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A.1.

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Post Office Engineering Department

TECHNICAL PAMPHLETS FOR WORKMEN

Subject:

Magnetism and Electricity

ENGINEER-IN-CHIEF'S OFFICE,
1919.

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FOR OFFICIAL USE.

MAGNETISM
AND
ELECTRICITY

(A.1).

The following pamphlets in this series are of kindred interest:

A.2. Primary Batteries.

G.1. Secondary Cells.

MAGNETISM AND ELECTRICITY.

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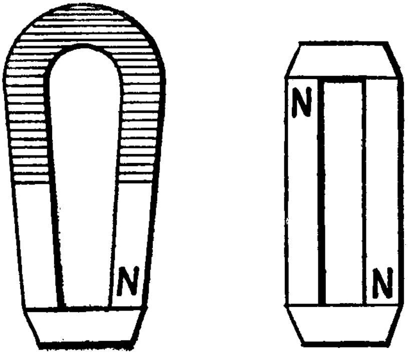
MAGNETISM AND ELECTRICITY.

PART I.—MAGNETISM.

MAGNETS.

The **magnet** is a familiar object to most of us, with its peculiar power of attracting and " sticking to " iron and steel. It is an artificial product; but a natural substance, the **lodestone,** possessing magnetic qualities, is found in the earth's crust. This substance is an ore of iron. Its magnetic properties, however, are feeble and irregularly distributed, so that the subject of magnetism is better studied by means of artificial magnets.



Figs. 1 and 2.

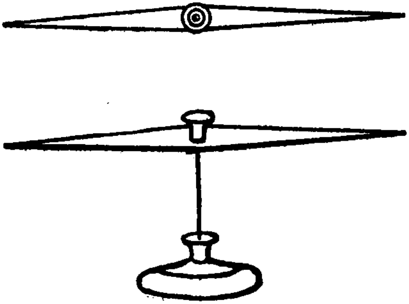


Fig. 3.

The magnets we are accustomed to see consist essentially of strips of hard steel, thoroughly magnetised. When left as a straight strip a magnet is known as a "bar magnet," and when bent so as to bring its ends near each other it becomes a "horseshoe" magnet. The latter shape allows both ends to be brought into play at once, and to combine their attractive force upon an object (Fig. 1). The "keeper" or armature, usually fitted across the ends of the horseshoe, is of soft iron, and its function—as its name implies—is to preserve the power of the magnet unimpaired. Bar magnets are generally arranged in pairs, and a pair of keepers employed (Fig. 2).

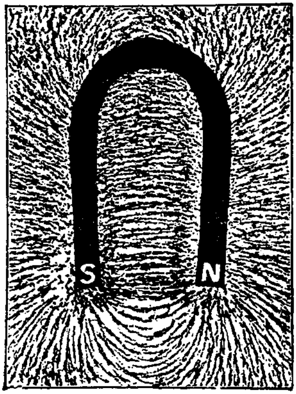


Fig. 4.

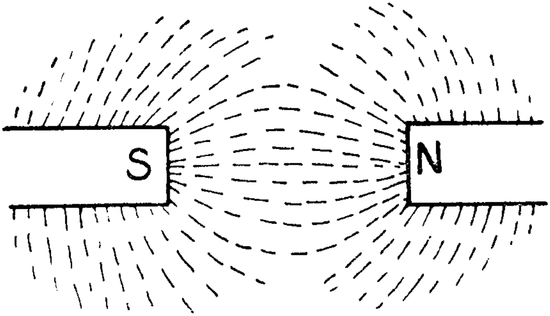


Fig. 5.

Another familiar form of magnet is the compass needle—a miniature bar magnet pivoted so as to be free to turn horizontally (Fig. 3). It is well known that such a needle always sets itself in a line pointing north and south; or, as the earlier observers remarked, it pointed to the pole star. For this reason the ends have been termed the "poles" of the magnet.

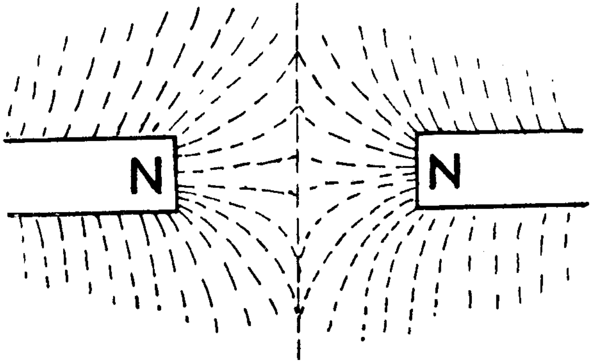


Fig. 6.

POLARITY.

Magnetic Power Resident at Poles.—If one end of a magnet is brought near to a piece of soft iron, attraction ensues; and if the two are allowed to touch, they will adhere to each other. It is immaterial which end of the magnet is used; both will equally attract the iron. If, however, the latter is presented to the centre of the magnet—that is, to the region midway between

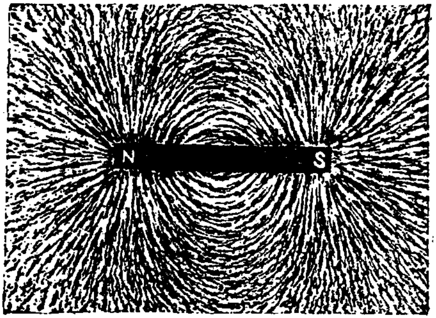


Fig. 7.

the ends—no attraction follows. The power of the magnet is resident at the ends.

Two kinds of Poles.—One end of every magnet is marked either with the letter N, or is in some way distinguished from the other. In fact, the two ends are commonly known as the North and South Poles, or as the "marked" and "unmarked" poles.

If the marked end of a bar magnet is brought near to the unmarked end of a compass needle, attraction takes place between them. Similarly, if we bring the unmarked pole of the bar magnet near to the marked pole of the needle, attraction takes place. But if we bring together the marked ends both of the magnet and of the needle, or both the unmarked ends, there is not only no attraction between them, but a new behaviour is seen—one pushes away or repels the other. Thus magnetism has a twofold or double character, giving rise to the equal but opposite effects of attraction and repulsion. This is summed up in the well-known law that "Like poles repel, unlike poles attract each other."

Between two magnets, then, we have attraction and repulsion, but between a magnet and a piece of iron we have attraction only—both magnet poles attract the latter equally.

FIGURES MAPPED OUT BY FILINGS.

The effects of attraction and repulsion are graphically shown by means of iron filings. Let a horseshoe magnet, with its keeper off, be placed on a table, and a sheet of smooth, stiff paper be placed over it. On sprinkling some fine iron filings over the paper in the region of the underlying poles we shall find that the filings do not fall haphazard, or in shapeless heaps, but take up a certain definite direction (Fig. 4). They arrange themselves in a series of lines or curves between the poles of the magnet, just as if there were something "flowing" between them. These curves are termed "**lines of force,**" and the region permeated by them a "**magnetic field.**"

The unlike ends of two-bar magnets may be substituted for the horseshoe (Fig. 5), and a similar figure will follow; but if we reverse one of them so that **like** poles face each other, the lines will present a very different appearance (Fig. 6). Instead of springing from one pole to another they seem to be avoiding each other in every possible way.

The lines issuing thus symmetrically from each pole are not wandering aimlessly into space, but are seeking a dissimilar pole—either of their own magnet or of another magnet. This is best seen by using a somewhat short bar magnet and scattering the filings over it (Fig. 7). The lines are flowing from one pole to the other, not only in the plane of the paper, but at right angles and at all other angles so as to form a kind of globe or sphere.

Direction of Lines.—For the sake of clearness, a direction is imputed to the lines of force—viz., from N. to S., or the direction in which a " free " N. pole would move.

Effect of Breaking a Magnet.—In all these experiments our original observation has been confirmed—namely, that the magnetic force, as indicated by the lines of filings, resides in the poles alone. But we are led to wonder what is going on in the mass of the magnet, and whether it is entirely inactive.

Imagine a horseshoe magnet to be broken into halves. This gives us two new ends at the fracture. On presenting each of these new ends in turn to the poles of a compass needle we get attraction and repulsion. We have indeed, in each half, a complete magnet. Further, if we break the magnet into any number of lengths, each piece will have its two poles, and these will be of dissimilar kind. An isolated pole or magnet with one pole is impossible.

CLOSED MAGNETIC CIRCUIT.

Having broken our horseshoe magnet into halves, consider the converse operation. Let us reunite the two parts as closely as we can. The poles which appeared at the fracture now disappear. We know that lines of force were passing from one face of the fracture to the other, and to do this they had to pass through the air between them. But they can now pass from one face to the other without encountering any intervening air. Hence the mass of the magnet is not inert or idle, but the lines of force are passing through the whole interior. In fact, the lines which we see springing from one pole to the other are really portions of endless " loops," the rest of which pass through the mass of the magnet.

If now the keeper is placed across the proper poles of the magnet, **these** poles also disappear. The magnet will now give no sign of magnetism, except for a small effect due to the imperfect contact between the keeper and the ends. This explains why, although the magnetic influence permeates the magnet, only the ends exercise magnetic power. This power is exhibited only where the lines of force stream into the air seeking another (unlike) pole.

Such an arrangement as this (that is, a horseshoe magnet with its keeper on, or two bar magnets with unlike poles adjacent, and with two keepers on) furnishes for the lines of force a complete metallic circuit, and is termed a " closed magnetic circuit." Such a closed circuit gives no external effects. For the production of magnetic effects, the magnetic circuit must always be incomplete, so as to provide two poles and a magnetic field between them.

MAGNETIC INDUCTION.

If we put a bar magnet on the table, and place a small length of soft iron in contact with one of its poles, we shall find that the remote end of the iron has become capable of attracting other pieces of iron. It has, in fact, become a magnet. We can place other lengths of iron in line, and the last one of the series will exhibit the same magnetic properties.

Actual contact is not however necessary. We can separate the magnet and the soft iron bar by a considerable space, but the bar will still be rendered magnetic, and will be capable of attracting other iron particles.

If the soft iron bar is placed **near** the N. end of the magnet but not in contact with it, and if we bring a compass needle near that end of the iron remote from the magnet, the S. pole of the needle will be attracted and the N. repelled. This is precisely the effect which the magnet pole itself (near which the iron is placed) would produce. That is, the mere presence of the magnet near the soft iron has made the latter into a perfect magnet for the time being, its S. pole being nearest to, and the N. pole farthest from the magnet. If the S. pole of the magnet be used, then the polarity of the iron will be reversed, the near end being N. and the remote end S.

This effect of magnetisation through space is termed **induction**; the permanent magnet is termed the **inducing** magnet; and the magnetism set up in the iron is termed **induced** magnetism.

When the magnet is removed, the soft iron at once loses its magnetic properties.

We can now understand the reason for the different behaviour of magnets upon each other, and upon soft iron. Between magnets we obtain both attraction and repulsion when we bring together unlike and like poles; but we invariably have attraction between a magnet and soft iron, whichever pole we use. The reason is that when the soft iron is brought into the " magnetic field" it is acted upon **inductively,** and an opposite pole is induced in the end near the inducing magnet, and **therefore** attraction ensues. If the inducing magnet were reversed so as to present its opposite pole to the iron, the induced polarity would also be reversed, and attraction again follow.

Repulsion the only true test of Magnetism.—It will thus be seen that repulsion is the only true test of magnetism; repulsion proving that an unknown body has magnetic qualities of its own. The mapping out of the lines of force, by means of iron filings is also clear. Each tiny particle within the magnetic field becomes a magnet, and the small magnetic particles set themselves in line.

SOFT IRON AND HARD STEEL. COERCIVE FORCE. RETENTIVITY.

We have seen that as soon as **soft iron** is removed from the neighbourhood of a magnet it loses its induced magnetic properties. If, on the other hand, we bring a piece of **hard steel** into the magnetic field the mere proximity of the magnetic affects it but slightly; but on being taken out of the magnetic field the steel retains some of its acquired magnetic power. The reason is that the process of magnetisation sets up molecular movements in the metal; but in steel these movements are only accomplished with difficulty because of its hardness. In the process of hardening, hammering, etc., the particles have been forced into the closest relationship; in other words steel possesses great "**coercive force,**" or the power of resisting molecular movement, and is therefore difficult to magnetise. When magnetised, however, this "coercive force" makes it difficult to reverse the process; the steel therefore retains its magnetism. A high degree of coercive force thus necessarily implies a high degree of "**retentivity.**" Soft iron, on the other hand, has but little coercive force, its molecular movements are easily effected, hence its magnetisation is easy. But it loses its magnetism as easily as it acquires it. That is to say, its "retentivity" is very low. Hence for temporary magnets the softest iron is used; whilst for permanent magnets the hardest steel is required.

RESIDUAL MAGNETISM.

It should be borne in mind, however, that the softest iron will retain some slight trace of magnetism after the removal of the magnetising cause: this is residual magnetism. The hardest steel likewise will slowly part with some of its magnetism under favourable conditions.

MAKING OF PERMANENT MAGNETS.

Since the bringing of a steel bar into a magnetic field has but little effect upon it, it is necessary to rub or stroke the bar to be magnetised with a powerful magnet. This rubbing or stroking must be done in a regular and methodical manner, care being taken always to repeat the strokes in the same direction. The usual workshop method of making magnets is, generally, either to use a powerful permanent horseshoe magnet of large size, or an "electro magnet" excited by an electric current. Both types are furnished with suitably shaped pole-pieces of soft iron, which are adjustable so that the space between them can be altered to suit the size of the bar to be magnetised. The bar is then placed across the poles so as to bridge the gap between them, and thus to concentrate the lines of force through it. It is then drawn along the poles and, at the end of the stroke, pulled off. The latter part of the operation is necessarily somewhat of a "wrench" and plays an important part in the operation. The bar is then again put on the poles and the operation repeated.

Consequent Poles.—Small bars are sometimes magnetised by stroking them with large magnets held in the hand. If this stroking is not done in regular manner or with proper regard to polarity, the bar may be irregularly magnetised; that is, not only may the required unlike poles appear at the ends but others may be formed in the length of the bar. Such irregular poles are known as "consequent" poles.

Saturation.—In making magnets, it is desired that they shall be magnetised to the utmost limit. This condition when no further increase is possible, is termed "saturation," and it is difficult to attain with hard steel. In fact, where very large permanent magnets are required, it is usual to employ a number of thin plates or laminæ bolted together, in preference to a solid bar. These thin plates are much more easily magnetised and the point of saturation more easily approached. When put together thev form a "compound" or "laminated" magnet (Fig. 8).

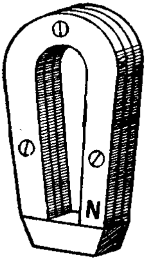


Fig. 8.

THE EARTH'S MAGNETISM.

We have seen that the compass needle sets itself pointing North and South. This is due to the Earth's magnetism. The terrestrial globe behaves as though a large bar magnet had been thrust through its mass, the ends coming to the surface near the geographic poles. The effect is that the whole of the surface of the earth is covered with lines of force—is a huge magnetic field.*

Taking any of the globes in common use in the schools we have two fixed points, the geographic North and South poles. The imaginary line joining these is the axis of the earth, on which it makes its daily rotation. On the surface we have the equator line, running East and West round the earth and equidistant at all points from both poles. Parallel with this line or circle are other circles, diminishing in size as they approach either pole; these are the parallels of latitude. They include the Arctic and Antarctic circles, the tropics of Cancer and Capricorn, etc., which can be seen on any map of

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* That pole of the magnetic needle which pointed north was naturally called the "north" pole. Its polarity really is the same as that at the Earth's south pole, since we have seen that unlike poles attract. The difficulty is got over by terming it the "north-seeking" or "marked" pole.

the world (in hemispheres). Further, from each pole to the other the meridians of longitude run. They diverge as they leave one pole, and when they cut the equator are at their greatest distance apart. They then converge and finally meet at the other pole. By means of these parallels and meridians the position of any spot on the earth's surface can be exactly stated (Fig. 9).

The earth, considered magnetically, has a precisely similar set of terms. With the magnetic North and South poles we have a magnetic axis; also a magnetic equator and magnetic meridians, etc. Now if the magnetic and geographic poles (and therefore axes) coincided, that is, occupied exactly the same positions, all the other members of the magnetic system would coincide with the members of the geographic system.

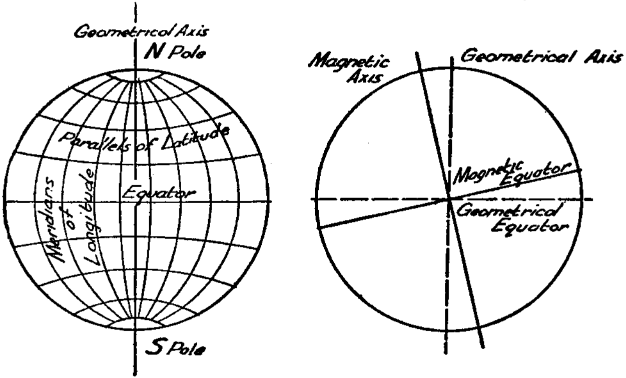

Fig. 9.

Declination.—But the magnetic and geographic poles do **not** coincide. Take our position in England; the magnetic pole in the Northern hemisphere is somewhat to the West of the geographic pole, and the magnetic pole in the Southern hemisphere is correspondingly somewhat to the East.

If we take any place on the earth's surface and imagine a line (more correctly a plane surface) drawn from the North to the South pole and passing through this place, such a straight line is the geographical meridian at that place. Similarly a line drawn from one magnetic pole to the other and passing through this place will be the magnetic meridian at that place.

In England, as we have seen, owing to the want of coincidence between the geographical and magnetic axes of the earth, the geographical and magnetic meridians make an angle with each other. This is the " angle of declination," and in London its value is about 20 deg.

As regards the declination at other parts of the globe, it will readily be seen that if we go round the earth on a circle running East and West (such as the equator), there will be two points at which the angle is at the maximum and two other points where it disappears, or at which the geographical and magnetic meridians coincide, and the compass needle points to the true North and South. Between these four points the angle is alternately increasing and decreasing.

Inclination.—But there is another effect of the earth's magnetism, which is masked in the ordinary compass needle. This is " dip " or " inclination." Imagine (in England) a compass needle carefully balanced and pivoted, before magnetisation, so as to be perfectly horizontal. It will of course come to rest in any position, having no polarity. We now magnetise it as completely as possible. It will now point North and South, but in addition to this the needle will no longer lie horizontally but the N. end will appear heavier and will " dip " or make an angle with the horizon. If we take it into the Southern hemisphere at a similar distance from the S. pole, the S. end will appear the heavier and will dip. Further, if it were taken to the S. magnetic pole, the angle would increase, and the needle would take up a vertical position—S. pole downwards—in line with the imaginary bar magnet to which we have ascribed the earth's magnetism. At the N. magnetic pole it would also be vertical, but with its N. pole downwards. The ordinary compass needle on a vertical pivot will not serve for these experiments, but a " dipping needle," balanced on horizontal pivots is used (Fig. 10).

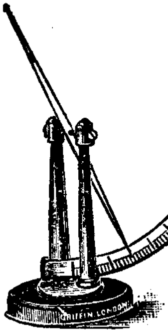

Fig. 10.

Thus the dipping needle at the magnetic poles will be vertical, or will make an angle of 90 deg. with the horizon. At the magnetic equator it will be horizontal, and in other positions will make varying angles. This is the " angle of dip " or " inclination." In England it is some 67 deg.

The force acting on the dipping needle is the " vertical component " of the earth's magnetism: that acting on the compass needle, the " horizontal component "; the " total force " of the earth's magnetism is the resultant of these two.

We have compared the earth's magnetism with the effects which would be produced if a bar magnet were pushed through an otherwise non-magnetic ball. It should, however, be understood that this comparison is very rough; the actual magnetic behaviour of the globe simply approximates to it. A " bar magnet" implies some regularity of shape and magnetic symmetry, but the earth possesses these characteristics in only a limited degree. Huge non-magnetic bodies, such as rocks, stones and seas are interspersed with irregular masses and veins of magnetic matter, rendering impossible any regular distribution of magnetic properties.

MAGNETISM INHERENT IN IRON AND STEEL.

We have seen that a magnet has the power of magnetising iron and steel. By various experiments and facts we are led to believe that the magnet does not give up anything, in imparting its magnetism. It becomes no lighter, nor does it become weaker. We therefore conclude that magnetism is inherent in iron and steel, and that all the magnet does, in magnetising these bodies, is to bring out this quality, previously latent. We know that if a magnet be broken into any number of pieces, each piece, however small, is a complete magnet. So we imagine that the particles themselves, of iron and steel, are tiny but complete magnets.

In the case of an unmagnetised bar of **soft iron,** the particles, having a certain freedom of movement, naturally try to satisfy each other's polarity—the N. end of one attracting the S. end of another—so that throughout the mass they form with each other "closed magnetic circuits," and thus exhibit no external effects. But when a powerful magnet is placed at the end of the bar these internal arrangements are upset, and all the particles turn symmetrically, with their similar poles in one direction. When the magnetising force is withdrawn the tiny magnets seek each other as before, and form new combinations and magnetic circuits.

In the case, however, of **hard steel,** the particles are driven much closer together by hammering and compression in the hardening of the metal. Hence when a powerful magnet is brought near they are not so free to obey its influence, but require repeated application in order to turn them. But when the magnetising force is removed the particles cannot easily return to their old natural positions, but remain as the magnet placed them, and we have a permanent magnet.

PART II.—ELECTRICITY.

The first method of producing an electric current was by chemical action in the "Voltaic" cell, so-called from its originator, Volta. Current on a large scale to-day, as for lighting, etc., is produced by steam-driven dynamo-machines; but for the comparatively small currents required in telegraphy and telephony, primary and secondary batteries are in exclusive use.

SIMPLE VOLTAIC CELL.

To make a simple primary cell we take a strip of clean, pure zinc and a similar strip of copper and immerse them in dilute sulphuric acid (Fig. 11). So long as the strips do not touch each other no action takes place. If, however, we connect the two metals by a stout copper wire, chemical action at once commences; the zinc is eaten away, and bubbles of gas rise from the copper strip.

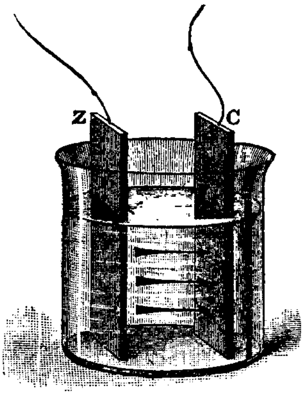

Fig. 11.

If we include in the path of the connecting wire a short piece of fine platinum wire, the latter will become heated. By suitably arranging the experiment the platinum wire may become white hot or even be fused. On breaking the connection between the two metals the action in the cell ceases, and the wire cools.

Again, we take a compass needle and bring a portion of the wire connecting the two metals beneath or above it and parallel with it in its position of rest, pointing North and South. The compass needle is at once deflected from its North and South position to the right or left. On breaking the connection between the two plates at any point, the needle returns to its position of rest.

These two effects are due to the fact that when the metallic path between the two strips of metal is complete a current of electricity passes through it—heating the platinum wire or deflecting the needle. It will be seen that the two metals are really in contact with each other by means of the liquid; when therefore we put them in metallic connection with each other outside the containing vessel, we make a second contact and thus set up a complete path. The current then starts from the zinc plate, where the chemical action is going on, passes through the liquid to the copper plate, heats up the platinum wire or deflects the needle, and then returns to the cell. So long as the chemical action goes on, so long the current flows along the path set up. This path is called the " circuit." When it is complete, or " closed," the current flows; but when it is incomplete, open or broken, even by the smallest interval of space, the current cannot flow. That portion of the path outside the cell is called the **external** circuit, and that within the cell is called the **internal** circuit.

CHEMICAL ACTION IN THE CELL.

The result of the action set up in the cell when the circuit is closed is that the zinc is eaten away and bubbles of gas rise from the copper strip. Sulphuric acid is composed of hydrogen, sulphur and oxygen, but in the presence of the zinc the sulphur and oxygen have a greater " chemical affinity " for that metal than for their neighbour, hydrogen. The latter is therefore set free and rises as gas from the copper strip. The zinc then enters into combination with the sulphur and oxygen, and forms a new substance, sulphate of zinc, a white salt which dissolves in the liquid as soon as it is formed.

Since we get sulphate of zinc as a result of the chemical action, it is evident that action must take place at the surface of the zinc strip. It would therefore appear natural to expect that the gas should be liberated at the zinc strip. But it actually appears at the copper strip. An ingenious explanation is to the following effect:—

The " molecules " of the dilute sulphuric acid in the cell arrange themselves in numberless chains, stretching from strip to strip as shown graphically on a large scale in Fig. 12.

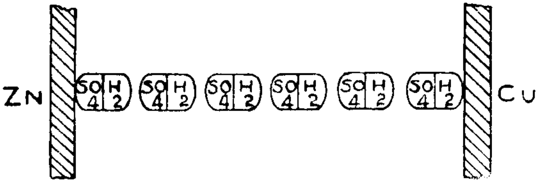

Fig. 12.

In this Figure H2SO4 is the chemical expression for sulphuric acid, indicating that it is composed of two parts of hydrogen by volume, and one of sulphur, and four of oxygen. A complete particle or " molecule " is shown in each oval.

When the action commences, the molecule next to the zinc is broken up, the SO4 combining with an atom of zinc to form zinc sulphate (Zn SO4). The hydrogen thus liberated combines with SO4 of the next molecule, setting free its hydrogen. This process goes on throughout the chain until the last molecule, touching the copper, is reached. When the hydrogen of this molecule is set free there is nothing with which it can combine, there being no " chemical affinity " between hydrogen and copper; hence most of it rises from the copper plate.

PURE AND IMPURE ZINC. LOCAL ACTION.

In setting up our simple cell we used " clean, pure zinc." This is in contrast with the zinc of commerce which contains many impurities, including traces of iron and other metals. If we had used this ordinary metal the mere act of putting the strip in the liquid would have started chemical action. Also when the cell is at work some of its energy would be wasted by reason of these impurities. They really form tiny cells. Suppose a small particle of iron to be fixed in the plate below the surface of the acid. Then obviously the iron and the zinc are in metallic contact, and are also connected by the liquid. These are exactly the conditions which are necessary for a cell.

It will be apparent too, that since all the electric current generated in these miniature cells simply passes round their own little " circuits," all the action thus going on is wasted; that is, none of it is sending current through the external circuit. This is termed " local action " and its effect is to consume the zinc needlessly. All the zinc of commerce is more or less impure, and to employ the pure metal would be expensive.

AMALGAMATION.

An entirely satisfactory method of getting rid of local action whilst using ordinary commercial zinc consists in " amalgamating " the zinc. The plate is cleansed in dilute acid and then dipped in, or covered by, mercury. Mercury possesses the peculiar property of entering into exceedingly intimate relation with many metals, and thus forming " amalgams." The layer of mercury completely covers over the impurities and takes the place of the liquid connection between them and the zinc plate. Thus treated, the plate behaves as practically pure metal.

POLARISATION.

If the simple cell is joined up to a suitable " galvanometer," consisting of a few turns of thick wire round a magnetised needle, and allowed to work continuously for some time, the current will be seen to fall off in strength. This is due to the liberated hydrogen gas, which is formed on the copper plate. A stream of bubbles rises to the surface of the liquid, but a large quantity remains on the surface of the plate. The effect of this is partly to " insulate " the copper plate from the liquid of the cell. The hydrogen gas on the copper plate also tends to set up an opposing current, i.e. from the copper to the zinc. This action of the adhering hydrogen is termed " polarisation."

DEPOLARISATION.

In all primary cells zinc is used as the " positive " plate or element, and polarisation due to the liberated hydrogen is more or less present in them all. It is in the means employed to prevent polarisation that voltaic cells differ from one another.

Daniell divided his containing vessel into two parts by means of a partition of porous (unglazed) ware. On one side are placed the zinc and dilute acid; on the other side the copper and a solution of copper sulphate ($CuSO4$). The porous division prevents the mixing of the two liquids, or renders it a very slow process, but allows the chemical action to go on through it and the current to flow. The hydrogen set free from the final molecule of the sulphuric acid (Fig. 12) now finds the copper sulphate in its path. It breaks up the molecules of this solution, as it did those of the sulphuric acid, but at the end of the chain we have metallic copper set free instead of hydrogen. This is deposited on the copper plate where it does no harm. This is an example of a liquid depolariser and of a " double-fluid " cell.

LECLANCHÉ CELL.

Perhaps the best known form of all primary cells is the Leclanché cell. As in all other forms, zinc is the positive element, and the consumption of the zinc furnishes the current. The negative element is carbon; the exciting fluid is a solution of ammonium chloride (sal-ammoniac) in water; and a black solid (manganese dioxide), is the depolariser.

In the common form of the cell (Fig. 13), the carbon, in the shape of a plate, stands in a circular porous pot, which is filled up with a mixture of carbon and manganese dioxide; both these substances being broken into small pieces. The porous pot, thus filled, is placed in a vessel usually of glass, containing a zinc rod and the ammonium chloride solution.

When used on a large scale slight alterations are made in the arrangement of the Leclanché cell. A large earthenware jar is used instead of the glass, and the zinc is cast in the form of a hollow cylinder so as to surround the porous cell.

Fig. 13.

When the battery is at work the ammonium chloride attacks the zinc, and chloride of zinc is formed. The remaining components of the ammonium chloride then split up into ammonia and hydrogen. The former is liberated as gas, and the hydrogen passes on towards the carbon; but is engaged by the surrounding manganese dioxide. In the process the manganese dioxide depolariser is reduced to a lower oxide, and water is also formed. The manganese dioxide, however, acts slowly; hence if the hydrogen is generated in large quantities by the withdrawal of a strong current from the cell polarisation occurs. If allowed to rest, the hydrogen is absorbed and the cell is ready for fresh action.

Some quite remarkable results have been obtained from cells of the wet Leclanché type by reducing to powder the mixed broken carbon and manganese dioxide with which the porous pots are filled. Formerly such dust or powder was rigidly excluded from the cell but it is now found that the mixture can scarcely be broken too small. It is well " punned " into position round the carbon plate, this operation being of first importance. Cells so set up have given much increased output and the tendency is to make this the only form of primary battery for telegraphic and telephonic use—displacing other types.

DRY CELLS.

The so-called " dry " cell is practically a Leclanché without actual liquid. The place of the liquid is taken by a moist paste consisting mainly of the usual materials of the Leclanché cell (Figs. 14 and 15).

Figs. 14 and 15.

SECONDARY CELL.

The Leclanché just described, the Daniell and many other forms, are " primary " cells, that is on bringing together the materials and setting up the battery, it is ready to give current. The " secondary " cell on the other hand, has no power to do this until a current has passed through it—hence its name.

When the electric current passes through certain liquids, they split up or suffer decomposition. This is termed " electrolysis " or electric analysis, and such liquids are " electrolytes." The orginial secondary cell was a pair of lead plates immersed in acidulated water. On connecting this with a suitable primary battery the acidulated water or electrolyte was split up, the oxygen going to the plate by which the charging current entered, and oxidising it whilst the hydrogen was given off at the other plate. This was the operation of " charging " the cell, and at the end of the charge, instead of two similar lead plates we had one plate of lead oxide (surface) and the other of plain lead. The cell was then capable of furnishing a current, the " discharge " current, at the end of which the oxidised plate was robbed of its oxygen and the original conditions restored of two similar lead plates.

Such an arrangement was of little use for practical purposes, the effects obtained being very small. The efforts of makers have therefore been directed to increasing the area of the plates without adding to their weight—that is, getting the utmost amount of **surface** from a given weight of lead, and also to facilitating the work of the charging current.

The plates are now cast full of corrugations, and are mere perforated shells or " grids," the interstices of which are filled in with a paste made up of lead oxide and sulphuric acid. The charging current has thus to act on a material of much looser texture than the solid lead, and, further, the active surface is enormously increased. Such are " pasted " plates. Other plates in use are not pasted, but after utilising every means for the increase of surface, are " formed " by repeated charging. The latter are more costly, but are less liable to disintegration.

The end aimed at by the charging current is to oxidise the positive plate to its utmost extent or to produce the greatest quantity of peroxide of lead, and that the negative plate, of plain lead, shall be in as spongy a condition as possible.

The function of the sulphuric acid was formerly regarded as simply to increase the conductivity of the water. But the quantity of acid used is greater than is required for this purpose. Also, during discharge, the specific gravity of the solution gradually falls; during charge it rises. The specific gravity of the electrolyte is indeed a valuable indication of the state of the cell. It therefore appears that the acid itself enters into the operation, and during discharge the specific gravity falls by the dilution of the electrolyte. The effect of charging is then to restore the diluted solution to its normal density.

The changes in the gravity of the solution are gauged by **the hydrometer,** a graduated pencil of glass weighted so as to float in a vertical position (Fig. 16). When placed in water it indicates zero; when in a fluid lighter than water it sinks deeper, and in a heavier fluid it sinks less. During charge the voltage also rises. When the gravity is in the neighbourhood of 1,200 to 1,210, and the voltage is in excess of 2 volts, the cell may be considered as fully charged. As discharge proceeds, both the gravity and the voltage fall, and discharge should not be carried farther when these values reach 1,170 and 1.85 volts per cell.

Secondary cells are made up with several positive and several negative plates per cell. The negatives—one more in number than the positives—are connected together to form one equivalent large plate, and similarly with the positives. When in use for electric lighting the individual plates are very large, and one cell may contain up to 20 or 30 plates. For telegraphic and telephonic use, smaller plates and a lesser number of them are required. A 7-plate cell is illustrated in Fig. 17.

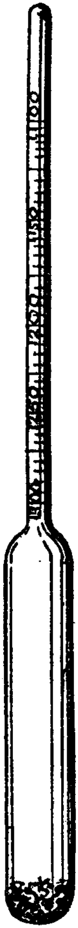

Fig. 16.

RESISTANCE—CONDUCTORS AND INSULATORS.

We spoke of using a stout copper wire to connect the poles of our simple cell (p. 16). The reason for the employment of this metal is that it allows the electric current to pass with great freedom—that is, it is an extremely good " conductor." If we had used a similar piece of indiarubber or of gutta-percha, the connection would have been useless, because these substances offer enormous " resistance " to the current. They are, in fact, extremely good " insulators." But between these two extremes of good conductivity and good insulation there are substances offering every gradation. The dilute acid of our simple primary cell, for instance, allows the current to pass, but it is not a good conductor, nor is it a good insulator. There is, moreover, no perfect insulator or conductor.

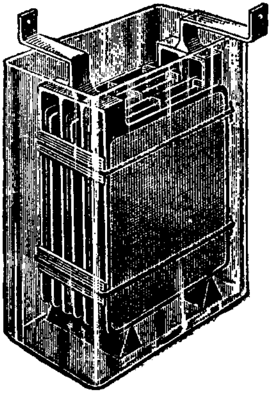
Fig. 17.

For a proper comparison of these properties we need to arrange the materials in the order of their qualities of conduction or of resistance. We can say of the metals that their conductive property is very high, and of substances like gutta-percha that their conductive property is very low indeed. On the other hand, in respect of resistance or the obstruction offered to the passage of a current, gutta-percha and indiarubber possess this property in a very high degree, but the resistance offered by metals is very low. In practice, references and measurements are universally made in terms of resistance.

UNIT OF RESISTANCE.

The **standard unit of resistance is the " ohm "** and is the resistance offered by a column of mercury 106.3 centimetres long and one square millimetre in cross-section at a temperature of O°C. The greater the length of a material of the same cross-section, the greater its resistance, and the greater its cross-section in the same length, the less its resistance.

SPECIFIC RESISTANCE.

The resistance offered by a certain definite length and sectional area of any material is called its " specific resistance." Similar lengths and areas of other materials then give us the means of comparison. The dimensions chosen are a centimetre cube—that is, a small block one centimetre long and one square centimetre in cross-section. The specific resistance of silver is 1.49 microhms (millionths of an ohm) of copper 1.57, platinum 8.98 carbon 4,000 microhms, or .004 ohm, whilst that of gutta-percha is some 460,000,000 megohms (million ohms).

Resistance also varies with temperature. When heated the resistance of metallic bodies increases, whilst the resistance of carbon decreases. Hence in defining the ohm it is necessary to specify the temperature at which the standard unit is fixed.

E. M. F.

Different types of primary cells have different degrees of power to generate current in a circuit. Imagine a circuit of very high resistance—say many thousand ohms—including a suitable galvanometer (*see* p. 28). A Daniell cell, a Leclanché, and a secondary cell form part of it in turn. The high external resistance of the circuit renders the small **internal** resistance of the cells negligible. The current set up by the Daniell cell will be of a certain strength; that set up by the secondary cell will be practically double this strength; whilst that from the Leclanché cell will have an intermediate strength. That is to say, they exert different degrees of force. This inherent quality is called **the electromotive force** (E. M. F.) of the cell, and it depends entirely upon the **kind** of materials used, and not upon the size of the plates. If we use zinc, carbon, sal-ammoniac solution, and manganese dioxide (as in the Leclanché cell), we have settled the E. M. F. of the cell, and this will be of the same value for all Leclanché cells, whether large or small. The large cell, however, will have a lower internal resistance than the small.

The **unit of E. M. F.** is the " volt," and is approximately the E. M. F. of a Daniell cell. The Leclanché gives an E. M. F. of about 1½ volts, and the working E. M. F. of the secondary cell is about 2 volts.

CURRENT.

Current is the **rate** at which electricity passes along a circuit. If we connect up a battery to a resistance of 20 ohms for five minutes a certain quantity of electricity will pass. But if we then connect it to a circuit of 100 ohms for a similar length of time, a much smaller quantity will pass. The current in the first case is much stronger than in the second.

We have defined out units for E. M. F. and resistance. The **unit of current** depends upon these, and is termed " ampère." When a circuit has a total resistance of one ohm and an E. M. F. in it of one volt, the resulting current is one ampère in strength. In telegraphy and telephony much smaller currents are employed, and to avoid the constant use of fractions, a thousandth part of an ampère is taken as the working unit, and is called a " milliampère."

OHM'S LAW.

This relationship between the three quantities, E. M. F., resistance, and current, is of great importance. It is stated in Ohm's Law, from its discoverer, as follows:—

> " Current is directly proportional to the E. M. F. producing it, and inversely proportional to the resistance opposed to it."

That is, if the resistance be constant, the greater the E. M. F. the greater the current; and with the E. M. F. constant, the greater the resistance the smaller the current. This relationship is indicated by the following:—

CURRENT (C) (in ampères) = E.M.F. (in volts) divided by RESISTANCE (in ohms).

and from this—

RESISTANCE (R) = E.M.F. divided by CURRENT.

and—

E.M.F. (E) RESISTANCE multiplied by CURRENT.

Examples.—6 secondary cells, each having an internal resistance of .01 ohm and an E. M. F. of 2 volts, are connected up to an external circuit of 5.94 ohms. What is the value of the current?

$$\text{Current} = \frac{\text{Total E.M.F.}}{\text{Total resistance.}}$$

$$= \frac{6 \times 2}{5.94 \text{ (external)} + 6 \times .01 \text{ (internal)}}$$

$$= \frac{12}{6} = 2 \text{ ampères.}$$

(2) What is the total resistance of a circuit in which 4 cells, each having an E. M. F. of 1.5 volts, are setting up a current of ½ ampère?

$$\text{Resistance} = \frac{\text{Total E.M.F.}}{\text{Current}} = \frac{4 \times 1.5}{.5}$$

$$= \frac{6}{.5} = 12 \text{ ohms.}$$

(3) A current of 10 milliampères (1/100 ampère) is flowing in a circuit from 5 cells. Each cell has a resistance of 5 ohms and the external resistance is 475 ohms. What is the E. M. F. of the battery?

$$\text{E.M.F.} = \text{Total Resistance} \times \text{Current.}$$

$$= (475 + 5 \times 5) \times \frac{1}{100}$$

$$= 500 \times .01$$

$$= 5 \text{ volts or 1 volt per cell.}$$

JOINING UP OF CELLS.

In practice several cells are usually required, a single cell rarely being sufficient. When the external resistance is high compared with the internal resistance of the cells, as in the case of a telegraph wire of some thousands of ohms, it is found advantageous to connect the cells in " series "—that is, the zinc or – terminal of one cell is connected to the carbon or + of the next, and so on, leaving a terminal zinc and a terminal carbon free for connection to the external circuit. By this arrangement the E. M. F.'s of the cells are added together, and also their internal resistances. Connecting up two Leclanchés in this way—each having an E. M. F. of 1.5 volts and an internal resistance of 2 ohms—we get a total E. M. F. of 3 volts and internal resistance of 4 ohms. 10 cells give us 15 volts and 20 ohms, and so on.

When, however, the external resistance is very low, this "series" arrangement is not of much use, since we increase the internal resistance at the same rate as the E. M. F. In such cases cells may be connected "in parallel," that is to say, all the zincs are connected together, and the wire from thence becomes the terminal of the battery, and all the carbons similarly are connected and their wire becomes the + terminal. The E. M. F. of the combination (the cells being all of one type and all of the same internal resistance) is that of a single cell; but the internal resistance is decreased inversely as the number of cells and the combination becomes equivalent to one large cell with a very low internal resistance. Two of the Leclanché cells already considered, joined up in parallel, have an E. M. F. of 1.5 volts, and the internal resistance is reduced to half, i.e., is 1 ohm. Ten such cells in parallel have an E. M. F. of 1.5 volts and internal resistance of 0.2 ohms. This plan, however, is not now much resorted to. A better plan is to employ larger cells having a smaller internal resistance.

RESISTANCES IN SERIES AND IN PARALLEL.

When any number of resistances such as the coils of instruments, etc., are connected together in "series," so that the current passes through them in succession, as in Fig. 18, the total resistance is the sum of them all. Thus in the figure the total resistance between A and B is 50 + 100 + 20 = 170 ohms.

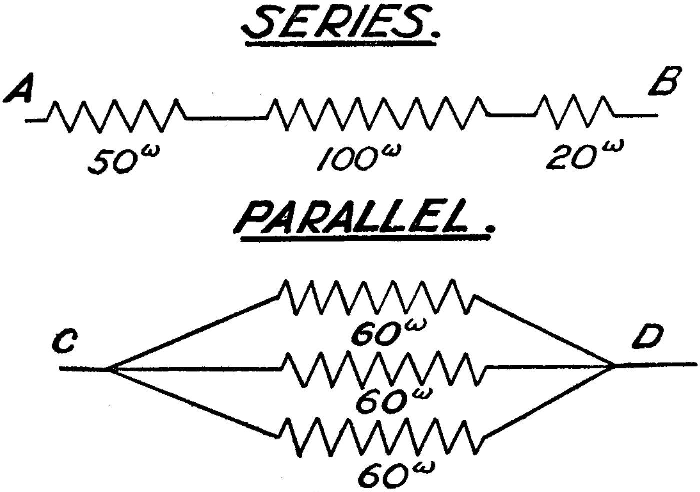

Fig. 18.

When resistances are placed in " parallel " or in " multiple-arc " with each other, so that the current can travel by several paths, the total or joint resistance between C and D will always be less than the resistance of the lowest path; that is to say, the total conductivity between the points will be increased. The arrangement is indeed equivalent to a thicker wire. If two equal resistances are in parallel, the resistance will be reduced to one-half: if three, as in the figure, to one-third (20 ohms), and so on.

With unequal resistances in parallel the calculation becomes more complicated.

MAGNETIC EFFECT OF CURRENT.

We have seen that when a magnetic needle is parallel to a wire above or below it, a current passing through the wire causes the needle to set itself at an angle with the wire. (Page 16.)

Asume the wire to be above the needle and the latter to move with its north pole to the right. If we place the wire below the needle it will now move to the left. Or if we reverse the direction of the current in any one case the movement of the needle is also reversed. The reason for these movements is as follows :—

Imagine a stout copper rod placed vertically through a piece of smooth cardboard and a powerful current to be sent through the rod. If we sprinkle some fine iron filings over the cardboard in the immediate neighbourhood of the rod, they will arrange themselves in concentric circles around the rod, showing that a magnetic field exists there, as illustrated in Fig. 19.

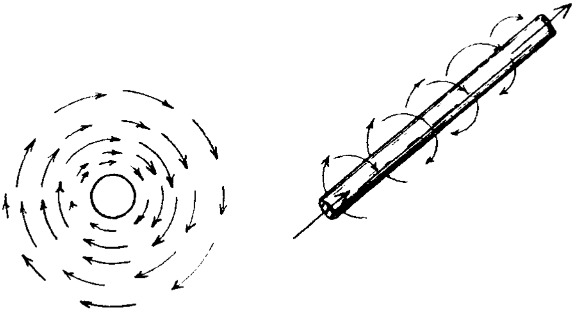

Fig. 19.

Bearing in mind the direction of the current, the direction of these circular lines for force will be as shown in the figure, and these indicate the direction in which an N. pole would move if placed in such a field. This is percisely what occurs with a magnetic needle; its N. pole moves to the right, as shown in Fig. 20. But it can only move horizontally. When it makes an angle of about 45°, the poles get beyond the effective magnetic field, and the needle will not be further deflected. If the needle were below the wire, the directive power of the field would be reversed, and the needle would move to the left.

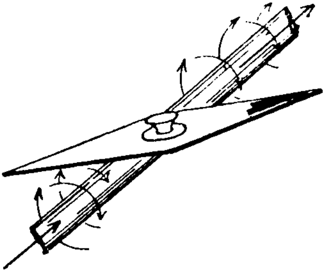

Fig. 20.

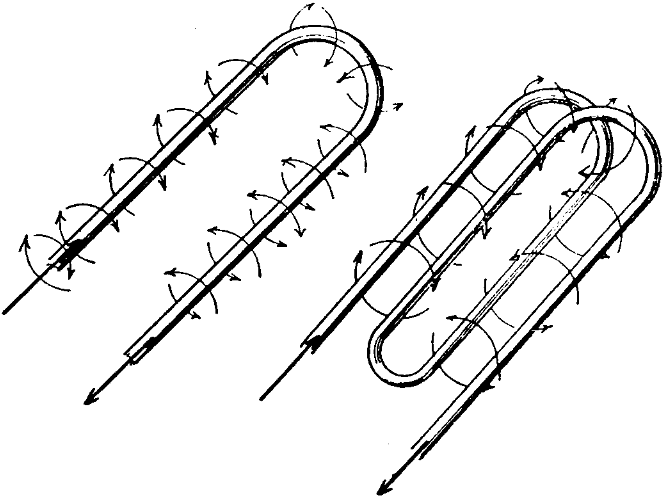

Fig. 21.

Again, if we bring the wire into a loop, as in Figure 21, so as to pass both above and below the needle, both the upper and lower portions act cumulatively, or in the same direction on the needle; and if we bring the wire round in a couple of complete turns, as in the same figure, the upper and lower members all multiply their effects on the needle. The wire must now be insulated, say with cotton or silk.

SIMPLE GALVANOMETER.

The foregoing arrangement is the germ of the simplest form of galvanometer. The essential condition is that the coil of wire must be parallel with the plane of the needle in its position of rest—they may be horizontal, vertical or inclined together, but the planes of the needle and the wires must be parallel.

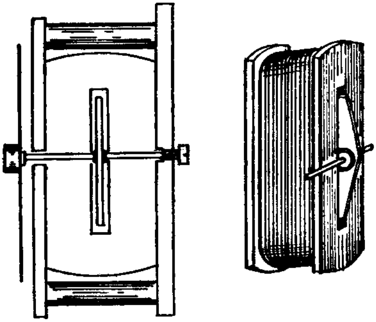

Fig. 22.

Fig. 22 shows the internal arrangements of such a galvanometer, consisting of inner magnetic needle, outer pointer and one half-coil. The needle is vertical and the wires of the coil also run vertically, thus being parallel with the needle in its normal position of rest.

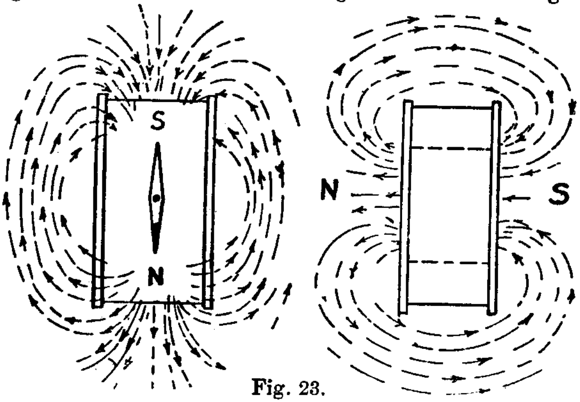

Fig. 23.

Figure 28 may serve to make this feature clearer. The rectangular frame indicates the galvanometer coils. The inner magnetic needle only is shown, and the field due to it is indicated by the arrows. When a current passes through the coil the magnetic field excited by it is at right angles to the field of the magnet. The two fields then try to set themselves in parallel with each other and in the same direction, that is, the N. pole of the magnet moves to the left. If the current is reversed the polarity of the coil is reversed and the N. pole of the magnet moves to the right.

It will be seen that the figure formed by the lines of force in the coil is exactly like that formed by a bar magnet. (*See* Part I., page 8.) The coil, indeed, when energised, behaves exactly as a bar magnet does. If it were pivoted so as to be free to turn it would point N. and S., and the N. pole of another magnet would repel one end and attract the other. For this experiment it is better to use a longer coil wound upon a circular form. This shape is termed a " solenoid." It is then when energised a perfect but comparatively feeble magnet. If, however, we insert in this hollow coil a cylindrical piece of soft iron this " core " is immediately magnetised, and instead of the feeble magnetism of the coil alone, we have a much stronger " electro-magnet." If we reverse the current the polarity of this electro-magnet is reversed. When the current is cut off the magnetism in the coil and core disappears.

ELECTRO-MAGNETIC INDUCTION.

Imagine now a coil of the solenoid type consisting of many thousands of turns of fine wire wound on a tube or bobbin so that there is ample space in the interior for the insertion of an iron core. The ends of the coil are connected to a sensitive galvanometer. (The instrument we have just described is not sufficiently sensistive for this purpose.) We now take a bar magnet which will slide into the interior of the coil, and thrust one pole, say the N., rapidly into the coil. The galvanometer needle is immediately deflected to one side and then returns to zero. Again, we withdraw the magnet as quickly as possible. The needle is again deflected, but in the opposite direction, and again returns to zero.

If we insert the S. pole we shall get a similar " flick " of the needle, but in the same direction as that produced by the withdrawal of the N. pole, and on its withdrawal a " flick " in the same direction as the thrusting in of the N. pole.

Now, as we have seen, the whole exterior of the bar magnet is a magnetic field, the lines being concentrated at the poles. (Part I., page 8.) When, therefore, we thrust the magnet into the coil, these lines of force necessarily move the magnet bodily, and cut across the layers of wire composing the coil.

This " cutting" sets up an "induced" current in the coil. The cutting only occurs when the magnet is in motion, i.e., in the act of being thrust into the coil: as soon as the magnet comes to a standstill, although the lines are still in existence the cutting ceases and the current dies away. The more powerful the magnet—that is, the greater the number of magnetic lines of force—and the larger the number of turns in the coil, and the quicker the movement of the magnet, the stronger will be the momentary current induced in the coil. But it is only transient; it lasts only while the magnet moves.

If we substitute for the permanent magnet an electro-magnet of a suitable size, and thrust this into the coil, we obtain similar results.

Further, if we place the electro-magnet permanently in the coil and lead its wires out to a suitable means of starting and stopping the current passing through them, we shall have similar results without any movement of the magnetic core. The closing of the circuit, and the consequent energising of the electro-magnet, is equivalent to thrusting in the permanent magnet; whilst the opening of the circuit is equivalent to withdrawal. On energising the electro-magnet we bring a magnetic field into existence, and its lines of force cut across the wires of the coil. When the current is cut off the field collapses, and in disappearing the lines of force cut across the wires of the coil in an opposite direction. In such an apparatus we have an " induction coil," the coil of the electro-magnet acting as the " primary " circuit and the outer coil as the " secondary " circuit.

LENZ'S LAW.

The actual direction of the induced current can always be predicted. This is expressed in "Lenz's Law," which states that " a current induced in a conductor by the relative movement of the conductor and a magnet will flow in a direction, the effect of which will be to oppose the originating motion," that is to say, if we thrust the N. pole of a magnet into the coil the induced current is in such a direction as to produce an N. pole at the end of the coil. Obviously such a pole would tend to repel the magnet or oppose its entry. On withdrawing the magnet the induced current is reversed and sets up an S. pole, which tends to attract the magnet or to oppose its withdrawal.

LIST OF

Technical Pamphlets for Workmen.

(Continued.)

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2. Automatic Telephony. Coder Call Indicator (C.C.I.) Working.
3. Automatic Telephony. Keysending "B" positions.

GROUP F.

1. Subscribers' Apparatus C.B.
2. Subscribers' Apparatus C.B.S.
3. Subscribers' Apparatus Magneto.
4. Private Branch Exchange—C.B.
5. Private Branch Exchange—C.B. Multiple, No. 9.
6. Private Branch Exchange—Magneto.
7. House Telephones.
8. Wiring of Subscribers' Premises.

GROUP G.

1. Secondary Cells, Maintenance of.
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GROUP H.

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9. Electrolytic Action on Cable Sheaths, etc.
10. Constants of Conductors used for Telegraph and Telephone Purposes.

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