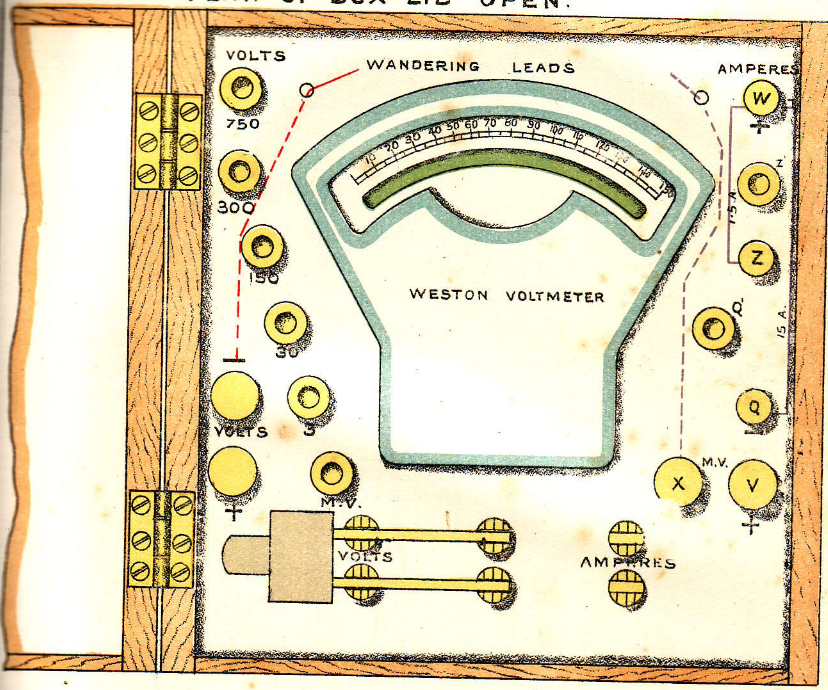
The range of the ammeter is altered by using four different shunts, all of which are supplied separate from the instrument, and when no shunt is in use, the instrument reads directly in milliamperes.

The range of the voltmeter is altered by putting different resistances in series with it. The resistances are all contained in the box, and are connected in series with the voltmeter by means of a small switch at the end. A fixed pointer on the box points to a number on the switch handle for each of its positions.

The voltmeter scale is marked in 100 divisions, and the voltage between the terminals is given by the scale reading multiplied by the number on the switch handle opposite the pointer. These numbers are $\frac{1}{1000}$, $\frac{1}{20}$, 1, 2, 4, 8.

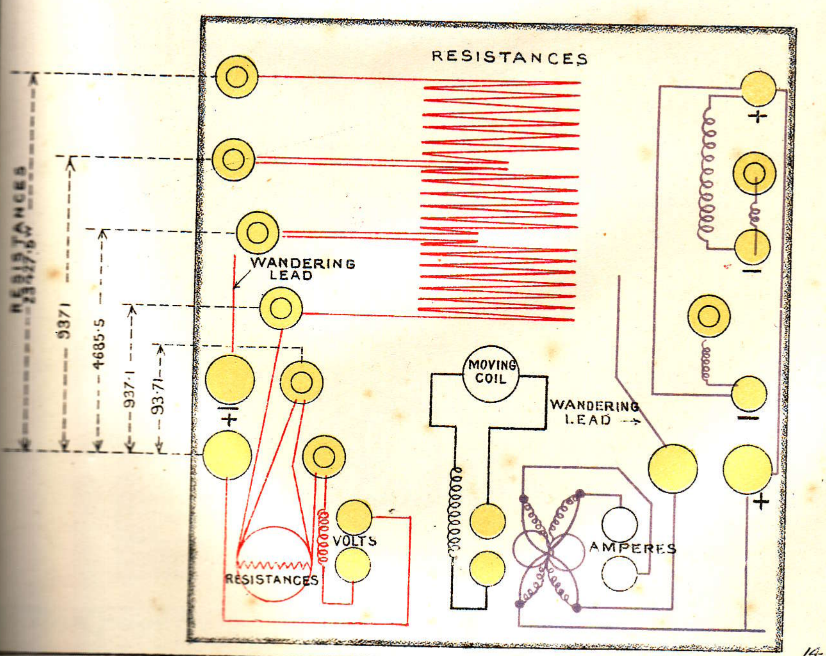
Century Test Set.

Plan of Box Lid Open.



Diagrammatic Sketch of Connections.

At Bottom of Ebonite Base



Weiler & Graham, Ltd Litho, London 1515. 07.

To face page 95.

Cell Tester.

Elevation.

Scale = Half size.

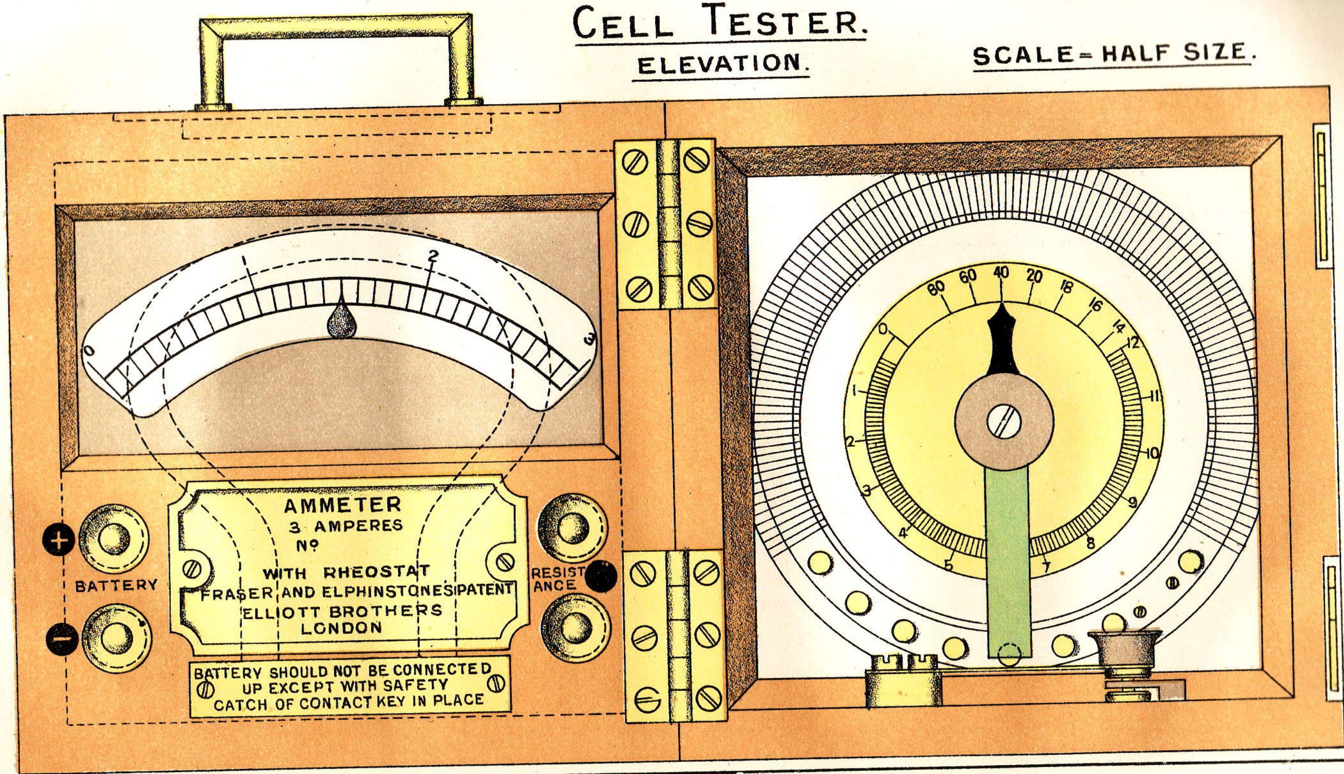


Plate XII

Weller & Graham, Ltd. Litho, London.

16.

Each shunt is marked with the number of amperes that will cause a full deflection, 100 divisions, with that shunt in use, so that the current is given by—

Scale reading	×	·1	for the	10-ampere	shunt.
"	" ×	1	"	100-ampere	"
"	" ×	3	"	300-ampere	"
"	" ×	10	"	1000-ampere	"

The instrument is not to be taken within four feet of a dynamo.

Cell Tester.

An instrument containing a moving coil ammeter is the cell tester, Plate XII. It is used for testing cells and batteries, and also for some other electrical measurements (*see* Chapter XXII.).

It consists essentially of a small moving coil ammeter, reading from 0 to 3 amperes and graduated in tenths, joined in series with a rheostat or adjustable resistance, reading from 0 to 80 ohms, and a testing key fitted with an ebonite safety arrangement.

Two terminals on the left of the ammeter and marked + and − are for the battery, and two others on the right of the ammeter are fitted for balancing resistances.

To Test a Cell or Battery.—Short-circuit the resistance terminals by means of a piece of fine cut-out wire, pattern 610. This will act as a safety fuse to prevent excessive current damaging the instrument. Set the rheostat to the resistance required as laid down in the drill book on p. 38, and join up the cell or battery to terminals marked + and −.

Make a *short* contact with the key, watching the ammeter needle to see that it registers ·5 ampere as shown by the red line on the ammeter.

The circuit inside the instrument is as follows:—From the terminal marked +, through the ammeter to the upper "resistance" terminal. From the lower "resistance" terminal through the key and rheostat in series, and back to the terminal marked −.

Hot Wire Instruments.

Instruments of the "hot wire" type are used extensively ashore, but only in the Service in connection with wireless telegraphy. As in the case of the moving coil instruments, the ammeter and voltmeter are essentially the same, but one is used with a shunt and the other with a series resistance.

The principle of these instruments is as follows:—When an electric current is flowing in a wire the wire is heated, as was pointed out in Chapter II. When a wire is heated it always expands, and this expansion of the wire is made to move a pointer over a scale.

These instruments will be described in the Manual of Wireless Telegraphy and its Addenda.

CHAPTER VI.

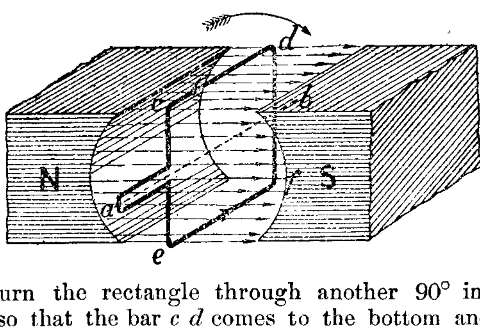
THEORY OF THE DYNAMO.

THE name dynamo is given to any machine constructed to convert mechanical power into electrical power by the operation of producing relative motion between conductors and magnetic fields, and thus making use of the principle of electromagnetic induction explained in Chapter III.

Elementary Dynamo.—Let us consider the effect of the revolution of a single rectangular coil in a magnetic field, as shown in Fig. 59.

As drawn in the figure, the rectangle is enclosing as many lines of force as possible; if now it is turned suddenly on its axis through an angle of 90°, it will lie parallel to the lines of force, and none of them will then pass through it. This revolution of the rectangle is therefore equivalent to withdrawing all those lines of force from the embrace of the rectangle, and will consequently give rise to a "direct" current (*see* table on page 61). This direct current, by the corkscrew rule, is in the direction from *d* to *c* and from *e* to *f*.

FIG. 59.



Now turn the rectangle through another 90° in the same direction, so that the bar *c d* comes to the bottom and *e f* to the top. It will again enclose the maximum number of lines of force, but they will be passing through it in the opposite direction. This second revolution is therefore equivalent to thrusting all the lines of force through the circuit in the opposite direction, and the "inverse" current that this operation gives rise to will be in the same direction as the "direct" current in the first 90° of revolution. Also as the number of lines of force cut is in each case the same, the induced D.P. is the same, providing the rates of moving were equal.

If, therefore, the rectangle had been rapidly turned at one sweep from its original position in Fig. 59 through 180° a current would have been induced in the direction shown by the arrows during the whole of the movement, that is, in the direction *d c e f*. Now mark the difference in the next 180° of revolution.

In the third 90° of revolution all the lines of force that were thrust through the rectangle in the second 90° are withdrawn, and consequently the current during the third quarter revolution is in the opposite direction through the wire of the rectangle to the current to the second 90°.

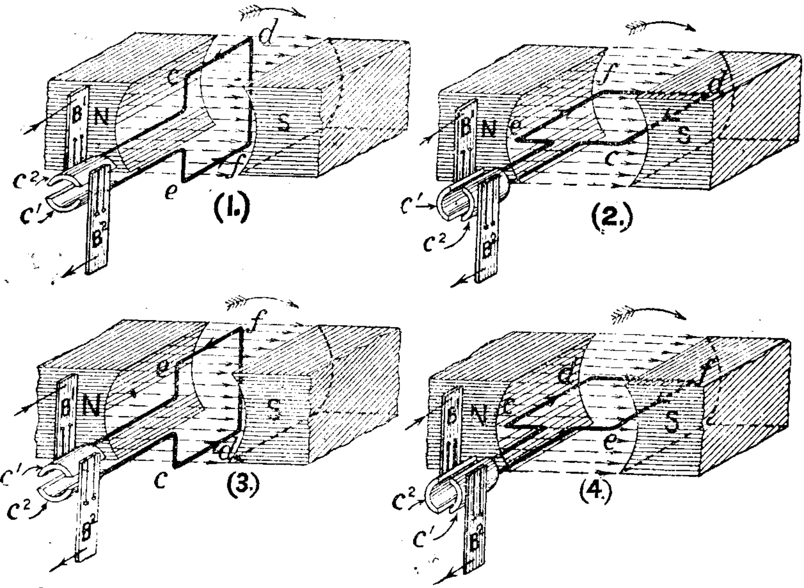
And, in the same way that the current during the second 90° was in the same direction as the current during the first 90°, so the current during the fourth 90° is in the same direction as the current during the third.

If the speed of revolution is the same, the induced D.P. will be the same as in the first half. So we see that a continuous rotation of the rectangle will give rise to a series of currents alternating in direction; two distinct currents being generated during each complete revolution, the reversal taking place every time the rectangle passes the points at which its plane is at *right angles* to the lines of force.

Now, assuming the field and the speed of rotation to have been uniform, let us consider the question of D.P. a little more closely.

When the rectangle begins to move from its first position in Fig. 60, although it encloses the maximum number of lines of

FIG. 60.



force, yet the number that pass through it is hardly changing at all. Therefore, since the E.M.F. produced depends on the rate of change of the number of lines of force passing through the circuit, at the beginning of the movement the E.M.F. is small. When the rectangle has turned through about 90°, the number of lines of force passing through it is changing at the greatest rate possible, and the E.M.F. has consequently risen to its maximum amount. It falls again as the next quarter revolution is passed through, reaching zero when the rectangle has turned through 180°, and then the reversal takes place.

In the next 180° of revolution back to the original starting point, the D.P. rises from nothing to a maximum and back again to zero, the current being induced, as we have seen, in the opposite direction.

Commutation of Current.—The currents flowing in the rectangle as it is revolved would be of no practical use, however, unless the rectangle is connected up in some way so as to enable the currents it produces to do work in an external circuit; and further it is more convenient in the Service, especially for working search lights, to keep the current always flowing in one direction; in order to arrange this in collecting the current it is therefore necessary to *commutate* or *change its direction*, so that in the outside circuit it always flows the same way.

The arrangement for doing this is called the *commutator*. In the following figures it will be seen that the two ends of the rectangle are connected to the two halves of a split ring or short tube, that brushes rest on these split rings, and that the outside circuit is connected up between the brushes.

In position 2 in the figure it will be seen that in the rectangle, the current is being generated in the direction shown by the arrows, and is flowing from B_2 to B_1 in the *outside circuit*. Now as the rectangle passes the vertical and arrives at position 3 the current is generated in the opposite direction in the rectangle, or from C_2 to C_1, but at precisely the same instant the brush B_2 leaves C_2, and touches C_1, and B_1 leaves C_1 and touches C_2; so that B_2 still collects the *leaving* current, which enters again by B_1. By this means the direction in the outside circuit is always the same.

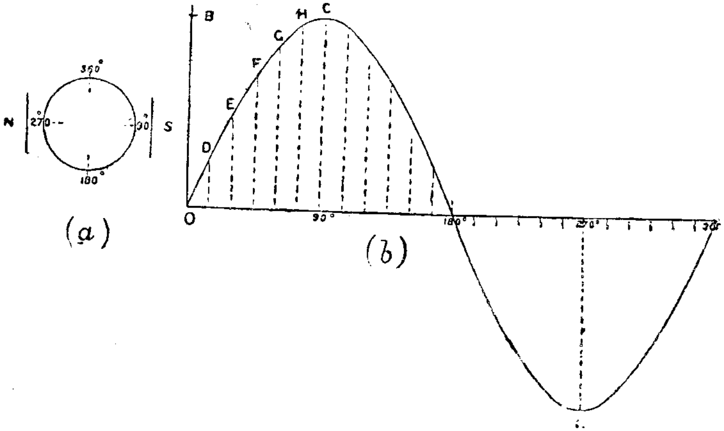
Fluctuation of D.P. and how it is Overcome.—A single rectangle of this sort would be very inconvenient, since during every half revolution the D.P. made would rise from nothing gradually to its greatest amount, and then fall again to nothing; the D.P. would therefore never be constant. This difficulty can be got over by using more than one rectangle, in fact a large number all connected in series, with the junction of each taken to an insulated rubbing contact called a commutator strip. To get a steady D.P. then, a large number of rectangles are required; some are for the moment doing no work, some are producing a slight D.P., and some are cutting the maximum possible number of lines of force and are consequently producing the maximum D.P.

Again, in order to produce a high D.P. between the brushes where the current is collected, without revolving the armature at an excessive speed, the rectangles are connected in series with one another, as well as each end of the individual rectangles being connected to a commutator strip as before stated; so that the D.P.'s of all the rectangles are *added together*, and the total D.P. formed at any moment between the brushes will be the sum of the D.P.'s of all the rectangles.

It can be shown very simply why it is that adding more rectangles reduces the fluctuation of the D.P.

First suppose the armature to consist of a single rectangle. Take two lines at right angles—one vertical, one horizontal—and let the horizontal one be divided up into a number of equal divisions to represent the angle the rectangle moves through, and divide the vertical line into equal divisions to represent D.P. generated—Fig. 61 (*b*).

Fig. 61.

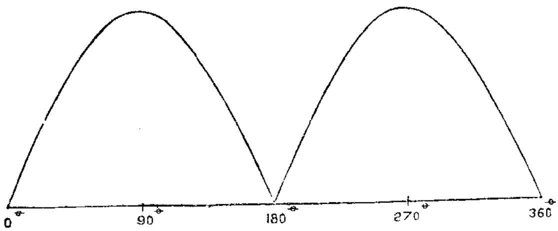


Referring to Fig. 61 (*a*), the rectangle when in the plane 360°, 180°, is generating no D.P.; and when in the plane 90°, 270°, will be generating the maximum D.P.

Let the D.P. at 90°, 270°, be represented by the vertical line 90° C. Now for every intermediate position between O and C, the rectangle is generating an *increasing* D.P. as indicated by the curve O D E F G H C.

In a similar manner we may continue the curve so as to represent the gradually *reducing* D.P. to a point 180°; where the rectangle will have accomplished half a revolution. At this point the direction of the D.P. generated in the rectangle will be reversed, and a similar curve K *below* the line O, 360°, may be drawn to represent the D.P. generated during the second half of the revolution. Now the commutator keeps the direction of the current in the outside circuit constant, as explained on page 98, and we may consequently represent the D.P. that would be generated by a single rectangle by the curve shown in Fig. 62.

Fig. 62.

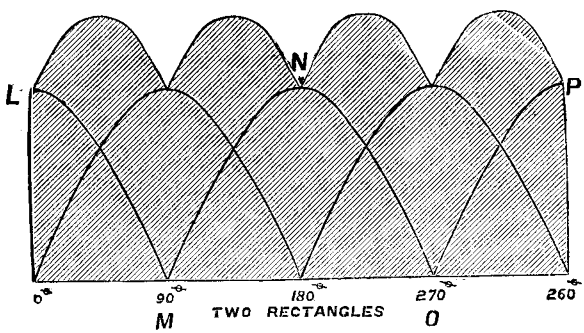


Now let us add a second rectangle, in a plane at right angles to the first, and in consequence generating its greatest D.P. when the latter is generating none.

This will give us a second curve, L M N O P, Fig. 63, and the two rectangles being joined in series, the total D.P. created will be represented, at any instant, by the sum of their D.P.'s.

This is shown in the figure by the double curve drawn above the other two; in which we find that instead of two greatests and leasts, we have four greatests, and the leasts never drop below the greatest D.P. made by one rectangle.

Fig. 63.



Adding on more rectangles, we get the summits of the curve increasing in number and more nearly approaching a straight line, until at last, with a large number of rectangles, we get a greatly increased D.P., which practically remains constant throughout the revolution.

Armatures.—Hitherto we have only considered the effect of generating currents in a large number of rectangles revolved in a magnetic field; and it is necessary before proceeding any further to explain how in practice these rectangles are built up into armatures, which is the name given to the part of the dynamo which revolves and generates current.

The magnetic circuit of a dynamo should be as good as possible, so as to obtain a maximum number of lines of force, or, in other words, a large flux, between the poles of the field magnets. Consequently the core on which the rectangles are wound must have only a small magnetic reluctance, it is therefore made of iron.

Lamination of Armature Cores.—Now we know that any conductor moving in a magnetic field will have a D.P. produced in it. Hence, in the drum of iron itself a D.P. is produced, tending to cause currents to flow in a similar direction to that in the rectangles. To minimise these *eddy currents*, as they are termed, the cores of armatures are *laminated*, that is divided into sections, or thin discs, insulated from each other ; so that resistance, due to the discontinuity of the iron is introduced into the path of the current, tending to reduce its strength ; but at the same time the metal is continuous in the direction of the magnetic lines of force, and so no extra magnetic reluctance is opposed to the flux.

FIG. 64.

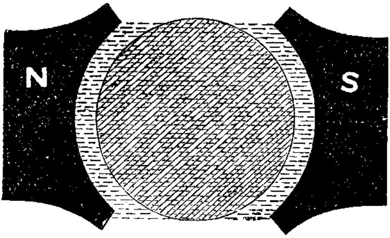
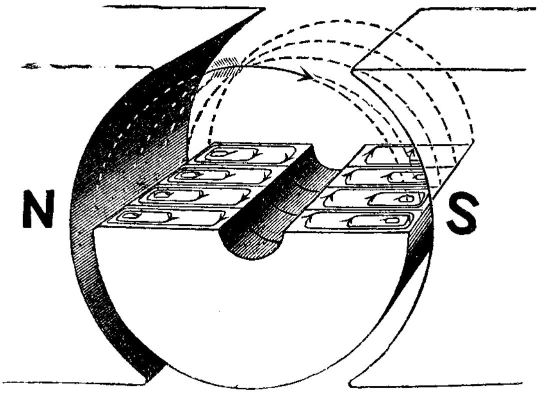


Fig. 64 represents the magnetic field in the case of the iron core of an armature.

FIG. 65.



Eddy Currents.—In Fig. 65 the eddy currents can be easily traced, and it will be seen that by sub-dividing the iron into discs, as shown by the dotted lines, resistances will be inserted, the arrows showing the induced currents. A certain D.P. is made, causing these currents to flow. The more resistance we insert the less current we shall get, and therefore the less heating there will be. Were it not for laminating a drum in a large machine, these eddy currents would generate sufficient heat to spoil the machine after five minutes running. It will be easily seen that the generation of a small D.P. will cause a very large current to flow, since, if the metal be continuous, the resistance of the circuit is very small. These eddy currents do no useful work; by heating the core they increase the magnetic reluctance; in so doing they also heat the copper conductors, increase their electric resistance, and damage the insulation; hence every care is taken to eliminate them as much as possible. Even in the copper windings, large spurious currents are generated due to the sides of the wires being at a difference of potential.

Stranded Armature Bars.—To eliminate these, armature bars are stranded or built up of separate copper strips, and at times a complete turn taken in the conductor, so as to neutralise the D.P. between the bottom and the top.

Since eddy currents in the core can never be entirely done away with, a certain amount of heating will always be caused. To reduce this the drum must be carefully ventilated. Some makers ventilate their drums by having the centre hole of each discs considerably larger than the spindle of the armature, and having a sleeve with three webs fitting over the spindle; the discs are then driven on over the webs, the channels between the webs forming ventilating passages for the air. Such a sleeve is called a "spider."

Ventilation of Armature.—Again, instead of all the discs touching each other, spaces are left at intervals to allow the air to circulate radially through the armature. In some armatures bent vanes are placed at the entrance of the sleeve so that the motion of the armature forces air through the sleeve and the radial spaces. It should be remembered that the armature of a large dynamo may be generating over 100 HP of electrical energy, and therefore that all connection between the drum and spindle must be thoroughly strong and mechanically well designed; so that when a dynamo is stripped for repair it is well to examine these mechanical fittings, of whatever kind they may be, and see that there is no play between the cores and the spindle and that every part is in good condition and not strained. The insulation between the discs need not be very good; varnish or paper is usually employed by the manufacturers.

The core, when mounted, should be perfectly balanced about the spindle, so that it will run evenly and true. It should then be thoroughly insulated before any conductors are laid on. The manner in which this is done will be subsequently described; for the present we have to deal with the *theory* of the windings only.

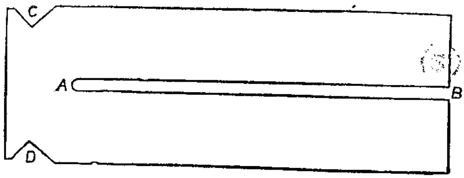
Each section of the winding forms a complete turn round the core. If a core be so wound with wire it will be easily seen that the wires must all cross one another at each end as they pass the spindle, so that wire after wire will lay on top of one another till a large bunch is formed. This method was adopted in the earlier dynamos, but was naturally found most objectionable, since no ventilation could be obtained, and any oil or moisture getting at the ends was certain to bring about short-circuiting; also, if any short-circuiting did occur in the underneath turns, the whole of the turns above had to be taken off and could not practically be replaced except with new wire. It will therefore be apparent that any device which does away with this crossing of the wires is a great advance in the winding of such armature, making it much more durable, and, at the same time, easier to repair.

These considerations led to the windings of armatures being divided into two distinct parts, firstly, *the bars*, or conductors, that run along the drum, and secondly, *the end connections* joining the bars at the ends of the core.

End Connections, Drum Armatures.—These end connections vary with different makers.

Fig. 66 shows a Siemens connection, which may be described as a flat piece of sheet copper slit longitudinally from A to B, and V-ed at C and D. Fig. 67 shows this strip bent as it would be when connected up. It will be seen that the ends of these strips

Fig. 66.

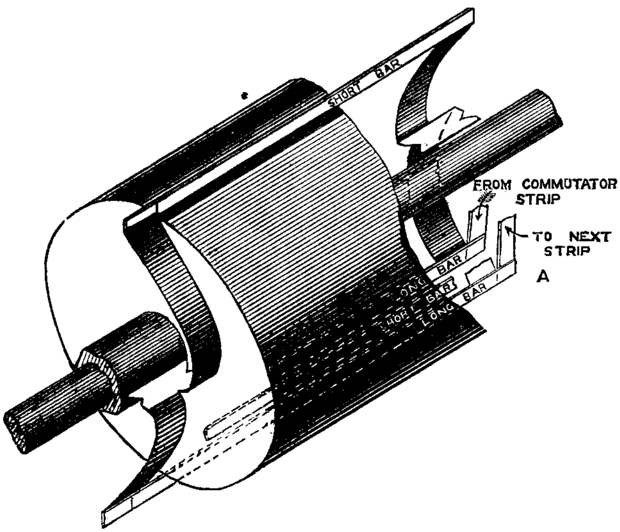


go practically to the opposite points of the diameter of the armature. A number of these built up form the whole of the end connection, and join the bars across the front and back of the armature. It will be seen that such a connection is capable of being perfectly insulated, good insulating material being inserted wherever the strips are close together; besides which, each strip being separately insulated with tape or silk, the chances of short-circuiting are enormously reduced. Also, should any defect occur here, the whole end may be taken off, repaired and put on again. The whole of these pieces are clamped together by means of a sleeve screwed into two V-ed nuts which fit in the V's cut in the strips; the nuts are, of course, carefully insulated on the inside. The sleeve then slides on over the spindle.

Long and Short Bars.—The fact that the two legs of the strips lie at different distances from the core necessitates the employment of two different lengths of bars, called respectively the *long* and the *short bar*; so that, as shown in Fig. 67, each complete turn round the core consists of a long and short bar and two end strips.

The rectangles are connected together as follows :—Starting with the long bar A, whose end is connected to a commutator strip, we pass along the long bar to an end connecting strip at the far end of the armature, by this strip to a top short bar, along this to the end connecting strip at the commutator end of the armature, and by this connecting strip to *the next long bar*. So that each complete turn is joined in series to the next complete

Fig. 67.



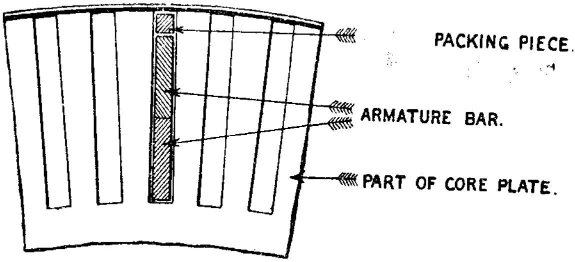
turn by the end connecting strips at the commutator end of the armature running to the next long bar.

Driving Horns.—When an armature is revolving in a magnetic field and generating current, the effect of this current, by Lenz's Law, will be to oppose the motion that produces it. Consequently, if the current is large, there will be considerable resistance to the revolution of the conductors.

Supposing, now, an armature completely wound with turns as described, the whole of the pull of the magnets being on the conductors carrying the current, these will have to be rigidly fixed to the core, otherwise it would revolve inside them. This is done in the older types of dynamos by means of *driving horns* (consisting usually of boxwood wedges), driven down into slots cut in the periphery of the core. The bars which bear against the driving horns are usually stouter than the average conducting bar, and are called *driving bars*; these bars and horns take the strain of the pull of the magnets.

Slotted Armatures.—In all modern machines another device has been adopted; the laminated discs, which, when built up, form the core of the armature, are stamped out of sheet iron, slots being cut at the same time around their circumference, giving them the appearance of a toothed wheel; and in these slots the bars are laid after being insulated. This method has the additional advantage of reducing the air space between the drum and the pole pieces, thereby decreasing the reluctance in the magnetic circuit.

FIG. 68.



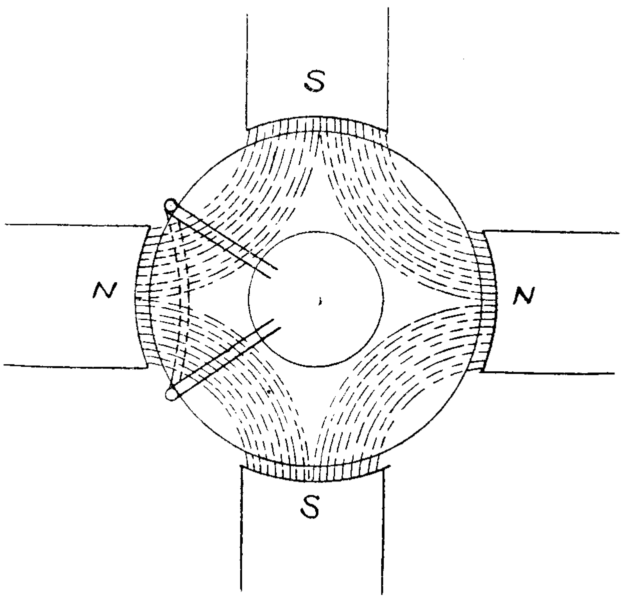
Method of Binding Drum Armatures.—To prevent the bars being *sprung* out towards the field magnets, binding bands are put on. These bands have to be very strong, gripping the winding closely, and yet be as thin as possible. Since no lap joint would be thin and strong enough, and would at the same time bind the windings closely enough to be of use, such a band is usually made by first insulating the space over which it is going with linen strips and then pieces of thin mica, and afterwards binding turns of phosphor bronze wire closely together with a considerable strain, and sweating the whole together.

Formerly a band of thin German silver was placed under the wire before serving on, but it has been found that the wire can be laid on tighter and just as efficiently without this. At intervals, however, pieces of German silver or copper are placed under the wire and their ends turned over and sweated, especially where the wire begins and ends. The bands are then coated with varnish.

Multipolar Dynamos.—Hitherto we have only considered the case of dynamos in which the magnetic field is produced by two magnetic poles opposite one another. All modern machines, however, have more than two poles, arranged at equal distances round the circumference of the armature, adjacent ones being always of opposite polarity.

Consider the case of a dynamo having four poles as compared with one having only two, and in which the coil on the armature, instead of going right round the core, is only of such a size as to lie on one quarter of the circumference, as in Fig. 69. The magnetic field will be as shown in the figure, and it will be seen that when a coil is in the position shown, opposite one of the pole pieces, it is embracing all the lines of force from that pole piece. When it has turned through an eighth of a revolution, and is midway between two pole pieces, it is embracing practically no lines of force; and when it has turned through a quarter of a revolution, and is opposite the next pole piece, it is embracing

Fig. 69.

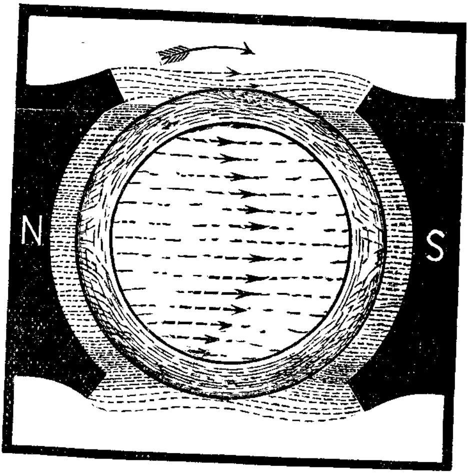


the same number of lines of force as before, but in the opposite direction. Following out this line of argument, we shall see that when the coil has revolved from a position cpposite one pole piece to a position opposite the next pole piece of the same polarity, it has gone through the same cycle of operations as regards the production of E.M.F. as the coil in the two-pole machine did in the course of a whole revolution. So that, if the poles are of the same strength as those in the two-pole machine, we shall only have to revolve the armature at half the speed in order to get exactly the same result.

There is another advantage which this form of machine has over the two-pole machine, however. Since the armature coils do not go right round the core, it is unnecessary to make the end connections separate from the bars. The coils can be formed in the shape that will fit the core, and put into place whole, the only connections requiring to be made being those to the commutator. This simplifies the operations of manufacture and repair very considerably. The connections of the coils will be considered in the chapter on armature windings.

Ring Armatures.—There is another form of armature that is used in small machines, namely, the "ring" armature. The core is a ring of iron, laminated, of course, as are all cores, and each coil is wound round the ring, going across the outside and back through the inside. Since the magnetic flux from the field magnets is nearly all concentrated in the iron of the ring, as shown in Fig. 70, and there is scarcely any flux inside the ring, a little consideration will show that the action of such a coil is exactly the same as that of the coil considered in the first chapter.

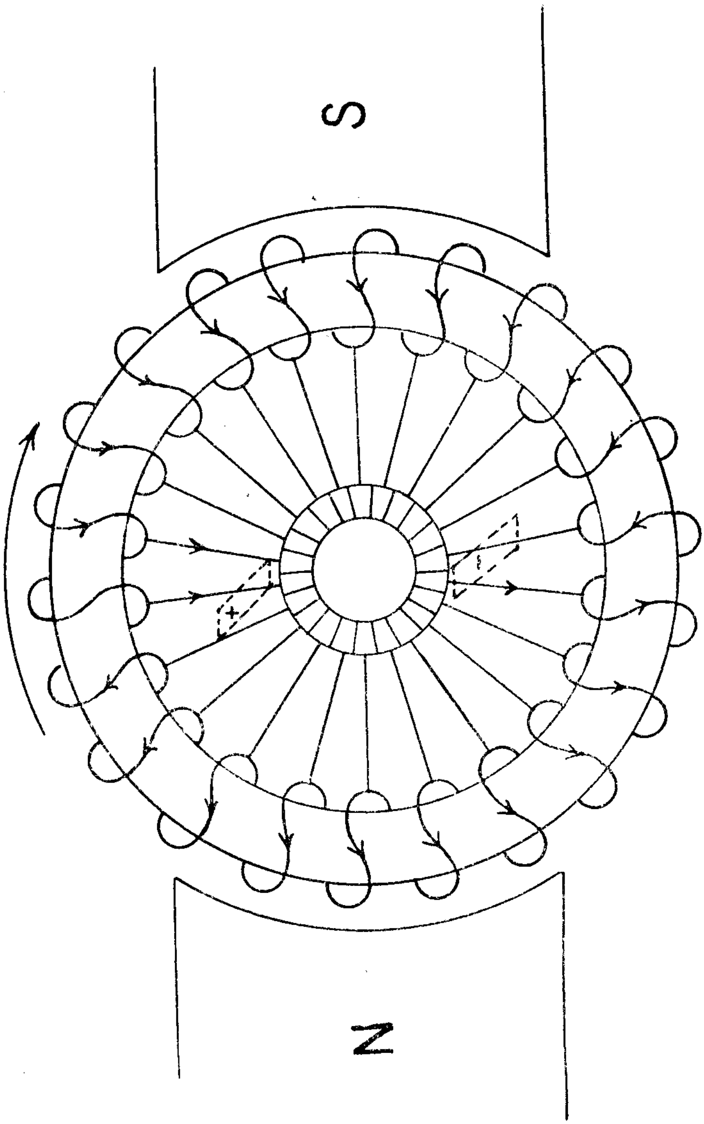
Fig. 70.



The coils on a ring armature are all connected in series, as are those on the ordinary or "drum" armature, and so form a closed coil right round the ring, as shown in Fig. 71, each turn on the ring being connected to a strip on the commutator. It will be seen that the current in one half of the armature is flowing in one direction through this coil while the current in the other half is flowing in the opposite direction, these two currents meeting and combining at the brushes.

The case of a drum armature is, in essentials, exactly the same, but the part of each turn which, in a ring armature, is inside the ring, in a drum armature is taken right outside the drums and comes back on the other side. Consequently, all the turns on a drum armature cross one another at the ends of the core, and it is almost impossible to draw a diagram like Fig. 71 for a drum armature which shall be intelligible. Since, however, the drum armature is just the same, except for the position of the return half of each turn of the winding, this diagram will be of use in studying drum armatures also.

FIG. 71.



COMMUTATORS.

We will now proceed to examine more closely that part of the armature where the current is commutated and collected :—

The function of the commutator has been explained to be twofold, viz. :—Firstly, to collect the current generated in the armature and pass it to the brushes, and, secondly, so to commutate its direction that the current always flows one way in the external circuit.

The commutator in fact simply taps each section of the armature winding, and being of bare metal, forms at the same time a rubbing contact from which to collect the current. Passing on to the points to be considered in the *manufacture* of a commutator, it is clear that they are :—

(1) Strength to withstand the centrifugal stresses resulting from the rapid revolution of the armature.

(2) Insulation of each strip from the next, and from all other metal, except its own armature coils.

The first condition is fulfilled by undercutting the ends of each strip and clamping all the separate strips into a solid mass by means of collars fitting the undercuts, and screw nuts.

The second condition necessitates the insertion of insulation between the strips, between the collars and the strips, and between the strip and the spindle, so that each strip is coated by an insulator on each face and end, except the upper side on which the brush rubs, and the whole structure of strips and insulation are pressed firmly together by the collars and nuts.

Commutators differ in design and method of insulation, but the same principles underlie the whole.

It will be sufficient for our purpose if we describe a typical form of commutator, which will give us the opportunity of pointing out the chief electrical considerations. Differences in mechanical details can easily be seen on taking any particular type to pieces, and for our purpose (that of repair and not design) such differences are of little importance.

The insulation most commonly used in commutators between the strips is micanite, since it will stand considerable compression, is easily split into thin sheets, and is non-absorbent. It is very essential that insulation for this purpose shall be non-absorbent, since, if it absorbs oil, sparking at brushes is apt to carbonise the oil and establish leaks between the strips. The insulation here has also to stand compression, since the firmness of the whole commutator depends on the degree to which the collars are compressed.

The insulation between the collars and the strips must therefore, as has been already said, be non-absorbent, but it must also readily lend itself to the peculiar shape of the undercut. Also, the insulation between the rings and strips, and strips and sleeve, have to withstand the greatest D.P. that the dynamo is capable of producing ; hence at these places good insulation is especially necessary. The best insulation for these end rings is micanite carefully built up in segments so as to lend itself to the peculiar shape of the collar, and to the different layers and segments cemented together. A ring so built up will stand pressure without damage, and be, of course, non-absorbent.

Between the sleeve and the strips asbestos fibre, mica, or air may be used. The insulation at this place is virtually protected by the strips and collars, from oil or moisture, so that there is very little chance of failure from this cause, but it is always advisable to put a layer of micanite over all before building up the commutator.

The methods of connecting of the wires or bars to the commutator strips are numerous; lugs being usually employed running up from the strip to the bar. The ends of these lugs are usually either forked, hooked, or bent completely round, so as to grip the wire, and are then well soldered.

Commutators that are much undercut do not have the same length of life as those left with fuller metal, since as the metal wears, the bridge conducting the current to the lug becomes smaller, and, if too small to carry the current, the metal will heat. In some cases the commutator is fixed on to the spindle of the armature by nuts or keys; in others the lugs are considered sufficient to hold it. Similarly in some cases the collars are keyed to the sleeves to prevent them slewing when being screwed up, or during use; since not only is the insulation damaged by any motion to the collars, but the strips themselves are apt to be slewed out of line.

Brushes and Brush Holders.

Since large currents have often to be collected by the brushes, it is essential to distribute the collection of this current evenly throughout the whole face of the brush.

Carbon Brushes.—In all recent dynamos carbon brushes are employed, plated with copper to increase their conductivity, and to lessen the resistance where they connect to the brush holder.

Owing to the high resistance of carbon, to avoid heating, the area of brush contact is such as to give an allowance of 30 to 40 amperes per square inch of contact area.

Carbon brushes materially aid the sparkless collection of current, and they should be adjusted with a pressure on the commutator of about 1·5 lbs. per square inch.

The pressure of the brushes on the commutator should be as small as possible compatible with absence of sparking. If the pressure be too small, sufficient of the brush is not in contact with the commutator, and any unevenness of the surface or jarring may cause the brush to lift and spark. But, on the other hand, if too firm a pressure be maintained heating by friction will result, and the brushes and commutators will be needlessly worn away. In practice, with a smooth commutator the pressure may be very slight.

With low voltage machines, such as are used in the Service, only the softest carbon brushes are suitable, the electrical resistance of the harder qualities causing too great a loss of voltage.

In all machines now in the Service the brushes will be found to be duplicated or triplicated according to the size of the machine; that is, either two or three brushes will be found at each neutral point. This admits of one being removed, replaced or readjusted without stopping the machine, which is a most necessary advantage. The exact position of the brushes is where there is least sparking, since sparking damages the commutators to an enormous extent. This position can be found by rocking the brushes forward or backward until the position of least sparking is arrived at, and then clamping the holders. Sparking should never be tolerated, but its cause remedied as soon as possible. The causes of sparking will be discussed on page 126.

Brush-holders vary in design. The principle of all is, however, the same, viz., to provide two or more insulated holders for the brushes, according to the type of the machine, and at the same time to allow of two motions, one a rotary one of the sets of brushes round the commutator, to enable them to be placed in the true neutral axis; and the other a motion whereby each brush may be separately lifted and held clear of the commutator. The first of these motions is allowed for by fixing the brush holder on a bush on the bearing bracket of the armature spindle, and allowing it a certain play round the bush.

Rocker and Clamp.—A handle called a rocker, or some similar arrangement, is fitted to the brush-holder for this purpose. A clamp is also provided for clamping the brush-holder and preventing its position from being altered by the vibration of the machine. The brush-holders proper are insulated by ebonite or micanite washers, and the bushes are also insulated from the rocking frame, so as to prevent leakage across from brush to brush, or to the metal of the machine. These washers require looking to at times, and all oil, dirt, &c., should be daily removed from them.

The brushes are lifted off the commutator differently in different holders, but a little inspection of any brush-holder will reveal its method of working, and it is the first point a man in charge of a machine should master, as otherwise he may be easily misled by imagining he has his brushes on properly, when in reality they are only just touching or are even perhaps clear of the commutator.

Brush leads are flexible leads of insulated wire joining up the brushes to the proper points of connection, which, as will be seen later, vary in the different types of dynamo.