Notes on Telegraphy

[illegible] EXPOSITION OF THE [illegible] OF TECHNICAL TELEGRAPHY [illegible]

[illegible] PRA[illegible] and G. MOHL.

PREFACE.

AN attempt has been made to set forth in these NOTES the subject of elementary technical Telegraphy and Telephony to meet concisely and adequately the requirements of the Syllabus of the City and Guilds of London Institute's Examination in the Ordinary Grade. Clearness of meaning, together with an accurate elucidation of essential principles, formulæ, laws, etc., has been the predominating aim of the authors throughout; but the outstanding feature, which it is hoped will prove of special value to the average student, is the numerous fully and simply worked arithmetical problems and examples.

Primarily these NOTES were written for the *Telegraph Chronicle* to enable students in the outlying districts, where facilities for organised classes do not exist, to obtain the necessary knowledge of the subject. But, incidentally, it is thought that the work in its present form will not be unacceptable to teachers, who will probably find the demands of the Institute's Syllabus amply and systematically met.

The authors have been frequently asked for advice with regard to the best method to adopt to ensure success at various examinations. They have found after several years' experience of class-work that a persistently carried out system of home-work is an invaluable help. The student should be set questions based upon the work of previous lectures, and, after reading other matter relating to the subject of the questions, he should express *in his own words* his ideas of the answers required. He should quote a law and furnish a sketch whenever practicable. The teacher in turn should very carefully examine such answers, correcting and encouraging the student by marginal notes at every semblance of error or confusion of thought. When this system of co-operation is adopted and persevered with the highest results are invariably assured.

In conclusion, the writers desire to express their indebtedness to the authors of the many standard works on the subjects of technical Telegraphy and Telephony, and also to the contributors to the various electrical periodicals dealing with them from time to time.

BRISTOL, *September, 1904.*

NOTES ON TELEGRAPHY.

CHAPTER I.

ELECTRICITY AND MAGNETISM.

An elementary knowledge of electricity and magnetism is essential to the student of telegraphy and telephony. Several theories have been set up as to the nature of electricity, but as they are of an academical rather than a practical character the usually accepted views will be dealt with. Electricity in a state of rest may be said to pervade all nature, but its effects are not apparent until it is disturbed. When two bodies are rubbed together and then separated a redistribution of the electricity quiescent in each may be said to take place. They have been brought from a non-electrified to an electrified condition. The assumption is that one possesses a greater amount of electricity and the other a smaller amount *than before.* The two conditions are termed *positive electrification* and *negative electrification* respectively.

When a dry glass rod is rubbed with a piece of silk, both the glass and the silk become electrified, and, upon separating them, experiment shows that each possesses properties which it did not previously possess. The glass rod becomes positively electrified and the silk rubber negatively electrified. Friction, then, is one of the causes of redistribution which produces electrification. It is only by the *effects* of electricity that its presence may be determined.

Bodies similarly electrified repel each other, and bodies dissimilarly electrified attract each other.

When two bodies are electrified by being rubbed together the charge of electricity generated on each is the same in amount but different in kind, the one being positively electrified and the other negatively electrified. If the two charges so produced be allowed to recombine, equilibrium will be restored. There is always a tendency for unlike charges to combine and neutralise each other, and mutual attraction, in the effort to produce equilibrium, results. Bodies electrified with like charges, whether positive or negative, repel each other.

An electrified body has the power to perform certain functions which it did not possess in an unelectrified state. It has the power of repelling light bodies similarly charged, and it also has the power of attracting light unelectrified bodies and bodies oppositely charged. An electrified glass rod on being brought near scraps of paper, feathers, or other light substances attracts them. The rod has assumed a power, or potentiality. The term electric potential is, generally speaking, the first stumbling block to the elementary student, but it will be sufficient to describe it as the power to do work possessed by all electrified bodies. The potential of an electrified body depends upon the amount of electricity it contains and the capacity the body has for holding it. All unelectrified bodies are said to be at zero potential, and electrified bodies are said to be at either positive or negative potential. Electrical potential may be considered as electrical pressure or level, for, as water impelled by the force of gravity runs down a hill, so a transference of electrical energy will take place from a point of high electrical level to a point of low electrical level. *Difference* of potential is termed *electromotive force*, and is the pressure which forces electricity through the conductor, in the form of a current to effect electrical equilibrium.

Conductors and Insulators.

All substances do not possess the property of allowing electricity to pass through them to the same degree. Bodies which allow electricity to pass through them freely are termed conductors; whereas, bodies which retard the passage of electricity in a marked degree are called insulators or non-conductors. The terms, however, are only relative, for all bodies, even conductors, resist the flow of electricity to a certain extent. This property is called *resistance*, and may be defined as the property possessed by all bodies in varying degree, by virtue of which the transference of electricity to produce equilibrium is retarded.

All metals are conductors, *i.e.*, they offer small resistance to the passage of electricity. Carbon, water, and acid solutions are semi-conductors, as they present a comparatively high resistance to the transference of electrical energy. India-rubber, gutta-percha, ebonite, oil, porcelain, wax, and dry air are insulators, as the resistance of either of these bodies is practically infinite.

Magnetism.

There are two kinds of magnets, natural and artificial. A natural magnet is called a lodestone, and is a compound of iron and oxygen found largely in nature. Its chemical formula is $Fe_3 O_4$, and attention was first directed to it by its power of attracting iron.

The magnetic properties of the lodestone may be transferred to iron and steel in several ways. Take a piece of ordinary watchspring and rub it from end to end a number of times, in one direction only, with the lodestone. The steel will now attract other pieces of steel and iron, having become what is termed an artificial magnet.

If a magnet be suspended or pivoted so as to be capable of rotation in a horizontal plane, it will come to rest with its two ends pointing, one in the

direction of the north geographical pole, and the other in the direction of the south geographical pole; moreover, the same end of the magnet will always point in the same direction. These facts lead to the conclusion that there is some influence, or force, acting upon the magnet. This directive force is due to the earth, which exhibits magnetic properties. The end of the magnet which points towards the north is called its *north-seeking* pole, while the other end is called its *south-seeking* pole.

The attractive power of a magnet is not evenly distributed along its whole length. Plunge a magnet into iron filings and note what happens. At the poles the filings adhere to the magnet in large clusters, but they decrease in number along the magnet towards the centre, at which point no filings are attracted.

The earth is a magnet having its magnetic poles situated near the north and south geographical poles. The magnetic and the geographical poles, however, do not exactly coincide, and the magnetic meridian of any place may be considered as an imaginary plane passing through the magnetic poles of the earth and the point immediately overhead. A magnet suspended in such a manner as to be capable of rotating in a horizontal plane will come to rest in the magnetic meridian, *i.e.*, pointing to the north and south magnetic poles.

The first law of magnetism states that unlike magnetic poles attract each other, and like magnetic poles repel each other.

From a consideration of this the reader will readily see the reason why the magnet comes to rest in the magnetic meridian. The two poles of the magnet are influenced by the magnetic poles of the earth. The north-*seeking* pole of the magnet is attracted by the north magnetic pole of the earth and repelled by the earth's south magnetic pole. The south-*seeking* pole of the magnet is influenced in a similar manner, being attracted and repelled by the south and north magnetic poles of the earth respectively. It should, however, be clearly understood that the magnet is not attracted bodily towards either pole of the earth. The terms "attract" and "repel" are used to indicate the direction in which the suspended magnet will turn. The earth's influence is directive and not attractive, for the earth's north magnetic pole will attract the one pole of the magnet with the same force as it will repel the other.

Magnetic Substances.

All bodies are not capable of being magnetised. Those which can be magnetised are few in number, and are called magnetic substances. The reader will readily call to mind iron and steel as being magnetic substances. There are, however, a few other such bodies, viz., nickel, manganese, cobalt, and chromium.

The physical theory of magnetism is the one generally accepted, and supposes that the molecules which make up the mass of a magnetic substance are themselves magnets. The act of magnetisation is the arrangement of the molecules in a definite order, the similar poles of the molecules all pointing in one direction. (Fig. 1.) This is borne out by experiment. When a magnet is broken into two or more parts, each part is itself a complete magnet. The magnet may be broken indefinitely until the smallest particles possible are arrived at, and each particle will exhibit the same properties as the whole magnet, though necessarily in a less marked degree. A small test tube filled with iron filings in their normal condition does not evince magnetic properties; but pass one pole

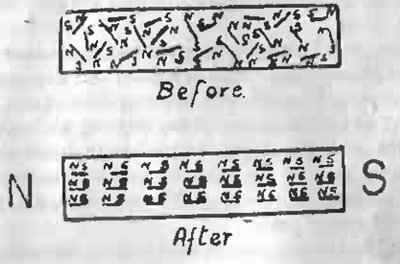

FIG. 1

of a magnet along the test tube a number of times in one direction, and it will be seen that the filings are now arranged in order. They have lost their higgledy-piggledy condition, and have been arranged lengthwise along the tube. The tube of filings is now a magnet, and exhibits the same properties as an ordinary magnetised bar. Upon shaking the tube the filings become disordered, and the mass, as a whole, loses its magnetic powers.

All magnetic substances cannot be magnetised with the same facility. Soft iron is readily magnetised, whereas, hard-tempered steel is magnetised with comparative difficulty. The iron, however, remains a magnet only as long as the effort to magnetise it is sustained. On the other hand, steel is not readily magnetised, but when once this condition is arrived at the steel permanently retains its magnetic properties. The difference between steel and iron in this respect is probably due to the molecular construction of the two substances. The particles of the iron are more easily arranged by the process of magnetisation than those of the steel, but when the latter has been magnetised the particles remain fixed. In the case of iron the particles return to their normal disordered condition. This property possessed by steel is sometimes called retentivity, or coercive force.

Lines of Force.

A magnet is surrounded by a field of force which extends so far as the influence of the magnet is felt. Lines of force pervade this magnetic field in varying degrees of intensity, and denote its extent. They are sometimes called lines of magnetic induction, and are in the shape of closed curves about the magnet. The intensity of these lines is greatest near the ends, or poles of the magnet. Take an ordinary bar magnet and place it immediately beneath a sheet of cardboard. Upon the cardboard sprinkle iron filings, and note how they arrange themselves. Near the poles the filings are seen to be in clusters, but towards the centre of the magnet they are few in number. A closer examination shows that the filings have arranged themselves lengthwise in the form of curves, as shown in Fig. 2.

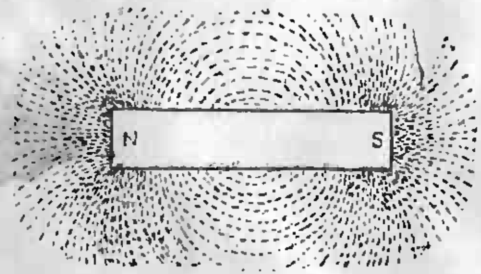

FIG. 2

Magnetic Induction.

When a piece of iron is brought into a magnetic field it becomes a magnet under the inductive influence of the magnet. Place a piece of unmagnetised iron in contact with one pole of a magnet, and it will be seen, by experiment, that the iron has assumed magnetic properties. The end of the iron in contact with the magnet will be of opposite polarity to the pole of the magnet with which it is in contact. (Fig. 3.)

FIG. 3

If the iron be placed at a little distance from the magnet the same effects will be apparent, the near end assuming an opposite polarity to the adjacent pole of the magnet. The other end of the iron will, of necessity,

Notes on Telegraphy

A SIMPLE EXPOSITION OF THE RUDIMENTS OF TECHNICAL TELEGRAPHY AND TELEPHONY.

BY

A. G. PRATT and G. MOGG,

Merchant Venturers' Technical College, Bristol,
and Postal Telegraphs, Bristol.

215 PAGES.

With 126 Illustrations and 52 fully worked Mathematical Examples.

LONDON:

Co-operative Printing Society Limited, Tudor St., New Bridge St., E.C.;
and at Manchester and Newcastle.

1901.

incomplete. By depressing the right-hand tapper the positive pole of the battery is connected to the line by way of the lower strip, and the other pole remains earth-connected. By releasing the right-hand and depressing the left-hand tapper a reversal of the battery connection is effected. For practical purposes the levers are made of ebonite with suitable contact points arranged to make the required connections. (Fig. 42.)

The most efficient form of receiving apparatus is that devised by Spagnoletti. A coil of wire in two sections is wound upon two bobbins

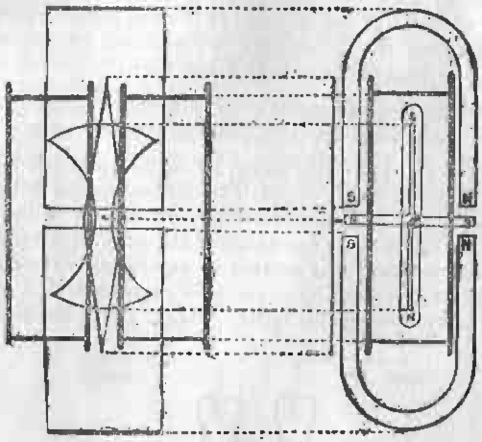

FIG. 41.

inside of which a peculiarly-shaped needle, rendered magnetic by two powerful permanent magnets of the horseshoe type, is deflected by the action of the current. (Fig. 41.) The upper and lower sections of the needle are magnetically separated by a small strip of spelter. The lower end of the upper section of the needle and the upper end of the lower section are extended and form the axle upon which the needle turns. The magnets are arranged so that their similar poles act inductively upon the same end of the axle and produce opposite polarities at the free ends of the needle. The North-seeking pole is invariably at the bottom, so that the inductive influence of the earth may assist in retaining the magnetic strength of the combination. The magnetic effect of the current upon the needle is increased by the extremities of the latter being widened, and also by closely winding the coil upon the bobbins, which are formed to allow just sufficient space for the free movement of the needle within them. The needle is pivotted exactly mid-way

between the two sections of the coils. Attached to the needle is a light pointer which obeys the movements of the needle and indicates at the exterior of the case the signals which are being received within. Two small ivory studs limit the deflections of the pointer. The latter beats with great firmness upon them, and by this means the visible signals are more easily read.

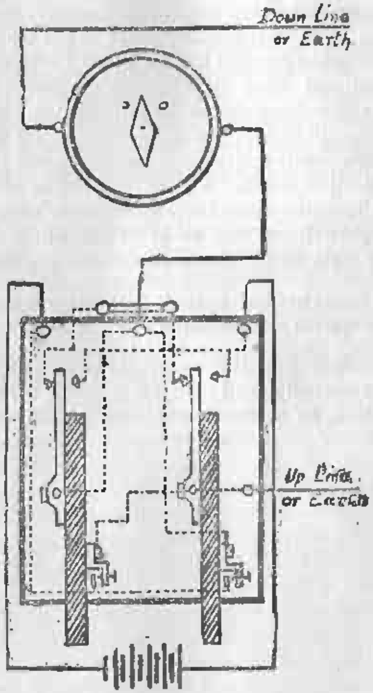

FIG. 42

The receiving instrument is in both the sending and the receiving circuits, and acts as an efficient substitute for a circuit galvanometer. The deflections are always in the same direction as that of the currents producing them, *i.e.*, a current passing through the coil from left to right will cause the upper portion of the needle to deflect towards the right hand. This principle of connection is adopted in joining up all galvanometers used by the British Post Office.

at B is joined up. The line is thus put to earth *via* the one-ampère fuse. A carbon lightning protector is also included in the very neat arrangement, and is shown at P. The normal path for an incoming current is through the one ampère fuse, heat coil, solder joint and spring to the instruments. The one-ampère fuse is a protection from currents greatly in excess of those used for telegraph purposes. It is employed where a possibility of a contact with the conductors of electric traction or electric lighting systems exist.

Protectors for Cables.

The effects of lightning upon submarine cables are very serious, and, in order to prevent damage, protectors having large brass plates are employed. Mica is used as the insulating medium. In the cable circuit a fine platinum fuse wire is also used in conjunction with a "reel" type of protector as an extra precaution. The latter form of protector consists of two silk-covered wires twisted together and wound upon a box-wood bobbin. One of these wires is earth-connected, and the other is placed in the line circuit. The passage of a lightning discharge through the latter breaks through the insulation of the wires and preserves the cable from damage.

CHAPTER X.

The Single Needle.

The direction in which a magnetic needle will turn when under the influence of a current depends upon the direction in which the current is flowing. The reversal of the current produces a reversal of the direction of the force acting upon the needle, consequently the deflections may be controlled by a reversal of the current. In the single needle system visible signals, representing the Morse code, are produced by combinations of deflections of a vertical needle to the left and right.

The single needle system consists essentially of two parts, one of which represents the sending and the other the receiving apparatus.

The sending section is a commutator, or current reverser, and usually comprises two tappers, levers, or pedals for connecting the battery to the line. By the depression of one lever the negative pole of the battery is connected to the line, while a depression of the other joins up the positive pole, and the direction of the current is consequently reversed at will. When one lever is depressed the other lever is normal, and the battery circuit is completed through the latter. Fig. 40 shows the theory of the

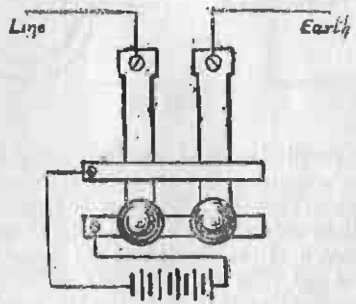

FIG. 40.

commutator simply. The levers are connected the one to earth and the other to line. Two metal cross-connecting strips, to which the poles of the battery are joined, are shown at right angles to the metal levers, one being above and the other below them. When both tappers are at rest they are connected with the upper strip and one pole of the battery, the other pole being left disconnected, and the battery circuit is is consequently very suitable for the work required of it. Two electro-magnets, to both cores of which two soft iron pole-pieces, one at each end, are attached, are in the line circuit. Between the two upper and also between the two lower pole-pieces a soft iron tongue, rendered magnetic by the inductive action of a strong permanent magnet, is fitted. The tongues are connected by means of a light delicately-pivoted brass rod, to which they are fixed at right angles. The permanent magnet is so arranged that its North-seeking pole is in close proximity to the lower tongue or armature, while its South-seeking pole is adjacent to the armature fitted to the other end of the connecting rod. The positions of the armatures and the permanent magnet are such that the extremity of the one which plays between the upper pole-pieces is

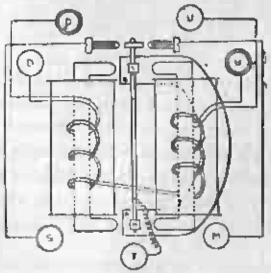

FIG 43

of South-seeking polarity, while that of the lower one possesses an opposite polarity (Fig. 43.) On account of the induced magnetic condition of the tongues the relay is said to be polarised in contradistinction to the type of instrument in which the tongues are not of definite polarity. The coils of the electro-magnets are differentially wound, each section having a resistance of 200 ohms. Four terminals are attached to the base of the instrument, and to these the ends of the coils are connected. By means of brass straps either the "series" or the "quantity" method of joining up the coils may be resorted to. Fig. 44, in which the coils are joined in series, shows the arrangement roughly. The Post Office standard relay owes its great degree of sensibility to the extreme delicacy with which it is constructed, and also to the fact that *four* forces act upon the movable armatures when a current passes through the coils. Suppose that the coils are joined in series, and that a current passes through them from "U-circle" to D. The upper pole-piece of the right-hand core (See fig. 43) assumes a North-seeking polarity and the lower one a South-seeking polarity. In the pole-pieces attached to the left-hand core exactly the opposite effects are produced by the opposite winding of the coil, the upper one becoming South-seeking and

the lower one North-seeking. These effects may be readily proved by the application of Ampère's rule. A little consideration will make it clear that the mutual forces of attraction and repulsion exerted between the pole-pieces and the armatures tend to turn the last named in the *same* direction; the armatures are attracted by the right-hand pole-pieces, and repelled by those upon the left-hand side. A reversal of the direction of the current will, of course, produce an opposite turning effect.

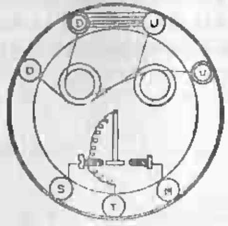

FIG.44.

Attached to the brass spindle which carries the armatures, and immediately above the latter, is a light contact tongue which plays between two adjustable contact screws. This tongue moves with the delicately-pivoted spindle, and makes contact with either the right-hand or the left-hand contact screw in accordance with the movements of the armatures.

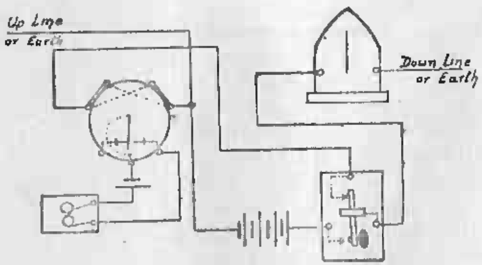

FIG.45.

The contact screws are connected to terminals at the base marked M and S, as shown in Figs. 43 and 44, while the tongue is in connection with the terminal marked T, to which the negative pole of the local battery is invariably joined. When no current is passing through the coils the magnetised tongues or armatures are attracted to either one side or the other by the soft iron pole-pieces. The relative positions of these tongues to the pole-pieces is controlled by an adjusting screw placed near the foot of the

The resistance of the instrument is 200 ohms, and a current strength of 15 to 20 milliampères is required to produce a workable effect.

When the universal battery system is employed slight modifications are required in joining up the commutators to prevent short-circuiting of the battery should both pedals be simultaneously depressed.

Fig. 42 shows the full connections of the instrument. The shaded portion of the commutator represents the ebonite tappers through which no current passes. The projections attached to the tappers are brass, and the path of the outgoing current can be readily followed from the commutator to the up and down lines by way of the contact points. The received currents pass through the brass levers and back stops of both pedals, and thence to line or earth. Owing to its simplicity of construction the single needle instrument rarely gets out of order, and needs practically no re-adjustments. A large number of offices can be fitted with this system upon the same line, and these are advantages which tend to retain the popularity of this mode of signalling. The instrument, however, is being replaced by the sounder wherever practicable.

The name of "single needle" is given to this instrument as a distinction from the obsolete system of "double-needle" working.

Although the system necessitates currents being sent to the line in both directions it is essentially worked upon a single current principle. It must not, therefore, be confused with the well-known double current system.

CHAPTER XI.

The Relay.

In the direct sounder system the instrument from which the signals are read is actuated by a current passing direct to it from the line. This arrangement produces very satisfactory results in the case of very short lines, but upon a circuit of any considerable length the "direct" system becomes impracticable for many reasons. The resistance of a long circuit is of necessity great, even if a wire having a comparatively large area of cross section is employed. The sending battery consequently must possess a high voltage to produce a current of sufficient strength to actuate a sounder, but beyond certain limits an increase of battery power is not practicable.

Again, the current received from a long line is subject to considerable variations in strength. The insulation resistance of the line fluctuates with varying climatic influences, and the amount of current which leaks to earth and becomes non-effective for receiving purposes is consequently a factor to be reckoned with. Upon long lines the effect of this loss of current is intensified, as every point of support opens up a possible path through which a fraction of the current may escape.

The joint resistance formed by the numerous paths of leakage is termed the "insulation resistance" of the line, and decreases as the length of the circuit increases. During wet weather it will be observed that the amount of current sent into a circuit is *above* the normal, as the resultant resistance of the whole line is reduced by the fall in insulation resistance. The amount of current received, however, is *less* than the normal, as the damp condition of the supports affords greater facilities for the escape of the current. It will, therefore, be seen that with a minimum working current of, say, 70 milliampères direct sounder working becomes impossible, except upon very short lines, and an instrument which will be actuated by a much smaller current is consequently introduced. Such an instrument is called a "relay," and takes the place of the sounder in the direct sounder circuit. The incoming current, although probably very weak, actuates this sensitive instrument, and by its effect causes a local battery to be joined up. The sounder is placed in the local battery circuit, and comparatively strong currents pass through the coils and produce audible signals corresponding with the currents received from the line.

The Post Office Standard Relay.

The Post Office Standard relay is the instrument used in the British Post Office. Its figure of merit is half a milliampère and this relay rod is fixed at right angles. At the end of the rod is a small brass knob which beats upon a sheet of metal each time the armature is attracted. A sharp metallic sound is thus emitted as the result of each signal being received. The sound upon the right-hand "bell," as it is termed, is dissimilar in tone from that upon the left-hand bell, and, consequently, the signals can be easily read by sound, while the sending portion is just as simple to manipulate as that used with the single needle instrument. When sending, the relay and local circuit are cut out, a "single current" galvanometer only, or, more strictly speaking, a galvanoscope, being in that part of the circuit with the commutator and main battery. The tappers are joined up so as to prevent short-circuiting of the sending battery should both be simultaneously depressed. When a current is received from the down line it passes through the galvanometer, thence to the brass connection upon the lower side of the left-hand tapper, through the wire joined to the left-hand terminal from which the strap has been removed, and through the relay coils from "right" to "left." It then passes to the right-hand terminal of the commutator, through the brass connection upon the under side of the right-hand tapper, and thence to earth. A current received in an opposite direction, *i.e.*, one assumed to come in at the "earth" connection, may be traced similarly, through the same path in an opposite direction, and it passes through the relay coils from "left" to "right." In the former case the contact tongue is drawn to the right-hand contact point, which movement operates the local battery and the right-hand bell. In the latter case exactly the reverse conditions are brought about. The tongue of the relay moves to the left-hand contact screw and joins up the left-hand bell. By thus reversing the direction of the received current by means of the commutator at the distant station, a very simple method of sound reading is established. The coils of the sounder are shunted to destroy the ill-effects of self-induction upon the relay contact points. A current strength of about 20 milliampères is provided upon this system, which has the advantage of a sensitive relay as the receiving instrument, and of being a quicker method of signalling than the single needle system.

Electro-Magnetic Induction.

Every wire carrying a current possesses a magnetic field; the lines of force, or lines of induction, surround the wire along its whole length in the form of concentric circles, the wire itself being their common centre.

When a current is started the lines of force spring into existence, and it may be said that they radiate in an outward direction from the wire. With an increase in the strength of the current the magnetic field becomes extended, and a further radiation takes place. A diminution of the current strength causes a partial collapse of the magnetic field, the tendency being for the lines of force to recede into the wire. At the cessation of the current the magnetic field collapses and the lines of force return to the wire from which they sprung.

When a conductor is cut by a line of force, or when a line of force is cut by a conductor, an electro-motive force is set up, and, if the conductor forms part of a closed circuit, a current will flow through that circuit. The direction in which the current will flow is determined by the direction in which the lines of force cut through the conductor. For instance, suppose that two wires AB and CD run parallel and in close proximity to each other, and that a current is started in the former in a direction from B to A (Fig. 47). The lines of force developed radiate outwards from the wire. Some of these lines of force cut through CD transversely and produce an electro-motive force which causes a momentary current to flow from C to D. An increase of the current strength in AB will cause a further radiation of the lines of force and another momentary current will flow through CD. These momentary currents will flow in an opposite direction to the original current. By a diminution of the strength of the current the magnetic field will partially collapse, and the lines of force will cut through CD in a reverse direction as they pass inwards towards AB. The momentary induced current in CD will now be in the same direction as the original current, and, obviously, with the cessation of the latter and the consequent total collapse of the magnetic field, the further induced current will also flow from D to C.

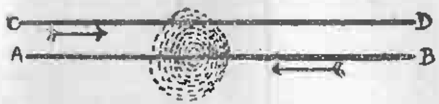

FIG 47.

Self-Induction.

When a wire is wound into a coil, or spiral, the effects of electro-magnetic induction are intensified. The lines of force, at their creation, cut through each adjacent convolution of the wire and induce a momentary current which opposes the original current, and prevents the latter from immediately rising to its maximum strength (Fig. 48). This momentary current is termed an extra-current *inverse*. When the battery circuit is broken and the lines of force collapse, the induced current follows the primary current, tending to prolong it and retard its prompt disappearance. This is termed the extra current *direct*.

If a soft iron core is introduced into the coil the effects of "self-induction" are increased because the lines of force are more numerous. As the electro-motive force of the induced currents depends upon the instrument. When the tongues are nearer to the pole-pieces upon one side than to those upon the other the attraction will be towards the nearer and the adjustment is said to have a "bias." To be in its most sensitive condition, however, the instrument should be adjusted so that the tongues remain on the side upon which they are placed. For sounder working the relay is adjusted so that it has a slight bias to the spacing side, and the terminal marked S is left disconnected.

Fig. 45 shows a single current sounder circuit worked by means of a relay, and it will be seen that the relay is the actual receiving instrument, while the sounder or reading instrument is simply under its control.

CHAPTER XII.

The Double Plate Sounder.

The "sending" part of this system is a commutator very similar to that used with the single needle, and the method of signalling is identical in each case. There is a slight alteration in the connections of the double plate sounder, the metal strap at the back of the commutator being removed and the two terminals joined separately to a relay (Fig. 46), which is the actual receiving instrument. The relay tongues are set

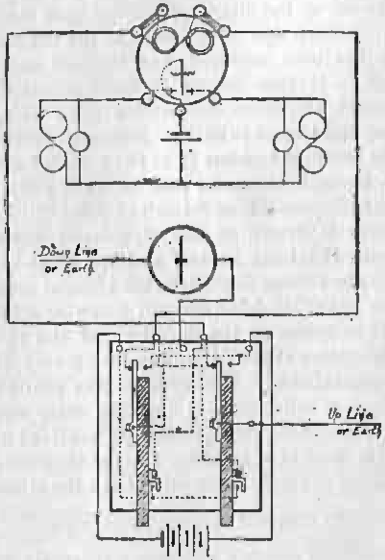

FIG. 46.

neutral by the ordinary means of adjustment, but the contact tongue is normally held midway between the contact points by means of two antagonistic springs. The local battery circuit is in two sections, and it depends upon the direction of the received current through the relay whether the right or the left-hand section is joined up. In each section of the local battery circuit is a simply-devised sounder or electro-magnet, to the armature of which a small metal receiving station, and it will be apparent that when signals of short duration are required to follow each other in rapid succession, some method of clearing the line must be adopted in order that distortion may be prevented. The difficulty is practically overcome by introducing a double-current system. Between each signal a current in an opposite direction to that required to produce a marking effect upon the relay is sent to line, and this clears the line of the retained charges by the act of neutralisation. These neutralising currents are termed "spacing" currents to distinguish them from the ordinary "marking" currents from

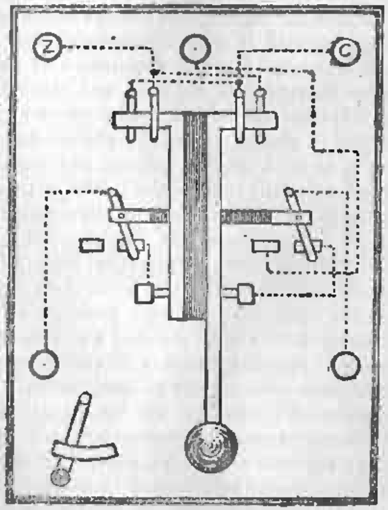

FIG 49

which the readable signals result. Not only does the double current system quicken the rate of working in the manner described, but the relay may be worked in its most sensitive condition, *i.e.*, without bias, as the "spacing" current causes the tongues of the relay to resume their normal position after each signal. It will also be noticed that for ordinary sounder working an antagonistic spring is not needed. In practice, however, a slight spacing bias is given the relay in order that the local battery circuit may not be closed when no current is being received from the line. Another advantage of this system is that the rapid and constantly reversing currents prevent the development of residual magnetism in the

cores of the relay; but a disadvantage is that the battery is worked twice as hard as in the single current system.

When circuits are worked upon the double current principle a specially devised key is employed to send a spacing current automatically after each marking current. This is done each time the key is allowed to resume its position of rest. By means of a switch the battery is disconnected at will, and the receiving instrument is then joined to the line.

The lever is divided into two parts, which are separated from each other by a strip of insulating material such as ebonite. It plays between four

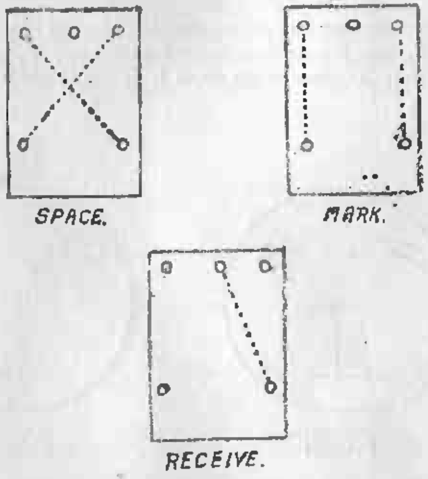

FIG. 50

contact springs, and the metallic sections make contact with the two lower springs when the lever is at rest, and with the upper ones when it is depressed.

Fig. 49 shows the internal connections of a five-terminal double current key, and Fig. 50 indicates the conditions existing when (1) a spacing current is being sent to line; (2) when the key is depressed and a marking current is being sent; (3) when the switch is to "receive"; in other words, when the line is joined to the receiving apparatus.

A key having only four terminals is used in the "universal battery system" of working, and a description of it will be given when dealing with that subject at a later period.

number of lines of force which cut through a conductor and also upon the rate at which they cut it, the sudden cessation or variation of a current passing through the coil of an electro-magnet, which is wound with many turns of fine wire, will produce a very high *induced* electro-motive force. Consequently self-induction, in these circumstances, is said to be comparatively great.

FIG. 48.

Self-induction is sometimes called "spurious resistance," on account of its retarding effect upon the primary current. Its unit is termed the "Henry" or "Seccohm."

It will now be necessary to consider the effects of self-induction in connection with a circuit such as that forming the local circuit of the double plate sounder system. By the action of the primary current passing through the coils of the relay the local circuit is closed and its battery joined up, and, as a consequence, a comparatively strong current passes through the electro-magnet, or sounder, coils. When the relay tongue resumes its normal position by the cessation of the primary or line current, the local circuit is disconnected, but a high induced electro-motive force is set up in the coils of the sounder. The tongue of the relay is separated from the contact screws by a small air gap; but the induced electro-motive force in the sounder coils will probably be sufficiently high as to produce a current capable of bridging across the air space, and cause a spark to pass. The effect of this spark will be to corrode the contact points, and ultimately to destroy the metallic connection necessary for the free passage of the current through the local circuit.

To prevent such damage a shunt is joined across the terminals of the sounder coils, and the momentary induced current, or rather the extra current *direct*, circulates through the shunt rather than pass across the air gap at the relay contact points.

CHAPTER XIII.

Double Current Working.

The single current system, already described, can be employed only upon circuits of comparatively short lengths, even when a relay is introduced. A current sent into a line "charges" it; the charge acts inductively upon the earth and neighbouring objects and produces *induced* charges upon them. The induced charges, in turn, react upon the wire, and the reactions cause a portion of the original charge to be held bound. The wire, as a consequence, is said to possess a static charge. The amount of electricity thus held depends upon the dimensions of the wire, both as regards its length and thickness, or diameter, and also upon its proximity to the earth and adjacent conductors. The property possessed by a conductor of retaining a charge is termed electro-static capacity, and this capacity has to be satisfied before a current, and consequently a signal, can reach the distant end of the line. As the initial portion of the charge is absorbed in satisfying the capacity of the line, the consequent effect upon a signal is to retard its appearance at the receiving office, and the rate of working is therefore kept very low. Upon short aerial lines the effects of electro-static capacity are negligible, but upon long wires and underground and submarine cables they are very pronounced. On account of the insulating material with which the last two named are surrounded being superior to air as an inductive medium, the capacity of such circuits is very great. The property possessed by di-electrics, such as gutta-percha, paraffin, etc., of allowing induction to take place across them is termed their "specific inductive capacity," and the comparison drawn is between that of any particular di-electric and air. Thus if gutta-percha were substituted for air, and all other conditions remained undisturbed, the capacity of a conductor would be increased to rather more than four times its capacity in air. Gutta-percha is very largely used as an insulator for underground and submarine lines, and, as a consequence, the electro-static capacity of these circuits is considerable. Again, as induction takes place across a comparatively short distance, owing to the contiguity of the earth and other conductors, the electro-static effects are still further intensified.

When the battery from which the current emanates is cut off, the static charge, retained by the wire, escapes to earth by the shortest possible route. If the circuit is imperfectly insulated as most aerial lines are, owing to a moist atmosphere, etc., a portion of the discharge takes place through the paths of leakage, but the remainder passes out at the earth-connected ends of the line. The effect upon the current is to unduly prolong it at the current passing through only one coil is shown diagramatically in Figs. 53 and 54, and in both cases "marking" effects result from the currents traversing the paths indicated in the directions shown by the arrows.

Duplex working may be arranged either upon the single current or the double current system. It is rarely necessary to work any circuit duplex continually, therefore a six terminal two-way switch is used, and by its means a simplex circuit may be readily converted into a duplex circuit. Before duplex working commences it is necessary for each station to balance its artificial circuit against the line circuit, so that the current may split equally between the two sections.

The Single Current Duplex System.

The switch at each office is turned to "duplex," and, by depressing the key separately at either station, it may be ascertained when sufficient resistance has been inserted in the set of resistance coils, or rheostat, to effect a balance of the resistance of the line and that part of the distant station's apparatus directly in the line circuit. This is determined by observing when the needle of the differentially-wound galvanometer is unaffected by the passage of the current through the coils, for, if the two equal portions of the divided current pass through them in opposite directions, the induced magnet will not be deflected. In the single current duplex system the galvanometer needle remains vertical and perfectly steady when the key is depressed. The differential galvanometer is identical in construction with the Spagnoletti needle already described, with the exception that the coils are differentially wound and joined up in series. This method of winding is invariably adopted for duplex working, but the galvanometer may be joined up in "series" or in "quantity" as necessity requires. Differential winding is resorted to in order that the difference between, or the equality of, the strengths of currents passing in opposite directions through the coils may be observed.

The rheostat in general use consists of a number of resistance coils so connected that, by the rotation of two arms over a number of contact points, as many of the coils as are required can be readily brought into use. The contact points, between which the coils are fitted, are arranged upon a circular dial, one-half of their number being used in connection with one arm and the other half with the other arm. The set of coils is divided into two sections. The one consists of ten coils, each of 40 ohms resistance, and the other of a similar number of coils, each having a value of 400 ohms. Connection between the two sections is made by means of the arms and contact points, and the coils are arranged so that any resistance up to 4,400 ohms, by gradations of 40 ohms, may be obtained by the manipulation of the revolving arms.

Three other resistance coils having values of 10, 20, and 4,000 ohms respectively are fitted to the rheostat, but these are independent of the arms. They can be used, however, in conjunction with the 40 and 400 ohms coils, and the range of the set is enlarged by their addition to 8,430 ohms, any multiple of 10 ohms up to that value being obtainable. These extra coils are brought into use by the withdrawal of conical brass plugs, in a similar manner to that described in connection with "resistance coils." Fig. 55 shows how the coils of a rheostat may be connected between the two terminals.

The connections of a single current circuit arranged for duplex working are shown in Fig. 56; the apparatus not essential to a theoretical explanation of the system being omitted.

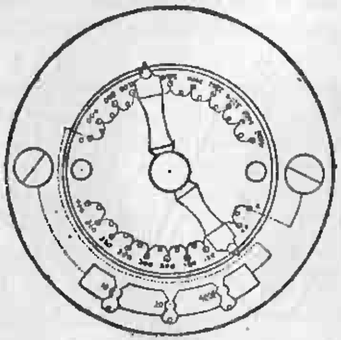

FIG. 55.

There are three conditions which have to be met in order that duplex working may be established, viz.:—

1. With one key only depressed a "marking" effect should be produced in the relay at the opposite end of the line.

2. With both keys depressed at the same time a "marking" effect should be produced in the relay at both ends of the line.

3. With one key depressed and the other in an intermediate position, i.e., when the lever is in contact with neither the back nor the front stop, a "marking" effect should be produced at the office where the latter condition exists.

It should be mentioned here that both relays are adjusted to have a slight spacing bias, so that the local circuits may not be joined up except when the currents produce marking effects upon the relays. It should also be borne in mind that as the "earth" return has no resistance the two earth connections, one at each end of the circuit, are practically joined together, and a current passing to earth at one office is assumed to come in at the earth connection of the other.

Consider the first condition in conjunction with Fig. 56, and assume that the key at the "up" station is depressed. The current from the battery at that office passes to the galvanometer, and divides equally between the artificial and line circuits. That which passes through the artificial circuit arrives at the battery *viâ* the D-U coil of the relay. The other half of the current, which passes to line, arrives at the U-circle terminal of the "down" office relay. After passing through the U-circle D-circle coil, the resistance block *r*, the back stop of the key and one coil of the galvanometer, it then finds "earth." It must now be assumed

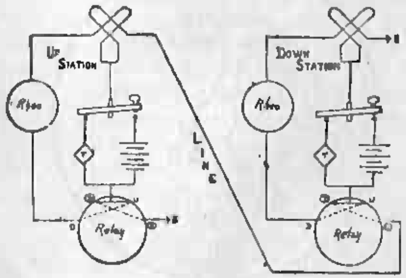

FIG. 56.

to have arrived at the U-circle terminal of the "up" station's relay, and its path is through the U-circle D-circle coil, and thence to the battery from which it emanated.

The effect of these currents upon the apparatus must now be considered. The galvanometer at the "up" station is not deflected, as equal currents pass through the two sections of the coils in opposite directions. The relay at this office is also unaffected, for the effect of the current passing through the D-U coil from the artificial circuit is neutralised by the effect of the line current passing through the U-circle D-circle coil. The two currents pass through the relay coils in opposite directions and recombine at the relay battery connection.

Now let us turn our attention to the "down" station. The line current traverses the U-circle D-circle section of the relay coils, and in the direction from U-circle to D-circle. There is no counterbalancing effect from the

other section of the coils, as there is no current in the artificial circuit, the "down" station's key being at rest and the battery disconnected. The current is in the correct direction to produce a marking effect, and the local circuit is consequently joined up and the sounder actuated. A deflection of the galvanometer is also produced, as the current passes through only one section of the galvanometer coils.

When the key at the "down" station is depressed the circumstances are somewhat similar. The current from the battery at that office passes to the galvanometer, where it splits equally, one part passing through the artificial circuit and the other to earth. The circuit is completed through the earth connection at the "up" station, the U-circle D-circle coil of the relay, and thence through the back stop of the key and one coil of the galvanometer to the line. Following the course of the current, it will be observed that the U-circle D-circle coil of the "down" station relay is traversed, and the battery is reached by way of the relay battery connection.

In condition 2 both keys are assumed to be depressed, and it is therefore desired to show that marking effects are produced in both of the relays. As in the previous cases the current from each of the batteries should be understood to pass to the galvanometer at the respective offices and split. A current is, therefore, flowing in each of the artificial circuits; but what is the effect upon the line circuit? One-half of the current from each of the batteries affects it, and reference to Fig. 56 will show that the batteries produce currents which flow through the line circuit in the *same* direction. The current in the line circuit is, therefore, twice as great as that in either of the artificial circuits, and the differentially wound apparatus is consequently actuated by the former or preponderating current. A deflection of both galvanometer needles is produced, and, as the direction of the line current in the relays is from U-circle to D-circle, a marking effect is registered.

The third condition assumes that one key is being depressed and the back contact is broken, while the contact at the front stop of the key has not been joined up. The lever, in fact, is in an intermediate position. The other key is assumed to be depressed. Suppose that the "up" station key is in the intermediate position, and the key at the "down" station is depressed. In these conditions it is necessary to demonstrate that a spacing effect is produced upon the "down" station's relay, and that a mark is recorded at the "up" office. Let it be first noted that, as there is no connection between the relay and galvanometer through the key at the "up" station, any current which reaches that office from the line must traverse the artificial circuit. The total resistance of the path of the current flowing through the line circuit is, therefore, approximately twice as great as before, and, upon considering the current leaving the battery at the down station, it will be readily seen that it splits unequally, the strength of the current in the artificial circuit being twice as great as that in the line. The effect of this preponderating current at the "down" station in its passage through the D-U coil of the relay is to cause the armatures to be held to the spacing side. At the "up" station the line current only has to be considered. It is now about half the strength of the currents which passed through one of the coils in conditions 1 and 2; but to compensate for this decrease the current now passes in the same direction through both coils of the

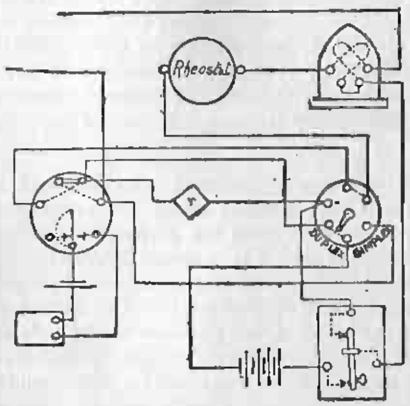

FIG 57.

relay and also through both coils of the galvanometer. It will, therefore, be seen that the magnetic effect upon the relay tongues remains unaltered, and they turn to the marking side with just as much force as before. The galvanometer deflection, for a like reason, remains unchanged.

The resistance block *r*, which is placed between the back stop of the key and the relay connection, has a resistance approximately equal to that of the battery. Its object is to ensure the same conditions as regards resistance when the key is at rest as when it is depressed.

The complete connections for the single current duplex system are shown in Fig. 57.

The Double Current Duplex System.

The double current system of duplex working is similar in many respects to that of the single current system; the chief difference being that the

conditions are altered by the use of a spacing current when either key is at rest. The three following conditions are imperative:—

(1) With both keys at rest spacing effects must be produced at both stations.

(2) With both keys depressed marking effects must be produced at both stations.

(3) With one key depressed and the other at rest, the relay must respond with a marking effect at the office where the key is at rest, and with a spacing effect at the other office.

Fig. 58 shows the theoretical connections for double current duplex working, both keys being at rest. The "duplex" switch, by which either duplex

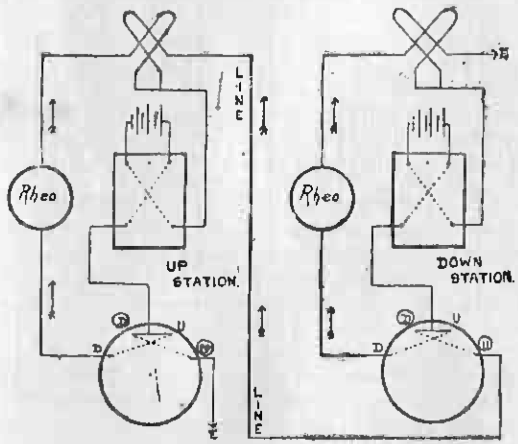

FIG 58.

or simplex working can be resorted to, is omitted. The key switches at both offices are kept in the position to "send" so long as duplex working is maintained. Both stations balance the artificial circuit against the line and the apparatus in the line circuit at the respective distant offices. A balance having been obtained it is desired to show that the necessary spacing effects are produced in both relays. Consider the "up" office first, and notice that the current leaving the positive pole of the battery passes through the key to the "split" of the relay where it divides, one part traversing the U-D coil of the relay, the rheostat and one coil of the galvanometer. From thence it passes through the key to the negative pole of the battery. The other half of the current flows through the D-circle U-circle coil of the relay to "earth." Its path, which we may term the line circuit, is continued through the earth connection at the "down" office, through one galvanometer coil, the key, D-circle U-circle coil of the relay, and thence to the line. It then passes through one coil of the "up" office galvanometer and re-unites with the current flowing in the artificial circuit. Now consider the current emanating from the "down" office battery—the circumstances are identical with those at the "up" office, except that the earth and line connections are reversed. One half of the current traverses the "down" office artificial circuit, and the other half the line circuit. It will, therefore, be seen

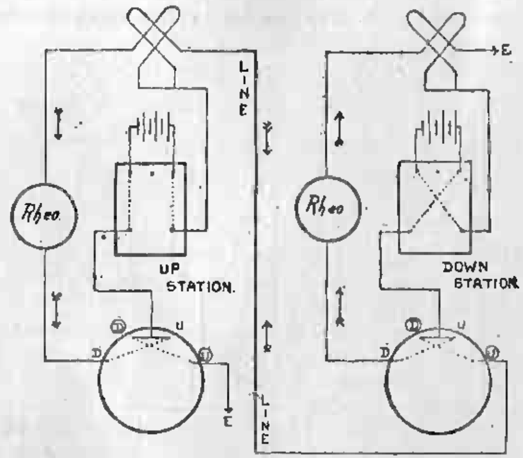

FIG 59.

that a current flows through each of the artificial circuits, and that each battery sends a current to the line circuit. The D-circle U-circle coil of each of the relays is in the line circuit, and the effects upon the sounders depend upon whether the currents flowing in this circuit are greater or less than those flowing in the artificial circuits, and also upon the *direction* of the preponderating current.

When both keys are at rest the batteries act conjointly upon the line circuit and supply currents in that circuit which flow in the *same* direction. The resultant current is, obviously, twice as strong as the current in either of the artificial circuits, consequently the relays are affected by the current flowing in the D-circle U-circle coils. The direction of this current in both cases is from D-circle to U-circle, and a spacing effect is produced at both offices.

Condition 2 provides for both keys being depressed. Clearly, the only difference from condition 1 is that the battery connections at both offices are reversed, consequently the relays are again affected by the preponderating current flowing in the line circuit. As the currents are now reversed, marking effects are produced and the sounders actuated.

In condition 3 one key only is depressed, the other being at rest. Fig. 59, in which the key at the "up" office is depressed, illustrates this diagramatically. The current from each of the batteries must be assumed to split as before, that emanating from the "up" office battery dividing through the galvanometer coils, and that from the "down" office battery at the "split" of the relay. The direction of the currents traversing the artificial circuits is indicated by arrows. As regards the line circuit, it will be observed that the current from one office is opposed by that from the other, and, as a consequence of the equality of the opposing currents, neutralisation ensues. The line circuit being devoid of current, the effects upon the apparatus are produced by the currents traversing the artificial circuits. At the "up" office the current passes through the D-U coil of the relay in a direction which results in a spacing effect, while at the "down" office a marking effect is produced by the passage of the current through the corresponding relay coil, but in the opposite direction.

A closer examination of the artificial circuit may now be made. Hitherto, in dealing with the duplex systems, the line has been considered as possessing the property of resistance only, the electro-static capacity of the line not having been touched upon in order to simplify the explanation of the theory of the systems. The "capacity," however, is a factor not to be overlooked. The influence of the static conditions of a long circuit, in producing retarding and prolonging effects upon the current, is such that, unless the electro-static capacity of the line is reproduced in the artificial circuit, imperfect signals are bound to result. The artificial circuit must resemble the line circuit as closely as possible. It should be made, in fact, *an exact electrical counterpart of the line* circuit. The static conditions are produced in the artificial circuit by means of a "condenser." This piece of apparatus in its simplest form consists of two conductors separated by an insulator. Take two brass plates, A and B, which are separated by a sheet of glass, as indicated in Fig. 60. When a charge of electricity is given to either of them, the charge acts inductively upon the other. A charge of electricity of an opposite kind is *induced* upon the near side of the latter, and an induced charge similar in kind to the inducing charge is repelled to the far side. Let the plate A be given a *positive* charge. The inductive action is to produce a *negative* charge upon the side of B near the glass, and to repel a *positive* charge to the far side of that plate. The negative charge is held bound by the attracting influence of the charge upon A, and the plate B may be said to have an *induced positive potential* by virtue of its free positive charge. It may not be inappropriate to reiterate here that electric potential is the term applied to the property possessed by a charged body which determines its preparedness to do work by overcoming resistance. If now the plate B be earth-connected there will be a momentary discharge of positive electricity, in the form of a current, from the plate to the earth. As the earth is at zero potential the current will flow from the point of the higher potential, *i.e.*, the plate, to the earth. The remaining charge, which is held bound, reacts upon the plate A, accumulating its charge upon the side near to the glass and making it possible for A to receive a further positive charge. The latter, in turn, induces a greater negative charge upon B, and there is an accompanying discharge of positive electricity to earth. The accumulation of

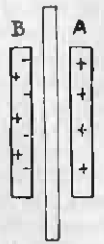

FIG. 60.

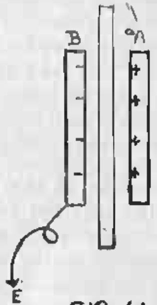

FIG. 61.

the charge upon A may be continued until a point is reached at which A is unable to hold a further charge. Its capacity is then said to be satisfied. With a discharge of the electricity from the plate A the charge upon the plate B is released and there is a momentary rush of negative electricity to earth, or perhaps it would be better to say the negative charge upon B is neutralised by a momentary transference of electricity in the form of a current from the earth to the plate. Such a piece of apparatus is a simple condenser, and its action is analogous to that which takes place in a telegraph circuit. When a battery is joined to a telegraph line the latter becomes charged with static electricity, and the reactions which take place between the line and the earth and conductors in its vicinity are similar to the effects of induction between the two plates of the condenser. The line, in fact, becomes one plate of a condenser, the other plate being the earth and neighbouring conductors. Until the line has been charged to its fullest capacity the current does not pass to the distant station, and the effect of retardation is produced.

As soon as the battery is cut off the charge accumulated upon the wire passes to earth, thus prolonging the current. The function then of the condenser in the artificial circuit of a duplex set is to reproduce the static effects of the line.

The practical form of condenser, to meet the requirements of a telegraph circuit, differs from that first described, but the theory of its action is the same. All condensers are composed essentially of two conductors separated by an insulator, the latter being known as the di-electric.

The capacity of a condenser depends upon the three following conditions, viz. :—

1. The size of the plates;
2. The distance between the plates;
3. The *specific inductive capacity* of the insulating medium or di-electric.

For a large capacity the plates opposed to each other must possess a considerable surface area. The larger the plates in this respect the greater will be the induction between them, and the capacity will accordingly increase in direct proportion to the surface area of the plates. In standard condensers mica is employed as the inductive medium, but its comparatively great cost precludes the general use of this material. Paraffined paper as a di-electric, however, is found to suit admirably for all practical purposes, and by its use in conjunction with sheets of tin foil as the plates the cost of making a condenser is considerably reduced. A large number of sheets of tin foil is employed, and the alternate sheets are so connected that they form two very large conducting surfaces, which are separated by a di-electric of comparatively high specific inductive capacity.

Owing to both paraffined paper and tin foil being manufactured in very thin sheets it is possible to compress them into a small compass, and consequently the plates are brought quite close together. By this means condition 2 is fulfilled, and the inductive effect between the plates is obviously increased.

The *specific inductive capacity* of a di-electric is the peculiar property possessed by all insulating materials, in varying degrees, of allowing induction to take place across them. Taking the specific inductive capacity of air as unity, the approximate relative values of other di-electrics are :—

Glass	1·9
Paraffin	1·9
India-rubber	2·8
Gutta-percha	4·2
Mica	5

It will, therefore, be seen that mica is the best substance to use in the construction of a condenser. Assuming all other conditions to be equal, the capacity of an air condenser is only one-fifth that of a condenser in which the di-electric is mica. The high specific inductive capacity of the latter renders it invaluable when a condensor of great efficiency and reliability is required. Mica, too, may be cut into very thin layers, and this is also an advantage over many other insulating materials. For various reasons the other di-electrics enumerated above are not suitable, and the best substitute for mica is found in paraffined paper, which is an efficient insulator and possesses a comparatively high specific inductive capacity.

Condensers intended for use upon telegraph circuits are made in sections, and by means of brass blocks and plugs they may be readily adjusted to the varying conditions of the line. The alternate sheets of

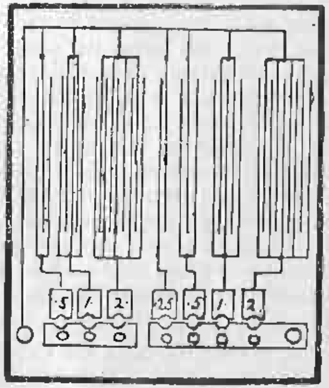

FIG. 62.

tin foil are connected together and joined to one terminal of the instrument. The remainder are divided into sections, each of which is connected to an insulated brass block. Connection between these blocks and a brass strip, upon which is fitted the second terminal of the condenser, is made by means of conical brass plugs. To obtain the maximum capacity the whole of the plugs must be *inserted* (an opposite operation to that required for bringing resistance into a circuit). The capacity of the condenser generally used upon land lines for balancing duplex circuits is 7·25 micro-farads, and by the manipulation of the plugs any value within that limit, by gradations of a quarter of a micro-farad, may be obtained. The arrangement is shown in Fig. 62.

The act of charging and discharging a long line is not effected instantaneously, and the charging and discharging of the condenser must, therefore, be delayed or slowed down in order that the static conditions in the artificial circuit may resemble those in the line. This retarding effect is brought about by including resistance coils in the path of the charge. The brass strip is usually divided into two portions, so that between them may be placed an adjustable set of resistance coils, called the "condenser" coils. In a condenser thus divided one portion represents the capacity of the near end and the other the far end of the line. The process of charging and discharging the condenser is also regulated by another set of resistance coils, through which the charge passes. These coils are termed "retardation coils." As the capacity of long cable circuits is considerable it is usually necessary to construct the condenser in three portions, between each of which a set of resistance coils is inserted, and this is termed a "triple" condenser.

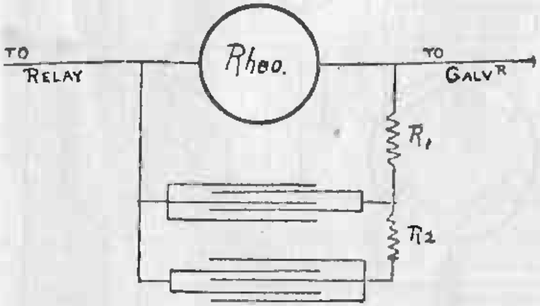

FIG 63.

The capacity of the artificial circuit may be adjusted by noticing the effect upon the differential galvanometer when charging and discharging the condenser. With a perfect balance the galvanometer will not be affected, as the discharges from the line and condenser will neutralise each other, but if the capacity of the one is greater than that of the other, a slight momentary deflection will be observed when the key is depressed or raised. If the capacity inserted in the condenser is not sufficient to effect a balance, the deflection of the galvanometer needle will be in an upward direction when the key is depressed, and downward when the key is released. If the deflections are in the opposite directions the effective condenser capacity is too great. A deflection in the same direction when the key is released as when it is depressed indicates that the retardation coils require re-adjustment. As the galvanometer, however, is not sufficiently sensitive to obtain a fine adjustment it is a much better plan to adjust the condenser to the passage of working signals. The effect of an imperfect electro-static balance is to produce false dots upon the

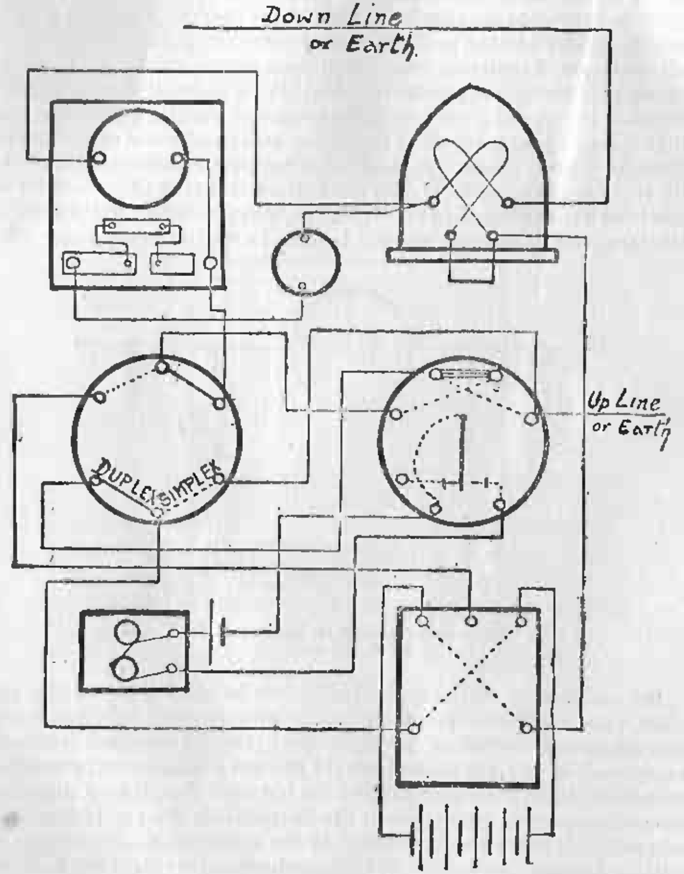

FIG. 64.

receiving apparatus at the sending station, and there distort the signals which are being received. A good plan which may be adopted to produce a fine adjustment is to first obtain an approximate balance, and then find

out by experiment the maximum and minimum capacities, in each division of the condenser, at which false signals appear. The mean between the two should be the required capacity for that section. The resistance in the condenser coils and retardation coils should be similarly dealt with separately, and the mean of the values at which the false signals are produced in each case should be adopted for working purposes. The theoretical connections of the artificial circuit are indicated in Fig. 63, R_1 representing the retardation coils, and R_2 the condenser coils, while a complete diagram of the apparatus and connections required for double current duplex working is shown in Fig. 64.

There are two methods of connecting condensers. Figs. 65 and 66 show how three condensers may be joined. The former illustrates the ordinary

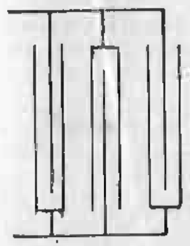

FIG 65.

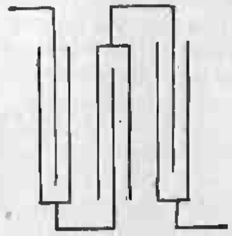

FIG. 66

method of augmenting the capacity by increasing the size of the opposing plates, the effective capacity of the three condensers C_1, C_2, and C_3 joined in this manner being the sum of their separate capacities.

Fig. 66 indicates the "cascade" arrangement, by means of which a capacity less than the smallest of the three is obtained. By this method one plate of the condenser C_1 is opposed to one of the plates of C_3 by way of C_2.

The distance between these plates, for purposes of induction, is three times as great as that between the plates of either one of the condensers, and, as the capacity is inversely proportional to the distance between the plates, the capacity in this instance will be only one-third that of one of the condensers, assuming that they each have the same capacity. The analogy between this system and the connection of resistances in "parallel arc" will be apparent, and the same law applies. The capacity of three condensers joined in cascade is

$$\frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

CHAPTER XIV.

The Differential Duplex System.

To increase the amount of traffic that may be dealt with upon a single wire circuit, means have been adopted whereby signals can be sent and received simultaneously at both ends of the line. This system of working is known as the "Duplex" system, and the "carrying capacity" of the circuit is approximately twice as great as that of a "simplex" circuit.

Experience, however, has shown that two circuits of the latter class will give better working results than one "duplex" circuit, and duplex working should only be resorted to when it is found that all the available

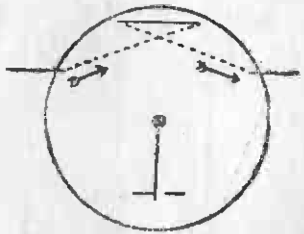

FIG. 51

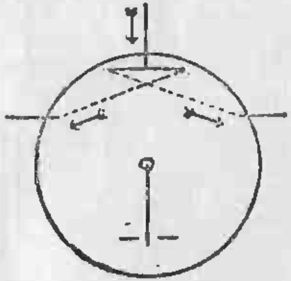

FIG. 52.

"simplex" circuits are insufficient to carry the traffic. The principle of the "differential" system of duplex working is based upon the fact that when a current splits through two paths of equal resistances, the currents which flow through them are equal. In the system under consideration the relay and galvanometer are differentially wound, so that when currents of equal strength pass through the two sections of the coils of either instrument in opposite directions, the effect of one section is neutralised by that of the other. When, however, the current in one section is greater than that in the other, the instrument is affected by virtue of the preponderating current and will respond according to the direction in which that current passes.

In the duplex system an artificial circuit is made up and balanced against the line circuit by means of resistance coils and, where necessary,

condensers. The object of the artificial circuit is to produce an exact electrical counterpart of the line, so that when a current splits through the circuits the currents which result shall be equal in strength and similarly affected by the static conditions prevailing.

Before attempting to describe the actual working of the duplex system it will be well, perhaps, to consider how the relay is affected by the currents passing through it. The relay should be looked upon as the receiving instrument, as the sounder is only actuated when the currents which pass through the coils of the relay are such as to close the local circuit. For duplex working the coils of the relay are invariably joined up in "series," and when a current passes through them from "left" to "right," as shown in Fig. 51, the effect upon the armatures is to cause the latter to turn towards the left. A current in the reverse direction produces an opposite or marking effect, and joins up the local battery circuit, and the sounder

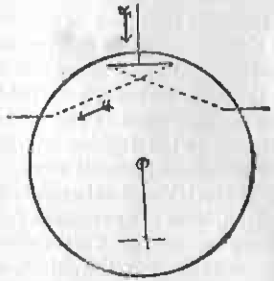

FIG. 53.

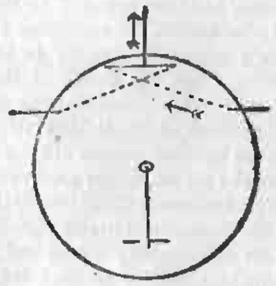

FIG. 54.

is actuated. It should be remembered that the current causes the armatures to turn in the opposite direction to that in which it is flowing. Fig. 52 shows the current coming in at the "split" of the relay, and, if the resistances upon either side of the relay are equal, it will divide equally through the two paths. The two currents thus produced will pass through the coils in opposite directions, and the effect of the one will neutralise that of the other. The armatures will consequently remain undisturbed. Should one of the currents be augmented in strength by combination with another the relay will be actuated by the increased current. When the current in either section of the relay is neutralised by the opposition of another current of equal strength, the effect upon the relay will be produced by the current in the other section of the relay coils, and will be "marking" or "spacing" according to the direction in which that current is flowing. The effect of a

The electrode in connection with the *positive* pole of the primary battery is termed the "anode," and its pole is the *positive* pole of the secondary cell. The electrode in connection with the *negative* pole of the primary battery is termed the "kathode," and its pole is the *negative* pole of the secondary cell. The reason for thus naming the poles is apparent upon consideration of the fact that the hydrogen at the kathode is electro-positive to the oxygen at the anode, and that the former acts as the positive and the latter as the negative *plate* of an ordinary cell.

There is a difference of potential of 1·47 volt between hydrogen and oxygen, therefore a greater electro-motive force than this must be employed to decompose water.

It will be seen from the above remarks that the *secondary* current is due to *chemical re-actions*, consequently the term "secondary" is more applicable to a cell of this kind than the more general term of "accumulator." To amplify this, consider an exhausted "Daniell" battery. When a comparatively strong current is passed through it in the direction from copper to zinc, *i.e.*, in the reverse direction to that of the proper current, chemical re-actions take place, and the battery is again capable of being used—in the primary sense—as a source of electrical energy.

The simple gas battery is of little practical use; but Planté, in the year 1860, introduced lead sheets as the electrodes, and a solution of sulphuric acid ($H_2 SO_4$) as the electrolyte. Upon passing a current through the electrolyte oxygen was found to combine with the anode—the plate at which the current enters the cell—and form, with the lead, peroxide of lead (PbO_2) while the evolved hydrogen was liberated at the kathode. Peroxide of lead is an insoluble compound, and when opposed to a clean surface of lead, the kathode, a difference of potential of about 2 to 2·5 volts is obtained. Planté used large sheets of lead rolled up spirally, but not in contact, and immersed them in dilute sulphuric acid. By repeatedly charging, discharging or recharging the cell in reverse directions the amount of active material was considerably increased by making the surfaces of the lead plates porous by chemical action. When the secondary current was produced the hydrogen adhering to the kathode combined with some of the oxygen of the peroxide of lead at the anode and formed water, while the surface of the kathode was also oxidised by the release of oxygen from the electrolyte. The peroxide of lead at the anode was deprived of some of its oxygen, and the surface of the anode was left in a porous or spongy state.

When the secondary cell had practically exhausted itself the primary current was again applied, and the oxidised lead at the kathode was reduced to spongy lead, while the enlarged surface of the anode again became covered with peroxide of lead. These actions of charging and discharging, which resulted in the enlargement of the surfaces of the plates, after having been in operation for some time were discontinued, and the "formation" of the plates proceeded by local action, the sulphion of the sulphuric acid combining with the lead. Although the peroxide still remained upon one of the plates, the local action took place between its particles, with the result that both plates eventually became coated with sulphate of lead.

This method of "forming," however, entailed considerable labour, expense and loss of time. It was also limited by the mechanical weakening of the plates by increasing their porosity.

In the year 1880 a considerable improvement was effected by Faure, who made a paste of lead sulphate ($PbSO_4$) by mixing sulphuric acid (H_2SO_4) and red lead, or minium (Pb_3O_4), and applying it to both plates.

The amount of electrical energy necessary to produce spongy lead was by this means considerably reduced. The paste at the positive plate, or anode, was converted into peroxide of lead (PbO_2), oxygen having been

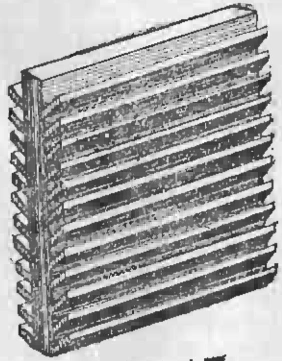

FIG 67

released from the dilute acid by the "charging" current, and that upon the negative plate or kathode, first to a lower oxide and then to spongy lead. The hydrogen evolved at the kathode combined with the sulphion (SO_4) of the sulphate of lead and formed sulphuric acid ($H_2 SO_4$).

A more modern method, however, is to form a paste of litharge ($Pb O$) and sulphuric acid for covering the negative plate, as the amount of energy required to deoxidise litharge is less than that necessary to reduce minium, which is a higher oxide.

THE ELECTRIC POWER STORAGE CELL.

The K7 E.P.S. cell is largely used by the Post Office. The number of plates employed in this cell is seven, four of which are negatives and three positives. The latter are comparatively thick and grooved, as shown in Fig. 67. A large quantity of the paste, which is a compound of minium and dilute sulphuric acid, can be worked into the grooves. This is an improvement upon the older type of plates, the surfaces of which were merely roughened. Litharge is added to the minium and

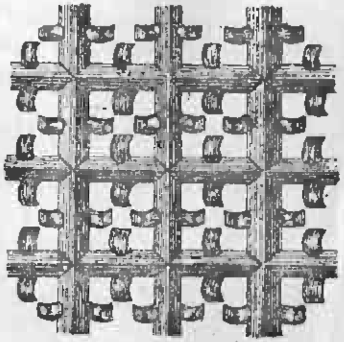

FIG. 68.

sulphuric acid upon the negative plates, which have holes in them with projections across the holes, shown in Fig. 68, to keep the paste in position. The excess number of negative plates is to ensure an approximate equality of chemical action upon both sides of the positive plates; "buckling" of the plates, due to an unequal expansion of the pastes, and a possibility of contact between them are thereby avoided, and their mechanical strength is not unduly reduced. To prevent the action of the electrolyte upon the plates or grids, and consequently maintain their mechanical strength, they are frequently alloyed with 10 per cent. of antimony. The positive and negative plates are arranged alternately, the three former being connected at the top, and the four latter at the bottom of the cell. This method of joining tends to produce an equality of chemical action.

For the obvious reason of reducing the resistance of the cell, which is about ·0015 ohm, the plates are kept as closely together as possible, without being in actual contact; but sufficient space is left to allow any detached fragments of the paste to fall clear of them.

Over each positive plate an ebonite fork is fitted to keep the plates from actual contact. The set rests upon a piece of H-shaped

paraffined wood placed horizontally at the bottom of the cell, and the whole is placed into a thick glass vessel containing the electrolyte. The detached pieces of paste, etc., fall clear of the plates to the bottom of the glass vessel, and this is the object for resting the set upon the wooden stand. The use of glass as the containing vessel enables a close examination of the cell to be easily made and a knowledge of its general condition to be readily ascertained.

Both electrodes may be pasted with sulphate of lead ($Pb\,SO_4$), made of a mixture of red lead (Pb_3O_4) and sulphuric acid. The effect of "charging" reduces the sulphate of lead to spongy lead at the negative plate and lead peroxide at the positive plate. The same result is also attained when litharge is employed. The "formed" plates are usually supplied by the makers ready for charging.

The chemical action which takes place in a secondary cell is very complicated, but may be represented by three chemical formulæ, from which it will be seen that the density of the electrolyte gradually increases by the formation of sulphuric acid. Before the cell is charged it may be assumed that the plates are sulphate of lead, and that the liquid is dilute sulphuric acid. The chemical formula is then

[BEFORE CHARGING]

$$Pb\,SO_4 + 2\,H_2O + H_2\,SO_4 + Pb\,SO_4$$

During the process of charging the water is decomposed into its constituent elements, the action being represented thus—

[WHILE CHARGING]

$$\overbrace{Pb\,SO_4 + O_2} + H_2\,SO_4 + \overbrace{2\,H_2 + Pb\,SO_4}$$

When the cell is fully charged the sulphion of the sulphate of lead has entered into chemical combination with the hydrogen, resulting in the formation of sulphuric acid, while the oxygen together with the lead at the anode has produced peroxide of lead. The formula may be stated thus—

[FULLY CHARGED]

$$Pb\,O_2 + H_2\,SO_4 + H_2\,SO_4 + H_2\,SO_4 + Pb$$

Summarised, the chief points about the "accumulator" are:—

During charging, the positive plate and pole of the secondary cell are in connection with the positive pole of the primary generator; the negative plate and pole being, perforce, in connection with the negative pole of the generator.

In discharging, *i.e.*, when the secondary current is flowing, the same terms are employed, albeit the *actual* conditions with regard to the plates, are reversed. The poles of the secondary cell, however, remain unaltered, because the current flows from the positive to the negative pole.

In the process of "forming" the reduction of the paste to a condition of spongy lead is aimed at, and this results in a larger surface of active material being created. The cell can thus be very highly "charged," and its capacity for storing up the essentials for an output of electrical energy is consequently materially increased.

In the Post Office the cells are joined up in rows of convenient numbers for the purpose of charging and to give certain voltages. For charging there is required a supply of power capable of giving a current at a slightly higher pressure than the cells to be charged.

This supply may be from one of the following sources, viz :—

(*a*) A battery of primary cells.

(*b*) A dynamo driven by a gas or steam engine.

(*c*) A motor-dynamo driven by power from a supply company's mains, the current generally being an alternating one.

(*d*) Power obtained *direct* from the supply company's mains.

The methods named in *b* and *c* are those generally adopted by the British Post Office.

In the case of *b* the gas engine and dynamo must have sufficient power to give a pressure about 25 per cent. greater than the electro-motive force of the largest group when the cells are fully charged. For example, a group consisting of 25 cells, which would have an electro-motive force of 62·5 volts when charged—the electro-motive force of each fully charged cell being 2·5 volts—would require to be charged from a dynamo capable of producing a pressure of about 75 volts. This will be understood from the following :—

The cells are supplied by the manufacturers already "formed," and, on being connected together in groups upon the racks, they are charged for the first time for a period of about 30 hours. During that time the current from the source of supply must not cease, except for a very brief period to oil the engine and dynamo.

The acid is poured into the cells before charging and the dynamo joined up as shown in Fig. 69.

When charging commences, the electro-motive force of an E.P.S. K7 cell is about 1·8 volt, which rises during the first hour or so to two volts, and afterwards very slowly until 2·4 or 2·5 volts is obtained when the cell is fully charged.

During the process of charging the specific gravity of the electrolyte undergoes a change. After a brief period bubbles of gas are evolved, and these increase in volume as time goes on, until the liquid has the appearance of milk. The cells are then assumed to be fully charged, and by means of the voltmeter and hydrometer their condition may be definitely ascertained.

The makers of secondary cells specify the current which is required for charging. In the case of E.P.S. K7 cells the current must be between 15 and 25 ampères.

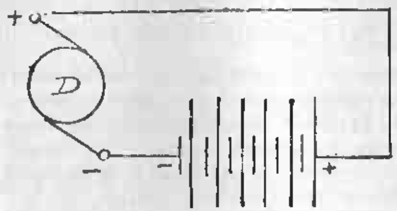

FIG. 69

From these figures the amount of energy needed can be calculated from the following formula :—

$$C = \frac{E - e}{R}$$

Where C = the current in ampères.
E = the required electro-motive force.
e = the electro-motive force per cell at the start.
R = the resistance of the battery.

Assuming that a charging current of 20 ampères is required and that a group of 25 cells is being charged the equation becomes

$$C = \frac{E - (25 \times e)}{R}$$

The resistance of the battery, however, is so small that it may be neglected, the equation then being

$$20 = E - (25 \times 1{\cdot}8)$$
$$20 = E - 45$$
$$E = 45 + 20$$
$$= 65 \text{ volts.}$$

At the commencement of charging the dynamo must be run to produce 65 volts. As the charging proceeds, however, the back electro-motive force of the cells increases, and the electro-motive force of the dynamo must, consequently, be increased.

This can be effected by increasing the speed of the gas engine, or the current may be augmented by cutting out resistance in the leads between the dynamo and the cells.

The method of obtaining the required energy for charging, as indicated in *b*, is becoming obsolete, and wherever it is possible to obtain the energy from a supply company the gas engine is dispensed with.

A motor-dynamo, taking its power from a supply company, is substituted, and this system is rapidly coming into general practice.

When only two condensers are joined in cascade the resultant capacity is the product of the separate capacities divided by their sum.

Example 44.—What is the capacity of two condensers joined in cascade, their separate capacities being respectively three and five micro-farads?

$$\text{Total capacity} = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{3 \times 5}{3 + 5} = \frac{15}{8} = 1\tfrac{7}{8}$$

Answer: $1\frac{7}{8}$ micro-farad.

Example 45.—The capacity of two condensers joined in cascade is ·75 micro-farad. If the capacity of one of them is three micro-farads, what is the capacity of the other?

$$\text{Total capacity} = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$\cdot 75 = \frac{3 \times C_2}{3 + C_2}$$

$$\text{Cross multiplying,}\quad 3\,C_2 = 2{\cdot}25 + {\cdot}75\,C_2$$

$$3\,C_2 - {\cdot}75\,C_2 = 2{\cdot}25$$

$$2{\cdot}25\,C_2 = 2{\cdot}25$$

$$C_2 = 1$$

Answer: 1 micro-farad.

Example 46.—What is the capacity of three condensers joined in cascade, if the separate capacities are 2, 3, and 4 micro-farads respectively?

$$\text{Total capacity} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} = \frac{1}{\frac{1}{2} + \frac{1}{3} + \frac{1}{4}} = \frac{1}{\frac{6 + 4 + 3}{12}} = \frac{12}{13}$$

Answer: $\frac{12}{13}$ micro-farad.

CHAPTER XV.

The Secondary Cell.

The theory of the secondary cell or "accumulator" is more easily understood after a brief survey of the Grove's gas battery.

In the description of the simple cell it was stated that "polarisation" quickly deprived the cell of its practical use. There existed a tendency for a *back electro-motive force* to be set up, consequent upon an accumulation of the electro-positive radicle, hydrogen, upon the negative plate. In the secondary cell, however, the effect of polarisation is turned to a useful account, the current being due to the counter electro-motive force set up as a consequence of certain chemical changes taking place in the cell when an electric current from a *primary* source is passing through it.

The type of secondary cell invented by Groves consists of two glass tubes having their upper ends closed. Into the closed end of each tube a platinum wire is fused, and to each wire a platinum strip, which extends to the base of the tube, is attached. The tubes are filled with water, a little acid being added to increase its conductivity, and placed vertically into a vessel containing a similar liquid, their closed ends being uppermost. The free ends of the wires are attached one to each pole of a primary battery, or any other generator of a fairly strong current. The passage of a current through the water (H_2O) results in the latter being decomposed into its constituent elements, H_2 (hydrogen) and O (oxygen). The hydrogen follows the path of the current, and is given off at the platinum strip in connection with the zinc or negative pole of the primary battery, while the oxygen is evolved at the strip connected with the positive pole of the primary battery. Hydrogen is electro-positive to oxygen so that, when the two wires attached to the platinum strips are removed from the primary battery and joined to a galvanometer, a current flows from the hydrogen-covered strip through the liquid to the strip at which the oxygen is evolved, and, if the galvanometer is sufficiently sensitive, a deflection is observed.

This secondary current, due to the difference of potential existing between the gases, is opposite in direction to that of the primary current, and it will flow until the separated hydrogen and oxygen have re-united and again formed water.

The two platinum strips are called the "electrodes," and the liquid is the "electrolyte." An "electrolyte" is a compound which is thus capable of decomposition, and "electrolytic action" is said to take place when a compound is electrically decomposed.

1,000, 900, 800, 700, and 600 ohms resistance respectively are to be grouped. The resistance representing a 25 per cent. reduction of 1,000 ohms is 750 ohms, and it will be seen that the circuits having resistances of 700 and 600 ohms require resistance blocks. The mean between 1,000 ohms and 750 ohms is 875 ohms, and to this value the resistance of each of the two circuits under consideration should be raised. Resistances of 175 ohms and 275 ohms should, therefore, be inserted in the battery leads of the 700 and 600 ohms circuits respectively. When standard resistance blocks of the exact value cannot be obtained, the nearest available should be used.

In single current working one pole of the battery is earthed, and the circuits are so grouped that "up" and "down" instruments are worked from different batteries. An "intermediate" instrument on a single current circuit cannot be worked on the universal battery system. In the case of "up" instruments the negative pole of the battery is earthed; with

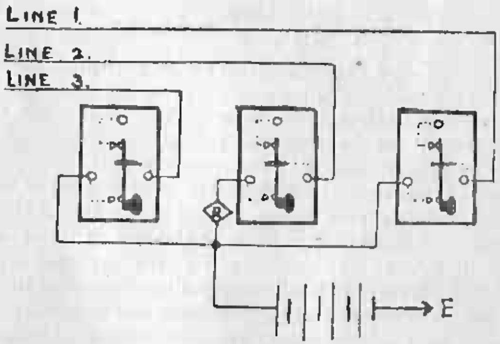

FIG. 70

"down" instruments the reverse condition prevails. The other pole in each case is joined to the left-hand terminal of the key of each circuit, and, where necessary, resistance blocks are inserted between these points. Fig. 70 shows the battery connections for "up" office working, the balancing resistance being shown in connection with circuit 2.

Upon systems in which double current working is adopted, and upon single needle and double-plate sounder circuits, it is necessary to use two batteries, each of which is earth connected. The reason for this will be readily seen if it is remembered that when only one battery is being used, and one key is joining the positive pole to earth while another is connecting the negative pole to earth, the battery is short-circuited, and no current

passes to either line. In practice, however, the two sets of cells are joined together in series, the centre of the combined battery being earth connected.

For double-current working upon the universal battery system a single current key fitted with a switch is used. Its connections with the switch in an intermediate position are indicated in Fig. 71. With the switch to "send"—*i.e.*, connected with the left-hand stop,— and the key at rest, the front right-hand terminal is joined to the left-hand back terminal, while the depression of the key connects the front and back right-hand terminals. With the switch in the "receive" position, the two front terminals are connected *viâ* the switch, the battery being disconnected.

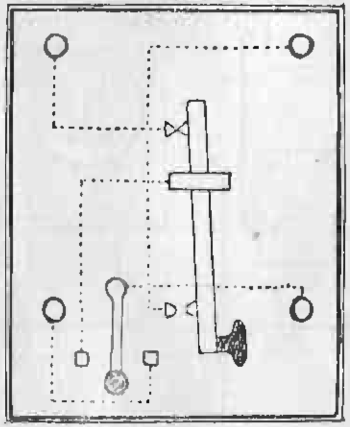

FIG. 71.

"Up" and "down" terminal sets of apparatus may be worked upon the double current system from the same battery. The necessary connections are shown in Fig. 72. "Intermediate" apparatus may also be grouped with "terminal" sets, but a resistance block, to make the "up" and "down" sections of the line approximately equal in resistance, should be inserted in the side having the smaller resistance. This resistance, which is independent of the previously mentioned balancing resistance, is arranged to be in the "sending" circuit only, so that a "received" current is not affected by it. An ordinary five terminal double current key is used for "intermediate" apparatus. The necessary connections are indicated in Fig. 73, the apparatus on the left showing the arrangement when the "down" section of the line has the smaller resistance, while upon the right-hand side of the diagram the equalising resistance is shown in the "up" line. When "intermediate" apparatus is grouped with "terminal" apparatus *each section* of the line upon which the former is inserted should be approximately equal to the resistance of the terminated lines.

For universal working upon duplex circuits a re-arrangement of the connections is necessary on account of the earth connection at the battery. The principle of the system of differential duplex working, however, is

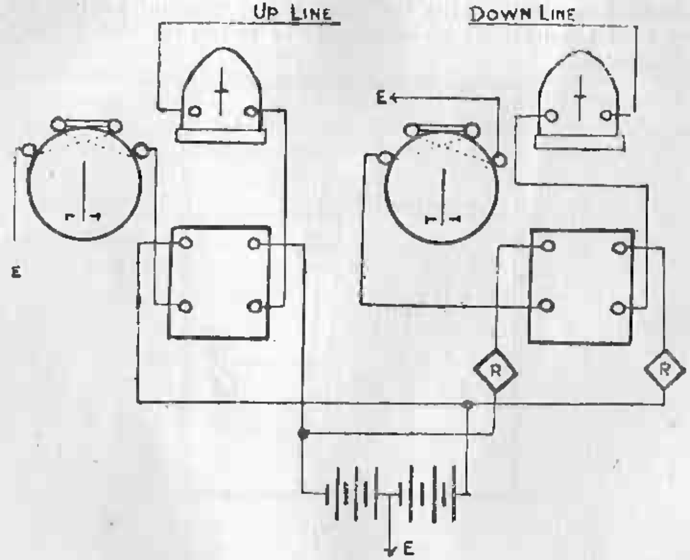

FIG 72

unaltered, and the student who has mastered the duplex system already described will find no difficulty in tracing the currents and understanding how the conditions necessary for duplex working are brought about. Fig. 74 shows the theoretical connections for duplex working at "up" and "down" stations. For double plate sounder and single needle instruments the same underlying principles apply as for double current working. At terminal offices, however, precautions must be taken to prevent the battery being short-circuited if both tappers be accidentally depressed at the same time. This is effected by a modification of the commutator. The front contact screw of the left-hand tapper is removed, and the back right-hand

spring is dispensed with, or so adjusted as to prevent contact being made when the right-hand tapper is depressed.

At offices where secondary cells are employed all the circuits are worked upon the universal battery principle. These cells are specially adapted for this system on account of their exceedingly low resistance, and not only are they used for supplying currents for the lines but for the local battery circuits as well. Practically the whole of the power required for any purpose whatever is obtained from the same set of cells.

The chief features of an installation of secondary cells are as follow: The storage capacity of the cells is fixed in accord with the work required

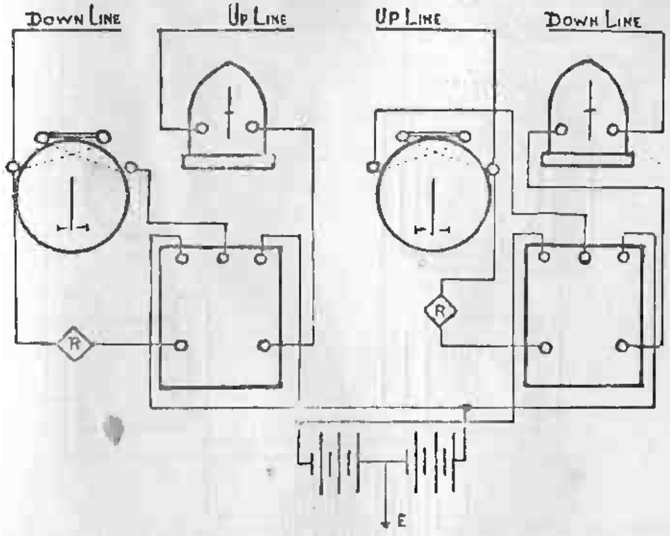

FIG 73.

of them. It is generally of 45 or 72 ampère hours, *i.e.*, the current in ampères multiplied by the time in hours. In some cases the mains are 45 and the locals 72 ampère hours—the locals being the harder worked of the two. For very large offices the main batteries may be 72 ampère hours and the locals still higher.

The main batteries, which give voltages of 40, 80, and 120, positive and negative, are provided, together with a local set of 24 volts. The latter also provides the working currents for short lines, and, being a double set with an earth connection at the centre, the relay is also earthed. The main batteries are arranged in six groups of 20 cells, and are placed upon racks of dimensions suitable to take two groups in a "bay"—one group on top and the other below.

The locals are in four sets of twelve cells each, so that when one double set (24 cells) is in use another double set is being held in reserve. A few spare cells are kept aside to replace any which may become defective.

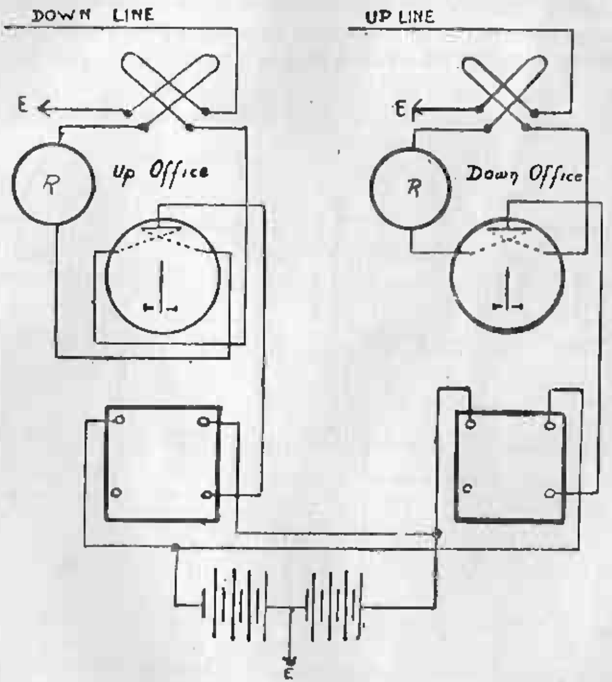

FIG 74.

An arrangement of the voltages frequently adopted is shown in Fig. 75, it being understood, of course, that similar sets of cells are either lying idle or being charged. As the inner sets of main cells are the hardest worked, being those from which the most current is drawn, they are liable to become exhausted sooner than the outer sets. By means of a switch the relative positions of the cells may be varied periodically and

the action of all the sets equalised. Another switch is also employed which, while joining up the one set of cells for use in the instrument room, leaves the other set connected with the dynamo for charging and removes the central earth connection. Distributing cabinets are provided both for the battery room and the instrument room, and in the latter room table distributing boxes are also arranged. One box supplies three tables, so that, starting from one end of the room, the first three tables are supplied from a box on table 2; tables 4, 5, and 6 from a box on table 5, and so on. All the voltages are led to each box, and provision is made for the connection of ten circuit leads.

At every circuit, or at the table distributing boxes, a one-ampère fuse is placed in each battery lead. Suitable fuses are also provided for each

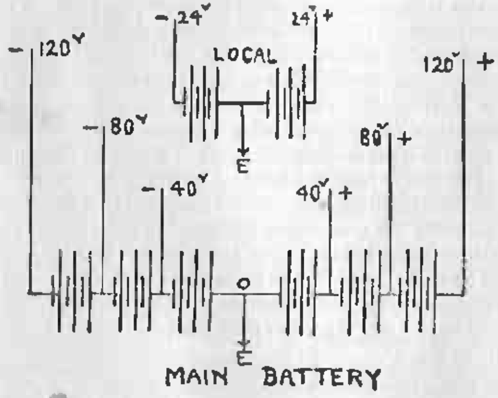

FIG. 75

voltage at the distributing cabinets in the instrument and battery rooms. The object of the fuses is to prevent the exhaustion of the battery through "short-circuit," and also to protect the instruments from the damage which would arise from the passage of currents of excessive strength through the coils.

Precautions also must be taken to prevent the battery discharging through the dynamo should the latter be accidentally stopped. The provision of a suitable "cut-out" switch and fuse ensures the breaking of the main circuit and leaving the battery insulated when the discharge current flows from the cells.

CHAPTER XVI.

The Universal Battery System.

When a large number of wires radiate from an office there are many very obvious reasons why the use of a separate battery for each circuit should be avoided. In certain circumstances, in fact, one battery provides the necessary current for several circuits. The latter, however, have approximately equal resistances, and, what is of greater importance, the resistance of the former is comparatively low.

The limitation of the number of circuits which can be advantageously worked from the same battery depends upon the resistance of the cells, and is best demonstrated by mathematical examples. If the battery has a negligible resistance an unlimited number of circuits can be worked from it, without in any way reducing the amount of current per circuit, whereas with a comparatively high battery resistance a practical limit is quickly reached.

First suppose that the battery resistance is inappreciable and that the electro-motive force is 50 volts; there are ten circuits connected to the battery and each circuit resistance is 1,000 ohms.

When only one circuit is being worked:—

$$C = \frac{50 \times 1000}{1000} = 50 \text{ milliampères.}$$

With two circuits working the lines are joined in multiple arc and the total resistance is reduced to 500 ohms. Consequently the strength of the current obtained from the battery is doubled.

$$C = \frac{50 \times 1000}{500} = 100 \text{ m.a.}$$

But as the current will divide equally through the two circuits, their resistances being equal, each circuit will get 50 milliampères, or the same current as when only one circuit was working.

If we take five of the circuits, each drawing its supply of current from the same source, the external resistance will be only 200 ohms, and

$$C = \frac{50 \times 1000}{200} = 250 \text{ m.a.}$$

Again the division of the current results in each circuit getting its full share of 50 milliampères.

No battery, however, is devoid of resistance, and the conditions enumerated above are purely hypothetical. If we consider the same circuits and the same battery, but assume that the latter has a resistance of, say, 50 ohms, it will be seen that as the number of working circuits increases, so will the current appropriated by each diminish.

With one circuit working:—

$$C = \frac{50 \times 1{,}000}{1{,}000 + 50} = 47\tfrac{13}{21} \text{ m.a.}$$

With two circuits working simultaneously:—

$$C = \frac{50 \times 1{,}000}{500 + 50} = 90\tfrac{10}{11} \text{ m.a.}$$

or, $45\frac{5}{11}$ milliampères for each circuit.

With five circuits working:—

$$C = \frac{50 \times 1{,}000}{200 + 50} = 200 \text{ m.a.}$$

or, only 40 milliampères for each circuit.

The lower the resistance of the battery, then, the greater the number of circuits which can be grouped, and if the battery resistance is approximately equal to half the joint resistance of the circuits a practical system can be established. Bichromate cells are better adapted for "universal" working than either Daniell or Leclanché cells. As the former have a comparatively high electro-motive force and a low resistance they are very suitable for the production of heavy currents. The number of circuits grouped together when the current is obtained from a primary battery is usually not more than five. The circuits must have approximately the same resistance to ensure each getting its proper amount of current. Their lengths also should not differ to any great extent, as the insulation resistance of the longer circuits will show a greater variation in wet weather than that of the shorter lines. If the circuits are of nearly the same length climatic influences will affect them equally, and the resulting fluctuations in the resistances will not materially affect the working of the system. The lowest resistance should be not more than 25 per cent. less than the highest. In cases where a greater disparity than this exists resistance blocks are introduced into the battery leads of the low resistance circuits. The method of calculating the necessary balancing resistance is to take the mean between the highest resistance and that which is 25 per cent. less than the highest, and level up the resistances of the circuits which fall below the 25 per cent. reduction to the mean resistance. For example, suppose that five circuits having termination of the spacing current, the upper contact joins up the other pole of the battery and a short-circuit of the cells ensues. If this momentary short-circuit occurs during the depression of the "B" key, and consequent action of the whole of the battery, the effect is to produce a "kick" in the "B" relay at the receiving end of the circuit. The conditions, of course, are the same if the reversal of current is being made from "marking" to "spacing." The effect of this "kick" has been practically counteracted by the introduction of a "relaying" or "uprighting" sounder between the relay and the reading sounder. The non-polarised relay, too, is rather sluggish in action, and the combined effect is such as to eliminate from the reading sounder the momentary break in the signal. The relaying sounder also performs useful service in another direction. In the normal state of affairs the tongue of the "B" relay is held by the antagonistic spring against the contact screw which joins up the local battery connected with the relaying sounder. As long as this condition prevails a current flows through the coils of the latter, and consequently the armature is attracted towards the pole pieces. The passage of a current through the relay coils of sufficient strength to merely break this contact causes the armature of the relaying sounder to be released. This results in the reading sounder being actuated by virtue of the contact made at the upper screw of the relaying sounder, the contact being effected with the full force of the latter's adjusting spring. It will be readily understood, therefore, that better effects are produced by this means than if a contact had to be made against the force of the strong antagonistic spring of the "B" relay.

The principle of the quadruplex system is based upon that of the differential duplex system. The current splits at the "B" relay, and one portion passes through one coil of each of the relays and one coil of the differentially wound galvanometer to the "earthed" artificial circuit, which is adjusted as for duplex working. The other portion of the current traverses the other coils of the relays and galvanometer, and thence to the line.

The arrangement shown in Fig. 76 is for an "up" office. The only alterations necessary at a "down" office are the reversal of the wires joined to the lower terminals of the galvanometer and the battery leads.

A skeleton diagram indicating the connections at "up" and "down" offices is shown in Fig. 77. This will probably assist the student in understanding the following brief explanation of the various conditions which have to be met in quadruplex working :—

1. All Keys at Rest.—The small batteries only are in operation and currents from both traverse the line circuit in the same direction. The preponderating current from the combined batteries passes through both "A" relays in a spacing direction, and no signal is recorded. The *effective* currents passing through the "B" relays, *i.e.*, the difference between the

currents flowing in the artificial and line circuits, are too weak to overcome the antagonistic springs, and the relays are not actuated.

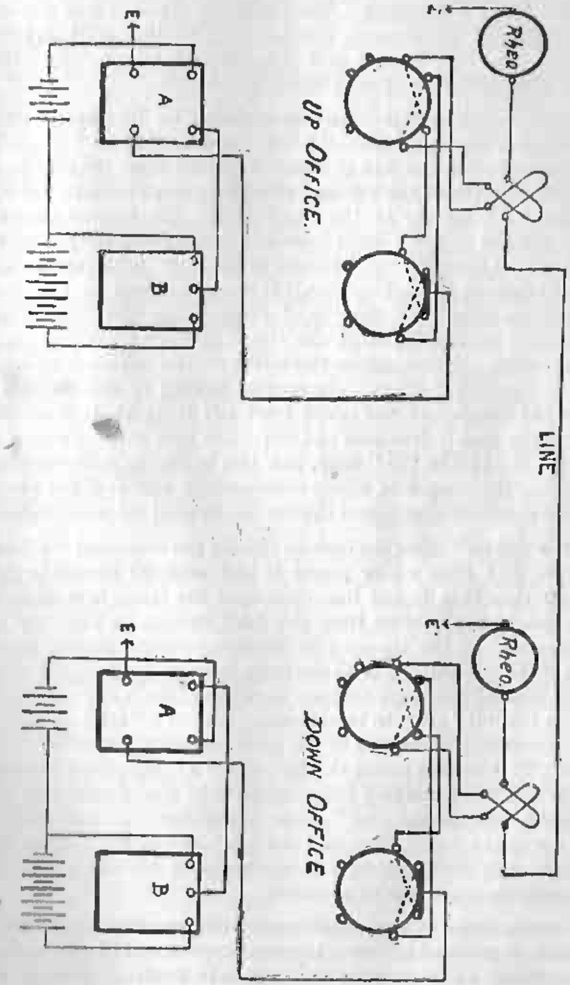

FIG 77

2. Both "A" Keys Depressed.—The currents are now reversed and the preponderating currents are in the direction to produce marking

effects in both "A" relays. The reversal of the current does not affect the "B" relays.

3. ALL KEYS DEPRESSED.—The conditions are as in case 2, except that the strengths of the currents are increased by the addition of the "B" batteries. The "B" relays now also respond, however, by virtue of a greater preponderating current in the line circuit.

4. "A" KEY AND "B" KEY DEPRESSED AT DIFFERENT OFFICES.—Suppose that the "up" office "A" key and the "down" office "B" key are depressed. In the line circuit the current from the combined "A" and "B" batteries at the "down" office is opposed by the smaller current from the "A" battery at the "up" office. The current from the combined batteries at the "down" station is approximately three times as strong as that from the "A" battery at the "up" office, consequently the resultant current in the line circuit is twice as strong as that traversing the artificial circuit at the "up" office. The direction of the preponderating current through the "up" office "A" relay produces a spacing effect. Now consider the action of the currents upon the "B" relay at the "up" office. The current passing to the artificial circuit, *i.e.*, at the "split" of the relays from left to right, is from the "A" battery only, and it traverses one coil. The line current passes through the other coil of the "B" relay, and this is also in a direction from left to right. The magnetic effects consequently combine, the result being that the armature is actuated against the force of the antagonistic spring.

At the "down" office the current is from the combined "A" and "B" batteries, and that which passes to the artificial circuit is greater in strength than that in the line circuit, as the latter is weakened by the opposition of the current from the "A" battery at the "up" station. A comparison of the strength of the two currents passing through the relays of the "down" office shows them to be in the proportion of three to two, and the difference between their strengths is not sufficiently great to cause the "B" relay to be actuated. The "A" relay at the "down" office, however, will respond to the preponderating current in the artificial circuit. This current passes through the "A" relay in a direction from right to left, and a marking effect, which is in accord with the depression of the "A" key at the "up" office, is registered in that relay. If the "B" key at the "up" office and the "A" key at the "down" office be simultaneously depressed, by similar reasoning it will be seen that the corresponding relays will be actuated.

The construction of the non-polarised relay requires a brief description. This relay is provided with two tongues or armatures of soft iron normally unmagnetised, as no permanent magnet is used. A current in either direction through the coils will consequently cause the armatures to be attracted and produce a marking effect. Clearly, this instrument on that

account would be useless upon a *double* current system, but it is highly adapted to the conditions upon the "B" side of the quadruplex circuit. A special kind of non-polarised relay, however, is used in this case. The two armatures are pivoted at their centres, the two sections of each being brazed together by a non-magnetic substance in the same way as Spagnoletti's needle. This arrangement prevents a closed magnetic circuit being formed between these and the poles of the electro-magnets, when attraction of each section of both armatures towards the nearest pole-piece takes place. A closed magnetic circuit would considerably increase the self-induction of the electro-magnet and act deleteriously upon the rate of working.

The keys are without switches, but in order that the line may be put to earth for balancing purposes, etc., a switch is placed between the "A" key and the split of the "B" relay. By turning the switch to the right the main batteries are cut out of the line circuit, and waste of energy may be prevented when the apparatus is not required for use. As the relays

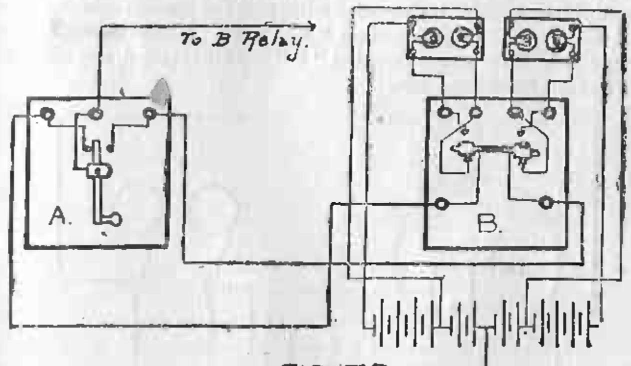

FIG. 78.

remain in circuit, however, signals from the distant station may be received, and attention gained. On the earth side of the switch a resistance is inserted. It is approximately equal to that of the whole battery and the spark coil. The latter is shown on the right of the "B" key, in Fig. 76. The spark coil prevents damage to the contact points when the whole battery is momentarily short-circuited. The resistance inserted at the left-hand terminal of the "B" key is approximately equal to both that of the larger section of the battery and the spark coil. This prevents any variation in the resistance of the circuit when the keys are being manipulated.

For universal working a special arrangement of the keys is necessary on account of the earth connection at the battery. This is shown in Fig. 78

for an "up" office. In this system it will be seen that a key having six terminals, which is used as the "increment" key, is employed upon the "B" side, whilst a three-terminal key, ordinarily used upon the "B" side, is used upon the "A" side for reversing the direction of the current. Four "vacuum" resistances are included in the battery leads connected with the "B" key. When the battery is accidentally left short-circuited through the springs of the "B" key the "lamps" glow, and an automatic warning signal is thus given.

In another system of quadruplex working, known as the "decrement" system, the "B" relay is worked by a *decrease* in the current. The magnetic force due to a comparatively strong "A" current holds the "B" relay tongue to *spacing*, or, in other words, *against the insulated contact stud.* When the "B" key is depressed the current is weakened, and the force acting upon the armature is also weakened. This results in the tongue being pulled over to *marking* by the force of an antagonistic spring, instead of breaking contact *against* it, as in the increment quadruplex. The uprighting sounder is dispensed with, and the reading sounder is connected direct to the non-polarised "B" relay. The connections of the two right-hand back terminals of the "B" key are reversed, and also those of the two left-hand terminals.

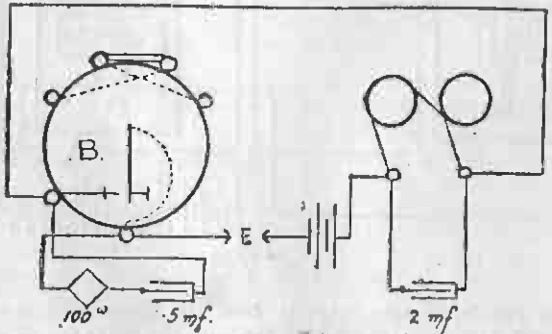

FIG. 79

A system of working the "B" side of increment quadruplex circuits without the aid of the relaying sounder has recently been introduced. The system involves the use of condensers for eliminating the "kicks" or "chatterings" in the sounder when a reversal of current is being effected at the opposite end of the circuit. The insulated and contact stops of the non-polarised relay are reversed in position, and the local circuit is joined up against the force of the antagonistic spring. The effect of the "kick" in the relay is nullified by the discharge from a condenser of two

micro-farads capacity, which is joined in parallel with the sounder coils. The momentary break in the local circuit is thus counteracted by the passage of the discharge through the sounder coils. The discharge sustains the magnetisation of the cores of the sounder and prevents a disruption of the signals. A condenser of half a micro-farad capacity and a coil of 100 ohms resistance to time its discharge are joined in series, and bridge the air space between the relay contact tongue and the contact screw. The object of this arrangement is to prevent "sparking" between the contact screw and the contact tongue when the local circuit is broken. The discharge from this condenser acts against the electro-motive force developed by the self-induction in the sounder coils, and the tendency to produce a spark is considerably reduced.

The arrangement of the condensers is shown diagramatically in Fig. 79.

CHAPTER XVII.

The Quadruplex System.

The quadruplex system is a combination of the double and single current duplex systems of working. By superimposing the latter upon the former system two messages in each direction may be simultaneously transmitted over the same line. Double-current working is resorted to upon one section, called the "A" side, while the single current system is used upon the other section called the "B" side. The receiving instrument in connection with the former is an ordinary polarised relay which actuates its sounder only when currents pass through its coils in a *marking* direction, exactly in the manner described in connection with the double current duplex system. Upon the "B" side a non-polarised relay, which responds to currents in either a *spacing* or a *marking* direction, is used. In the case of the "B" relay, however, a strong antagonistic spring prevents that instrument from being actuated except when currents of relatively great strength pass through its coils. Both relays are differentially wound so that the *outgoing* currents may pass through their coils in *opposite* directions, the instruments being unaffected when the circuit is balanced for quadruplex working. Briefly, then, the principle of quadruplex working is based upon the fact that two kinds of receiving instruments may be employed in connection with the same line—one to respond to comparatively weak currents flowing in a certain direction, and the other only to currents of greater strength, irrespective of their direction.

The "A" key, which has only four terminals, is of the ordinary double current pattern without a switch, and is called the "reversing" key, because its action reverses the direction of the current. At the distant station the "A" relay is actuated by this current, and records a "mark" only when the key is depressed. The "B" relay does not respond to either the marking or the spacing currents sent by the "A" key, as they are not sufficiently strong to overcome the force of the antagonistic spring by which the tongue of the non-polarised "B" relay is held. The key upon the "B" side is of the single current pattern, and is called the "increment" key, because on being depressed it increases the strength of the current by including more cells in the battery circuit. When the "B" key is depressed and the "A" key is at rest the distant "B" relay responds because the current is strong enough to overcome the tension of the antagonistic spring. The "A" relay is not actuated in consequence of the current being in a spacing direction. When both keys are depressed both relays respond, as the current is sufficiently strong to actuate the "B" relay and is also in a proper direction to produce a marking effect in the "A" relay.

The main battery is in two sections, one being composed of a greater number of cells than the other. The smaller section, which has an electro-motive force of about 30 volts, is connected with the key upon the "A" side, and a spacing current of *ordinary* strength passes to the line from that section of the battery when both keys are at rest. The larger section, having an electro-motive force of about 70 volts, is joined to the

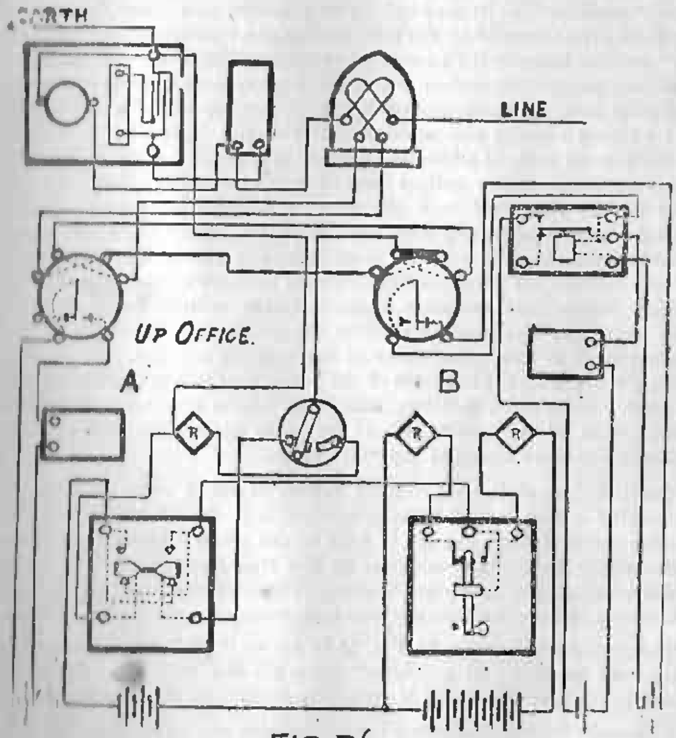

FIG. 76.

"B" key, the depression of which connects the larger section of the battery to the smaller, by way of the upper contact spring. The current from the *whole* battery passes through the contact points of the "A" key, consequently the *direction* in which the current flows is controlled by the position of that key.

The upper and lower contact springs of the "A" key are so arranged that just before contact is broken at the latter, *i.e.*, immediately prior to the

The water in which the cable is immersed should either be connected with the positive pole of the battery or make a good electrical connection with the earth. The negative pole of the testing battery is invariably joined to the cable for testing purposes, because a "negative current" tends to develop a fault, whereas a "positive current" is liable to temporarily veil it by oxidising the conductor. The static capacity of the cable in the tank may be ascertained by comparing the discharge obtained from it with that from a standard condenser, when the cable and condenser are charged for equal periods of time from the same battery. The condenser is first charged and then discharged through a sensitive galvanometer. Let the capacity of the condenser be C and the deflection produced by the discharge d. The cable under test, with its free end insulated, is then substituted for the condenser and tested under similar conditions. If the capacity and deflection in this case are represented by C_1 and d_1 respectively,

$$\text{then} \quad C_1 : C :: d_1 : d$$

$$\therefore C_1 = \frac{C \times d_1}{d}$$

The "insulation" test is made with a battery of about 200 cells of either the Minotto or Leclanché type; a highly sensitive instrument, such as the D'Arsonval galvanometer, being in circuit. When the cable is not of great length this test may be made by comparing the insulation resistance with a standard megohm. The galvanometer is shunted to obtain a suitable deflection through the megohm (R), which is earth-connected. Call this deflection d; next take a reading d_1, upon the unshunted galvanometer from the same battery joined to the cable, the latter being disconnected. The insulation resistance (R_1), in megohms, may then be obtained from the following formula, where $\frac{G}{S} + 1$ represents the multiplying power of the shunt.

$$R_1 : R :: d\left(\frac{G}{S} + 1\right) : d_1$$

$$\therefore R_1 = \frac{R \times d\left(\frac{G}{S} + 1\right)}{d_1}$$

$$\text{or} \quad \frac{d\left(\frac{G}{S} + 1\right)}{d_1} \text{ megohms.}$$

By *multiplying* the number of megohms into the number of knots the insulation resistance per knot is obtained. This resistance should not be less than 250 megohms per knot after the battery power has been applied for one minute, and it frequently reaches 1,000 megohms, or 1,000,000,000 ohms per knot. It is necessary to take the resistance tests at a comparatively high temperature, about 75deg. Fahr., because the resistance

of the di-electric increases with a decrease of temperature. This, it will be observed, is the reverse to that of a conductor; the insulation of a cable consequently improves in the comparatively low temperature at the bottom of the sea, and the conductor resistance is not likely to increase. Incidentally it may also be mentioned that the resistance of gutta-percha increases with pressure, which also tends to improve the insulation of a cable after it is laid.

The above tests are taken each day, and to rid the cable of any residual charge, due to "electrification," the conductor is "earthed" subsequent to each test.

Electrification of a cable. For the insulation test a battery of very high electro-motive force is employed and the deflection of the galvanometer needle at the outset is comparatively great. This rapidly decreases during the first minute or so, however, as if the insulation of the cable improved. The deflection then decreases at a much slower rate until finally it becomes fairly constant. This phenomenon is thought to be due to the polarisation of the di-electric of the cable. The decrease is much more rapid at a low than a high temperature, and an india-rubber di-electric is affected to a greater extent than gutta-percha. If electrification proceeds regularly and the consequent deflection diminishes steadily, the insulation is not considered to be imperfect. The polarisation and depolarisation, in fact, should be effected regularly and in equal periods of time if the conductor is uniformly insulated.

The di-electric of a cable during its electrification apparently absorbs a portion of the charge, which appears to gradually soak into the first layer next to the conductor. This layer is quickly polarised or electrified, the next and subsequent layers being affected more and more slowly.

When a high voltage has been applied to a cable a residual charge is always present after a discharge has been obtained from it. This condition is analogous to both that of a Leyden jar and a condenser. If either be left disconnected immediately after its first discharge and subsequently joined to a sensitive galvanometer, a deflection due to the residual charge will be observed.

These residual charges appear to gradually leak out from the underlying layers of the di-electric, and a perceptible period of time is taken up in effecting a thorough discharge. A test for the insulation resistance of a cable, however, may be taken after one minute of electrification; but it is obvious that if the capacity test were taken too quickly after an insulation test the residual charges would produce errors. It is always safer, therefore, to test for capacity first, and it is essential that *all* tests in connection with cables should be made with instruments well insulated.

With the same resistance, the capacity of a strand conductor is greater than that of a solid one, as the diameter of the former is slightly greater than that of the latter. The strand is preferable, however, on account of its greater flexibility.

A cable is practically a cylindrical condenser, the conductor acting as one plate and the metal sheathing, the water or the earth, the other plate. The gutta-percha has a comparatively high specific inductive capacity, and, as a large conductor surface is exposed to induction, the static capacity of a cable is very great. There are practical limits to the size of both conductor and di-electric, therefore the capacity and resistance are invariably high. *For a given diameter of the core* an increase in the size of the conductor to reduce the resistance would mean an increased capacity, because the *plates* would be brought nearer together; while, on the other hand, if the di-electric were increased to reduce the capacity, the conductor would be reduced in diameter and the resistance accordingly increased.

The following laws govern the working speed of cables:—

1. The relative speed of two cables of the same length varies inversely as the product of their respective capacities and conductor resistances.

2. Cables similar in all respects except length have working speeds inversely proportional to the squares of their respective lengths.

The rate of working of a cable depends upon the time a current takes to rise from zero to its maximum strength and fall again to zero. This is called the "time constant," and it is inversely proportional to the product of the capacity and the resistance of the circuit. When the capacity (k) and the resistance (r) per unit length (l) are given the total capacity (K) is obtained by multiplying k by l. The total resistance (R) is similarly found by multiplying r by l.

$$\text{Hence } KR = krl^2.$$

It will therefore be understood why the working speed varies inversely as the square of the length of the circuit.

To further increase the speed of working, receiving instruments of extreme sensitiveness are employed, for if the battery power were increased the static charge would be greater, therefore it would be impracticable to attempt more rapid signalling by this means. Ordinary receiving apparatus lacks the essential sensitiveness; but by using a delicate instrument such as Thomson's mirror galvanometer, or the syphon recorder invented by the same eminent scientist, highly satisfactory results are obtained. These instruments, in addition to being affected by very minute currents, are actuated without friction, consequently there is a maximum freedom of their movable parts. The

mirror galvanometer has already been described, so also has the D'Arsonval galvanometer which is the same type of instrument, in principle, as the syphon recorder. In the last-named, and under the control of the movable coil, a glass syphon is used, one end of which dips into an ink-well, while the other end vibrates horizontally above a slip of paper, without touching it, and spurts the ink upon its surface. Friction between the syphon and the paper is by this means avoided. A small coil is suspended in a strong magnetic field between the poles of a very powerfully magnetised horseshoe-shaped magnet, and in the centre of the coil a small piece of soft iron is fitted. The coil is suspended by fibres of silk, therefore its action is frictionless. When the coil moves either in the one direction or the other, according to the *direction* of the received current the syphon is actuated and registers undulatory signals upon the paper.

The ordinary "dash" and "dot" system is not practicable, consequently the sending apparatus is designed upon the same principle as the commutator of the single-needle instrument. The equivalent of a dash in this system takes no longer to signal than a dot, whereas a dash in the ordinary Morse system would produce a greater static charge in the cable. One very important advantage the "mirror" possesses is that its zero is movable. A very long cable is not wholly discharged after each signal, but the reversal of the battery increases, neutralises or reverses, what may be considered as a permanent charge in the circuit. A slight variation of the charge affects the delicate receiving apparatus, and a signal may be received by merely an increase or a decrease in the deflection without actual reversal being effected. A disadvantage of the mirror instrument is that no permanent record of the signals is made, and a darkened room and two operators are essential to its practical use.

In order to eliminate earth currents a condenser is interposed between the receiving apparatus and the line. A continuous current is therefore impossible, and the apparatus is actuated by condenser impulses controlled by the reversing mechanism of the signalling commutator.

For duplex working the "bridge" system is adopted, in which the receiving apparatus is "bridged" between the line and the artificial circuit. The receiving instrument is actuated by the varying potentials produced at its terminals by the signalling apparatus at the ends of the circuit. The "artificial" circuit for balancing is now made up in one piece of apparatus, known as a "grid" condenser, which combines resistance and capacity and represents the electrical conditions of the line. The alternate plates of tinfoil are cut to represent certain resistances, and when they are joined in series, the required capacity and resistance to represent various sections of the cable are thus readily brought into circuit.

CHAPTER XVIII.

SUBMARINE CABLES.

The efficiency of a submarine cable depends chiefly upon the three following conditions :—

1. Its mechanical strength.
2. The durability of its insulator and protecting material.
3. The speed of signalling.

The first condition is met to a very great extent by using several wires twisted together instead of a solid conductor. A central copper wire is surrounded by others wound spirally along its length. The wires are of about 98 per cent. purity. If a seven-strand conductor is employed, and each wire has the same weight for a given length, the central one is exactly surrounded by the remaining six. A conductor of this make is comparatively flexible, consequently the risk of a total fracture is considerably reduced. As long as a few wires remain intact the continuity of the circuit is maintained, and the advantage is apparent.

The insulation of the conductor is of the utmost importance, for the slightest undetected fault in this respect would eventually lead to very serious consequences. A layer of Chatterton's compound, which is a composition of gutta-percha, resin and tar, is given to the conductor as a first coating. Then follows a layer of gutta-percha, the compound and gutta-percha being served alternately, sometimes to as many as seven or eight layers. A brass tape is wound upon the *core*, as the conductor and insulating material are termed, to resist the attacks of a maritime vermiform insect, known as the teredos worm. This insect bores into the unprotected gutta-percha, and eventually destroys it and produces a fault. The brass tape, however, is impervious to such attacks, and the insulation is preserved. The cable is then served with a coating of Russian hemp and finally covered with steel wires. The latter, which exactly surround the cable, are wound spirally along its length to act generally as a protector of the various coverings beneath them. The cable is constructed in two-knot lengths, and then jointed to form any continuous length desired. The several wires of the strand are first soldered into a solid mass and then scarf-jointed. The joints are frequently wired and re-wired, the ends only of the last layer being soldered. In the event of a disconnection of the conductor at the joint the binding wires stretch out and maintain the continuity of the circuit.

The Post Office seven strand conductor weighs about 107 lbs. per nautical mile, or 15·2 lbs. per knot for each strand, and its insulator, or di-electric,

150 lbs. per knot. The protecting material varies in diameter—a large size being used for the shore end, where friction is likely to be greatest, a medium size next, and the ordinary size for the deep sea portion. After about a fortnight the gutta-percha becomes thoroughly set, and then the cable is laid into a tank of water, which should be heated to the standard temperature of 75deg. Fahr. This temperature should be maintained for a period of 24 consecutive hours before the cable is tested. A cross-section of a four conductor cable is shown in Fig. 80. The advantages of this cable over the single conductor are that the conductors may be revolved

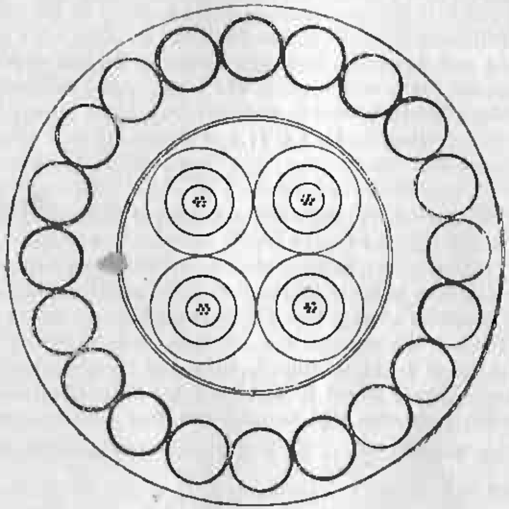

FIG 80

in pairs to nullify the effects of induction, and in case of a fault arising a loop test can be readily made.

The first test is for the resistance of the conductor, which should not be less than 11·18 nor more than 11·65 ohms per knot at standard temperature. The next test is for the electro-static capacity of the cable. A battery of ten cells only is employed for this test. A reflecting galvanometer and a key of the "trigger" pattern are also in circuit. With the trigger key in operation the change of connections from the battery circuit to the galvanometer circuit can be promptly made. Directly the trigger is lifted the key is pulled away from the battery contact point, and it may be either sharply brought over against the galvanometer circuit contact point by the force of a spring or left midway between the two.

on a piano and a violin a difference in the tone of the two sounds is readily detected. The number of vibrations is the same, and the volume of sound emitted by the instruments may be equal, yet there is a striking difference in tone. Vibrations seldom have a straight backward and forward motion, but are usually accompanied by slight intermediate pulsations. The intermediate movements are responsible for the tone or quality of the sound.

Before proceeding it will also be well, perhaps, to review our knowledge of magnets and magnetic substances.

A magnet is surrounded by lines of force, which pervade the magnetic field in varying degrees of intensity. The extent of the magnetic field is determined by the lines of force and can be demonstrated by scattering iron filings in the vicinity of the magnet. The filings which fall within the magnetic field will arrange themselves along the lines of forces in the form of closed curves. The greatest intensity of the magnetic field is at, or near the poles of the magnet.

When a magnetic substance is brought into the magnetic field the lines of force are distorted from their natural positions, and a large number of them pass through the magnetic substance. As long as the substance lies in the magnetic field the lines of force remain distorted, but they fall back to their normal positions with its removal. If the magnetic substance be made to vibrate there will be corresponding redistributions of the lines of force, which will vary with the movements of the vibrating body.

When a line of force cuts a conductor, or when a conductor cuts a line of force, an electro-motive force is set up, and, if the conductor forms part of a closed circuit, a current will flow through that circuit. The strength of the current generated depends upon the electro-motive force developed; the value of the latter is enhanced by an increase in the intensity of the magnetic field and the quickening of the rate of motion at which the conductor is cut. The direction of the current is dependent upon the direction of the motion. If a coil of wire, the ends of which are connected to a galvanometer, be wound upon a permanent magnet and moved rapidly from one end to the other, it will cut through the magnetic field, and the current generated will cause a momentary deflection of the galvanometer needle. A movement in the opposite direction will produce a reverse deflection. By fixing a coil upon one pole of a magnet and causing a magnetic substance to vibrate near the pole the distribution of the lines of force will be altered with every movement. With every variation of the magnetic field the lines of force will cut through the coil. If, then, the coil forms part of a closed circuit currents will pass through the latter and correspond in direction and strength with the vibratory action of the magnetic substance. When the latter is approaching the magnet the direction of the current will be such

as to reduce the attractive force of the magnet. An opposite effect will be produced when the magnetic substance is receding from the magnetic pole.

The direction of a current circulating in the coil of an electro-magnet determines the polarity developed at the ends of the core. Similarly, if a coil of wire be placed upon one pole of a permanent magnet and a current circulated through it the attractive force of the magnet will be either augmented or diminished according to the direction of the current.

The earliest form of Bell telephone consists of a circular flexible ferrotype disc or diaphragm, firmly clamped at its edge, and fitted in front of and at about one-hundredth part of an inch from the North-seeking pole of a permanent bar magnet. A small coil of insulated copper wire,

FIG. 81.

wound upon a bobbin, is placed upon the pole of the magnet, and is consequently in the most intense part of the magnetic field. The whole is enclosed in an ebonite case, the diaphragm being held in position by an ebonite mouthpiece screwed on to the casing of the body of the instrument.

The Bell telephone may be used both as transmitter and receiver, and by completing a circuit including two such instruments, as shown in Fig. 81, telephonic communication becomes practicable.

A large number of the lines of force about the magnet passes through the air-space and diaphragm. The latter is consequently attracted, and the central or mobile portion is drawn towards the magnet.

When a sound is produced in the vicinity of the diaphragm the wave vibrations of the air impinge upon the latter, causing it to vibrate in synchronism with the sounding body. This diaphragm controls, by magnetic and electrical action, the diaphragm of the other instrument, which, in vibrating, emits a sound similar to that which caused the first diaphragm to be set in motion.

The action of the Bell telephone has been summed up as follows:—

As a Transmitter:

1. When a sound is produced in the vicinity of the instrument the sonorous vibrations of the air due to that sound transmit their energy to the diaphragm and cause it to vibrate in synchronism with the sounding body.

2. The vibrations of the diaphragm produce redistributions of the lines of force due to the magnet.

3. The lines of force, while changing from one position to another, cut through the coil and set up currents varying in direction and strength.

4. These currents traverse the line circuit and pass through the coil of the receivor.

As a Receiver:

1. The Incoming currents vary the attractive force of the magnet according to their direction and strength.

2. The diaphragm obeys these changes of magnetisation, receding from the magnet by its own elasticity when the attractive force of the magnet is reduced, and approaching it when the magnetic strength of the magnet is increased.

3. By this undulatory action the diaphragm vibrates in synchronism with the diaphragm of the transmitter.

4. The vibrating receiver diaphragm produces sonorous vibrations of the air and emits a sound similar to that which caused the diaphragm of the transmitter to vibrate.

Transmitters.

The Bell telephone, as a transmitter, has long since given way to more modern instruments, of which there are three distinct types, viz:—

1. Carbon and metal transmitters.
2. Microphones.
3. Granular transmitters.

With the Bell instrument, the transformation of wave vibrations of the air to electrical waves is the result of electro-magnetic induction, but with each of the above-mentioned forms of transmitters the currents are obtained from a battery. The sonorous vibrations of the air impinge upon the diaphragms and cause the electrical resistance of the transmitters to be varied. The battery is connected with the transmitter in each case, and the currents fluctuate in strength with the varying resistance in accordance with Ohm's law.

The first instrument of the carbon and metal type was invented by Edison. It was followed by Blake's transmitter, and as the latter is the best known of its class, a brief description of this instrument is here given.

The Blake Transmitter.—Immediately behind the mouthpiece M (Fig. 82), which is carried by the case of the instrument, a ring of iron is fixed, and to it are fitted iron projections A A^1, one at the top and the other at the bottom. The diaphragm D is a mobile ferrotype disc, which

is fitted into a rubber ring, the whole being held in position by means of steel springs attached to the iron ring. To the upper projection is secured a flexible brass spring, which carries an angle-piece K, the lower portion of which abuts against an adjustable screw S carried by the lower projection. At the upper end of

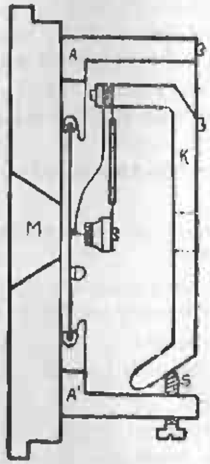

FIG 82.

the angle-piece are two steel springs, insulated one from the other. The spring next to the diaphragm has its free end fitted with a platinum contact point. The other spring terminates in a circular brass plate carrying a small carbon disc. The latter presses upon the platinum contact and holds it against the centre of the diaphragm. These springs are joined to the terminals of the instrument and the current passes through them and the carbon-platinum junction. The instrument is adjusted by means of the screw at the lower projection, the pressure existing between the diaphragm, platinum contact and carbon disc being varied at will. The vibration of the diaphragm, caused by sound waves impinging upon it, produces a greater or lesser intimacy of contact between the platinum point and carbon disc, and the electrical resistance between them fluctuates with the nature of the vibrations imparted to the diaphragm. The current is consequently of a varying character and the receiving apparatus is actuated accordingly.

The Microphone.—The microphone is an instrument the use of which depends upon a system of loose contacts, and was invented by Professor

Hughes in 1878. Many experiments have been made to determine the best substance to be employed, but the merits of carbon have rendered its use exclusive. The instrument may be considered as a wholly carbon transmitter, and the arrangement of the loose contacts may be varied in many ways. One of the earliest forms of microphones consisted of a single carbon pencil arranged loosely between two fixed carbon blocks. Experience soon showed, however, that better results were obtained by using more than one pencil, and in all the later forms of microphone the battery current passes through a number of pencils arranged in parallel.

Carbon is inoxidisable and infusible, and the heat effects produced by the passage of a current through it enhance its value in connection with transmitters.

Three accepted facts must be here stated in order that the heat effects may be understood.

1. That an electric current passing through any conductor raises the temperature of that conductor.

2. That the amount of heat is greatest at the point of greatest resistance, albeit the strength of the current is uniform in the whole circuit.

3. That carbon possesses the peculiar property of increasing in resistance when its temperature is lowered. Most metals, of course, are oppositely affected.

The theory of the microphone may be stated thus: The mechanical vibrations of the pencils cause the resistance at the points of loose contact to be varied. An increased resistance causes the current to be reduced in strength. The temperature at the points of contact, therefore, falls, and the resistance is further increased. With a decrease of resistance, caused by an increased pressure at the points of contact between the pencils and carbon blocks, the current is augmented and the temperature increased. The heat effect produces a further reduction in the resistance, and it will, therefore, be seen that a greater variation in the current is ensured by the mechanical vibrations of carbon pencils than would be the case if any other substance were used.

The Gower-Bell Transmitter.—This instrument is the best-known transmitter of the microphone class. The diaphragm is a deal board, beneath which are eight carbon pencils arranged in sets of four. Attached to the diaphragm are two thin V-shaped strips of copper, upon each of which are fitted four circular carbon blocks. Midway between the copper strips a somewhat larger carbon block is fixed, and between it and the eight blocks are eight carbon pencils, so arranged that one end of each rests loosely in an opening in the central block. The other extremities of the pencils are supported by the eight surrounding blocks. (Fig. 83.) The copper strips virtually form the terminals of the instrument. The

current divides through one set of four pencils, passes through the central block, and again divides through the second set of pencils, leaving the instrument by way of the copper strip. The diaphragm rests upon india-rubber washers, which tend to damp out vibrations continued after the sound waves have ceased to influence the diaphragm. The latter is usually covered by a wooden casing, at the centre of which a porcelain mouthpiece is attached to direct the sound waves to the diaphragm, which is fixed in a sloping position.

The sound waves impinge upon the diaphragm and cause it to vibrate, and by the movements so produced the electrical resistance of the loose contacts is varied. When the diaphragm performs a downward motion, carrying the carbon blocks with it, the pencils do not immediately follow their supporting blocks, and the *amount* of contact is thereby reduced. When an upward movement is executed the pencils are raised by their supports against the force of gravity, and, in consequence of the increased pressure, a diminution of the resistance at the points of contact results.

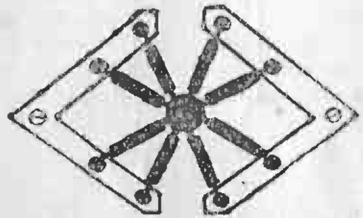

FIG. 83.

Professor Hughes attributed the varying resistance to the fact that the amount of contact, or the number of molecules of carbon at the point of contact taking part in the transmission of the current, varied with the changes of position of the pencils, due to the vibration of the diaphragm. This, however, can perhaps be summed up in the words of Du Moncel—that an increase of pressure between two conductors in contact produces a diminution of their electrical resistances.

Granular Transmitters.—In order that this class of transmitter may be properly understood it will be well to follow up the many improvements which have been made upon the first of the granular type, known as the Hunning's transmitter. In this instrument two platinum discs, one of which serves as the diaphragm, are separated by a space of about one-eighth of an inch, which is filled with carbon granules. The front disc, A, Fig. 84, is held in position by a metal ring R, and the whole is enclosed in a wooden case, the front portion of which carries a mouthpiece M and clamps the diaphragm and ring in position. A fine wire gauze is fitted between the mouthpiece and diaphragm and serves to protect the latter from moisture and damage. The back platinum plate **B** is connected with one terminal of the instrument, while the second terminal is joined to the diaphragm. When the latter is caused to vibrate by sound waves impinging upon it, the resistance between the platinum plates varies in accordance with the fluctuating pressure exerted upon the granules, and the strength of the current rises and falls in inverse ratio to the total resistance of the circuit. The great drawback to this instrument is that, after a time, the granules settle down, and those at the bottom become firmly wedged together. The latter then

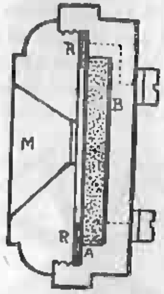

FIG. 84

form a short-circuit across the operative granules at the centre of the instrument, where the amplitude of vibration is greatest. The effect upon the varying resistance of the transmitter may be graphically demonstrated by applications of the law of joint resistances. Suppose that the transmitter has a normal resistance of 8 ohms, and that with a certain vibration the resistance is varied between 6 and 10 ohms. The current will fluctuate with the changing resistance. Imagine, however, what would be the effect if the granules at the bottom of the instrument should become so packed as to offer a resistance between the two platinum plates of only 4 ohms. The operative granules at the centre would be practically short-circuited, and the vibration instead of producing a variation of 4 ohms would result in a variation ranging between the joint resistance of 4 ohms and 6 ohms and that of 4 ohms and 10 ohms. The former resistance is $2\frac{2}{5}$ ohms and the latter $2\frac{6}{7}$ ohms, the difference between them being less than half an ohm. The fluctuation of the current would consequently be very little, and the receiver would be but feebly actuated, whereas in the absence of the packing of the granules a good result would be obtained with the variation in the resistance of the instrument between 6 and 10 ohms.

This "packing difficulty" was a serious drawback to the HUNNING'S transmitter, and many modifications of the instrument have been devised with a view to its elimination. In the Moseley transmitter the platinum diaphragm was replaced by a thin pine board, to the centre of which a small disc of carbon was attached. The latter acted as the front electrode, and the space between it and the back electrode was made wedge-shaped by inclining the diaphragm and the back plate together, the angle formed being at the bottom of the instrument. By this arrangement the contact between the granules and the back electrode was more uniform, but the "packing" was not altogether eliminated. The granules which had become wedged together, however, formed no part of the circuit, as they were not in contact with the carbon disc. They were thus rendered inoperative and a greater efficiency was produced.

The Hunning's-cone or Deckert transmitter is another instrument of the granular type. It is in extensive use by the Post Office and gives general satisfaction. The diaphragm and back electrode are both carbon, the former being a thin disc and the other a circular block, the front of the latter being carved into the shape of pyramids. The arrangement of the pyramids or cones is shown in Fig. 85. Immediately behind the diaphragm is a woollen ring which allows only the granules at the centre of the instrument to be in contact with the diaphragm. The woollen ring serves

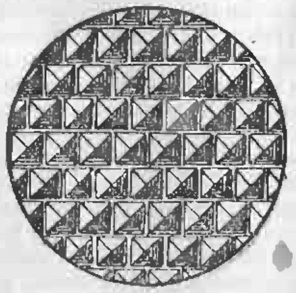

FIG 85

the purpose of cutting out of the circuit the granules which, perchance, have become packed at the bottom of the transmitter. The object of the carved back electrode is to promote greater uniformity of contact with the granules and, in order to ensure a proper distribution of the latter, the apex of one pyramid is situated immediately opposite the groove formed by the two adjacent pyramids in the next row. (Fig. 85.) The pyramids facing the centre of the diaphragm, *i.e.*, the portion not shielded by the woollen ring, are slightly flattened or truncated, and to them are gummed small tufts of silk. The latter bridge the space between the electrodes and tend to damp out vibrations not sustained by continued sound waves impinging upon the diaphragm.

The instrument known as the "solid-back" Transmitter is an American production and is very effective for long distance telephony. The two carbon electrodes are arranged in a small chamber filled with carbon granules. The chamber is lined with an insulating material and is slightly larger in diameter than the carbon discs. By this arrangement the granules at the bottom of the cell are not in the path of the current, and consequently the packing difficulty is practically overcome. The front electrode is attached to a ferrotype diaphragm by means of a small screw and washer, while the second carbon disc is arranged at the back of the containing cell and is capable of adjustment by means of a screw. The two discs are connected to the terminals, and the instrument, which is a very efficient transmitter, is practically free from the packing trouble.

The Induction Coil.

The function of the transmitter in a telephone circuit is to produce a variation in the electrical resistance of the circuit by means of sound waves impinging upon the diaphragm. The receiver responds not to the actual strength of the current passing through its coils, but to the *variation* in the strength of the current. It will, therefore, be seen that in order to obtain as great an effect as possible, the varying resistance of the transmitter must produce a maximum fluctuation in the strength of the current. This can only be done by keeping the resistance of the battery circuit as low as possible, so that the slightest change in the resistance of the transmitter will produce an appreciable effect upon the current. For instance, suppose that a certain sound wave causes the transmitter to increase in resistance by 1 ohm, and that the instrument forms part of a circuit of 500 ohms resistance. The additional 1 ohm will cause the strength of the current to be altered very slightly, for the resistance of the whole circuit will be altered only from 500 to 501 ohms, and the current will vary by about one five-hundredth part of its former value. But if the transmitter had formed part of a circuit of 5 ohms resistance, which was increased to 6 ohms by the action of the diaphragm, the current would have been decreased by one-sixth of its strength. It will, therefore, be apparent that in order to obtain a maximum variation of current the resistance of the transmitter circuit should be as low as possible, and to bring about this result an induction coil is introduced. The battery employed for speaking purposes is usually of the Agglomerate Leclanché type, which has a resistance of about half an ohm per cell. Two such cells are sufficient for the purpose.

An induction coil consists essentially of two coils of insulated wire wound one upon the other around a soft iron core. The latter is not

an ordinary bar o iron, but is composed of a bundle of very soft iron wires. A core of this description facilitates magnetisation and demagnetisation. The *primary* coil, or the coil wound immediately upon the core, is composed of fairly thick wire and is comparatively short. Its resistance is, therefore, very low.

The *secondary* coil is wound upon the primary coil, and as its resistance is not of serious moment, it is possible and advantageous to employ a conductor of smaller gauge and greater length. The transmitter and battery are connected to the primary coil, and a closed circuit is thus formed. The secondary coil is connected with the line. When sound waves impinge upon the diaphragm of the transmitter the resistance of the instrument varies in accordance with the nature of them, and the current becomes undulatory. In consequence of the exceedingly low resistance of the circuit the current is comparatively strong, and a strong magnetic field is developed in the primary coil. The current, however, being of a fluctuating character, causes a redistribution of the lines of force with every variation, and the action upon the secondary coil (see Chap. XII.) is to induce an undulatory electro-motive force which rises and falls with

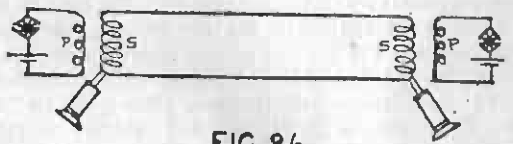

FIG. 86

the current in the primary circuit. The electro-motive force developed depends upon the intensity of the magnetic field and also upon the surface exposed to induction. The strength of the current passing through the primary coil determines the former and the number of turns of wire in the secondary coil the latter. In order, therefore, to ensure the outer convolutions of the secondary coil being well within the magnetic field a wire of small gauge is employed. The line is connected with the secondary coil, and currents flow through it which vary in direct ratio to the electro-motive force generated. Fig. 86 indicates the theoretical connections of the induction coil.

The following figures indicate the relative dimensions of the coils, and an induction coil of this construction serves its purpose admirably :

Primary Coil.—106 convolutions, the wire having a diameter of 20 mils and the exceedingly low total resistance of ·5 ohm.

Secondary Coil.—4,000 convolutions, the wire having a diameter of 6 mils and a total resistance of 250 ohms.

Receivers.

The Bell telephone already described is a uni-polar instrument as only one pole is presented to the diaphragm. By utilising both poles of the magnet, however, a stronger magnetic field is produced. An instrument constructed upon this principle is termed a bi-polar or double pole telephone. The modern form of Bell receiver, which has been adopted by the Post Office as a standard instrument, contains in an ebonite case a horse-shoe shaped permanent magnet, upon the poles of which are screwed two soft iron pole-pieces. Two coils are placed upon the latter, and are wound to various resistances—usually 120 to 200 ohms. The coils and cores are not circular but slightly elongated, and lie parallel with each other. This arrangement tends to promote a greater efficiency of the instrument by concentrating a larger number of lines of force through the centre of the diaphragm.

The ferrotype diaphragm is held in position by the ear-piece which screws on to the ebonite case. An adjustable screw at the back of the instrument regulates the distance between the pole-pieces and the diaphragm. The latter should be quite clear of the pole-pieces, but as close to them as possible without actual contact. The coils are connected with two terminals at the end of the ebonite case. A sketch of the instrument is shown in Fig. 87. In climates having a great variation of temperature, difficulty is frequently experienced by the contraction and expansion of the permanent magnet. The ebonite case, by which the diaphragm is held, is not subject to the same effects of temperature variation, and the unequal expansion and contraction of the magnet and the case cause the distance between the diaphragm and the magnet to fluctuate with the rise and fall of temperature. The magnet in the ordinary receiver is fixed at its end remote from the diaphragm, and the maximum effect of the variation is experienced. The difficulty is overcome in the Ericcson pattern, however, by making the attachment to the case at the diaphragm end, thereby allowing for temperature variations at the opposite end of the magnet. In another type of receiver the ebonite is substituted by a metal case having a similar co-efficient of temperature variation as the magnet. The distance between the diaphragm and the pole-pieces consequently remains uniform.

Ader's Receiver is a modification of the double pole Bell receiver. The magnet is circular shaped, and serves as a handle for the instrument. The coils are arranged upon two soft iron pole-pieces attached to the poles of the magnet. The chief feature of this instrument is a somewhat massive ring of iron termed the *sur-excitateur* or over-exciter, which is placed upon the side of the diaphragm remote from the coils. The object of the iron ring is to concentrate the lines of force through the diaphragm. The

theory of the instrument is that the nearer the size of the armature approaches that of the magnet the greater is the mutual induction between them. It is apparent that the diaphragm cannot be increased in size without affecting its flexibility, but the ring of iron, which acts magnetically as part of the diaphragm, serves the same purpose. The lines of

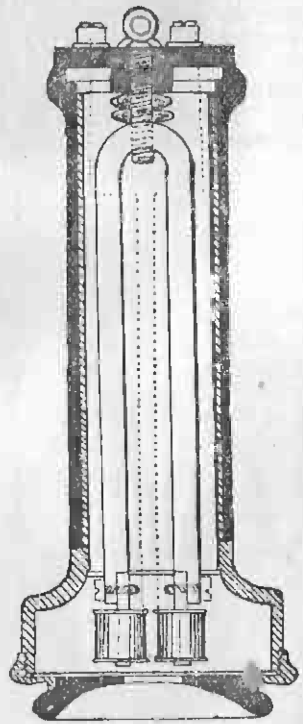

FIG. 87.

force of a strong magnetic field are thus concentrated through the diaphragm and the currents traversing the coils produce a maximum effect. The instrument is highly sensitive, and is largely used on the Continent.

D'Arsonval's Receiver is another bi-polar instrument. The magnet is nearly circular, and upon its poles are fitted two soft iron pole-pieces. Upon one of them a coil is placed, and the other, which is virtually a cylinder, surrounds the coil and its core. It will thus be seen that the

For fast speed working shunted receiving and signalling condensers are also employed. The use of the former tends to neutralise the self-induction of the receiving apparatus, while the function of the latter is to nullify the effects of the capacity of the line. The discharge from the signalling condenser fills the capacity of the cable, and the ordinary working current, which passes through the shunt, is timed thereby to reach the cable when the capacity or "swallow" of the line has been satisfied.

As the static capacity of a cable is very great an opposing or neutralising current, termed the "curbing" current, is automatically sent out between each signal. The cable is also put to earth by the same movement after each curbing current. A very delicate adjustment of the latter to the ordinary current is necessary, and it has been found that the proportion of the curbing current to the ordinary current should be as 4 : 5 to ensure the best results.

CHAPTER XIX.

The Telephone.

The idea of transmitting sounds to a distance is some centuries old, but it was not until the middle of the nineteenth century that attempts were made to electrically produce the desired effects. The electrical transmission of articulate speech, however, was not made a success until the year 1876, when the first "speaking" telephone was produced by Professor Graham Bell.

Before attempting to describe this instrument, some little attention should be paid, perhaps, to the cause and effect of sounds. A sound is produced by any action which sets up a sufficiently vigorous state of vibration in the air. When a body vibrates, the vibrations are communicated to the surrounding air, which is alternately rarefied and condensed by the motion of the vibrating body. When a tuning fork is struck the prongs vibrate at a great rate, and the air in their immediate neighbourhood is carved into waves which spread in all directions. These air waves, which impinge upon the tympanum or drum of the ear and cause it to vibrate in synchronism with the vibrating body, are conveyed to the auditory nerves and the sensation of sound is thus produced. If the tuning fork had been caused to vibrate in a vacuum there would have been no sound, as the medium by which sound is transmitted would have been absent.

The three characteristics by which sounds are distinguished from one another are *pitch*, *intensity*, and *quality* or *timbre*.

Pitch is that characteristic which determines the note of a sound. It depends upon the number of vibrations the sounding body performs in a given time. The higher the note the greater will be the number of vibrations per second, while for a lower note a fewer number of vibrations will be required.

Intensity depends upon the amplitude of the vibrations. When a tuning fork is struck it vibrates *at the same rate* during the whole of the time the vibrations are sustained, hence there is no variation in the note. The loudness or intensity of the sound, however, depends upon the amplitude of the vibrations, or the distance which the prongs move in performing a complete vibration. The vibrations may be seen with the naked eye when the fork is first struck, but their amplitude gradually diminishes. The sound is loud at first and slowly dies away, until, when the prongs cease to vibrate, no sound is emitted.

Quality or timbre may be best illustrated by producing the same note on two different musical instruments. When the same note is produced

The difference of potential between zinc and copper immersed in liquid such as hydrochloric or sulphuric acid, is, roughly speaking, one volt.

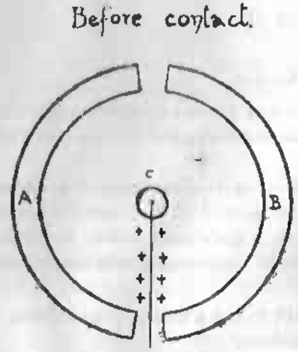

FIG. 5.

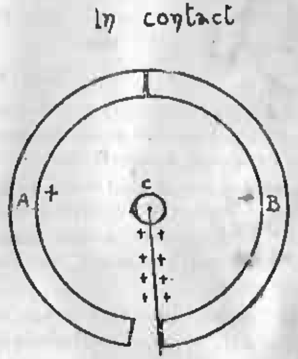

FIG. 6

THE SIMPLE CELL.

Copper (Cu) and zinc (Zn) are the two metals, or elements, used in what is known as the simple cell, and these are placed in a suitable vessel, such as glass or glazed earthenware, containing pure water (H_2O). (Fig. 7.)

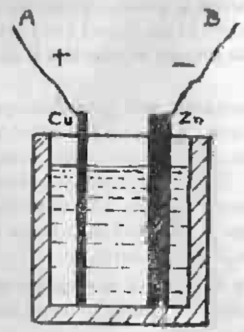

FIG. 7

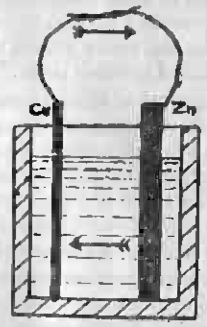

FIG. 8

So long as the plates are kept separate, and no conducting wire connects them outside the liquid, no current of electricity can flow; but the two pieces of wire, A and B, possess certain electrical properties not

hitherto observed in them, and which, for convenience, are termed *electro-positive* and *electro-negative*. In these conditions it is clear that the *circuit* is incomplete; it lacks *continuity*, yet a tendency exists even now for a current to be urged through the liquid of the cell, starting from the surface of the zinc plate.

When the wires A and B are joined, however, as shown in Fig. 8, an electric *circuit* is established, and an unbroken path for the current may be traced from its supposed source, the zinc plate, through the liquid to the copper plate, along the connecting wire and back again to its starting point. The arrows indicate the path and direction of the current.

The chemical action set up to produce this current may be stated as follows:—

The oxygen (O) attacks the zinc and combines with it, the two forming zinc oxide (ZnO), while hydrogen (H) is released, and eventually collects upon the copper plate, or is given off as bubbles at the surface of the liquid.

Represented symbolically the action may be expressed thus:—

Before contact. *After contact.*

$$Zn + H_2O + H_2O + H_2O + Cu = ZnO + H_2O + H_2O + H_2Cu.$$

The action of a cell of this kind soon ceases, because the zinc oxide formed is a non-conductor, and is insoluble in water. The zinc plate becomes covered with this insulating compound, and the cell quickly becomes inactive.

When dilute sulphuric acid is substituted for pure water a slightly better result is obtained. The sulphion (SO_4) of the sulphuric acid (H_2SO_4) combines with the zinc, and a salt of that metal, zinc sulphate ($Zn\,SO_4$) is formed, the resistance of the cell being slightly decreased. Zinc sulphate is soluble in water, and, as a consequence, the zinc plate is left entirely clear, the action of the acid upon it being continued. The nascent hydrogen released by this action is very active, and immediately combines with the sulphion of another molecule of sulphuric acid. These changes continue until a film of hydrogen is eventually deposited upon the copper or negative plate, which soon destroys the utility of the cell by causing *polarisation*.

POLARISATION.

Hydrogen is an electro-positive gas; it is electro-positive to copper, as zinc is, and the conditions become as if two similar plates were opposed to each other, a weakening effect upon the current is quickly apparent, and the latter is observed to diminish rapidly and ultimately to cease.

A study of Fig. 9 will aid the reader in his desire to comprehend the generally accepted theory of the simple cell, and the cause of polarisation.

In the sketch the molecules of sulphuric acid are represented elliptically, the shaded portions denoting the hydrogen and the unshaded portions the sulphion. In the upper row each molecule is depicted as being complete, and represents the conditions before action takes place, whilst the lower row shows the sulphion attacking the zinc and the hydrogen adhering to the surface of the copper plate, the interchange of partners having resulted in the decomposition of one molecule of sulphuric acid.

Having described how a current of voltaic electricity may be generated, it will now be opportune to proceed a little further and explain how the constancy, or steadiness, of the current emanating from a combination of the kind already described may be improved and maintained; for it is to the constancy of the current produced by a cell that its chief utility is due.

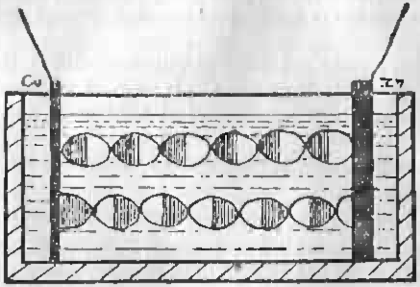

FIG. 9

The great aim, then, is to destroy the deleterious effects of the free hydrogen in the cell. Hydrogen gas offers considerable resistance to the passage of a current of electricity, and is the direct cause of polarisation.

If a second liquid or a substance with which the free hydrogen can chemically combine is introduced into the cell, and, by such combination, a harmless compound formed, then polarisation practically ceases.

A consideration of the Daniell cell will furnish a good instance of such a method alluded to above.

The Daniell Cell.

The Daniell cell is comprised of a zinc plate as the positive element, and a thin sheet of copper as the negative element. The vessel containing the liquid is either divided into two sections by a porous partition, or a porous pot of unglazed porcelain is placed in the containing vessel.

Into the porous pot is placed the copper plate, and a solution of copper sulphate ($Cu\ SO_4$) surrounds the plate, a small quantity of copper sulphate crystals being added.

The outer vessel contains dilute sulphuric acid, and the zinc plate immersed therein.

The sulphuric acid and the sulphate of copper, respectively, are the *exciting* fluid and the *depolarising* agent, and they are kept separate by the porous partition.

By osmotic action—which is the tendency of two different fluids, separated by a porous partition, to mingle—the outer and inner cells are chemically connected.

The sulphion of the sulphuric acid attacks the zinc plate, forming, with zinc, sulphate of zinc, and the hydrogen, released, enters into combination with the sulphion of the sulphate of copper, producing sulphuric acid. Pure copper instead of hydrogen is eventually deposited upon the copper plate, where it preserves a bright, clean surface of copper, and maintains the potential difference between the *negative* and *positive* plates of the cell.

A vertical section of the Daniell cell is shown in Fig. 10.

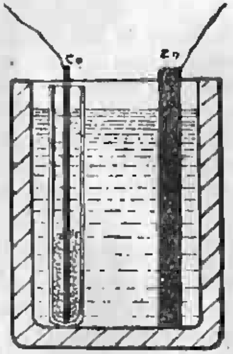

FIG. 10.

When this cell is required for immediate use a weak solution of zinc sulphate takes the place of the dilute sulphuric acid in the outer compartment, and a saturated solution of copper sulphate is placed in the porous pot. By this means hydrogen is excluded from the cell, and polarisation entirely avoided so long as the saturation of the copper sulphate is maintained.

Generally speaking, the chemical re-actions are the same as if sulphuric acid were used. The zinc sulphate attacks the zinc plate, forming fresh molecules of that salt, and metallic zinc, instead of hydrogen, is liberated. The zinc now set free decomposes the copper sulphate forming more zinc sulphate, and liberating pure copper, which is deposited upon the copper plate.

The chemical action in this case may be symbolically expressed thus:—

$$Zn + SO_4Zn + Cu\,SO_4 + Cu = Zn + 2Zn\,SO_4 + Cu + Cu$$

By using sulphate of zinc instead of sulphuric acid the unnecessary waste of the zinc plate is materially reduced.

On account of its constancy the Daniell cell is known as a "standard" cell, with an electo-motive force, or potential difference, of 1·08 volt.

Local Action.

In ordinary commercial zinc many and various extraneous substances such as particles of carbon, lead, tin, iron, etc., become embedded during its manufacture. A difference of potential between them, and also between the zinc plate and these particles, consequently exists, and minute currents are set up when the cell should be quiescent. All the essentials for tiny batteries exist, and unnecessary waste of materials is continuously going on.

This can be obviated, however, by first dipping the zinc plate into an acid for cleansing purposes, and then applying mercury to its surface with a piece of flannel or a brush. An amalgam of mercury and zinc is thus formed as a paste, and the foreign particles are surrounded by the amalgam, zinc and mercury alone remaining in contact with the acid.

Mercury is not chemically acted upon by the acid, and, therefore, does not interfere with the working of the cell, for the acid acts only upon the particles of pure zinc.

The Leclanché Cell.

There are three types or modifications of this cell which will require attention: (*a*) ordinary Leclanché; (*b*) agglomerate; (*c*) the dry cell.

(*a*) The ordinary Leclanché cell consists of an outer containing vessel, a porous pot, a zinc rod as the positive element, and a slab of prepared carbon as the negative plate. The exciting fluid is a saturated solution of sal-ammoniac, or chloride of ammonium (NH_4Cl), whilst peroxide of manganese (MnO_2) acts as the depolarising agent.

The carbon plate is inside the porous pot, and is surrounded by granules of crushed carbon and peroxide of manganese, all dust and powdered carbon being carefully excluded from the cell. The zinc rod, immersed in the solution of sal-ammoniac, is placed in the outer vessel. (See Fig. 11.)

In action the chlorine of the sal-ammoniac combines with the zinc, forming zinc chloride ($ZnCl_2$), ammonia (NH_3) and hydrogen being consequently released. A large quantity of the ammonia, however, is dissolved in the water until saturation point is reached, after which condition is arrived at the ammonia escapes as a gas. The released hydrogen finds its way into the inner vessel and combines with a portion of the oxygen of

the peroxide of manganese, reducing the latter to a lower oxide (Mn_2O_3), and forming water.

Represented equationally the action of this cell is:

$$Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + 2NH_3 + OH_2 + Mn_2O_3.$$

Considerable care is necessary in the construction of the various parts of this cell. The zinc rod has either a rubber ring at the top and bottom to avoid contact with the porous pot, or the upper portions of the rod and pot are covered with pitch.

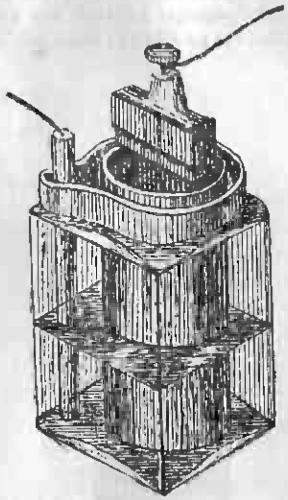

FIG. 11.

The top of the carbon is dipped in melted paraffin wax to close the pores and prevent the ascension of the liquid by capilliary attraction. A leaden cap is also fixed to the carbon plate and the terminal screw set in the lead. Copper, brass, and such-like metals are readily corroded by sal-ammoniac and ammonia, whereas lead is not very easily assailed. The porous cell is closed by a layer of pitch to keep the negative element in position, but holes for the escape of gases are pierced through the pitch.

The exterior of the outer vessel should be kept perfectly dry, and its top is usually coated with pitch to prevent the sal-ammoniac from crystallising out—a tendency that salt possesses in a marked degree—which, if permitted, would result in a loss of material, and the efficiency of the cell would be considerably impaired.

(*b*) The *agglomerate* Leclanché. In this type of Leclanché cell the porous pot, which in all cases introduces comparatively high resistance, is dispensed with, and the internal resistance of the cell is consequently much reduced.

The type known as the "6-block agglomerate" is here described.

The negative element is a block of carbon having six fluted sides. Into each recess is laid an agglomerated rod, made up of carbon and manganic oxide; the whole is then wrapped round with a piece of canvas sacking. Two rubber bands encircle the canvas to keep the materials in position and preserve the necessary pressure between the rods and the carbon block. (Fig. 12.) The canvas acts in the same way as the porous pot by

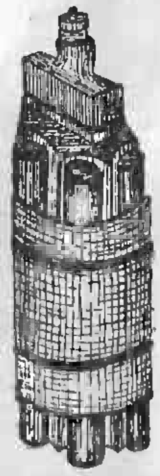

FIG. 12.

permitting the solution to come into contact with the rods, and prevents "short circuiting" in event of portions of the agglomerated rods becoming detached. A zinc plate of special shape partly surrounds the above combination, and acts as the positive element of the cell. The general construction of this form of Leclanché results in a considerable reduction of its internal resistance.

(*c*) The "dry" cell. This form of cell is useful chiefly on account of its portability. It is without liquid, and, consequently, there is no risk of

spilling corrosive solutions. The ingredients, however, are kept in a *moist* condition, for, if allowed to become dry, the cell would be rendered useless, as chemical action would cease, and so long as the moisture is well maintained the internal resistance is kept low.

A description of the E.C.C. "dry" cell, which is an important pattern of the kind, is here given :—

The containing vessel is of zinc, and acts as the positive element of the cell. A paste, composed principally of plaster of Paris, chloride of zinc, sal-ammoniac, and water, is then added to the surface of the zinc, and forms an inside coating. Around the carbon plate is a thick paste made up of carbon, peroxide of manganese, chloride of zinc, and water.

During action of the Leclanché cell it will be remembered that chloride of zinc is formed, and this, together with that added as part of the pastes, preserves, to a certain extent, the necessary moisture of the cell.

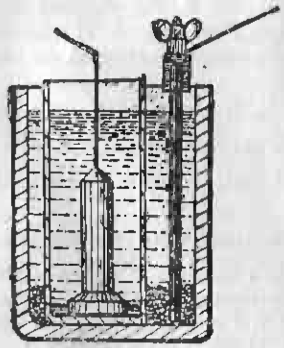

FIG. 13.

The electro-motive force of a Leclanché cell is, approximately, 1·5 volt, but the internal resistance varies from ·25 to 4 ohms, according to the pattern of the cell and the size of the plates.

The Leclanché cell is very serviceable where only occasional use is needed, but when constantly worked it quickly polarises on account of the peroxide of manganese not yielding its oxygen freely enough to arrest the released hydrogen. The cell quickly recovers, however, if allowed to rest, and no waste of materials takes place when it is out of action. Furthermore, polarisation is not so evident if the cell is worked through a high external resistance, for the current is then proportionally feeble, and chemical reactions are consequently much reduced.

The Bichromate Cell.

The bichromate cell is noted for its high electro-motive force and comparatively low internal resistance. In the "Fuller" bichromate (Fig. 13) the zinc, or positive element, is in the form of a rod cast upon a copper wire and widened at its base. The rod is placed in a porous pot together with a small quantity of mercury. A solution of dilute sulphuric acid is added as an excitant.

The mercury ascends the zinc rod by capilliary attraction and amalgamates with it, forming an amalgam of zinc and mercury. Local action by this means is considerably diminished.

The chemical action of the bichromate cell is somewhat complicated, but an idea may be gathered from the following equations :—

Inner Cell : $3Zn + 3H_2SO_4 = 3Zn\,SO_4 + 3H_2$.

Outer cell : The negative plate is carbon, and the depolarising agent, which is a mixture of bichromate of potash ($K_2Cr_2O_7$) and dilute sulphuric acid, surrounds it, the chemical reactions of which produce chromic acid (H_2CrO_4), and sulphate of potassium (K_2SO_4). The latter is a harmless product, while the oxygen in the former arrests the hydrogen and forms water :—

$$K_2Cr_2O_7 + H_2SO_4 + H_2O = K_2SO_4 + 2H_2CrO_4$$

The final equation may be represented thus :—

$$3H_2 + 2H_2CrO_4 + 3H_2SO_4 = Cr_2(SO_4)_3 + 8H_2O.$$

Latimer Clark's Standard Cell.

This cell is used as a standard of electro-motive force, consequently its chief utility is in measurements and comparisons. It should never be put on "short circuit" nor used with very low external resistances. The internal resistance of the cell is comparatively high ; but this is immaterial considering the high degree of uniformity of its electro-motive force.

In size the cell is very small, and its materials are essentially pure. To ensure the latter condition both the zinc and mercury used in its construction are specially prepared.

The outer containing vessel may be of glass—a short, wide test tube answering the purpose very well. (Fig. 14.) A layer of pure distilled mercury, which acts as the negative element, is placed in the bottom of the tube to the depth of about half an inch. Over this is placed a mixture of mercurous sulphate and a saturated solution of zinc sulphate in the form of a thick paste. The positive element is of pure zinc inserted in the paste, and a copper connecting wire is soldered to the top of the zinc rod. A platinum wire is fused into the bottom of the glass tube, one end being in contact

with the mercury inside the tube, and the other end projecting to form a connection. The vessel is then sealed with a suitable mixture such as marine glue.

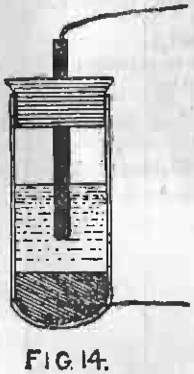

FIG. 14.

The chemical action of the cell results in the decomposition of the mercurous sulphate, and pure mercury is deposited at the bottom of the cell. The zinc rod is attacked by the sulphion of the mercurous sulphate, and sulphate of zinc is formed. The result of this chemical action, it will be seen, is to increase the quantity of pure mercury already in the cell, while sulphate of zinc is constantly being formed at the expense of the positive element.

The electro-motive force of Clark's cell is 1·434 volt ; but in order to preserve the uniformity of this difference of potential the terminals should never be put on short circuit nor joined to a low external resistance.

Summary of Cells.

The following conditions are the chief points to be aimed at in the construction of Voltaic cells :—

1. High and constant electro-motive force.
2. Low internal resistance.
3. Freedom from polarisation.
4. Local action to be reduced to a minimum.
5. Cheap and durable materials.

A comparison of the principal cells which have been described may be made by a perusal of the following table :—

be of like polarity to the inducing pole of the magnet (Fig. 4), as it is impossible to obtain a magnet with only one pole.

FIG. 4.

It will now be apparent why a magnet attracts a piece of iron. The iron has become an induced magnet, and, as the unlike poles are adjacent, it will be seen by the application of the first law of magnetism, which says that unlike magnetic poles attract each other, that mutual attraction ensues. Consequently induction always precedes attraction.

CHAPTER II.

BATTERY CELLS.

A current of electricity can flow from one point to another only when a difference of potential exists between those points, and a conductor, which offers resistance, connects them.

Volta discovered that mere contact of dissimilar metals produced a difference of electrical condition between them, and he formed a "contact series" by arranging several metals in a particular order, so that, by placing any pair in contact, their relative electrical conditions could be readily known.

The "series," including carbon, which is not a metal, is as follows :—

—Graphite or carbon.
Platinum.
Silver.
Copper.
Iron.
Lead.
Tin.
+Zinc.

The first named in the "series" assumes what is termed a *negative* potential to those following, and the last named a *positive* potential to all those preceding it, and, for any pair, the nearer to the top of the list in the one case, and to the bottom in the other, the greater will be the *difference* of potential between them.

Carbon and zinc, for instance, when in contact, will produce a greater difference of potential than copper and zinc, while, on the other hand, carbon and platinum, or tin and zinc as respective pairs, will cause but comparatively little difference of potential. The signs + and —, shown in connection with the series, are used to denote *positive* and *negative* conditions respectively ; but it should be always understood that these terms merely indicate a relatively higher or lower electrical level.

A simple experiment showing that mere contact of dissimilar metals produces a difference of electrical condition has been made by Lord Kelvin, which places Volta's theory beyond dispute.

A thin strip of metal, electrified from a known source, is suspended so as to turn about a point "C" (Fig. 5). Under it are placed two semi-circular discs of dissimilar metals, A, B. Neither attraction nor repulsion of the strip takes place until the discs are brought into contact (Fig. 6), or joined by a wire, when *attraction* and *repulsion* immediately ensue.

drawn away from the screw. The continuity of the circuit is thus broken and the armature, having been released, falls back. The circuit is consequently again joined up, but is broken immediately by a further attraction of the armature. A trembling or vibrating motion is thus imparted to the hammer and a continuous ringing is set up. The body of the instrument is enclosed in a wooden case to shield it from dust, which is a frequent source of trouble if allowed to lodge between the contact screw and spring. The coils are usually wound to a resistance of about 100 ohms. The ringing of the bell is controlled by a press-button, which is simply a device for joining up the battery. The latter usually consists of a suitable number of Leclanché cells, which are better adapted for ringing purposes than other types. The Bichromate and Daniell cells are subject to local action when out of use, and consequently are not fitted for intermittent working.

The *Magneto Bell* is an instrument which is actuated by alternating currents. Its main feature is that the armature is magnetised inductively by a permanent magnet in such a manner as to render its extremities of similar polarity. The action of the bell will be readily understood by reference to Fig. 89, in which N S is a permanent magnet. The south-seeking pole of the latter acts inductively upon the armature A B, and produces south-seeking poles at the ends. The armature

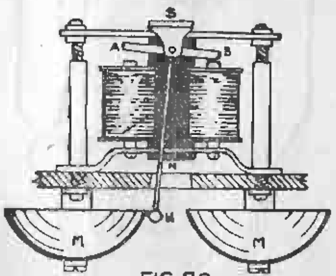

FIG 89.

is pivoted at its centre, and a metal rod is attached at that point. The rod terminates in a brass ball, H, which plays between two gongs, M M. When alternating currents pass through the coils of the electro-magnet the poles of the latter are reversed with every change in the direction of the current. It will, therefore, be seen that when the end of the armature at A is attracted by the adjacent north-seeking pole of the electro-magnet the end B and the south-seeking pole of the electro-magnet will be mutually repellent. A reversal of the current causes the forces of attraction and repulsion to change places, and the

action of an alternating current will therefore produce a vibratory motion of the pivoted armature, and the hammer H will oscillate between the gongs, striking each in turn. The coils are wound to a resistance of 1,000 ohms.

The *Magneto Generator* is used in conjunction with the magneto bell. Its function is to supply alternating currents in return for mechanical energy expended in turning a crank handle. A strong magnetic field is produced by means of three or more powerful permanent horse shoe magnets, which have their similar poles adjacent and connected by pole-pieces. The inner sides of the latter are curved and between them a pivoted armature,

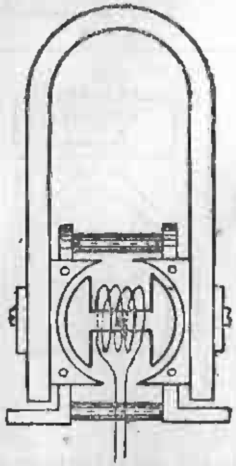
FIG. 90.

carrying a coil of insulated copper wire, is rapidly revolved by means of a crank handle and suitable gearing wheels. The armature is really a peculiarly-shaped electro-magnet, the core of which is a soft iron cylinder having two wide and deep grooves, in which the coil is wound, running along its length. The ends practically form the letter H, and the armature is termed Siemen's H—shaped armature. When it is in such a position that the parts of the cylinder which form the sides of the letter H are perpendicular, the lines of force bridge the small air-gaps between them and the pole-pieces, and pass through the part forming the horizontal of the letter H. This position is shown in Fig. 90. When the armature has been turned a quarter of a revolution, the curved sides of the cylinder nearly bridge the space between the pole-pieces, and the majority of the lines of force consequently follow this path. It will, therefore, be seen that while the armature is in motion, there is a continuous redistribution of the lines of force, and the majority of the latter in their transition cut through the coil, first in one direction, and then in the other. The necessary electro-motive forces for producing alternating currents are thus set up. One end of the coil is connected with the spindle of the armature, and the other is joined by means of an insulated screw with a pin, which passes into the spindle, but is insulated from it by an ebonite sleeve. The resistance of the coil is 200 ohms, and a good generator will ring a magneto bell through a resistance of 10,000 ohms.

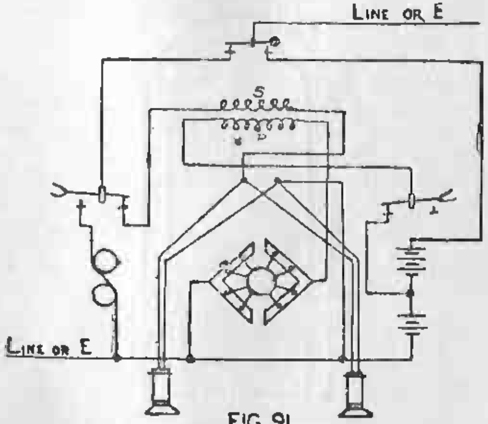

FIG 91

As it is undesirable for the coil of the instrument to be in the path of currents coming from the line many ingenious automatic "cut-outs" have been devised. One of these consists of a switch, or spring, which normally short-circuits the coil, but immediately the handle is turned the position of the switch is altered. By this means the short-circuit is automatically removed and the induced currents leave the instrument and traverse the line.

The connections of a telephone set of the simplest description are shown in Fig. 91. The receiver-rests, shown at the sides of the diagram, are automatic switches which exclude all apparatus except that used for ringing purposes when the receivers are in position. The speaking apparatus is joined up automatically by the levers of the switches falling back and making contact with the back stops when the receivers are removed.

The speaking battery is composed of two Agglomerate Leclanché cells, and the ringing battery of a greater number of ordinary Leclanché cells joined in series with them. Modern automatic switches are provided with two sets of contact springs, and one switch serves the purpose of the two shown in Fig. 91. The two receivers are joined in parallel, but, of course, one only is necessary; with the double form of switch only one receiver is employed. The telephone set shown in the sketch is intended to indicate the position of the various pieces of apparatus, and is introduced on account of its simplicity.

whole of the coil is in the inter-polar space through which the lines of force of the magnet are concentrated. The object of this arrangement is to have the whole of the coil in the most intense part of the magnetic field. In the ordinary receivers having two coils, only the parts of the coils lying between the two pole-pieces are effective for purposes of induction, whereas those portions which are remote from the inter-polar space are practically out of the magnetic field, and introduce a resistance without any corresponding advantage. In the D'Arsonval receiver, however, the whole of the one coil lies between the central core and the outer shell. The coil and pole-pieces are enclosed in a case, which carries the ferrotype diaphragm. The magnet serves the purpose of a handle, and the instrument is productive of very good results.

CHAPTER XX.

AUXILIARY APPARATUS.

The Trembler Bell is, perhaps, the simplest device for gaining attention. It consists essentially of an electro-magnet arranged upon an iron frame, which is screwed to a stout base-board. The frame carries a soft iron armature upon a steel spring. The armature plays in front of the poles of the electro-magnet and terminates in a metal rod carrying a brass hammer. The latter beats upon the gong which is supported upon

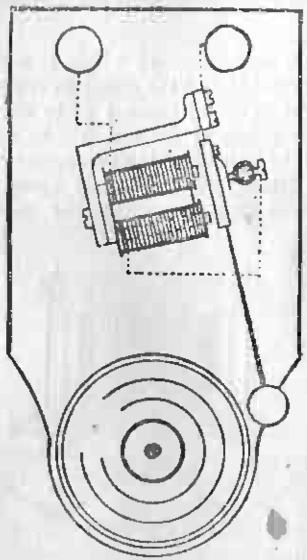

FIG 88

an iron pillar. The armature carries a light contact spring which normally presses against an insulated adjustable contact screw. Two terminals are fixed to the base-board and the current passes through the electro-magnet coils and contact screw and spring. The connections of the instrument are indicated in Fig. 88. The action of the bell is very simple. The passage of the current through the coils causes the attraction of the armature and the contact spring to be partial collapse of the lines of force, but, as the direction of their movement will be similar to that produced by the cessation of the primary current, the direction of the induced current will not be altered.

When the primary current is started or increased in strength the induced current takes an opposing course to it. With the cessation or decrease in the strength of the primary current the induced current is in a similar direction to that of the inducing current. The effects are shown diagramatically in Figs. 95 and 96.

If induction takes place between two telephone circuits "overhearing" or "cross-talk" results. The induced currents rise and fall in synchronism with the primary currents, and the receivers of the circuit which is acted upon inductively respond accordingly. The chief cause of overhearing, however, is leakage from one circuit to another, but this is obviated by the precaution of "earth wiring," which is dealt with in the chapter devoted to the construction of aerial lines.

The effects of induction are overcome by dispensing with the earth return and using a metallic loop. The circuit is so arranged that the induced currents are equal in both wires of the loop, and will neutralise

FIG. 96.

each other at the ends of the circuit where the receivers are situated. To ensure the effect of complete neutralisation, the two wires forming the metallic loop must be alike in all respects. The circuit is then said to be balanced, and should fulfil the following conditions:—

1. The wires of the loop must maintain throughout the same average distance from the inducing bodies.
2. They should be of the same material and have the same conductivity.
3. The electro-static capacity of the two wires should be equal.
4. The co-efficient of self-induction of the two wires should be the same.
5. The wires should possess the same degree of insulation, high or low.
6. The resultant faults due to imperfect insulation should be at the same distances electrically along each wire from the ends of the circuit.

The first condition is fulfilled by symmetrically twisting the wires throughout their whole length. The effects of induction will then be similar in both wires. With static induction the po entials induced in both of the lines forming the loop will be equal. If, however, one of the wires should be

nearer the inducing body than the other, the effect would be to produce unequal induced potentials, and currents would flow from the line of higher potential to that of the lower in order to restore electrical equilibrium. These currents, of necessity, would pass through

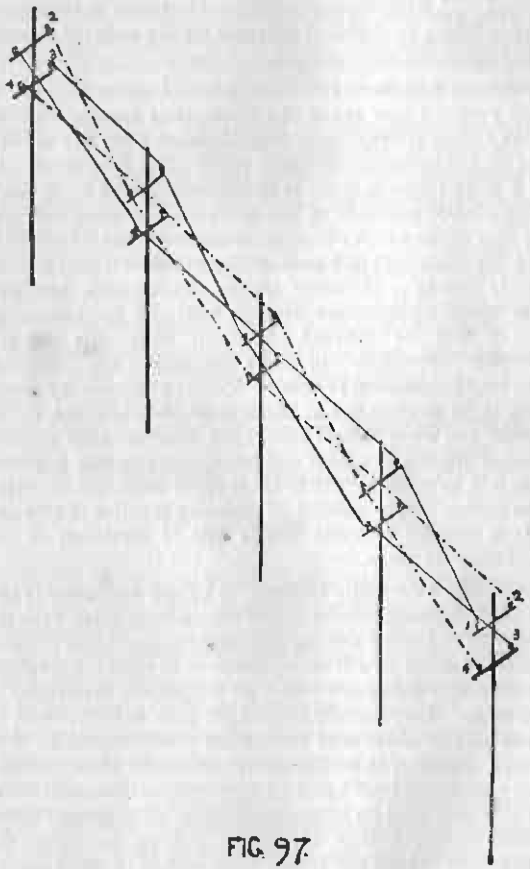

FIG. 97.

the ends of the circuit and actuate the receivers, and a silent circuit would be impossible in the vicinity of other wires. Considering dynamic induction the magnetic field is most intense near the conductor carrying the inducing current. If, therefore, the lines of the metallic circuit are at unequal distances from the inducing wire the one which is nearer to it is cut by more lines of force than the other. The induced electro-motive force is proportional to the intensity of the magnetic field, and, as a consequence, the currents are unequal in strength and complete neutralisation is not effected. If, however, the conditions are such as to produce equal electro-motive forces the induced currents nullify each other, and the ill-effects of the induction are overcome.

In constructing telephone lines two pairs of wires, *i.e.*, two metallic circuits, are revolved one round the other, thus making the individual wires of each circuit at the same average distance from the earth and all other wires carried by the same line of poles. The four wires are at the corners of a perfect square, those at the opposite angles being the wires of a loop. The relative positions of the wires on the arms will be understood from Fig. 97, in which the wires numbered 1 and 3 form one circuit and 2 and 4 the other. It will be seen that in four spans one complete revolution is made. If more than two circuits are upon the same poles more squares are formed and the conductors similarly revolved. It will be noticed, however, that the wires which occupy similar positions in the squares are parallel and overhearing may be expected to result. This is overcome by crossing the wires of the loops forming one of the squares at certain set distances, so as to make the two wires of each circuit the same average distance from the other set of wires. If a large number of circuits run together many such crosses will be necessary in order to make each circuit equi-distant from all the others. This method of crossing is called the "cross-over" system. It is effected by using double sets of insulators on the arms where the crosses are made.

Conditions 2 and 3 are easily fulfilled. A copper conductor is invariably chosen for long telephone circuits and, of course, both wires of the loop have the same specific resistance and are similar in gauge. The resistance and static capacity of each line will consequently be the same. Phosphor-bronze and silicium-bronze, which are alloys of copper, are frequently used for subscribers' lines. They contain about 3 per cent. of tin in their composition, and are used on account of their great tensile strength. The resistance of alloys, however, is comparatively high, and these conductors are consequently precluded from being used for circuits of considerable length. Iron wires are rarely used for telephone circuits. The specific resistance of iron is about 5½ times that of copper, and in order to replace a copper wire by one of iron, the area of cross section of the latter would be 5½ times as great as the former in order to maintain the same resistance. The strain upon the supports, therefore, would be much greater in the case of the iron conductor, and, in addition to this, the capacity of the circuit would be increased, as the wire, acting as one plate of a condenser, would be enlarged. Electro-magnetic inertia, which is practically absent

in a copper conductor, is considerable in the case of iron, and this is another potent reason in favour of copper. Stranded iron wires are sometimes used, but there are several reasons why a conductor of this description should be avoided. With the same resistance as a solid wire a stranded conductor has from 5 to 10 per cent. greater static capacity than a plain wire. It also affords a large and favourable surface for the deposit of snow, and, moreover, impurities which impair the durability of the wire become lodged between the strands.

If the wires of the loop are of similar dimensions and material the balance of the circuit as regards self-induction is assured. Electro-magnets should be avoided in the actual line circuit, and should be joined in "bridge" across the lines. The reason for this arrangement will be explained later.

When the foregoing conditions have been fulfilled they are stable, but the insulation of the loop is a quantity which is subject to continual variation. If each of the wires is uniformly insulated, and the total

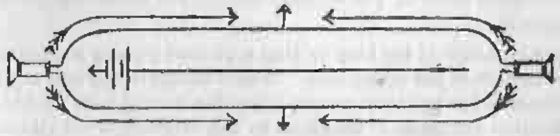

FIG. 98.

insulation resistance is the same, the amount of leakage from each wire is identical. The insulation resistance will be equivalent to a fault, termed the *resultant* fault, at the centre of each line. The resistance of the resultant fault will be equal to the joint resistance of all the paths of leakage. The balance will be thus maintained, and the neutral points of the circuit will remain at the ends (Fig. 98). If the insulation of one wire be more perfect than that of the other there will be a greater leakage from the latter, and the balance of the loop will be upset. Considering dynamic induction, there will be a preponderance of induced current retained by the more perfectly insulated wire, and complete neutralisation will not be effected. The receivers will consequently be actuated and the circuit will be noisy.

If the leakage from one of the wires be not uniformly distributed, or if a specific fault exist, the position of the resultant fault will be changed. By thus altering the point of discharge the neutral points of the circuit will be moved and induced currents will pass through the receivers. (Fig. 99.)

CHAPTER XXI.

The Metallic Loop.

Very early in the history of telephony it was discovered that the use of a single-wire circuit with an earth return was not productive of good results. A telephone receiver is a very sensitive instrument, and is consequently actuated by very minute currents or slight changes in the strength of a current. Leakage, earth currents, and many other causes

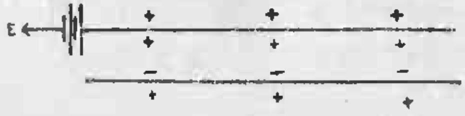

FIG. 92.

tend to produce what is known as a noisy circuit. The chief factor, however, in producing a disturbance of this kind is induction. There are two kinds of induction, viz., electro-static induction and dynamic, or electro-magnetic induction.

Static induction has already been dealt with at some length in connection with the theory of the condenser. It will be remembered that a charged

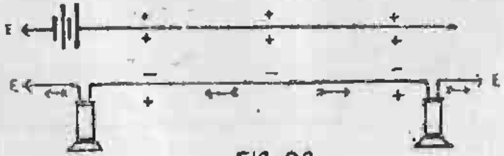

FIG. 93.

body acts inductively upon all neighbouring conductors, inducing a bound charge of opposite kind upon the near side of them, and repelling a free and similar charge to the far side. Consider these effects in connection with two adjacent telegraph or telephone wires. Suppose one to be charged positively by an earth-connected battery, and the other to be insulated at each end as indicated in Fig. 92. The second wire will have an induced positive potential, and, if the circuit be earthed at each end through a telephone receiver (Fig. 93) there will be a discharge of positive

electricity in the form of a momentary current through each instrument. As soon as the inducing charge is removed from the first wire currents flow from the earth to the second wire and produce a neutralising effect upon the now released negative charge. This effect is shown in Fig. 94. Electro-static induction may be summed up by saying that a charged wire produces a redistribution of electrification in neighbouring wires, and if the latter form parts of closed circuits currents of momentary duration

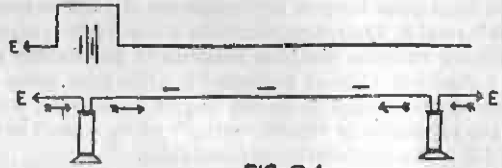

FIG. 94.

will flow through them. A wire carrying a current possesses a static charge by virtue of its electro-static capacity, and a succession of currents in a telegraph circuit induce many momentary currents which actuate the receivers in neighbouring telephone circuits.

Dynamic or electro-magnetic induction is produced by electricity in motion. A wire carrying a current is surrounded by a field of force and exhibits magnetic properties as long as the current flows. The lines of force of the magnetic field radiate in concentric circles from the wire, which is their common centre. When the current is started the lines of force may be said to radiate in an outward direction from the wire, and if

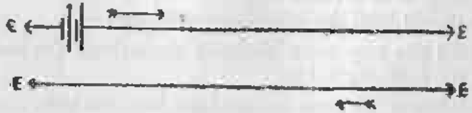

FIG. 95.

the lines of force cut through an adjacent conductor, forming part of a closed circuit, an induced current will be set up in the latter. An increase in the strength of the primary current will cause a further radiation of the lines of force and a similar result will ensue. With the cessation of the primary current the lines of force may be assumed to collapse, or recede into the wire. As they will now cut through an adjacent conductor in the opposite direction the induced current will be reversed. A decrease in the strength of the primary current will cause a

In the single line system it is advantageous to join up intermediate apparatus in "leak," and where the office is some distance from the main route the saving of material is a consideration. If the apparatus at an intermediate station were joined in "series" a fault in it would interrupt communication between the offices on each side. This, however, is not so with the leak system, as will be readily seen by reference to Fig. 101. The objection to a single line, however, is the necessity for an earth return, the serious disadvantages of which have already been described.

The Permanent Current System.

This system has been generally adopted by the British Post Office.

At each end of a trunk circuit two batteries of Leclanché cells are employed. One is called the main battery, and produces the main permanent current from its six cells, whilst the other, consisting of three cells, supplies a local permanent current. A polarised indicator relay, and the larger battery are in series at the end of the circuit with the two lines, while the smaller battery is joined across *one* coil, viz., the right-hand coil, of the relay (Fig. 102). Both main batteries have their positive

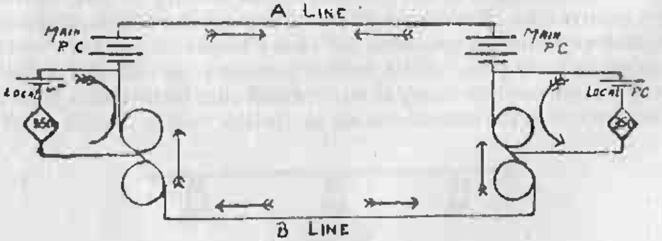

FIG 102

poles connected with the "A" line, and the electro-motive forces being equal and opposite tend to set up opposing currents which neutralise each other. Each local battery, however, produces a deflection of the indicator towards the *right*-hand side.

Now, when an operating peg is inserted (Fig. 103) at either end of the circuit the local polarised indicator relay and main battery are automatically cut out. This enables the main battery current from the distant station to flow through *both* coils of the indicator relay at that station and an increased magnetic effect is produced. The main current through the right-hand coil preponderates and is in an *opposite* direction to that of the local permanent current; it actuates the relay accordingly. The needle of the indicator is thus deflected towards the *left*-hand side and a call signal is produced. A coil of 350 ohms resistance is joined in circuit with

the local battery at each end. This prevents a large amount of the main current from passing through the otherwise comparatively low resistance of that circuit. Without such coil it is obvious that the greater portion of the main current would not pass through the right-hand coil, and the effect upon the indicator relay would be considerably diminished.

The advantages of the permanent current system are that attention is gained automatically and a "ring off" signal is produced by the same means. The insertion of a peg into the switch springs joins up the operator's telephone and the "ring off" apparatus in bridge across the cord, which serves as the connection between two circuits.

The permanent current system is also used for subscribers' lines, and in this case the current is from the subscriber's end only. The indicator shutter at the Exchange is held magnetically by the effects of this current. The latter is cut off by the removal of the subscriber's receiver

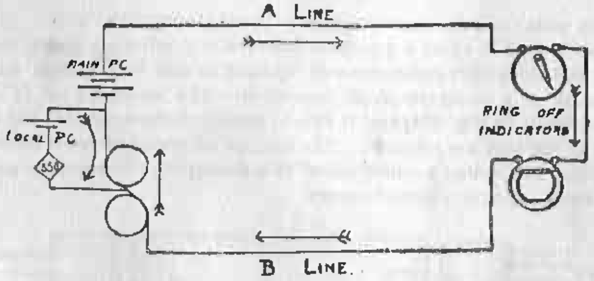

FIG. 103.

from its position on the automatic switch-lever. A breakdown of the line is readily detected, as attention is drawn to the circuit by the failure of the current. The Exchange gains the attention of a subscriber by augmenting the strength of the permanent current, which passes through a relay at the subscriber's office. This relay responds to the increased current only, and is not actuated by the ordinary permanent current.

The Transformer.

Transformers or translators are specially constructed induction coils for use upon superimposed circuits and for translating the currents from a single line to a metallic loop circuit, and *vice versa*. The core comprises a bundle of very soft iron wires about double the length of the coils. The primary and seconda[illegible] coils are both of a comparatively high resistance and the proportion of the former to the latter is small compared with that of the ordinary induction coil. A primary coil of 140 ohms and a secondary coil of 290 ohms wound closely and regularly in *alternate* layers produce satisfactory results. The object for winding the coils to a comparatively high resistance is that each must act as primary or secondary coil in turn, according as the speaking is in one direction or the other. The alternate method of winding is to produce an equality of magnetic effects in both coils. The protruding ends of the wire forming the core are spread out and doubled back over the coils and made to overlap. A complete magnetic circuit is thus formed, and the inductive effect is increased by the wire acting as a

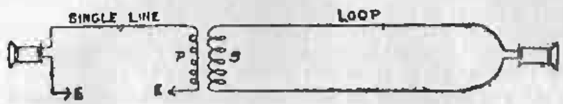

FIG 104.

sheath which concentrates the lines of force through the coils. A transformer is used to effect a junction between a single wire and a metallic loop, and the higher resistance coil is joined to the loop circuit, which is generally of a relatively high resistance. The arrangement is shown theoretically in Fig. 104, and it will be readily understood that the advantages of the loop are retained. The number of transformers is necessarily restricted in forming connections of this description, however, as each one in a circuit entails a loss of energy.

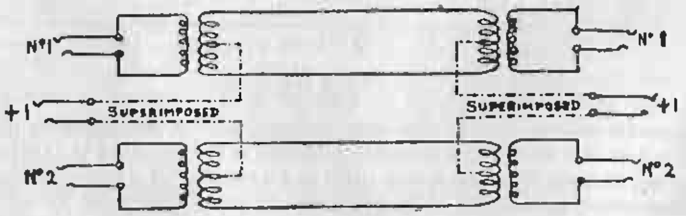

FIG. 105.

THE SUPERIMPOSED CIRCUIT.

When two circuits connect two offices a third circuit may be worked by means of superimposing. In the Post Office superimposed working is effected by the use of transformers. The arrangement is shown diagramatically in Fig. 105. At both ends of the circuits the switch-springs of each circuit are connected to the primary coils of transformers. The secondary coils are divided into two equal sections, the switch-springs of the superimposed circuit being connected to the junctions of the sections as indicated.

The two loops utilised for superimposing should have the same conductor resistance, insulation resistance and capacity. In fact, they should be similar in all respects. Further, the four wires should form the diagonals of a square upon the poles and be symmetrically revolved. One loop serves the purpose of the "A" line and the other that of the "B" line of the superimposed or + 1 circuit. The two main circuits are worked through transformers. The currents traversing the primary coil from the transmitter induce similar currents in the secondary coil and pass to the line. The induced currents circulate through the secondary coil at the distant office and, by induction, similar currents pass through the primary coil, and thence through the switch springs to the receiver. The effect upon the superimposed circuit, however, will be nil, as the centre or

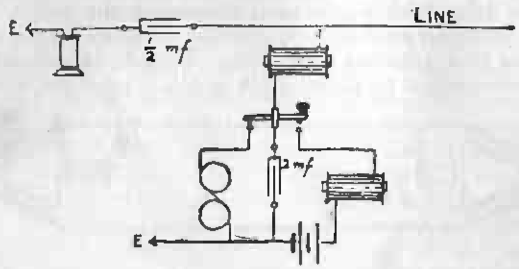

FIG. 106.

junction of the two sections of the secondary coil will be at zero potential. Currents from the apparatus used for the superimposed circuits, however, will divide at the junction, and, after traversing the "A" and "B" lines, will reunite at the centre of the corresponding transformer at the distant station and pass through the superimposed apparatus at that office. The return circuit will be *viâ* the secondary coils and the "A" and "B" lines of the second circuit through which the currents will again split and re-combine as before. The apparatus connected with the two main circuits, however, will not be actuated, as in each of the four transformers the currents induced in the primary coil, by the divided currents traversing the two sections of each secondary coil, will be neutralised, being equal and in opposite directions.

Superimposed working renders the abandonment of permanent current working necessary on the two main circuits, and ringing upon these circuits is effected by means of alternating currents, a non-polarised indicator relay being used.

By a simple re-arrangement at the test-box superimposed working may be readily dispensed with, and ordinary working restored upon the two main circuits.

Superimposing has a great disadvantage from a traffic point of view, as the breakdown of one loop reduces the available outlets from three to one, and congestion inevitably results. This system, however, saves the cost of erection and maintenance of a third loop. Under good conditions it works satisfactorily, and is being largely adopted in the Post Office.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY.

The Van Rysselberghe system of combined telegraphy and telephony is one of many systems for effecting telegraphic and telephonic communication upon the same circuit. The speed of working the telegraph portion of the apparatus, of necessity, must be limited. The rise and fall of the telegraph currents are rendered comparatively slow by the introduction of retardation coils which possess great electro-magnetic inertia, and condensers. Telephone receivers being actuated by rapidly varying currents, or currents of a pulsating nature, are practically unaffected by the retarded currents used for the telegraph system. Upon the other hand,

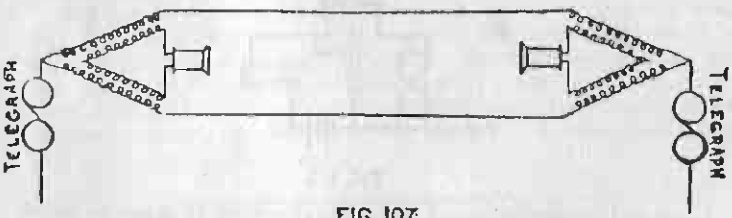

FIG. 107.

the telegraph apparatus is not actuated by the minute and ever-changing currents which are indispensable for effective telephony. The telephone circuit is worked through a condenser of half a micro-farad capacity, and the receiver is actuated by the condenser impulses. This condenser also breaks the continuity of the circuit in the telephone section of the apparatus, and the retarded telegraph currents consequently traverse the line. A theoretical diagram is shown in Fig. 106.

A telegraph circuit may be worked upon a metallic loop by joining its apparatus in bridge.

A better system of simultaneous working is effected by superimposing a telegraph circuit upon a metallic loop by means of transformers. The arrangement is shown in Fig. 107. The currents from the telegraph battery divide equally through the secondary coil and, after traversing the wires of the loop, re-combine at the corresponding junction at the distant station and pass to earth through the telegraph apparatus. The currents induced in the primary coils are equal in strength

and opposite in direction and the telephone apparatus is consequently not actuated. Telephonic communication is effected by induction between the primary and secondary coils of the transformers. The induced currents traverse the sections of the secondary coil at the "speaking" office and pass through the whole coil from end to end, acting in synchronism with those in the primary circuit. After flowing along the loop they induce similar currents in the primary coil at the receiving end, and the receiver is consequently actuated.

It should be emphasised, perhaps, that by constructing a balanced circuit induction is not obviated, but its *effects* are merely overcome. It should also be pointed out that not only is the revolving or twisting of the wires carried out on aerial lines, but the same conditions exist in cables and covered wires.

This system of revolving is carried out along the entire length of all

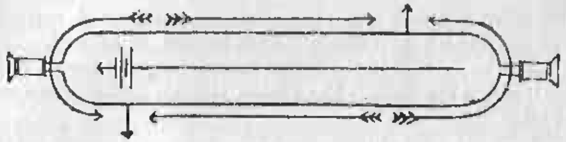

FIG. 99.

telephone circuits; sometimes the pairs of a loop are twisted, but more frequently the wires forming two distinct circuits are uniformly revolved to effect a balance.

Another advantage of the loop is that a current passing along one wire induces a current in the other wire. The induced current flows in the *same* direction as the primary current along the second wire of the loop, and the mutual induction is beneficial to the working of the circuit.

CHAPTER XXII.

Methods of Working.

Intermediate Stations.—There are three methods of joining up intermediate apparatus upon metallic loops; (*a*) "ordinary" or "series," (*b*) "differential," (*c*) "bridge."

The first introduces difficulties through the balance of the circuit being disturbed, and the ill-effects of induction result. The objection to the

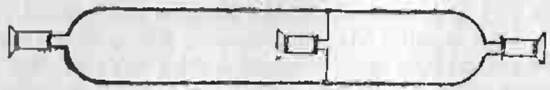

FIG. 100.

differential method is in the necessary double winding of the induction and receiver coils. There are both mechanical and electrical disadvantages in double winding the apparatus, but from a telephonic point of view this method is fairly good. The "bridge" method is pre-eminently superior to the other two. As many as ten stations may be in circuit upon the same loop when the instruments are in "bridge," as the choking effect of

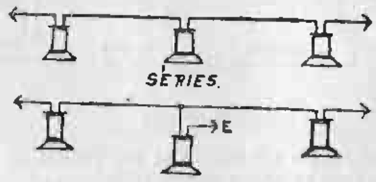

FIG. 101.

the intermediate apparatus due to the electro-magnetic inertia or self-induction of the coils, serves a useful purpose. The intermediate apparatus will be actuated by a part of the current, but the remainder will be choked out, and caused to pass to distant stations. Further, a fault in the apparatus, other than that of short-circuit, will not break down communication with other offices, and the total resistance from any ringing point will be decreased. The "bridge" system is shown diagrammatically in Fig. 100.

CHAPTER XXIII.

The KR Law.

Sir William Thomson, now Lord Kelvin, established this law after investigating the effect that resistance and capacity of a cable have upon the rise and fall of electric currents. For the practical purpose of ascertaining the dimensions of cables to ensure a given speed the question of the total impedance of the circuits had to be settled. The "time constant" of a circuit is the time that a current takes to rise from zero to its maximum strength and fall again to zero. Omitting the point of electro-magnetic inertia, which is absent in copper conductors, the impedance to the rise and fall of the current is directly proportional to the capacity, K, multiplied by the resistance R—hence the KR law.

For high speed telegraphic purposes the time constant must not exceed $\frac{1}{250}$ of a second, whereas in telephony, in which the ever-varying currents rise and fall with great rapidity, articulate speech is not ensured if it exceeds $\frac{1}{5000}$ of a second. From this, then, it will be seen that the total impedance of the circuit which controls the rise and fall of the currents should be kept at a minimum, in order that distortion of speech may be prevented.

The limiting KR values to which speech has been ascertained to be possible have been found experimentally to be as follows: Copper (open), 15,000; copper (covered), 12,000; iron, 10,000. These figures were arrived at by multiplying the capacity in micro-farads by the resistance in ohms. The low value for iron is due to the electro-magnetic inertia of that substance, and the formula is more completely stated as:—

$$KR + \frac{l}{R}$$

where l represents the electro-magnetic inertia of the conductor.

The limiting distance may be approximately calculated from the formula:—

$$l = \sqrt{\frac{A}{kr}}$$

in which l = the length of the circuit in miles.
k = the capacity per mile.
r = the resistance per mile.
A = the value determining the limiting distance.

The total capacity of the circuit = kl.
" " resistance " " = rl.
and the KR " " = kl × rl = krl²

$$\therefore A = kr\,l^2$$

$$l^2 = \frac{A}{kr}$$

$$\text{and } l = \sqrt{\frac{A}{kr}}$$

A comparison of the working speed of a metallic loop and a single wire circuit is frequently made. A metallic loop is analagous to two condensers joined in "cascade," and its capacity is consequently only half that of a single wire circuit between the same points. The resistance of the metallic loop, however, is double that of the single wire, and the KR of the circuits is therefore the same.

circuit is completed through a one-ampère fuse fitted in the chamber. Two holes which run into the insulator allow connecting wires to be carried from the fuse to the two sections of the line. Where damage from contact with power circuits is anticipated this insulator is of great service, as apparatus and the insulating material of underground sections are preserved from harm by the fuse disconnecting the circuits. Difficulty, however, is sometimes experienced from the breakdown of the circuit, due to heavy lightning discharges passing through the fuse.

Extra strong insulators are fixed and steel spindles used upon terminal poles where the *stress* is abnormal.

A wire is frequently run along the top of a pole, and a "saddle" stay, in the form of a galvanised iron band, is attached to an ordinary saddle

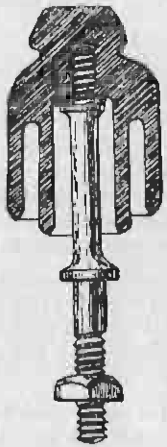

FIG 108.

bracket. This arrangement, together with two blocks of wood, one upon each side of the pole, adds strength to the insulator support.

In erecting poles along road and railway routes the aim is to so arrange them that the prevailing gales may blow any falling wires or the poles themselves away from the traffic. As an extra precaution a short wire is sometimes fitted upon the arm on the traffic side of a pole, and bends over the insulator, forming a hook. A wire becoming detached from the insulator and falling upon this side would be intercepted before reaching the passing traffic. Iron shields are sometimes placed over insulators as a protection against wilful damage. These, however, should never be

employed along a sea-coast route, if exceptional circumstances demand such a route being selected. The salt from the atmosphere and spray would accumulate upon the insulators, and reduce their efficiency; but when unprotected they are kept clean by rain-storms.

SUPPORTS.

Wooden poles are generally used as the supports, and, if thoroughly preserved before erection, they are very durable. Iron poles are employed where an artistic effect is an object, but a disadvantage of iron is that a displaced wire in contact with it would be put to "full earth." Iron poles are made in sections and are portable in consequence, but their initial cost is relatively great.

The wooden poles are in two shapes, "round" and "square," and their sizes vary with the weight of the wires they have to carry, and the stress to which they may be subjected at certain points *en route*. All "terminal" poles are extra large, and they are usually of the "square" pattern. Terminal poles are erected both at the ends of a section and also where the wires form angles approximating to 90deg. The "round" poles are the red fir trees of Norway and Sweden specially selected and "preserved."

With few exceptions the chosen trees are felled in winter. Their bark is stripped off, and they are then stacked in sheds where a free circulation of air generally dries up the sap. They are sometimes charred at their lower ends to destroy vegetable and animal life and to close the pores against the ingress of moisture. A mixture of tar and lime, called "Stockholm" tar, is applied to the butt end, and this prevents rapid decay. It is at the ground line that signs of deterioration usually first appear, therefore this treatment should be extended a few feet above the ground line. The upper ends of the poles are then painted; this is the external treatment for preservation. Terminal poles at the ends of a line are all treated in this way because the popular method of "creosoting" is unsuitable. *Leading-in* wires at such poles are india-rubber or gutta-percha covered, and creosote tends to destroy those materials.

The internal process of preservation is the injection of metallic salts into the pores of the poles, and these salts aid in preventing premature decay.

Burnetising and *Kyanising* each consists of a systematic soaking of the poles, when well seasoned, in a tank containing chloride of zinc in the former, and perchloride of mercury in the latter case.

Boucherising is done when the trees are newly-felled. The spring or autumn is a good time of the year for this treatment, while the vascular systems of the trees are open. The poles readily absorb a solution of copper sulphate and become impregnated with it. There is a serious objection to boucherising, however, as the sulphate of copper has a deleterious effect upon the bolts and staples used for securing the arms, etc., to the poles, by acting chemically upon them.

Creosoting is performed when the trees are perfectly seasoned. This method of preservation is in general use, as its effects are enduring. Creosote is an oily substance; it prevents the ingress of moisture and destroys vegetal and animal life. Creosoting is done in a tank exhausted of air, and the liquid is forced into the wooden poles in quantities of 10lbs. to 12lbs. per cubic foot. The chief draw-back to creosote is its ill-effects upon gutta-percha and india-rubber.

Pole-setting.—The positions the poles are to occupy are first marked out, and the holes are then dug without removing more earth than is really needful. Roads, etc., should not be crossed unnecessarily, and the inside of curves must be invariably taken. Each hole is dug to a depth of from 4ft. to 6ft., the deepest part being reached by a step-like arrangement. A rectangular surface is marked out, and the hole is gradually decreased in size until the proper depth has been made. These excavations are usually made with ordinary tools, but in easily worked soils "borers" are employed which drill circular holes just large enough to receive the poles, and a minimum amount of earth is disturbed. The rectangular excavation is usually necessary, however, and its length is always parallel with the wires. This prevents loosening of the earth at the two sides of the pole where the tendency to draw it from a perpendicular position exists. At the sides of the hole, which are parallel with the wires, the earth near the pole remains firm and undisturbed. The buried portion of the pole should be about one-fifth of the total length, and 25 poles to the mile are ordinarily employed. The punner should be used freely in filling in the holes to make the earth firm and prevent the poles from canting over after setting. Light poles carry one to five wires, medium six to ten, stout poles above ten; the latter are also used at sharp angles.

Struts and Stays are used respectively to counteract the pressure and tension of forces acting upon the poles. In many instances, however, the struts are arranged to counteract the effects of both forces. On heavy work, if neither strut nor stay can be used, two poles are scarf-jointed at their tops and bolted firmly together, their bases being fixed about 2ft. apart. At a distance of about 18in. from the bottom a piece of "preserved" timber is fitted across the poles and secured to each by means of a bolt. This underground arrangement prevents one pole from lifting the other out of the earth. A few feet above the ground an iron tie-rod connects the two poles. Such a support as this is called an "A" pole. Where the work is exceedingly heavy, *i.e.*, where a very large number of wires is necessitated upon one support, or at points where many wires converge, and for telephone wires the "H" pole is

erected. In this case two parallel poles are set about 3ft. apart and bolted together at certain distances with tie-rods. The opposite angles of the interspaces are also connected with iron rods and a lattice

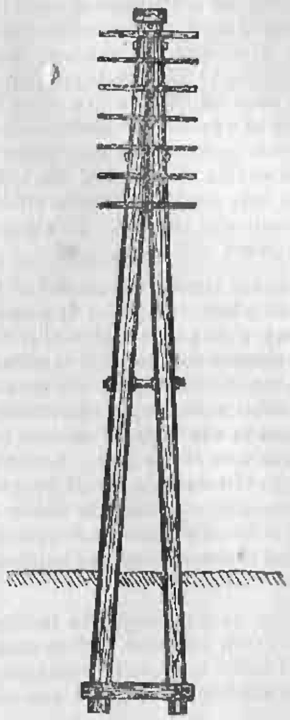

FIG. 109.

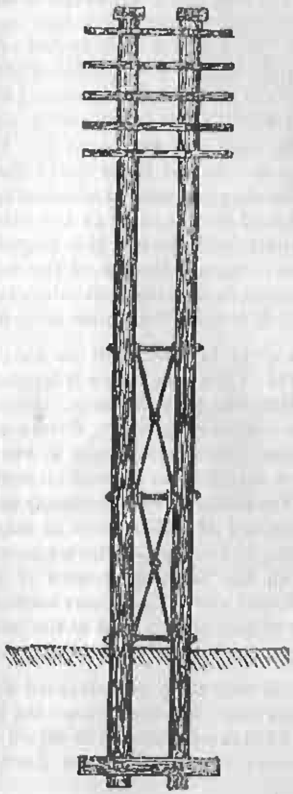

FIG. 110.

work is thus formed. Great strength and rigidity of the combination are by these means ensured. For telephone circuits it is imperative that the wires should run in uniform squares, and "H" poles are best suited for this arrangement. Sketches of "A" and "H" poles are shown in Figs. 109 and 110 respectively.

A stay is made of three or more iron wires twisted together in long turns. One end of the stay is passed twice round the pole and fixed with staples. The exact position on the pole for a stay to be secured is known as the "resultant point." It is midway between the top and bottom wires on the pole, and is where the effect of the joint forces is greatest. The end of the stay is spliced back into the stay itself, both at the upper and lower end. The splice is made by first selecting one of the wires and turning it out at right angles. The remaining wires are then laid longitudinally along the stay and the selected wire wound neatly around them. At the termination of this winding one of the remaining wires is selected and similarly dealt with, until the treatment has been extended to the whole number of strands. At the lower end of the stay a stay-rod, fitted with a screw for tightening purposes, is attached to a baulk of "preserved" timber at one end and to the stay at the other. Before splicing the stay, where it connects with the rod, it is looped around an iron thimble, and the latter passes through the eye of the rod. The hole for the preserved timber attached to the stay is undercut in the direction of the pole. This undercutting ensures the timber being banked against solid earth.

A strut is secured at its base by a piece of timber, and scarfed at its top to fit the pole, where it is attached with a bolt. The joint is painted or tarred to prevent decay. About midway a tie rod is used to bind the pole and strut together. Poles erected in elevated positions and on railway routes, even where a curve is but slight, are double-stayed. Struts and stays should make as great an angle as possible with the pole up to 90deg., for the actual stress is inversely proportional to the distance between the lower end of either strut or stay and the base of the pole. An extra strong stay is required for terminal poles, and its strength should be equal to all the breaking stresses of the wires added together. A forked or V-shaped stay is sometimes necessary. It is forked at the stay-rod, and its two upper ends are fixed to the pole at equal distances from the resultant point, one being above and the other below that point.

Ordinary stays are attached to the poles at right-angles to the line of the route, but others are used in a line with the poles. These latter are fixed at a distance of about a quarter of a mile apart, and prevent many spans of wire being pulled down by the accidental collapse of any one span.

The top of each pole is painted or tarred, and a galvanised iron roof, arranged transversely to the line of the wires, assists in protecting the pole from decay.

To each pole an "earth wire" is secured with staples. This wire conducts direct to earth any possible leakage of current due to defective insulation. The earth wire is fixed beneath the washer, which is interposed between the heads of the arm-bolts and the pole, and then continued

to the top of the pole, where it acts as a lightning conductor. The lower end is coiled up and embedded in the soil at the foot of the pole on the side remote from the traffic. Without such a wire any leakage of current would pass from one wire into others upon the same support, and possibly interfere with passing signals.

When a line wire is run along the tops of poles "saddle" brackets support the insulators, but where masonry work is utilised as supports the "bridge" bracket, which is an iron abutment, is employed. "Shackles" are sometimes used on terminal poles, but they are electrically unsatisfactory, as a double connection with the arm is necessary. Specially strong insulators, however, are usually adopted for this purpose.

The arms to which the insulator spindles are bolted are of well-seasoned oak let into *slight incisions* upon the "up" side of the poles, and bolted through the latter. The arms are frequently of unequal lengths upon the same pole to ensure a broken wire falling clear of others beneath it.

Wiring.—The wire is run out from the drums upon which it is coiled and then lifted into position upon the arms of the poles. It is then strained up to allow of the required dip or sag, due regard being paid to the time of year at which the work is done. A smaller actual dip is given in the winter than in the summer, to allow for a perceptible expansion with an increase of temperature. This work, however, is generally done in the summer months. The draw-tongs are used for straining up the wires, and a tension ratchet and indicator ensure the proper stress being applied. The wire should not be so slack at its greatest dip as to produce contact with other wires, nor too tight to cause its breakage. The standard dip to suit temperature variations is found from the following formula:—

$$d = \frac{l^2 w}{8s}$$

where l = the length of the span in feet,
d = the dip in feet,
w = the weight in lbs. per foot,
s = the stress in lbs.

It will thus be seen that for comparisons when other conditions are equal the dip is directly proportional to the *square* of the span. As the actual length (L) per span of wire is greater than the distance from pole to pole, on account of the dip, another formula for this is needed, viz.;—

$$L = l + \frac{8\,d^2}{3\,l}$$

A safety factor of four is always allowed in regard to the dip, so that a wire is only strained up to a quarter of its breaking stress. The breaking stress of a wire is directly proportional to the weight per unit length, or the area of the cross section.

For wires of the same material, irrespective of their weights, the same dip with the same proportional strain is required. Copper has a higher co-efficient of expansion than iron, consequently this metal and iron should be used together only upon spans not exceeding 80 yards in length, or contacts will probably ensue. For line wires the weight per mile represents the standard gauge, 25lbs. per statute mile being the unit fixed, and all other calculations are based upon these figures. The term "ohm-mile" signifies the weight in lbs. per mile multiplied by the resistance per mile. It is a constant, and is used to compare the conductivity of various gauges of wire.

Binding.—The wire is brought into the groove of the insulator, and, if iron wire is used for the conductor it is bound on with No. 16 gauge galvanised iron wire, which is relatively thin.

In attaching the conductor to the insulator the binding wire is wound twice *over* the line wire upon one side of the insulator, the end nearest the insulator is passed round it in the groove, and *under* the line wire in one turn upon the other side of the insulator. The binder is then taken back round the insulator and given a dozen neat turns along the length of the line wire. The other end of the binder is brought *under* the line wire, round the insulator and *over* the line wire upon the other side, and given a dozen laps along the length of the line as described before.

In binding copper wire, however, a copper tape is wrapped round the line wire and extended to a short distance upon each side of the insulator. A binding wire somewhat similar to the conductor is flattened at its ends and passed round the insulator groove. One end is then brought *over* and the other *under* the conductor, and each is carefully wound along the length of the copper tape.

When one complete length has been run off the drum its end is joined to the beginning of a fresh length. The "Britannia" joint is the popular method of effecting the necessary connection with both copper and iron aerial wires. The ends of the conductor are carefully cleaned and laid side by side for at least two inches. The ordinary binder, used at the insulator, is then wound tightly around the two ends, commencing at the centre of the joint, bringing them into close contact. The binding is continued for a short distance upon each side of the joint. Upon this a coating of Baker's fluid is smeared, and the whole is finally soldered, to form a mass of metal and maintain the electrical continuity of the line. The ends are then cut close to the binder to prevent entanglement with other wires when they are swaying.

The lines are systematically numbered in the following manner:—No. 0 is always at the top of the pole. From a position on the "up" side of the pole, where the arms are fixed, No. 1, upon a four wire arm is on the extreme left of the top arm and No. 2 on the extreme right, the inner left-hand wire being No. 3 and the inner right-hand wire No. 4, and so on. All odd numbers are thus upon the left side of the pole and all evens upon the right side. Terminated wires are brought to specially strong insulators and "leading in" wires from the terminal poles are made of copper covered with gutta-percha, and surrounded with tarred hemp, which latter acts as an efficient protecting material.

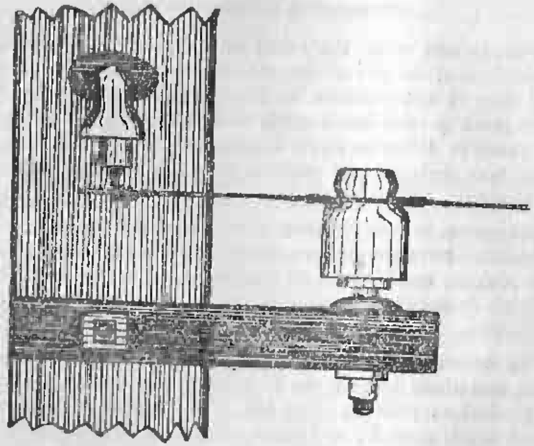

FIG. 111

The wires are led into a wooden casing which extends along the length of the pole; a leading-in cup, through which the conductor connected to the line wire is run is then fitted to the pole as shown in Fig. 111.

This cup prevents moisture entering at the junction of the outside and inside sections of the wires. When an iron wire is brought to a copper wire both are either terminated or run into separate grooves of a "Langdon" insulator, the "tails" being brought over the insulator and joined together.

Inside the office the bundles of wires are now laid in iron channelling, the individual wires being insulated with a mixture of cotton and silk. Several wires are then grouped and a lead sheathing surrounds each group. These precautions are made to prevent extensive damage from fire, which would probably ensue if gutta-percha covered wires were used.

When wires are suspended over housetops iron poles and the best materials generally are employed. To reduce objectionable vibrations a chain is frequently attached to the line wire and holds it to a "shackled" insulator; but a strand of copper is more effective than the chain. An iron band should always encircle a chimney stack in preference to fixing a bracket to it, and copper wire, on account of its durability, is always preferred as the conductor. The supports are stayed in every possible direction, and the wires should cross busy thoroughfares at right angles. These precautions are imperative to minimise risks of damage and accidents due to falling wires or supports.

Underground Construction.

In large towns and cities the aerial or open system of construction is not practicable, so it becomes necessary to adopt an underground system. The initial cost of subterranean work is very great, and the strictest attention is given to every detail of the work. The slightest defect existing at the outset is liable to cause endless trouble and expense, consequently the best material and workmanship are essential to ensure a complete success.

When the system is in or adjacent to a town a trench is dug, preferably along a footpath; but upon country roads waste land at the side of the road is the position usually selected for the operation, the object being to avoid probable damage to the pipes, etc., due to the heavy traffic of the roads and streets.

In digging the trench sharp curves and the crossing of thoroughfares are avoided, and where a difference of level is a necessity the incline is made as gradual as possible. The bed of the trench is also made firm where loose earth prevails, and large stones are removed where their presence is likely to cause subsequent damage to the pipes. The latter are usually cast from good quality soft pig-iron, and their internal diameter is 3in. or 4in. The upper exterior surface of the pipes should be buried to a depth of about 2ft. below the level of the footway, and flush boxes, for drawing-in purposes, are fitted at intervals of 100yds. Every fourth box is called a "jointing" box because the wires, being made in lengths of 400yds., require to be jointed at such points.

The pipes are carefully examined for flaws, special attention being paid to the interior of the pipes with a view of removing excrescences, the presence of which would destroy the insulating material of the wires during the process of "drawing in." The pipes are heated and dipped into a mixture of coal-tar, tallow, quicklime, resin, and naphtha at the required temperature, and a glaze is by this means imparted to them. They are made in lengths of 6ft. or 9ft., and three lengths are jointed together before laying in. The joints are made air and gas-tight, yarn, clay, and molten lead being used for the purpose. To facilitate the drawing-in process a wire is threaded through the pipes when they are being laid. To prevent damage to the insulating material mats are placed in the boxes, and rollers at the ends of the pipes. The spigot end of the pipe, and not the socket end, is always brought into a flush box. Pillar test boxes are fixed at certain intervals, and brick manholes built where several conduits concentrate.

There are two kinds of material in general use for insulating underground wires, *i.e.*, gutta-percha or india-rubber, and specially prepared anhydrous paper manufactured in a perfectly dry atmosphere. For gutta-percha cables a copper conductor of about 60 mils diameter and weighing about 40lbs. per mile is used, and the standard diameter of the *core* is 174 mils. The copper wire, having a conductivity of 100 per cent., has a resistance of about 22 standard ohms per mile at 75deg. Fah., while the inductive capacity must not exceed ·29 micro-farad per mile. As a protection to the insulating material a prepared tape is wound around each wire, or around groups of four in the case of a quadruple cable.

For telephone work quadrupled cores are used, and the pairs are symmetrically twisted to prevent inductive disturbance. The wires are numbered from one upwards where the number of wires in a cable is limited; but where a great many wires radiate such a system becomes less practicable. They are then numbered in sections.

Probably the most important work of the subterranean system is the jointing of the various lengths. Cleanliness and good health of the workmen are absolutely essential. The wires are cut to a uniform length, and the tape stripped back for a distance of about 15in. and fastened round the cable. The gutta-percha is then removed for about two inches from the ends of the two wires to be joined, great care being taken not to "nick" the conductors. The latter are then scraped perfectly clean. Half-an-inch from the gutta-percha the two wires are crossed and the ends twisted by means of pliers. The superfluous ends are removed and the joint soldered. Resin is used with all soldering of this kind. The gutta-percha is made warm for about two inches of its length, and one side of it is drawn half-way over the twisted wires. The other side of the gutta-percha is then worked down to meet the first portion, tooled with a heated iron and made to overlap it. The whole of the gutta-percha covering the joint is warmed and worked with the finger and thumb into a homogeneous mass, and allowed to set. Chatterton's compound is then applied at the centre of the joint. A gutta-percha tape, 6in. long and 1in. wide, is thoroughly warmed through, then wound around the joint and worked down with the finger and thumb until it spreads over about 4½in. Where the ends of this tape meet the undisturbed gutta-percha the tape is tooled down; the joint is then soaped over, and the prepared binding tape, as an outer protection, is wrapped around the gutta-percha. During these operations excessive moisture, over-heating of the gutta-percha, and decentralisation of the conductors must be particularly avoided.

Dry Core, or Paper Cables.—These cables result in economy of space, relatively small cost, very high insulation resistance, and a quarter the electro-static capacity of either gutta-percha or india-rubber-covered cables. The electro-static capacity per mile of a paper-covered wire of 20lbs. or 40lbs. weight per mile may be as low as ·08 micro-farad, while that of a 100lbs. wire is only ·1. The tests for this are made with all the other wires in the cable and the sheathing to earth. This low capacity is one of the greatest advantages in connection with telephony. As regards economy of space, about four times the number of wires can be laid in a given space when paper is substituted for gutta-percha. The cost for pipes is therefore considerably less. The paper is wound on spirally or longitudinally, and, if carefully manufactured and applied as regards dryness, and afterwards kept free from moisture, it is practically imperishable. The electrification of a paper cable, too, is comparatively slight, and there is little risk of the insulation breaking down, except through defective sheathing or jointing, in which cases all the wires in one cable are liable to be affected. One wire of a pair is insulated with white paper, while the other is made distinctive by the use of coloured paper. The pair, after the wire has been twisted, is further insulated with another paper covering, and the cable is then made up in layers, each layer being twisted oppositely to the adjacent layers to obviate the effects of induction. A small air space is left between the insulated conductors and the lead sheathing, so that dry air may be forced into the cable. The insulation resistance per mile, with all other conductors and the sheathing to earth should not be less than 10,000 megohms, and it sometimes reaches 200,000 megohms at 60 deg. Fah., after one minute's electrification. As lightning discharges act seriously upon paper cables extra precautions have to be made to prevent damage by them. Protectors are therefore placed at the switchboards and the ends of the cables.

Paper cables are jointed at every 75 or 220 yards, according to the weight of the individual wires, and during the operation of jointing wet and damp air should be carefully excluded from them. The two ends of the conductors are bared and, if their diameters are relatively small, the ends are crossed and then neatly twisted together. The end of the joint is soldered and the twisted portion of the wires is turned back parallel and close to the conductor. A paper sleeve, previously placed upon one of the wires, is slipped over the joint and properly secured, and the prepared paper is wound spirally over each pair. In jointing the larger diameter wires the

two ends are cleaned and tinned. They are drawn close together, and a copper jointing sleeve is brought over the joint and soldered, resin being always used, and a paper sleeve is then slipped over the connection. After all the wires of which the cable is composed have been similarly treated they are served *en bloc* with a further covering of spirally wound insulating paper. A lead sleeve is then slipped over the whole and secured by means of carefully made plumbers' wiped joints. The iron containing pipe is then jointed by means of an iron slide pipe, which is caulked and leaded, and the operation is complete.

As dryness is absolutely imperative in the process of jointing charcoal braziers must be freely used, together with a mirror for detecting the presence of moisture.

To test for the insulation resistance of a dry core cable, a battery composed of 300 dry cells, having an electro-motive force of 450 volts is employed. The Wheatstone Bridge and galvanometer are quite inadequate for this test, and a specially devised testing set is utilised. The galvanometer, which is horizontal and of an exceedingly sensitive character, is wound to a resistance of 25,000 ohms. It is fitted with a shunt, which is normally in circuit, having a multiplying power of 1,000. The instrument is 30 times as sensitive as the ordinary Tangent galvanometer, and has a figure of merit of ·00041. The battery must be well-insulated, and all masses of magnetic substances which are liable to be moved during testing operations must be taken from the vicinity of the galvanometer. The constant of the instrument is taken through a resistance of 1,100 megohms, when a deflection of one degree may be obtained.

Composite Dry-Core Cables comprise a number of paper-insulated conductors of varying sizes.

The large-sized conductors are arranged in the centre of the cable, while the smaller ones are laid around them. The former are used for trunk lines and the latter for junction circuits and the wires of private renters and subscribers to exchanges. The standard sizes are generally adopted, and all the space in a three-inch cast-iron pipe is utilised. With the exception of the method of stranding these conductors the general construction of the cable coincides with that of the multiple dry cores already described.

CHAPTER XXIV.

CONSTRUCTION.

There are two comparatively large sections of this very extensive branch of telegraphy, viz., *aerial*, or open lines, and *subterranean*, or covered lines. Each has its advantages and disadvantages, but only the chief points of both sections can be dealt with in these notes. Open lines generally predominate, on account of their comparatively low initial cost and the greater facilities which exist for their subsequent maintenance. A main road or railway route is selected for open work, the former being preferred. The chief materials for the construction of an aerial line are suitable conductors, such as iron or copper wires, selected well-grown poles of great strength for their suspension, and insulators of high resistance to insulate the wires from the supports. The tensile strength and durability of the wires are factors of great importance, while their conductivity, and, in certain cases, *electro-magnetic inertia* must be amply considered.

Iron is relatively cheap, and after an iron wire has been well galvanised it is durable, and acts as an efficient conductor for general purposes. As iron is a magnetic substance, however, it becomes magnetised while carrying a current of electricity, and under those conditions an iron wire has been likened to a lineal magnet. The act of magnetising and demagnetising it produces deleterious effects in telephony, and when fast speed working is resorted to. Consequently, iron, on account of its electro-magnetic inertia, is being rapidly substituted by copper, the market value of which has been considerably reduced during recent years.

In large towns, or when in close proximity to chemical works, iron rapidly deteriorates through the effects of atmospheric chemistry upon it, while copper is unaffected, and has the great advantage of being a better conductor.

There is a Swedish method of smelting iron with charcoal, and "charcoal" iron possesses a higher conductivity than the ordinary metal. The foreign material has been very freely used in consequence; but English iron is now being utilised to a large extent.

The pig-iron is first puddled, and then beaten out and rolled into suitable bars and passed through the rolling mill. The latter consists of a series of rollers grouped in pairs which are placed alternately horizontally and vertically. Each roller is grooved, and the size of each succeeding pair is reduced and the speed of rotation increased. Wires of a smaller size than that of the smallest groove are obtained by drawing them, when cold,

through proper dies; but as this tends to harden the metal and increase its resistance, it is subsequently annealed.

To prevent rust and consequent mechanical deterioration the wire is galvanised. It is then wound upon suitable drums to prevent "kinks." Each length should be free from welds, cinders, and other impurities, all of which tend to weaken the wire. A uniform breaking strain is essential, and to improve each length in this respect, the wire is not made from one solid mass, but from several layers, which, after manufacture, possess the homogeneity of a mass with an increased ductility. There are several tests for the mechanical strength of a wire. The latter is passed alternately over and under a series of pulleys; it should be bent backwards and forwards a given number of times at right angles without breaking, and wound upon itself and also twisted without splitting. It should carry a certain weight and resist a specified stress without breaking.

INSULATORS.

The insulators fitted to the arms of the poles are usually made of porcelain, well vitrified. Glazed earthenware is a cheap material, but the use of an exterior glaze only, which frequently cracks and affords a channel for the accumulation of moisture, is a precarious method of maintaining good insulation. Glass has been tried, but that substance being hygroscopic and brittle has been abandoned. Ebonite has been experimented with, but its surface becomes spongy and indented after a time, and the insulation consequently suffers.

There are several forms of insulators, the double-shed or double-cup pattern (Fig. 108) being pre-eminently superior to other types for general purposes. This pattern interposes a great amount of insulating surface between the wire attached to the outer section and the metal bolt screwed into the inner section, and has a minimum bulk.

The exposed surface of the outer shed is kept clean by frequent rain storms, whilst the inner cup remains dry, being protected by the outer one. The newest kind of double-shed insulator—the "Cordeaux"—is moulded in one piece, and screws on to the iron spindle or bolt. (Fig. 108.) An elastic ring is clamped between the insulator and the shoulder of the spindle; it prevents fracture of the insulator due to the unequal expansion of the porcelain and spindle when the temperature varies. The Cordeaux insulator is an improvement upon the older type, in which cement was used between the sections of the insulator and to fix the spindle to the inner cup. To remove an old type insulator the spindle itself had to be removed, and this was a serious drawback.

A recently introduced insulator carries a fuse and is termed the "fuse" insulator. It is in two sections, a cover being made to screw down over a chamber at the top. The lines are terminated at the insulator, and the

All testing offices are provided with a vertical "galvanometer" and testing switch, by means of which the positions of faults may be readily located between two testing points. The "galvanometer" is placed in a prominent position at the test-box. The switch is composed of four brass quadrants, surrounded by an earth-connected brass ring. Two of the quadrants are connected to the poles of a testing battery, a third marked G to one terminal of the "galvanometer," and the fourth marked X to an adjacent terminal at the test-box. The second galvanometer

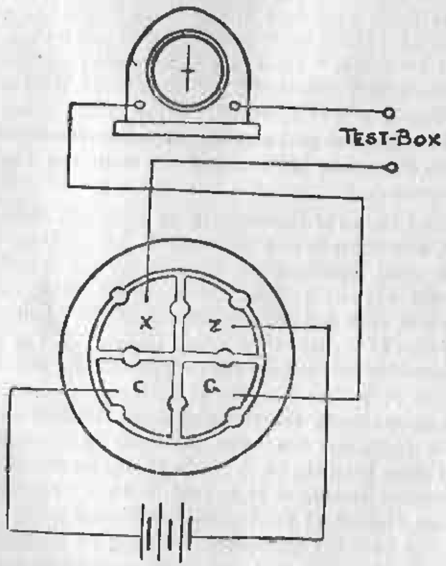

FIG. 113.

terminal is also connected to a test-box terminal. The arrangement is shown diagramatically in Fig. 113. The locality of disconnection, earth, and contact faults may be roughly determined by the use of the test-box "galvanometer" and switch. In the case of disconnections the testing points *en route* are in turn requested to "earth" the wire. Suppose that a testing office midway between the terminal offices has been requested to make an "earth" connection. The office at which the test is being conducted joins the negative pole of the earthed testing battery to the line through the galvanometer, by means of the switch. If no deflection is observed the line has been earthed beyond the fault. The other testing points on the fault side are then similarly

dealt with in turn until a deflection is obtained, and it is then known that the fault exists between the office at which the last earthing operation was effected and the office where the earth connection established the continuity of the circuit.

When an earth fault exists a somewhat similar procedure is adopted. In this case the testing points in turn *disconnect* the line, and at the office where the test is being made the same arrangements as before are necessary. Now, however, the conditions are reversed. As long as the line is disconnected beyond the fault a deflection is observed, the current passing to earth at the fault; but as soon as the disconnection is made between the testing office and the point of interruption, a deflection is not observed, as the continuity of the circuit has been broken. The locality of the earth fault is thus determined.

In the case of a contact between two lines the testing office joins one pole of the earth-connected testing battery to one of the lines, and the other line is "earthed" through the galvanometer. A current then passes from the first wire through the point of contact to the second wire, and thence to earth through the testing galvanometer. At the testing offices on the line disconnections of both wires are effected, and it is apparent that when the disconnections are made between the office conducting the test and the fault the galvanometer needle ceases to be deflected, but when the disconnections are made beyond the fault they do not affect the current passing from one line to the other through the contact, and the deflection is undisturbed.

Intermittent faults are localised by successively crossing sections of the faulty wire with those of a wire which is known to be in good working order. When the fault has been transferred from one circuit to the other it is obvious that the interruption exists between the points where the "crosses" were last effected.

Measurement of Resistance.—The simplest method of measuring resistance is to join up the conductor to be tested in circuit with a battery and galvanometer. The deflection produced on the galvanometer should be noted and then a suitable set of resistance coils substituted for the conductor. The coils should be manipulated until the same deflection is obtained as when the conductor formed part of the circuit. The resistance of the coils will then be the same as that of the conductor under test, as will be readily understood by an application of Ohm's law.

Another method of measuring resistance is by the use of a differential galvanometer. The object under test is joined to one of its coils and to the other coil is joined a set of adjustable resistances. The galvanometer is joined in "series," and at the junction of its coils a battery is connected. The arrangement is shown in Fig. 114, but it should be understood that if an earthed line is under test it will be necessary to earth the battery and the resistance coils. The latter should be manipulated until no deflection of the galvanometer needle is observed. The current from the battery splits through the two galvanometer coils, and, if the resistances of the two paths are equal, the current will divide into two equal portions, which will traverse the coils of the galvanometer in opposite directions. The effect of one will consequently neutralise that of the other, and the galvanometer needle will be unaffected. This condition is brought about by the adjustment of the resistance coils. The resistance required in the latter to effect a balance is the resistance of the object under test.

Battery Resistance.—The resistance of a battery, r, may be ascertained by what is known as the *half-deflection* method. The battery is first joined up in circuit with a galvanometer, G, and set of resistance coils, and the latter is adjusted until a suitable deflection, say, 60 tangent divisions, is obtained. Call the resistance R_1. The deflection is then halved by an addition to the resistance of the coils, and, of course, the current in the

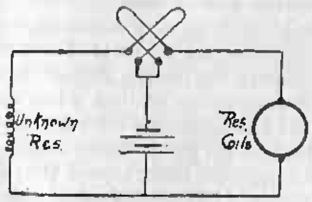

FIG. 114

circuit is only half of its former value. Let the required resistance in this instance be denoted by R_2. But as the current has been halved it follows that the *total* resistance is twice what it was in the first case. An equation may now be stated thus :—

$$2\,(r + G + R_1) = r + G + R_2$$
$$\therefore r = R_2 - (2\,R_1 + G)$$

Example 47.—With a galvanometer having a resistance of 320 ohms (G) and a battery, the resistance (r) of which was to be ascertained, a deflection of 60 tangent divisions was obtained when a resistance of 440 ohms (R_1) was inserted in the resistance coils. On increasing the resistance of the latter to 1,240 (R_2) the deflection was only 30 tan. divisions. What was the resistance of the battery ?

Answer.—
$$2\,(r + G + R_1) = r + G + R_2$$
$$2\,(r + 320 + 440) = r + 320 + 1{,}240$$
$$2\,r + 640 + 880 = r + 320 + 1{,}240$$
$$2\,r + 1{,}520 = r + 1{,}560$$
$$\therefore r = 1{,}560 - 1{,}520$$
$$= 40$$

Answer : 40 ohms.

The battery resistance may be readily ascertained by adding twice the smaller resistance to that of the galvanometer and subtracting the result from the larger resistance.

Diminished Deflection Method.—In the preceding test the original deflection was halved in the second case by the addition of resistance. It is not imperative, however, that this should be so, for in the "diminished deflection" method it is not necessary that the two deflections should be in the proportion of two to one.

Example 48.—It is desired to determine the resistance of a battery by means of a tangent galvanometer having a resistance of 20 ohms. By joining up the battery to the galvanometer, together with a resistance of 45 ohms, a deflection of 40 divisions is obtained, but by increasing the resistance of the coils to 120 ohms a deflection of 25 divisions only is registered. What is the battery resistance ?

As the electro-motive force is the same in each case, the currents, and, consequently, the deflections, are inversely proportional to the total resistances.

Let r = the battery resistance,
G = the galvanometer resistance,
R_1 = the first resistance in the coils,
R_2 = the increased resistance in the coils,
d_1 = the first deflection,
d_2 = the diminished deflection.

Then
$$d_1 : d_2 :: r + G + R_2 : r + G + R_1$$
$$40 : 25 :: r + 20 + 120 : r + 20 + 45$$
$$40\,(r + 65) = 25\,(r + 140)$$
$$40\,r + 2600 = 25\,r + 3500$$
$$40\,r - 25\,r = 3500 - 2600$$
$$15\,r = 900$$
$$r = 60$$

Answer : 60 ohms.

The electro-motive force of a battery may be determined by the *equal deflection* method, in which the battery is joined to a galvanometer and set of resistance coils. The latter is adjusted until a suitable deflection is obtained, and the *total* resistance of the circuit is then noted. In the next operation the battery is removed, and in its place a standard cell, the electro-motive force of which is known, is inserted in the circuit. The resistance coils are again adjusted until the same deflection as in the first instance is recorded. As the currents are equal in strength in the two cases, it follows that the electro-motive forces required to produce them are in the same proportion as the resistances which are essential to the production of the equal currents. If E_1 and E_2 and R_1 and R_2 represent the electro-motive forces and resistances respectively in the two cases—

$$C = \frac{E_1}{R_1} \quad \text{and} \quad C = \frac{E_2}{R_2}$$

but as the value of C is the same in each case

$$E_1 : E_2 :: R_1 : R_2$$

Example 49.—With a battery of 50 ohms resistance joined to a galvanometer of 100 ohms resistance, and a set of resistance coils, in which a resistance of 3,450 ohms is inserted, a certain deflection is obtained. By the substitution for the battery of a standard cell having an electro-motive force of 1½ volt and a resistance of 5 ohms it is necessary to unplug only 75 ohms to produce a similar deflection. What is the electro-motive force of the battery?

Answer: The total resistance when the battery is in circuit is 3,600 ohms (50 + 100 + 3,450). When the standard cell has been substituted the resistance of the circuit has been reduced to 180 ohms (5 + 100 + 75). The electro-motive force of the battery is in the same proportion to that of the cell, as the resistance in the first case is to that in the second.

$$E_1 : E_2 :: R_1 : R_2$$
$$E_1 : 1{\cdot}5 :: 3{,}600 : 180$$
$$180\ E_1 = 3{,}600 \times 1{\cdot}5$$
$$\therefore E_1 = 30$$

Answer: 30 volts.

The answer may be verified by applying Ohm's law to show that similar currents are obtained.

In the first case $C = \frac{E_1}{R_1} = \frac{30}{3{,}600} = \frac{1}{120}$ ampère,

and in the second case $C = \frac{E_2}{R_2} = \frac{1{\cdot}5}{180} = \frac{1}{120}$ ampère.

The Wheatstone Bridge.

The Wheatstone Bridge is an instrument employed for measuring resistances. It is usually depicted diagramatically as a parallelogram of resistances, three of which really comprise the actual instrument, the fourth being the unknown resistance. Fig. 115 shows the theoretical arrangement. The opposite angles of the parallelogram are "bridged," in the one case by a very sensitive horizontal galvanometer, and in the other by a battery. Two of the resistances, each of which is usually made up of three coils of 10, 100, and 1,000 ohms resistance, are termed the ratios, and are shown in the diagram as a and b. The third resistance of the bridge, called the rheostat, is marked d, and is

generally made up of resistance coils of 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1,000, 2,000, 3,000, and 4,000 ohms resistance respectively.

When a balance has been effected by the adjustment of the rheostat, that is to say, when the points A and C are at equal potentials and the galvanometer needle is undeflected, the resistances of the arms of the bridge bear a fixed ratio to each other:—

$$a : b :: d : x$$

If a and b are equal in value, then

$$d = x$$

They may be made unequal, however, but the proportion stated above holds good. It is essential that the ratios a and b should have some

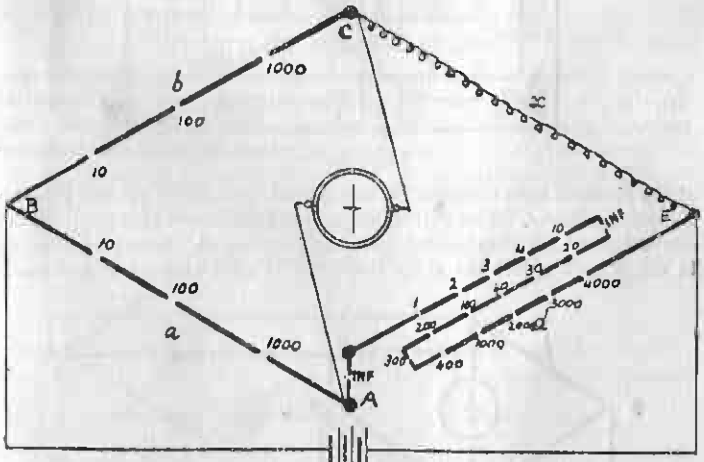

FIG 115.

resistance, or the galvanometer would be short-circuited through them. By making the resistance in b 10 or 100 times as great as that in a a resistance equal to 10 or 100 times that of the rheostat (11,110 ohms) may be measured.

The arrangement of the coils in the practical form of Wheatstone Bridge is shown in Fig. 116. Two simple keys are employed for joining up the galvanometer and battery. When the resistances of the ratios have been determined and brought into circuit an approximate resistance should be unplugged in the rheostat. The battery key should then be depressed and the galvanometer key tapped momentarily so that the *direction* of the deflection may be observed. The latter key should not be held down firmly at first, for, if a balance has not been effected, the passage of a strong current through the galvanometer coil will result in a violent swinging of the needle, and much valuable time will often be lost. The key may be held down subsequently, however, when re-adjustments

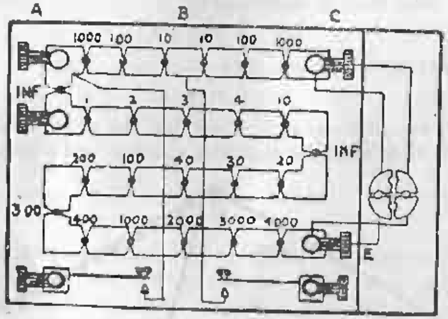

FIG 116

of the rheostat have modified the strength of the current passing through the galvanometer. Two of the plugs are marked INF. (Infinity), by the removal of which the rheostat may be disconnected. Great care should be taken to keep all the plugs clean, for if good contact is not made

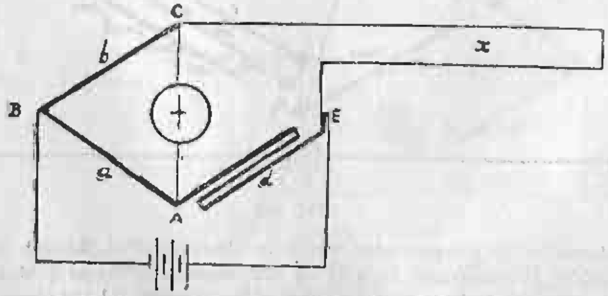

FIG 117

incorrect results will be obtained. A "quadrant" switch for reversing the direction of the battery current is also employed.

The battery used for testing with the Wheatstone Bridge is composed of Daniell cells, the number of which varies from 10 to 40, according to the nature of the test. Twenty Daniell cells may be taken as sufficient to provide the average electro-motive force.

Resistance of a Loop.—In the *conductivity* test, or measurement of resistance, two wires are generally looped. The loop is then the unknown resistance, x, and the two wires are joined as shown theoretically in Fig. 117.

Example 50.— If

$$a = 1{,}000$$
$$b = 100$$
$$d = 6{,}954$$

then

$$a : b :: d : x$$
$$ax = bd$$
$$x = \frac{bd}{a}$$

and substituting,

$$x = \frac{100 \times 6{,}954}{1{,}000}$$
$$= 695{\cdot}4 \text{ ohms.}$$

If a and b are equal the resistance required in the rheostat to effect a balance will be the resistance of the loop. If the wires are of the same gauge and follow the same route the resistance of each may be stated approximately as half the measured resistance.

In the case of a single wire test the line is earthed at the distant station and joined to C at the testing office. The point marked E in the Bridge is

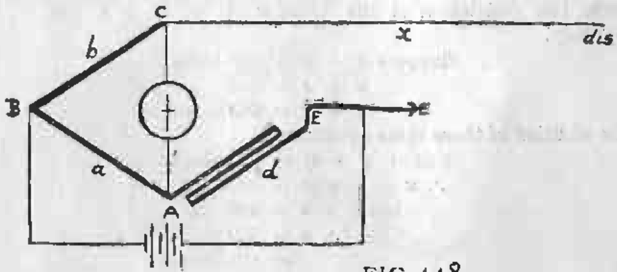

FIG 118

also earthed. To ensure accuracy the test should be repeated with the battery current reversed, and the mean of the two results recorded as the true resistance of the line.

Insulation Resistance.—The connections necessary for the measurement of the insulation resistance are shown in Fig. 118, and are similar to those required for the single wire test. In this case the line is disconnected at the distant station, the circuit being completed through the points of leakage. The insulation resistance, that is to say, the resistance of the paths of leakage, will now probably be greatly in excess of the limits of the rheostat, and it will consequently be necessary to make the resistance of the arm b 10 or 100 times greater than that of a, in order to bring the instrument within range.

Example 51.— If $a = 100$
$b = 1{,}000$
$d = 7{,}600$
x = insulation resistance of the line,

then $a : b :: d : x$

$$x = \frac{bd}{a} = \frac{1{,}000 \times 7{,}600}{100} = 76{,}000 \text{ ohms.}$$

The insulation resistance *per mile* is ascertained by *multiplying* 76,000 by the number of miles.

Three-wire Loop Test.—When three wires connect two stations the individual resistance of them may be accurately determined by taking three loop tests.

Example 52.—Let x = the resistance of the first wire,
y = „ „ second wire,
z = „ „ third wire.

Measure the resistances of the loops $x + y$, $x + z$, and $y + z$ successively.

Suppose $x + y = 240$ ohms
$x + z = 260$ „
$y + z = 280$ „

By the addition of these three equations,

$2(x + y + z) = 780$ ohms
$\therefore x + y + z = 390$ „
but $y + z = 280$ „
$\therefore x = 390 - 280$
$= 110$ ohms,
and $x + z = 260$ „
$\therefore y = 390 - 260$
$= 130$ ohms,
and $x + y = 240$ „
$\therefore z = 390 - 240$
$= 150$ ohms.

The three wires x, y, and z have 110, 130, and 150 ohms resistance respectively.

To Find the Distance to an Earth Fault.—This is usually done by means of a loop test, the faulty wire being looped to a known good wire. If the

normal resistance of the loop cannot be ascertained from existing records, an ordinary loop test, in which there is no earth connection (Fig 117), should first be made. The bridge is then joined up as shown theoretically in Fig. 119.

Let L = the resistance of the loop.
And x = „ „ to the fault along one wire.
Then $L - x$ = „ „ „ fault along the other wire.

The rheostat (d) now has the resistance x added to it, and the fourth arm of the parallelogram is $L - x$.

The following ratio may, therefore, be stated :—

$$a : b :: d + x : L - x$$
$$a(L - x) = b(d + x)$$
$$aL - ax = bd + bx$$
$$bx + ax = aL - bd$$
$$x(a + b) = aL - bd$$
$$\therefore x = \frac{aL - bd}{a + b}$$

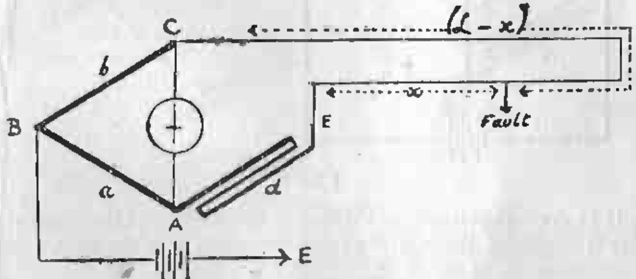

FIG. 119.

The resistances of a, b, d, and L are all known, and by substitution the value of x may be determined.

If a and b are equal, then

$$d + x = L - x$$
$$\text{and } x = \frac{L - d}{2}$$

If the resistance of the section of the wire (x) be uniform throughout, the distance to the fault may be readily ascertained by dividing the value of x by the known mileage resistance of the wire. For instance, suppose that x is shown to be 90 ohms, and the resistance of the conductor is 15 ohms per mile. The distance to the fault is six miles.

In the foregoing it has been assumed that the resistance (x) to the fault is uniform. It sometimes happens, however, that underground work, which usually has a resistance of about 24 ohms per mile, is included in this section of the line, and it is, therefore, necessary to modify the calculation somewhat. If the underground portion is three miles in length, its resistance (72 ohms) must be first deducted from x, leaving only 18 ohms to be calculated at 15 ohms per mile. The aerial section is, therefore, $1\frac{1}{5}$ mile, and the total distance to the fault $4\frac{1}{5}$ miles.

To Find the Distance to a Contact.—The arrangement of the bridge for this test is indicated in Fig. 120. The arm b is now plugged up and the galvanometer joined between B and E. One of the lines is earthed at the distant station, and the other, which serves as a battery lead and is used only to the fault, is left disconnected. The resistance of the earthed line

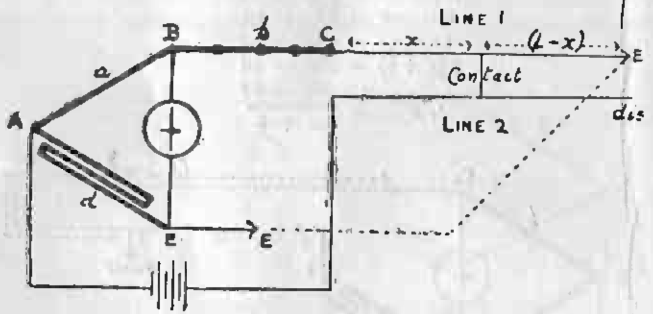

FIG 120

should be first ascertained, and it should be noted that the circuit of the bridge is completed through the earth connections at the further end of the line and at E, as shown by the dotted line in Fig. 120.

Let L = the total resistance of the earthed wire,
and x = the resistance of the earthed wire up to the fault;
then L—x = " " " beyond "

It will, therefore, be apparent that with the conditions shown x and L—x are two of the resistances forming the parallelogram, d and a being the other two.

The proportion may, therefore, be stated thus :—

$$d : a :: L-x : x$$
$$dx = aL - ax$$
$$dx + ax = aL$$
$$x(d + a) = aL$$
$$x = \frac{aL}{d + a}$$

The resistances of a, d, and L are known, and the ohmic distance may be readily calculated, the actual mileage being ascertained in the manner previously shown.

To Find the Resistance of an Earth Connection.—The resistance of an earth plate should not be greater than 10 ohms, and may be ascertained by making the two following tests. In the first test a line wire, L_1, is earthed at y and joined to the bridge as shown in Fig. 121. The "earth" being tested is shown at x, and, having effected a balance, the proportion of the resistances is—

$$a : b :: d : L_1 + y + x$$
$$bd = a(L_1 + y) + ax \quad \ldots\ldots\ldots\ldots \quad (1)$$

The connections for the second test are shown in Fig. 122, a second earthed line, L_2, being used for the battery circuit. This line, if possible, should run at right angles to L_1. In this test the battery is reversed and increased

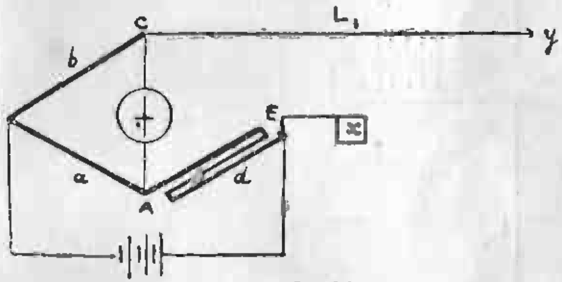

FIG. 121.

by an addition of cells, so that the strength of the current passing through the earth connection x may be approximately equal to, and in the same direction as in the first test. In this case let the resistance required in the rheostat be denoted by r.

Then

$$a : b :: r + x : L_1 + y$$
$$b(r + x) = a(L_1 + y) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Now subtract equation (2) from equation (1) and

$$bd - [b(r + x)] = a(L_1 + y) + ax - a(L_1 + y)$$
$$bd - br - bx = ax.$$
$$bd - br = ax + bx.$$
$$\therefore x = \frac{b(d - r)}{a + b}$$

The value of x may be determined by substitution.

To Determine the Resistance of a Distant Earth-Plate.—The resistance of the earth connection at a distant office may be ascertained by making single-wire conductivity tests of two of the lines earthed at that office. The two lines should then be looped instead of earthed, and a loop conductivity test made. The difference between the sum of the two results obtained with the single wires and the resistance of the looped wires is twice the resistance offered by the earth plate.

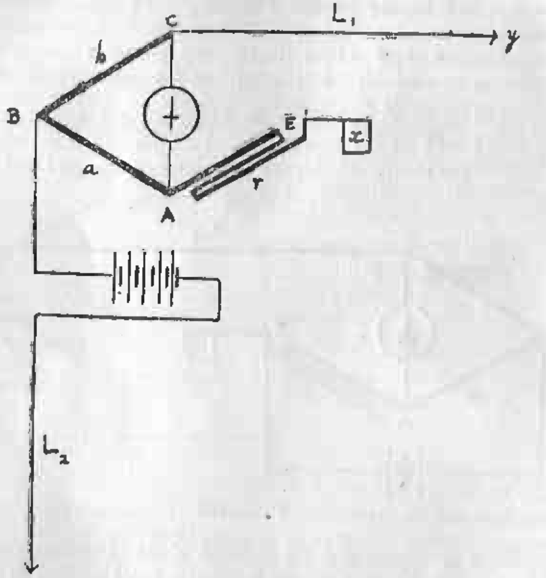

FIG 122.

Example 53.—If the individual resistances of two wires earthed at a distant office be 340 and 360 ohms respectively, and if a loop formed by these two wires be 680 ohms, what is the resistance of the distant earth connection?

The resistance of the two lines added to twice the resistance of the "earth" is 700 ohms (340 + 360). The resistance of the two lines looped, *i.e.*, without the earth connection, is 680 ohms. Therefore, the difference between 700 ohms and 680 ohms divided by two is the resistance of the earth plate, which in this instance is 10 ohms and the maximum resistance allowed.

Tests while a Cable is being Laid.—It is very important that a fault should not occur while a cable is being submerged in the sea, and tests are applied continuously during the process to enable a break in the continuity of the conductors or a failure of insulation to be readily detected.

If the cable is composed of a number of conductors they are all joined together to form a continuous conductor, and a battery of one or two cells sends a current from the ship through the series. Two galvanometers are included in the circuit, one being at the shore and the other at the ship end of the cable. This serves as a "continuity" test, and a failure of the current indicates that a fracture has occurred. If there is an odd number of wires in the cable, two of them are joined in "parallel." Should either of these be broken during the operation of laying, the resistance of the circuit is increased by the failure of the joint resistance, and an immediate decrease in the deflection ensues. It is imperative that the battery and galvanometers should be *well*-insulated in order that the insulation test may not be affected.

In order that a continuous insulation test may be effected, an earth-connected battery of about 200 cells is joined through a galvanometer,

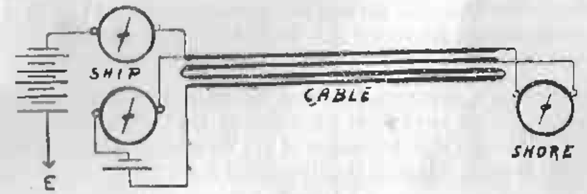

FIG. 123.

specially devised for use at sea, to the cable. A current is thus sent from the ship through the conductors and the insulating covering of the cable to the sea. Should the insulation break down at any point, and thus afford a ready escape for the current, the deflection of the galvanometer immediately becomes abnormal, and steps are taken to locate the fault. The arrangement of the batteries and galvanometers for these tests is shown in Fig. 123.

To enable the ship to keep up communication with the shore the current applied to the cable for the "continuity" test is periodically reversed. If this reversal does not take place at the proper time, or if the deflection becomes unsteady, communication with the ship is established by means of "speaking" apparatus. The galvanometers used for the "continuity" test are used for this purpose, and "speaking" keys are brought into the circuit.

The Morning Test.

In order that the general condition of the main telegraph and telephone lines may be ascertained before the actual work of the day commences, they are subjected to an ingeniously devised test each morning between 7 and 8 o'clock. Whenever practicable the telegraph lines are looped in pairs, and in the case of telephone circuits the wires of the loop are connected at a convenient point for the tests to be made from a distant testing office. At the office at which the test is made a current is sent through a resistance coil of 10,000 ohms and one coil of a differentially wound tangent galvanometer. After traversing the loop, the current passes through the other galvanometer coil and a second resistance block of 10,000 ohms, in such a direction that, if the strength of the current received is equal to that sent out, the galvanometer needle will not be deflected. If, however, any loss has occurred during the passage of the current through the loop, the difference between the strengthe of the two currents will be recorded. It should be emphasised, perhaps, that the deflection records neither the strength of the current sent out nor that of the current received, but simply the *difference* between them. In fact the deflection is a measurement of the actual loss of current which has been sustained at the points of leakage in the loop. In the case of a perfectly insulated loop there will be no deflection, and the nearer this condition is approached the smaller will be the reading.

When the loop is *uniformly* insulated the effect of the leakage will be equivalent to that of one leak at the centre of the line; the resistance of such leak will be the joint resistance of the distributed paths of leakage. This central leakage is termed the "resultant fault."

The object of the two high resistance blocks at the ends of the loop is to place the latter, which has a relatively low resistance, at the electrical middle of the circuit. As the loop is the only part of the circuit at which leakage can occur the conditions are such that a resultant fault actually exists, unless, of course, the loop is perfectly insulated.

When these conditions exist the mean of the sum of the "sent" and "received" currents is equal to the current which would have been both sent *and* received if no leakage had occurred, and the same voltage had been employed. In fact the sum of the currents sent out and received is always the same, whether any loss occurs or whether the circuit is perfectly insulated, provided that no alteration has been made in the voltage. This can be made clear arithmetically. Suppose that an electro-motive force of 40 volts is applied to a perfectly insulated circuit of 400 ohms resistance. The "perfect" current is 100 milliampères, and this current will be both sent and received. Now consider the same circuit with a central leakage which offers 100 ohms resistance. The joint resistance formed by the distant half of the line (200 ohms) and the path of leakage (100 ohms) is $66\frac{2}{3}$ ohms, and, neglecting the battery, the total resistance is $266\frac{2}{3}$ ohms. By Ohm's law it is found that

a current of 150 milliampères leaves the battery, but as two-thirds of it escapes at the central leakage one-third only, or 50 milliampères, represents the received current. It will, therefore, be seen that the mean of the sum of the sent and received currents is 100 milliampères, or the same as the perfect current. Similarly, if the resistance of the resultant fault had been 200 ohms it may be shown that the sent current would have been $133\frac{1}{3}$ milliampères and the received current $66\frac{2}{3}$ milliampères. In this case it will be observed that the mean of the sum of the two currents is again 100 milliampères. This may be summed up by stating that for any number of milliampères sent out in excess of the perfect current a similar number of milliampères must be deducted from the perfect current to obtain the received current.

Suppose that an electro-motive force, sufficient to produce a perfect current of 100 milliampères, has been applied to a circuit of 20,000 ohms resistance, and that there is a central leakage or resultant fault in the circuit which causes a deflection to be registered on the tangent galvanometer equivalent to 20 milliampères. From previous calculations it is evident that the current sent out is $100 + \frac{20}{2} = 110$ milliampères, and the current received is $100 - \frac{20}{2} = 90$ milliampères. Now, from these data the resistance of the path of leakage, *which is the insulation resistance* of the whole line, may be calculated. The sent current after traversing half of the circuit (10,000 ohms) divides at the point of leakage, and 90 milliampères pass through the remaining 10,000 ohms of the circuit, while the 20 milliampères escape through the fault. What then, is the resistance of that fault? The resistances of the two paths are in inverse proportion to the currents passing through them.

Therefore if

$$
\begin{aligned}
R &= \text{the resistance of half the circuit} \\
x &= \quad \text{,,} \qquad \text{,,} \qquad \text{the fault} \\
C_1 &= \text{the received current} \\
\text{and } C_2 &= \text{the leakage current} \\
R : x &:: C_2 : C_1 \\
10{,}000 : x &:: 20 : 90 \\
20\,x &= 900{,}000 \\
\therefore x &= 45{,}000.
\end{aligned}
$$

The resistance of the resultant fault, or the insulation resistance of the circuit is thus shown to be 45,000 ohms.

At all testing offices where morning tests are conducted a properly equipped testing set is provided for the purpose and fixed near the test-box. By means of a four-position switch the connections are altered to meet all requirements. Before these operations commence the tangent galvanometer should be adjusted by means of the standard cell, so that by using both coils a deflection of

80 tangent divisions is equivalent to one milliampère. The testing battery is composed of from 37 to 42 dry cells. The cells are so arranged that the minimum number may be added to as required. The "constant" of the battery is taken by joining the latter in circuit with the two 10,000 ohm blocks and one galvanometer coil. A deflection of 110 divisions should then be observed, and if it is less than 108½, cells should be added until the required deflection is obtained. As only one coil of the galvanometer is employed 40 divisions represent one milliampère, and the strength of the current is, therefore, 2¾ milliampères. The electro-motive force of the battery may be calculated by Ohm's law.

$$\begin{aligned} E &= C \times R \\ &= 2{\cdot}75 \times 20{,}190 \\ &= 55{,}522{\cdot}5 \text{ milli-volts.} \end{aligned}$$

The resistance of 20,190 ohms is made up as follows: Two 10,000 ohm blocks, one galvanometer coil (160 ohms), and the battery (30 ohms).

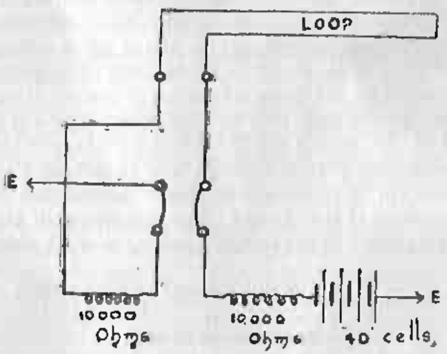

FIG. 124.

The perfect current in tangent divisions may now be calculated for any loop, the conductor resistance of which is known.

In the case of a loop having 1,000 ohms resistance

$$\text{The perfect current} = \frac{55{,}522{\cdot}5 \times 40}{20{,}000 + 1{,}000 + 320 + 30} = 104 \text{ tangent divisions.}$$

It should here be noted that calculations are made as though one coil only were in use. The current flowing through the leak is indicated in the galvanometer by the excess of current flowing in one coil over that in the other. The resultant deflection is consequently only the effect of the current in one coil. The whole resistance of the galvanometer, however, has to be dealt with.

The connections for making a test are as shown theoretically in Fig. 124, the switch being in position 3. The deflection then observed is a measure of the loss of current and from it the resistance of the resultant fault, or the insulation resistance of the circuit, may be calculated.

When an abnormal deflection, indicating a specific fault, is observed when testing a loop, the switch is turned to position 1. The current now splits through the galvanometer coils and the wires of the loop, the circuit being completed through the fault. If the wires are approximately equal in conductor resistance, and the direction of the deflection remains unchanged, the wire connected to the right-hand test-box terminal is the one upon which the fault exists. If the direction of the deflection is reversed, or it represents a "minus" deflection, the other wire is the more faulty. If, however, no deflection is observed, the fault is probably near the distant, or looping office, and may be upon either one wire or the other. In these circumstances the specific fault is approximately at the centre of the loop, and the current will consequently divide equally through the two paths.

When it is not possible to obtain a loop for testing purposes, a single line is earthed through 10,160 ohms at the distant office. The record book shows the "perfect current" deflection and the deflection which would be obtained if the wire were to full earth in the form of a fraction, thus $\frac{95}{185}$. The numerator indicates the perfect current reading and the denominator the full earth reading. If a deflection less than the perfect current deflection is recorded the line is probably disconnected. To record the actual loss in tangent divisions, the perfect current deflection is subtracted from the actual reading and the result multiplied by two. If a reading of 115 is obtained on a line, the perfect current reading of which is 95, the actual loss in tangent divisions will be 2 (115 − 95) = 40.

In practice the testing officer is supplied with tables, by means of which the loss recorded in tangent divisions is readily converted into megohms per mile. The actual insulation resistance of any line should not be less than 200,000 ohms per mile in wet weather.

CHAPTER XXV.

Tests and Measurements.

Telegraph and telephone circuits are liable to interruption from various causes. Faults arise in the line or apparatus which render communication impracticable. In order that the cause of the stoppage may be located quickly all circuits of any considerable length are led into the principal offices *en route*, and facilities are afforded which enable the locality of an interruption to be quickly determined.

At all large offices the wires are led to a test box, from which the lines may be controlled and tested, or re-arrangements of the apparatus and

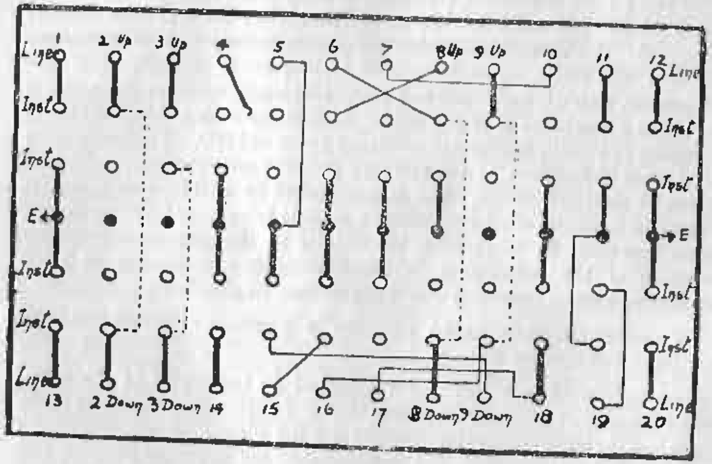

FIG. 112.

lines made, without loss of time. At offices from which a large number of wires radiate the wires are grouped together according to the routes they follow. There are usually four terminals allotted to each circuit, and in the case of terminated lines one terminal is used as the earth connection. The arrangement of a test-box is shown in Fig. 112, and a few of the conditions to be met with are indicated. The earth terminal is black, and two circuits are usually connected with it. Lines 1 and 13, which follow different routes, are shown in their normal condition, as also are those numbered 11, 12, 14, and 20. The line terminal is connected by means of a brass strap to the adjacent instrument terminal, from which a lead runs to the apparatus. The

circuit is completed by a return lead connected to the second instrument terminal, which is strapped to the earth connection. Line 2 is a "through" wire, which requires no instruments. The dotted line indicates the connections made at the back of the test-box. Line 3 shows the connections for "intermediate" working. In this case the return instrument lead is connected to the "down" line as shown. Line 4 is disconnected, the strap between the line and instruments having been removed. Line 5 is "earthed" direct, the instruments being cut out of the circuit. Line 6 is crossed with the "up" side of number 8, and those numbered 7 and 10 are looped to form a metallic circuit. Lines 15, 16, and the "down" side of line 9 show the position of affairs when a "double" cross has been made; numbers 15 and 16 have been crossed, and afterwards a further cross was desired between line 16 and the down side of number 9. Lines 17 and 18 are shown to be "forked," and are being worked from the apparatus usually allotted to the latter. Line 19 shows how to "reverse," the earth and line connections having been crossed.

The three chief causes of interruption on telegraph circuits are disconnection, earth, and contact, and they may be either total, intermittent, or partial. A total disconnection means that the continuity of the circuit has been entirely broken. Intermittent disconnections result from many causes, such as loose connections of the apparatus terminals, or imperfect joints in the line wire, which make contact at intervals only. Partial disconnections are usually the outcome of the introduction of an abnormally high resistance into the circuit, such as would result from improperly made joints in the line wire, loose terminals or dirty contact points. Earth faults are due to the conductor being connected to earth at some point other than the earth plates at the ends of the circuit. If the fault offers no resistance it is said to be a "full earth," and the current escapes, instead of passing to the distant office. Intermittent earth faults arise from the conductor touching at intervals other bodies which are earth-connected and are good conductors. Partial earth results from the conductor making imperfect contact with an earth-connected conducting body, or a good contact with a partial conductor which is earth-connected.

Contact results from two or more wires becoming joined together. A full contact implies that the wires are in metallic contact, either direct or by means of another wire. An intermittent contact needs no explanation, but a partial contact is produced by any means which allows a portion of the current from one circuit to pass into another. It should be here pointed out that an earth plate, which offers a considerable resistance, causes a semblance of partial contact by allowing part of the current to escape from one circuit to the others connected with the same plate, instead of the whole of it passing direct to earth.

be forked, each is led to one of the switch springs of a group, and the apparatus connection is made by means of another switch spring of the

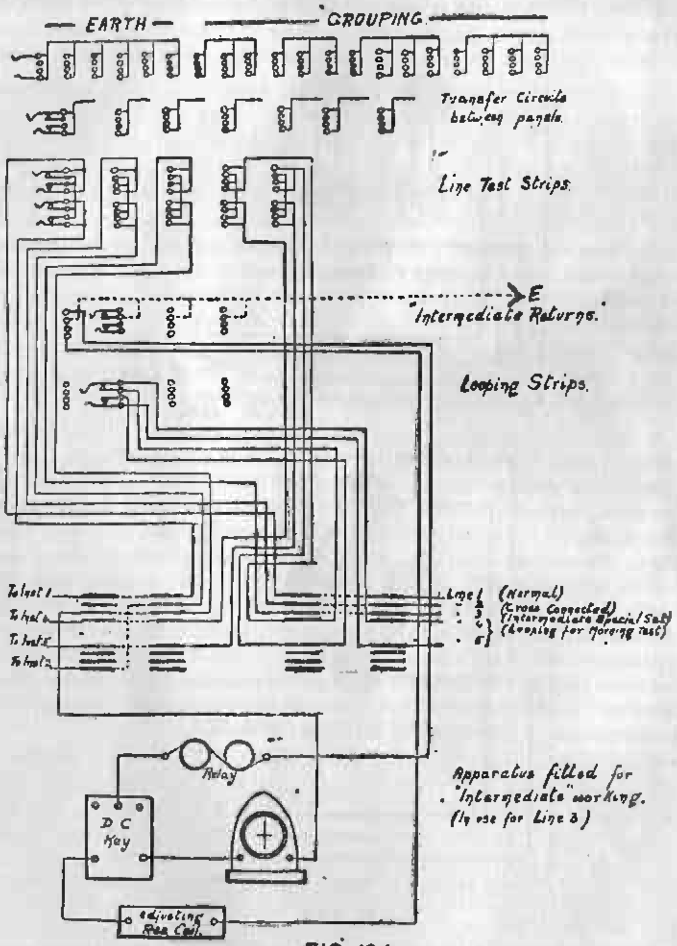

FIG. 126.

same set. The lines are thus forked and connected to the set of apparatus to be utilised. Vertical test-box galvanometers are provided, each of which is supplied with a testing switch manipulated by "U" links.

The planning out of the arrangement of wires on a large test-box is a subject which requires very careful consideration. Sufficient space has to be allowed for the growth of each "road," for, inasmuch as all connections are made with solder, the alteration of connections and the rearrangement of the box are troublesome and tedious operations which must be avoided.

The system of leading in wires from the street to the instrument room has recently undergone a complete revision. Owing to the great strides made in recent years with electric traction, and the increased risk of fire or other injury resulting from contacts between telegraph lines and the conductors used for electric tramways and other electric installations, the method adopted is as follows:—

All wires before entering an office are led to a fuse-box. In the case of underground lines the fuses should be placed at the terminal poles, but where lines terminate on overhead standards the fuse case is placed on the standard.

From the fuse cases the wires are led by means of lead covered cables through iron tubing, or in the case of a number of wires iron troughing, to lightning protectors and heat coils.

In large offices an easily accessible fireproof chamber is built underground outside the building, but as near to it as possible. The various underground routes terminate in this chamber, so that in the event of fire the main circuits can be readily joined up. Provision is also made here to effect a prompt connection between main circuits and wires leading to adjacent offices, where the traffic of the large towns can be immediately taken in hand. In the case of "through" wires communication can be quickly restored by connecting the two sections of the lines. In this chamber cable connection boxes are also provided for terminating the gutta-percha or paper covered wires. The cable extensions from these boxes are lead covered and run through earthenware ducts to an inner chamber, constructed in the basement of the building, and in which the heat coil fittings are placed.

From the heat coils the wires are led to the test-box in lead covered cables, each containing 127 wires running through iron troughing. The lead sheathing of the cables is soldered to lead strips clamped to the back of the troughing at every few yards to ensure the cables being immovable. From the test-box the wires are led in five or seven wire lead covered cables to the instrument tables, where they are distributed from strips of connecting tags.

CHAPTER XXVI.

Modern Test Boards.

The test-box used for trunk telephone and junction lines differs from the one already described. Instead of terminals and brass connecting straps, test-holes and U-shaped links are employed. As each circuit is a metallic loop four test-holes are necessary, two being for the lines and two for the instruments. The test-holes form a square, the two lower ones being connected to the lines and the upper ones to the apparatus at the switch section, as shown in Fig. 125. By means of cross-connecting strips beneath the test-holes permanent re-arrangements of the lines and apparatus are facilitated. Localising tests are made by means of a vertical galvanometer and a simple testing switch manipulated by "U" links. Temporary alterations are made by using covered wires, fitted at each end with a split metal plug, which fits into the test-holes. The arrangement of the battery tablet used in connection with this board is also shown in Fig. 125.

The latest form of test-box for telegraph circuits worked from Secondary batteries is a great improvement upon the older type, which has four terminals and two brass connecting straps for each circuit. In the new form switch springs and test-holes are employed, and cross-connecting strips are fitted at the foot of the test case. The arrangement of the switch springs will be readily understood by reference to Fig. 126. Normally there are no connections at the front of the test-box, but, when lines are taken for testing purposes or re-arrangements are made, the alterations are effected by means of covered wires, which are terminated in connecting plugs. The latter fit into the test-holes and establish connection with the outer switch springs. The line is joined to one set of outer switch springs and the apparatus with the other, the circuit being completed through the inner springs, which are electrically connected. It will thus be seen that operations are very much simplified, as by the act of inserting a plug the outer springs are disconnected from the inner ones. By inserting a plug into the line test-hole the apparatus is automatically cut off, and, similarly, the line is disconnected from the apparatus when a plug is inserted in the test-hole allotted to the latter. The earth connection is effected at the instrument table, and this results in a saving of wire, as one lead only is necessary between the test-box and the apparatus. The conductors for the instrument leads are made up into cables, which contain five or seven wires insulated with a mixture of silk and cotton. From the foregoing it will be noticed that it is not possible for two lines to be connected and

the apparatus remain in the circuit. This, however, is provided for by terminating a few of the sets of apparatus at the test-box through an additional switch spring. Switch springs used for this purpose are grouped

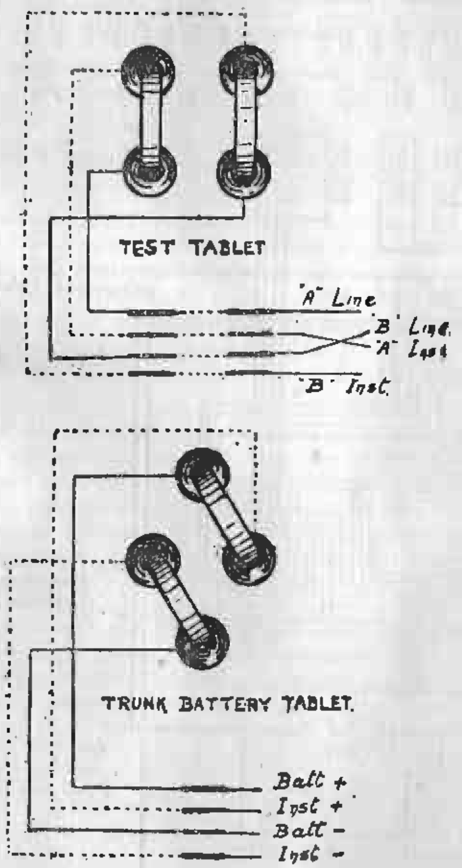

FIG. 125.

together and labelled "intermediate returns." In order that two or more wires may be "forked" and worked as a divided circuit, sets of switch springs are provided. They are labelled "grouping," and all the outer springs of each set are connected together. Respecting the lines to

Magnetic Units.

There are two magnetic units, viz.: (*a*) The unit *magnetic pole* and (*b*) the *magnetic field* of unit intensity.

(*a*) A unit magnetic pole is one of such strength that when placed at a distance of one centimetre in air from a similar pole of equal strength repels it with a force of one dyne.

(*b*) The magnetic field of unit intensity exerts a force of one dyne on a unit magnetic pole.

Electrical Units.

Two systems of electrical units, termed the *electro-static* and *electro-magnetic* units, have been devised in connection with the fundamental and derived units. The electro-static system, which deals with electricity in a state of rest, is based upon the repulsion and attraction between electric charges, and includes the units of quantity, potential, and capacity. The electro-magnetic system is used in connection with current electricity. In this system are included the units of current, resistance, electro-motive force, and quantity.

The units of these two systems are frequently termed "absolute" units, and are either too small or too large for ordinary work. A practical system, however, has been devised by a Committee of the British Association, the units of which bear certain fixed ratios to the "absolute" units.

Practical Units.

The *unit of electro-motive force*, or unit difference of potential, is called the *volt*, and is about the electro-motive force of a Daniell cell. The *milli-volt* is one-thousandth part of a volt.

The *unit of resistance* is the *ohm*, and is the resistance of a column of mercury 106 centimetres (about 3½ft.) long, one square millimetre (about $\frac{1}{645}$th of a square inch) in cross section, at 0° centigrade. The *megohm* is one million ohms, and the *microhm* one-millionth part of an ohm.

The *unit of current* is the *ampère*, and is the current produced by an electro-motive force of one volt through a resistance of one ohm. The *milliampère* is one-thousandth part of an ampère, and is the current produced by an electro-motive force of one volt through 1,000 ohms resistance.

The *unit of quantity* is the *coulomb*, and is that quantity of electricity which flows in a current of one ampère lasting one second.

The *unit of capacity* is the *farad*. A condenser of one farad capacity will contain one coulomb of electricity with a difference of potential of one volt between the plates. The *micro-farad* is one-millionth part of a farad.

Note.—Care should be taken to distinguish between the prefixes "milli" and "micro." "Milli" signifies "one-thousandth part of," and "micro" "one-millionth part of."

Ohm's Law.

It has already been shown that a current of electricity is the outcome of two points at different electrical potentials being joined by a conductor. The strength of the current depends entirely upon the difference of potential between the two points, and the resistance of the path provided for it. So long as the difference of potential and the resistance remain constant, a steady current will be maintained. Any variation in the electro-motive force or the resistance will produce a variation in the strength of the current. The function of the battery is to provide the necessary difference of potential to promote the flow of current.

Ohm's law states that the strength of a current is directly proportional to the electro-motive force, and inversely proportional to the *total* resistance of the circuit.

In other words, the current will *increase* in strength in direct proportion to an *increase* in the electro-motive force, and will *decrease* with an *increase* in the resistance of the circuit. Ohm's law may, therefore, be stated thus:—

$$\text{Current} = \frac{\text{Electro-motive force}}{\text{Resistance}}$$

These three quantities should be expressed in terms of their units, and the beginner should be careful to note that, with the electro-motive force given in volts and the resistance in ohms, the current will be in *ampères*, not milliampères.

The symbols generally used to denote current, electro-motive force, and resistance are respectively C., E., and R., so that the law may be briefly stated as—

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

$$\text{Therefore} \quad E = C \times R$$

$$\text{And} \quad R = \frac{E}{C}$$

Bearing in mind these three simple formulæ, if any two of the quantities be given the third can always be ascertained.

Example 1.—With an electro-motive force of four volts and a resistance of two ohms, what is the strength of the current?

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

and, substituting the values of the known quantities for their relative symbols—

$$C = \frac{4}{2}$$

$$\therefore C = 2 \text{ ampères.}$$

Example 2.—What is the strength of the current produced by an electro-motive force of ten volts through a resistance of 20 ohms?

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

$$C = \frac{10}{20}$$

$$C = \frac{1}{2} \text{ ampère}$$

$$\text{or } C = \frac{1}{2} \times 1{,}000 = 500 \text{ milliampères.}$$

As there are 1,000 milliampères in one ampère, to express the answer in milliampères the number of ampères should be multiplied by 1,000.

Example 3.—What electro-motive force is required to produce a current of 2 ampères through a resistance of 2 ohms?

$$E = C \times R$$
$$= 2 \times 2$$
$$= 4 \text{ volts.}$$

Example 4.—If a current of 500 milliampères is obtained through a resistance of 20 ohms, what electro-motive force is used?

$$E = C \times R$$
$$= \frac{1}{2} \times 20$$
$$= 10 \text{ volts.}$$

Example 5.—What is the resistance of a circuit in which a current of 2 ampères is produced by an electro-motive force of 4 volts?

$$R = \frac{E}{C}$$
$$= \frac{4}{2}$$
$$= 2 \text{ ohms.}$$

Example 6.—If a current of half an ampère is produced by an electro-motive force of 10 volts, what is the resistance of the circuit?

$$R = \frac{E}{C}$$
$$= \frac{10}{\frac{1}{2}}$$
$$= \frac{10}{1} \times \frac{2}{1}$$
$$= 20 \text{ ohms.}$$

Note.—The student should note the relation which exists between examples 1, 3, and 5, and between 2, 4, and 6.

When a circuit is made up of a number of separate resistances joined together in *series*, the total resistance is found by adding the individual resistances together. Care should be taken to include the resistance of the battery.

Example 7.—A battery having an electro-motive force of 20 volts and an internal resistance of 25 ohms, is joined to a circuit composed of a galvanometer of 75 ohms resistance and a wire of 400 ohms resistance. What current flows through the galvanometer?

Where C = Current in ampères.
E = Electro-motive force of the battery.
R = Resistance of the wire.
G = Resistance of the galvanometer.
and r = Resistance of the battery.

$$C = \frac{E}{R + G + r}$$
$$= \frac{20}{400 + 75 + 25}$$
$$= \frac{20}{500}$$
$$= \frac{1}{25} \text{ ampère}$$

$$\text{or } C = \frac{1}{25} \times 1{,}000 = 40 \text{ milliampères.}$$

Example 8.—What is the resistance of a battery having an electro-motive force of 20 volts if a current of 40 milliampères is produced through a total external resistance of 475 ohms?

The 40 milliampères must now be divided by 1,000 to bring that quantity to the proper unit, viz., ampères.

$$40 \text{ milliampères} = \frac{40}{1000} = \frac{1}{25} \text{ ampère.}$$

In this case let R = total external resistance

$$\text{then } C = \frac{E}{R + r}$$

$$\frac{1}{25} = \frac{20}{475 + r}$$

Cross multiplying

$$475 + r = 500$$
$$\therefore \quad r = 500 - 475 = 25 \text{ ohms.}$$

Name.	Positive plate.	Exciting fluid.	Negative plate.	Depolarising agent.	Electro-motive force per cell.	Approximate resistance per cell.
Daniell	Zinc	Sulphuric acid (H_2SO_4)	Copper (Cu)	Sulphate of copper ($CuSO_4$)	1·08 volt	Varies from 3 to 10 ohms.
Leclanché ..	Zinc	Salammoniac (NH_4Cl)	Carbon (C)	Peroxide of manganese (MnO_2)	1·5 volt.	Varies from ·25 to 4 ohms.
Bichromate..	Zinc	Sulphuric acid (H_2SO_4)	Carbon (C)	Mixture of bichromate of of potash ($K_2Cr_2O_7$) & dilute sulphuric acid (H_2SO_4), which forms chromic acid (H_2CrO_4), the depolarising agent.	2 volts ..	2 ohms.

It will be noticed that in each case zinc is used as the positive plate. The reason for this will be readily understood by a reference to the contact series in which zinc is shown to be positive to all the other bodies given. In the Leclanché and Bichromate cells carbon is the negative element, but in the Daniell cell the negative plate is copper. In the latter case the difference of potential between the plates is not so great as in the other two, but by the chemical action which takes place in the Daniell cell the deposition of copper upon the negative plate would render carbon unsuitable. The difference in the electro-motive force of the Leclanché and bichromate cells, notwithstanding the similarity of the plates, is brought about by the other ingredients used in their construction. The object of the depolarising agent in each case is to arrest the hydrogen evolved and produce a harmless compound. In the Daniell cell sulphuric acid is formed by the chemical combination of the hydrogen with the sulphion of the sulphate of copper, pure copper being deposited on the copper plate. In the Leclanché and Bichromate cells the depolarising agents have a large proportion of oxygen in their composition, which, when chemically united with the evolved hydrogen, forms water.

CHAPTER III.

UNITS.

To express the magnitude of any physical quantity it is necessary to make use of a unit of measurement. To state the weight of a body a unit of weight must be employed. Weight may be expressed as so many pounds or tons, and it would be useless to attempt to convey the idea of the weight of any substance, say copper, by using the term "ten copper." A unit of weight must be used, and the expression amended to "ten pounds of copper" or "ten tons of copper," before any idea of the weight can be comprehended. All physical quantities must be expressed as the product of a unit and a number. Thus "ten tons" expresses a definite weight, "five seconds" a definite time, and "fifteen yards" a definite length.

Electricity, however, cannot be measured by any of the ordinary standards of measurement, as it does not possess the attributes which enable other physical quantities to be stated in terms of a unit. The presence of electricity can only be demonstrated by the effect produced, by means of which a system of electrical units has been devised.

FUNDAMENTAL UNITS.

The fundamental system of units has been almost universally adopted by scientists, and is so called because upon it other systems of scientific measurements are based. It is frequently called the C. G. S. system from the initial letters of the units employed, viz. :—

Centimetre,

Gramme,

Second.

The centimetre is the unit of length, and is represented by about two-fifths of an inch. The gramme is the unit of mass, and is about 15½ grains; the last unit, which is the unit of time, being the ordinary second.

From these three units others, called "derived" units, are obtained.

The *dyne* is the unit of *force*, or that force which, acting upon a mass of one gramme moves it a distance of one centimetre in one second.

The *erg* is the unit of work or energy, and is the amount of work done, or energy expended, against a force of one dyne through a distance of one centimetre.

There are other derived units, viz., the unit of weight, the unit of velocity, the unit of acceleration, and the unit of heat, but it is thought they do not call for definition in these notes.

By Ohm's law—

$$C = \frac{\text{total electro-motive force}}{\text{total resistance}}$$

$$C = \frac{n \times e}{(n \times r) + R}$$

$$C = \frac{4 \times 2}{(4 \times 2) + 8}$$

$$C = \frac{8}{16}$$

$C = \frac{1}{2}$ ampère, or 500 milliampères.

To ascertain the number of cells which should be joined in series in order to produce a certain current through a given external resistance,

$$n = \frac{C R}{e - C r}$$

$$\text{for } C = \frac{n e}{n r + R}$$

Cross multiplying

$$n e = C n r + C R$$

$$n e - C n r = C R$$

$$\therefore n = \frac{C R}{e - C r}$$

Example 11.—**How many cells joined in series must be employed to send a current of 500 milliampères through an external resistance of 8 ohms, if each cell has a resistance of 2 ohms and an electro-motive force of 2 volts?** (See example 10.)

$$n = \frac{C R}{e - C r}$$

$$n = \frac{\frac{1}{2} \times 8}{2 - (\frac{1}{2} \times 2)}$$

$$n = 4 \text{ cells.}$$

NOTE.—Example 10 shows this result to be correct.

Very little advantage is gained by joining cells in series to a low external resistance. Under these circumstances any increase in the number of cells results in the total resistance being increased in very nearly the same proportion as the electro-motive force. Consequently the current is not appreciably augmented. If, however, it is desired to send a current through a high external resistance, the cells should be joined in series, and the electro-motive force will rise in proportion to the number of cells added; but the additional battery resistance will not materially affect the total resistance.

The electro-motive force of a cell depends entirely upon the materials of which the cell is composed, and is independent of its size. The resistance, however, varies with the dimensions of the cell and also with the bodies of which the cell is composed.

The resistance of a conductor varies directly as the length and inversely as the area of the cross section of the conductor. That is to say, a long wire will have a greater resistance than a short one, provided that the two are identical in other respects, and, of two wires of the same length and material, the thicker will have the smaller resistance. The same may be said of batteries. If cells are joined together in series the resistance increases with every cell added. It is sometimes necessary, however, in order to get good results from a given number of cells, to join them up in such a manner as to produce a low battery resistance. Imagine how the resistance of a combination of two cells is affected if, instead of joining them in series, the two positive plates and the two negative plates are joined together. The two cells are practically made into one, having its area of cross section double that of one of the original cells. The plates of the combination are twice as large as those of one cell, and the path for the current through the liquid is doubled in area of cross section, without increasing the distance between the plates. The resistance is, therefore, *half that of one cell.* The cells are now said to be joined in *parallel arc*, or *quantity.*

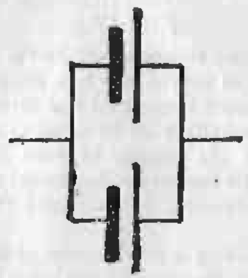

FIG. 16

Fig. 15 shows, diagramatically, two cells joined in series, and Fig. 16 two cells arranged in parallel arc. It has already been explained that the electro-motive force of two cells joined in series is twice that of one cell, and a little consideration will show how the electro-motive force is affected by the *quantity* method of grouping. As there are practically only two plates in the latter case, one positive and one negative, the similar plates of the two cells being connected, the electro-motive force is only that of one cell.

There is, however, an intermediate method between the two systems of grouping already described. A number of cells can be arranged to form several rows, and the rows joined for quantity. For instance, twelve cells may be joined up in three rows of four cells each.

The four cells in each row are joined in series, and the three rows arranged in quantity. Fig. 17 shows the arrangement diagramatically. By

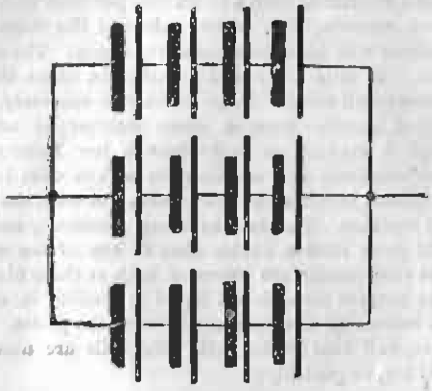

FIG. 17

this method the total battery resistance will be the resistance of one cell multiplied by the number of cells in each row, divided by the number of rows. This will be apparent from what has already been explained in connection with cells joined either all in series or all in quantity. The resistance increases with the number of cells joined in series, and diminishes as the path for the current increases in area of cross section. The greater the number of rows of cells arranged the smaller will be the resistance.

The electro-motive force of a combination of cells arranged partly in series and partly abreast depends entirely upon the number of cells in each row. Thus, if twelve cells are arranged in two rows of six cells each the electro-motive force of the combination will be six times that of one cell. If they are arranged in three rows of four cells each the electro-motive force will be four times that of one cell.

Where n = the number of cells in a row,
m = the number of rows of cells,
e = the electro-motive force per cell,
and r = the resistance per cell,
the total electro-motive force = $n \times e$

and the total resistance $= \dfrac{n \times r}{m}$

Example 12.—Four cells, each having an electro-motive force of $1\frac{1}{2}$ volt and a resistance of 2 ohms, are joined up in parallel arc. What current will they produce through an external resistance of 4 ohms?

Let m = the number of cells joined in quantity,

$$\text{Then } C = \frac{e}{\frac{r}{m} + R}$$

$$= \frac{1\frac{1}{2}}{\frac{2}{4} + 4}$$

$$= \frac{1\frac{1}{2}}{4\frac{1}{2}}$$

$= \frac{1}{3}$ ampère, or $333\frac{1}{3}$ milliampères.

Example 13.—A battery of 16 cells is joined up in 4 rows of 4 cells each to send a current through an external resistance of 30 ohms. It each cell has an electro-motive force of 2 volts and a resistance of 2 ohms, what will be the strength of the current?

Where C = current in ampères,
e = electro-motive force per cell,
r = resistance per cell,
R = external resistance,
n = number of cells in a row,
and m = number of rows of cells,
the total electro-motive force = $n \times e$

and the total battery resistance $= \dfrac{n \times r}{m}$

$$\therefore C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

And substituting,

$$C = \frac{4 \times 2}{\frac{4 \times 2}{4} + 30}$$

$$= \frac{8}{\frac{8}{4} + 30}$$

$$= \frac{8}{32}$$

$= \frac{1}{4}$ ampère, or 250 milliampères.

Example 14.—If 100 cells, each having an electro-motive force of 1·5 volt and a resistance of 3 ohms, are joined up 20 in series and five abreast to an external resistance of 48 ohms, what is the strength of the current ?

$$C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

$$= \frac{20 \times 1{\cdot}5}{\frac{20 \times 3}{5} + 48}$$

$$= \frac{30}{\frac{60}{5} + 48}$$

$$= \frac{30}{60}$$

$$= \frac{1}{2} \text{ ampère,}$$

or 500 milliampères.

Example 15.—100 cells, each having a resistance of 3 ohms, are joined up 20 in series and five abreast to an external resistance of 48 ohms. What is the electro-motive force per cell if a current of half an ampère is produced ?

$$C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

$$\frac{1}{2} = \frac{20 \times e}{\frac{20 \times 3}{5} + 48}$$

$$\frac{1}{2} = \frac{20\ e}{60}$$

Cross multiplying,

$$40\ e = 60$$

$$e = \frac{60}{40} = 1{\cdot}5 \text{ volt.}$$

Example 16.—A current of 500 milliampères is produced by a battery of 100 cells when joined up 20 in series and five abreast. If the electro-motive force of each cell is 1·5 volt and the external resistance 48 ohms, what is the resistance per cell ?

$$C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

$$\frac{1}{2} = \frac{20 \times 1{\cdot}5}{\frac{20 \times r}{5} + 48}$$

$$\frac{1}{2} = \frac{30}{\frac{20\ r}{5} + 48}$$

Cross multiplying,

$$\frac{20\ r}{5} + 48 = 60$$

$$4\ r = 60 - 48$$

$$\therefore\ r = 3 \text{ ohms.}$$

Example 17.—Through what external resistance would 100 cells, each having an electro-motive force of 1·5 volt and a resistance of 3 ohms, send a current of 500 milliampères if the cells were arranged 20 in series and five abreast?

$$C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

$$\frac{1}{2} = \frac{20 \times 1{\cdot}5}{\frac{20 \times 3}{5} + R}$$

Cross multiplying,

$$12 + R = 60$$

$$\therefore\ R = 60 - 12 = 48 \text{ ohms.}$$

The maximum current is obtained from a battery when the internal resistance is equal to the external resistance. If by an arrangement of the cells the battery resistance can be made equal to the resistance of the circuit outside the battery, then the current obtained will be greater by this arrangement than by any other method of grouping. If the two resistances cannot be made equal, then the arrangement which most nearly approaches this condition will be the one which will produce the greatest current. With a high external resistance the cells should be joined in series. It will be seen that by the series method the battery will have a greater resistance than by any arrangement of the cells abreast. With a low external resistance a suitable method of grouping the cells can be devised to produce a resistance of the battery equal to, or nearly equal to, the resistance of the external part of the circuit.

To obtain the maximum current from a given number of cells through a given external resistance

The number of cells arranged in series $= \sqrt{\frac{T \times R}{r}}$

where T = the total number of cells,

R = the external resistance,

and r = the internal resistance *per cell.*

Example 18.—How would you arrange 60 cells, each cell having an electro-motive force of 2 volts and a resistance of 2 ohms, to send the strongest possible current through an external resistance of $7\frac{1}{2}$ ohms?

$$\text{The number of cells in series} = \sqrt{\frac{T \times R}{r}} = \sqrt{\frac{60 \times 7\frac{1}{2}}{2}} = \sqrt{\frac{450}{2}} = \sqrt{225} = 15$$

∴ The cells should be arranged in four rows of 15 cells each.

By this method of grouping—

$$C = \frac{n \times e}{\frac{n \times r}{m} + R} = \frac{15 \times 2}{\frac{15 \times 2}{4} + 7\frac{1}{2}} = \frac{30}{7\frac{1}{2} + 7\frac{1}{2}} = 2 \text{ ampères.}$$

The internal resistance is $7\frac{1}{2}$ ohms, or the same as the external resistance.

To prove that the maximum current is obtained by this arrangement, the current should be compared with (*a*) that obtained by grouping the cells with a smaller number of rows and more cells in series, and (*b*) the current produced by the arrangement of a greater number of rows and less cells in series.

(*a*) 20 in series and 3 abreast.

$$C = \frac{n \times e}{\frac{n \times r}{m} + R} = \frac{20 \times 2}{\frac{20 \times 2}{3} + 7\frac{1}{2}} = \frac{40}{13\frac{1}{3} + 7\frac{1}{2}} = 1\frac{23}{25} \text{ ampère.}$$

(*b*) 12 in series and 5 abreast.

$$C = \frac{n \times e}{\frac{n \times r}{m} + R} = \frac{12 \times 2}{\frac{12 \times 2}{5} + 7\frac{1}{2}} = \frac{24}{4\frac{4}{5} + 7\frac{1}{2}} = 1\frac{39}{41} \text{ ampère.}$$

With the battery resistance $13\frac{1}{3}$ ohms, the current is $1\frac{23}{25}$ ampère.

" " $7\frac{1}{2}$ " " 2 ampères.

" " $4\frac{4}{5}$ " " $1\frac{39}{41}$ ampère.

It will be seen, therefore, that with the battery resistance equal to the external resistance the current obtained is greater than by any other arrangement of the cells.

It may be of interest to see how the formula $\sqrt{\frac{T \times R}{r}}$ is obtained.

Where R = the external resistance,
T = the total number of cells,
r = the resistance per cell,
n = the number of cells in series,
m = the number of rows of cells,

the battery resistance $= \frac{n \times r}{m}$

∴ to obtain the maximum current

$$R = \frac{n \times r}{m} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

but, as

$$T = n \times m$$
$$m = \frac{T}{n}$$

and, substituting this value of m in equation (1)

$$R = \frac{n \times r}{\frac{T}{n}}$$
$$R = \frac{n^2 \times r}{T}$$

Cross multiplying,

$$n^2 \times r = T \times R$$
$$n^2 = \frac{T \times R}{r}$$
$$\therefore n = \sqrt{\frac{T \times R}{r}}$$

A consideration of the following will show mathematically why the maximum current is obtained when the battery resistance equals the external resistance.

$$C = \frac{e\,n}{\frac{n\,r}{m} + R} = \frac{e\,n\,m}{n\,r + m\,R} = \frac{e\,n\,m}{\left(\sqrt{n\,r} - \sqrt{m\,R}\right)^2 + 2\sqrt{n\,m\,r\,R}}$$

For any arrangement of a given number of cells the quantity n m is constant, as it represents the total number of cells. The numerator (e n m), in the final value of C shown above, is therefore also constant, and the strength of the current will depend upon the denominator. Here we have $2\sqrt{n\,m\,r\,R}$ also a constant quantity. If, then, by an arrangement of the cells we can make $\left(\sqrt{n\,r} - \sqrt{m\,R}\right)^2 = 0$, the denominator will be as small as possible, and, as a consequence, the current will be the greatest obtainable. This will be so when

$$n\,r = m\,R$$

$$\text{or} \quad R = \frac{n\,r}{m}$$

i.e., when the external resistance equals the internal resistance.

Example 19.—How many cells, each having an electro-motive force of 2 volts and an internal resistance of 3 ohms, must be employed to send a current of 1 ampère through an external resistance of 10 ohms?

An examination of this question reveals the fact that with the cells arranged in series it is impossible to obtain a current of 1 ampère. Even if the cells are joined up without any appreciable external resistance the total resistance in ohms must always be numerically greater than the total electro-motive force in volts. Neglecting the external resistance, one cell, or 100 cells joined in series, cannot produce more than two-thirds of an ampère. Allowing for the external resistance, the current, of course, will be less than two-thirds of an ampère.

If the cells are all joined in parallel arc, the electro-motive force will be 2 volts. With an external resistance of 10 ohms and a negligible internal resistance the current will be only one-fifth of an ampère.

It is, therefore, apparent at the outset that the cells must neither be arranged all in series nor all abreast. How then should the cells be grouped?

$$C = \frac{n \times e}{\frac{n \times r}{m} + R}$$

$$1 = \frac{n \times 2}{\frac{n \times 3}{m} + 10} \quad \cdots\cdots \quad (1)$$

To obtain a maximum current from a given number of cells the internal resistance of the battery should equal the external resistance. From this it follows that, in order to produce a given current from a minimum number of cells, the same conditions should exist.

Therefore, from equation (1),

$$\frac{n \times 3}{m} = 10$$

$$n \times 3 = 10 \times m$$

$$\text{and} \quad m = \frac{n \times 3}{10} \quad \cdots\cdots \quad (2)$$

Substitute this value of m in equation (1).

$$1 = \frac{n \times 2}{\frac{n \times 3}{\frac{n \times 3}{10}} + 10}$$

$$1 = \frac{n \times 2}{10 + 10}$$

$$2 \times n = 20$$

$$\therefore \quad n = 10$$

$$\text{and, since} \quad m = \frac{n \times 3}{10} \quad \cdots\cdots \quad (2)$$

$$m = \frac{10 \times 3}{10}$$

$$m = 3$$

but the total number of cells, $T = n \times m$

$$\therefore \quad T = 10 \times 3 = 30$$

ANSWER.—Thirty cells should be used, joined 10 in series and 3 abreast.

It sometimes happens, more often by accident than design, that cells are joined up in opposition. Instead of the cells being grouped as in the series method, one portion of them is reversed, so that one section of the battery tends to send a current in one direction, and the other portion in the opposite direction. In a case of this kind the resultant current is found by making calculations which allow for the difference between the electro-motive force of the two sections. As all the cells are in the path of the current, the resistance of the whole of them must be included when calculating the total resistance.

Example 20.—Ten cells are joined up so that six of them tend to send a current in one direction, and the remainder in the opposite direction. If each of the ten cells has a resistance of 3 ohms and an electro-motive

Example 9.—A battery having a resistance of 25 ohms is joined to a circuit of 475 ohms resistance and produces a current of 40 milliampères. What is the electro-motive force of the battery?

$$C = \frac{E}{R + r}$$

$$\frac{1}{25} = \frac{E}{475 + 25}$$

Cross multiplying

$$25\ E = 500$$

$$\therefore E = 20 \text{ volts.}$$

CHAPTER IV.

The Grouping of Cells.

A voltaic cell is usually shown, diagramatically, as two vertical parallel lines; a short thick line to denote the positive plate, and a thin line to represent the negative plate. A battery of cells is depicted as a number of these pairs joined in a row, the negative plate of one cell being joined to the positive plate of the next, and so on, until all the cells comprising the battery are connected. A positive plate at one end and a negative plate at the other end are left free, and form the points of connection to the external part of the circuit. (Fig. 15.)

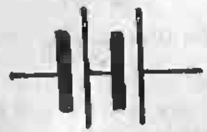

FIG. 15.

The above arrangement is termed joining the cells "*in series*." The resistance of a battery of this description is the resistance of one cell multiplied by the number of cells employed. As an illustration, take four bichromate cells, each having a resistance of two ohms, and connect them in series; the total resistance of the battery will be four times that of one cell, viz., eight ohms. The electro-motive force of such a battery will also be four times that of one cell. Assuming each cell to have an electro-motive force of two volts, then the total difference of potential between the terminals of the battery will be eight volts.

Where the number of cells joined *in series* is represented by n, the resistance per cell by r, and the electro-motive force per cell by e, then

The total battery resistance $= n \times r$,

and the total electro-motive force $= n \times e$.

Example 10.—Four cells joined in series are connected to a wire having a resistance of eight ohms. If each cell has an electro-motive force of two volts and a resistance of two ohms, what is the strength of the current?

Where C = the current in ampères,
e = the electro-motive force per cell,
r = the resistance per cell,
R = the external resistance,
and n = the number of cells joined in series.

In Fig. 18 imagine the circle A to be the cross section of a wire, and the current to be flowing from the reader into the plane of the paper. A swimmer would dive into the paper head foremost, and, upon turning to face the magnet, or any one of the filings in this case, the north-seeking pole would be upon the side of his left hand, as indicated. A *free* north-seeking pole, were it possible to produce a single pole magnet, would rotate around the wire in the direction shown by the arrows, while a *free* south-seeking pole would, of course, be urged in an opposite way.

From the foregoing, then, it will be readily understood that a freely suspended magnetic needle may be deflected from its normal position in the magnetic meridian, if brought within the magnetic field surrounding a wire conducting a current of electricity.

Oersted discovered this phenomenal action upon a suspended magnetic needle, and the construction of galvanoscopes and galvanometers, to respectively indicate the presence of electric currents and to measure them, is based upon this knowledge.

The important point to be given prominence at this juncture, however, is the effect of this electro-magnetism when the wire is wound into a spiral or helix. (Fig. 19.)

FIG 19.

With a given current each turn of the wire increases the magnetic effect of the spiral. This effect, roughly speaking, is proportional to the product of the current in ampères and the number of turns of wire in the coil. In other words the magnetic effect increases as the "ampère turns."

The helix, or solenoid as it is sometimes called, is a magnet only so long as the current flows. Its magnetic lines of force are similar to those about an ordinary bar magnet. Outside the coil they form closed curves, while inside they run parallel to its length and protrude at the ends.

A solenoid possesses the powers of attraction and repulsion, but its polarity depends upon two things, (*a*) the direction in which the coil, or helix, is wound—whether right-handedly or left-handedly—and (*b*) the direction of the current. With a thorough knowledge of Ampère's rule, however, no difficulty will be experienced in finding the polarity of a solenoid when the *direction* of the current is known. Further, looking at a known south-seeking or north-seeking pole (Fig. 20) the *direction* of the magnetising current can be ascertained. When looking at a south-seeking pole the current traversing the spiral circulates in the direction of the hands of a clock, but when looking at a north-seeking pole the magnetising current circulates in the opposite direction.

This rule is correct either for a right-handed or a left-handed helix.

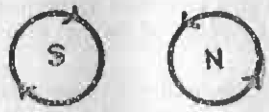

FIG 20.

PERMEABILITY AND SUSCEPTIBILITY.

Permeability, or the co-efficient of magnetic induction, may be defined as the ratio of magnetic conductivity existing between various substances and air from a given magnetising force. The number of lines of force per square centimetre in any substance determines its degree of permeability.

In air and non-magnetic bodies the number of lines of force is very small, while in magnetic substances, such as iron, the number of lines of magnetic induction is relatively large.

It will be seen, therefore, that by placing a soft iron core into a helix, a much greater number of lines of magnetic induction will be concentrated in the iron than was formerly contained in the air space; consequently the magnetic strength of such a combination will be much greater than that of the solenoid.

Suppose a certain magnetising force created, say, 50 lines of force per square centimetre in air, the same force would produce about 16,000 lines of force per square centimetre in soft iron. The permeability of the latter, therefore, would be 320 times greater than the former.

The number of lines of force per square centimetre in air is usually denoted by the letter H, and the number per square centimetre in magnetic substances by the letter B.

The relation of B to H may be taken as the permeability (μ) of the material.

$$\mu = \frac{B}{H}$$

$$\text{and } B = \mu H$$

Taking the above figures as an example,

$$B = 16{,}000$$

$$\text{and } H = 50$$

$$\therefore \text{ The permeability of the iron } = \frac{16{,}000}{50} = 320$$

The degree of permeability of magnetic substances is compared with the permeability of air, the latter being taken as unity. The value of the permeability of a body, however, decreases as the magnetisation increases beyond a certain point towards saturation. That is to say, with an increase of the magnetising force, the value of the permeability is not maintained beyond certain limits.

Iron is, therefore, highly *susceptible* to magnetisation, and, in consequence, strong poles are produced at its ends when the metal is placed in a magnetic field.

The *co-efficient of magnetisation* or *susceptibility* of any substance depends upon the number of units of magnetic strength developed at its poles.

Electro-Magnets.

A helix into which a soft iron core is placed forms, with the core, an electro-magnet; the magnetic strength of the combination being much greater than that of the helix. The magnetic effect may be further increased by winding a large number of turns of well-insulated wire, layer upon layer, around the core. There are limits, however, to the number of convolutions that may be usefully employed, for, unless the core lies within the magnetic field of each turn of wire, a useless resistance is introduced without augmenting the magnetic strength of the electro-magnet.

It is frequently stated that electro-magnets wound to a high resistance should be used upon long lines, while those wound to a low resistance should be employed upon short lines. It is, however, more a question of the number of turns of wire in a given space than the actual resistance of the electro-magnet. When a large number of convolutions is used, which would be the case upon long lines of high resistance, the wire would necessarily be of a small gauge to ensure that the magnetic field due to the outer layers should affect the core. If the incoming current is weak a large number of convolutions is required to multiply the magnetic effect; but the increased resistance does not appreciably affect the incoming current, as the resistance of the line is comparatively high. When a strong current is received the number of turns of wire may be much less to produce an equal magnetic effect—hence the employment of electro-magnets of varying resistances upon circuits of varying lengths.

When it is required to wind an electro-magnet to a given resistance it should be remembered that the thicker the wire the greater will be the number of convolutions; there is also less risk of the coils becoming fused if very strong currents are accidentally passed through them.

The wire used by the British Post Office is of pure copper, well insulated with silk, and usually wound upon the core from left to right, *i.e.*, right-handedly. Surrounding the soft iron cores are ebonite bobbins whose diameters do not exceed two-fifths of the length of the cores, and the wire

is wound upon the bobbins. The cores are cylindrical, and have soft iron pole pieces attached.

A typical electro-magnet of the horse-shoe pattern is shown in Fig. 21.

The two sections must be wound in the same direction; theoretically, the two limbs represent a straight electro-magnet, bent into this shape; the winding would therefore be continuous throughout the whole length, and in the *same* direction.

In practice a soft iron armature placed adjacent to the pole pieces is acted upon inductively by the magnetised cores and attracted towards them.

When the magnetising current ceases the armature is restored to its normal position by means of a spring, or some other mechanical contrivance. Sometimes, however, *residual* magnetism affects the rapid working of the armature and produces sluggishness. The effects of residual magnetism are usually apparent when the cores are not well annealed, or when the armature has been allowed to touch them. This small amount of retained or residual magnetism is due in a great measure to the chemical composition and mechanical construction of the material used as a core, its effects being very pronounced in badly annealed iron after the cessation of the magnetising current.

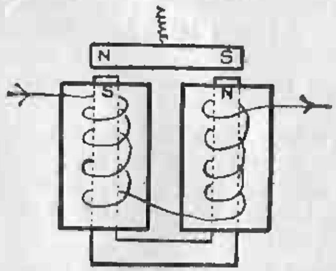

FIG. 21.

Electro-magnets, the coils of which are traversed by rapidly alternating currents, *i.e.*, currents which pass first in one direction and then in the other with great rapidity, have cores which are either composed of a bundle of soft iron wires, or have hollow cores with a short slit made lengthwise in them. The latter form is most generally used. The object of those special cores is to eliminate what is termed "eddy currents" set up in solid cores. In high speed working, and when alternating currents are applied, these eddy currents are generated in solid cores consequent upon the rapid magnetic changes in the iron.

force of 2 volts, what is the resultant current through an external resistance of 180 ohms?

$$C = \frac{6e - 4e}{10r + R} = \frac{12 - 8}{30 + 130} = \frac{4}{160} = \frac{1}{40} \text{ ampère, or 25 milliampères.}$$

If the cells were equally divided, and the two sets arranged in opposition, no current would flow, as the opposing electro-motive forces would be equal. In other words, there would be no difference of potential between the terminals of the battery.

CHAPTER V.

Electro-Magnetism.

A wire through which a current is flowing exhibits magnetic properties so long as the current is sustained. A conductor may be either a magnetic substance or a non-magnetic substance without affecting either the distribution or the extent of its field of force. The magnetic field is denoted by the lines of force which radiate in concentric circles from the wire, their common centre.

Plunge a copper wire, through which a fairly strong current is flowing, into iron filings, and observe that the filings are attracted and adhere to it. Also notice that they become detached immediately the current ceases.

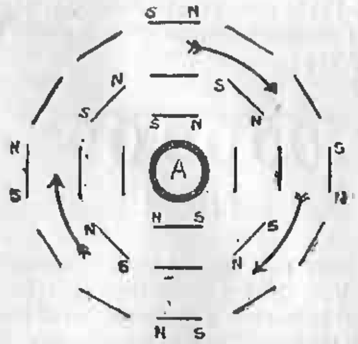

FIG. 18

Pass the wire through a sheet of cardboard and sprinkle iron filings upon the latter. The filings will arrange themselves in circular order and indicate the extent of the magnetic influence of the current. They will set themselves with their axes at tangents to the lines of force (Fig. 18), and become tiny magnets.

The relative positions of the poles of these magnets depend upon the direction of the current, knowing which, the north-seeking and south-seeking poles can be determined by Ampère's rule, which reads: *Suppose a man swimming in the wire, with the current, and that he turn so as to face the magnet, then the north-seeking pole will be in the direction of his left hand.*

The resistances are in *inverse* proportion to the squares of the diameters, and if d_1 and d_2 represent the respective diameters—

$$R_1 : R_2 :: (d_2)^2 : (d_1)^2$$
$$128 : R_2 :: (80)^2 : (90)^2$$
$$6{,}400\ R_2 = 128 \times 8{,}100$$
$$\therefore R_2 = \frac{128 \times 8{,}100}{6{,}400} = \frac{10{,}368}{64} = 162$$

Answer : 162 ohms.

Example 24.—Two iron wires of equal lengths have respectively resistances of 128 and 162 ohms. If the diameter of the first wire is 90 mils, what is the diameter of the second?

$$R_1 : R_2 :: (d_2)^2 : (d_1)^2$$
$$128 : 162 :: (d_2)^2 : (90)^2$$
$$162\ (d_2)^2 = 128 \times 8{,}100$$
$$(d_2)^2 = \frac{128 \times 8{,}100}{162} = 6{,}400$$
$$\therefore d_2 = \sqrt{6{,}400} = 80$$

Answer: 80 mils.

In the two preceding formulæ the lengths and diameters of conductors are dealt with separately in relation to resistance. The lengths and diameters will now be considered together.

From the two formulæ

$$R_1 : R_2 :: L_1 : L_2$$
$$\text{and } R_1 : R_2 :: (d_2)^2 : (d_1)^2$$

The following compound proportion is formulated—

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$

Example 25.—If two miles of wire 50 mils in diameter has a resistance of 48 ohms, what is the resistance of six miles of similar wire having a diameter of 60 mils?

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$
$$48 : R_2 :: 2 \times (60)^2 : 6 \times (50)^2$$
$$R_2 \times 2 \times (60)^2 = 48 \times 6 \times (50)^2$$
$$R_2 = \frac{48 \times 6 \times 2{,}500}{2 \times 3{,}600} = 100$$

Answer: 100 ohms.

Example 26.—If two miles of wire 50 mils in diameter has a resistance of 48 ohms, what is the length of a wire 60 mils in diameter having a resistance of 100 ohms?

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$
$$48 : 100 :: 2 \times (60)^2 : L_2 \times (50)^2$$
$$L_2 \times (50)^2 \times 48 = 2 \times (60)^2 \times 100$$
$$L_2 = \frac{2 \times 3{,}600 \times 100}{2{,}500 \times 48} = 6$$

Answer: 6 miles.

Example 27.—If two miles of wire having a diameter of 50 mils has a resistance of 48 ohms, what is the diameter of six miles of similar wire which has a resistance of 100 ohms?

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$
$$48 : 100 :: 2 \times (d_2)^2 : 6 \times (50)^2$$
$$100 \times 2 \times (d_2)^2 = 6 \times (50)^2 \times 48$$
$$(d_2)^2 = \frac{6 \times 2{,}500 \times 48}{100 \times 2} = 3{,}600$$
$$\therefore d_2 = \sqrt{3{,}600} = 60$$

Answer: 60 mils.

Example 28.—Two wires of equal resistances are respectively 8 miles and 18 miles in length. If the diameter of the first is 120 mils, what is the diameter of the second?

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$
$$\text{but as } R_1 = R_2$$
$$\therefore L_1 \times (d_2)^2 = L_2 \times (d_1)^2$$
$$8 \times (d_2)^2 = 18 \times (120)^2$$
$$(d_2)^2 = \frac{18 \times 14{,}400}{8} = 32{,}400$$
$$\therefore d_2 = \sqrt{32{,}400} = 180.$$

Answer: 180 mils.

Example 29.—Two wires equal in resistance have diameters of 120 mils and 180 mils respectively. If the length of the second wire is 18 miles, what is the length of the first?

$$R_1 : R_2 :: L_1 \times (d_2)^2 : L_2 \times (d_1)^2$$
$$\text{but } R_1 = R_2$$
$$\therefore L_1 \times (d_2)^2 = L_2 \times (d_1)^2$$
$$L_1 \times (180)^2 = 18 \times (120)^2$$
$$L_1 = \frac{18 \times 14{,}400}{32{,}400} = 8$$

Answer : 8 miles.

The weight of a conductor depends upon the length, area of cross section, and the material of which the conductor is composed. It should be assumed, however, in making comparisons, that wires of the same material are being considered unless it is definitely stated to the contrary, for, not only do the weights of different metals vary, but the resistances also. Weight may, therefore, be expressed relatively as the product of length and sectional area.

Where W signifies weight, L length, and A area of cross section,

$$W = L \times A \quad \ldots \ldots \quad (1)$$

$$A = \frac{W}{L} \quad \ldots \ldots \quad (2)$$

$$\text{and} \quad L = \frac{W}{A} \quad \ldots \ldots \quad (3)$$

$$\text{but} \quad R = \frac{L}{A}$$

therefore, substituting the value of A shown in equation (2),

$$R = \frac{L}{\frac{W}{L}} = \frac{L^2}{W}$$

The resistance of any conductor is, therefore, directly proportional to the *square* of the length and inversely proportional to the *total* weight. Hence the formula—

$$R_1 : R_2 :: (L_1)^2 \times W_2 : (L_2)^2 \times W_1$$

Example 30.—If three miles of copper wire weighing 1,200lbs. has a resistance of 6½ ohms, what is the resistance of five miles of wire of the same material weighing 750lbs.?

$$R_1 : R_2 :: (L_1)^2 \times W_2 : (L_2)^2 \times W_1$$
$$6\tfrac{1}{2} : R_2 :: (3)^2 \times 750 : (5)^2 \times 1{,}200$$
$$R_2 \times (3)^2 \times 750 = 6\tfrac{1}{2} \times (5)^2 \times 1{,}200$$
$$\therefore R_2 = \frac{6\tfrac{1}{2} \times 25 \times 1{,}200}{9 \times 750} = 28\tfrac{8}{9}$$

Answer: 28⁸⁄₉ ohms.

Resistance may also be expressed in terms of weight and sectional area.

$$R = \frac{L}{A}$$

and, substituting the value of L found in equation (3),

$$R = \frac{\frac{W}{A}}{A} = \frac{W}{A^2}$$

and, as the sectional area is proportional to the square of the diameter,

$$R = \frac{W}{d^4}$$

Example 31.—Two wires weigh 300lbs. and 600lbs. respectively. If the first wire has a diameter of 80 mils and a resistance of 26 ohms, what is the resistance of the second wire if it has a diameter of 110 mils?

$$R_1 : R_2 :: W_1 \times (d_2)^4 : W_2 \times (d_1)^4$$
$$26 : R_2 :: 300 \times (110)^4 : 600 \times (80)^4$$
$$\therefore R_2 \times 300 \times (110)^4 = 26 \times 600 \times (80)^4$$
$$R_2 = \frac{26 \times 600 \times (80)^4}{300 \times (110)^4}$$

Answer: 14½ ohms (approximately).

In cases where the weight per unit length is stated, *i.e.*, the weight per mile, or the weight per yard, instead of the total weight, the resistance is directly proportional to the total length and inversely proportional to the weight per unit length.

Example 32.—If ten miles of wire, weighing 110lbs. per mile, has a resistance of 80 ohms, what is the resistance of 30 miles of wire of the same material weighing 350lbs. per mile?

$$R_1 : R_2 :: L_1 \times W_2 : L_2 \times W_1$$
$$80 : R_2 :: 10 \times 350 : 30 \times 110$$
$$10 \times 350 \times R_2 = 80 \times 30 \times 110$$
$$R_2 = \frac{80 \times 30 \times 110}{10 \times 350} = 75\tfrac{3}{7}$$

Answer: 75³⁄₇ ohms.

Specific resistance may be defined as the relative resistance of one conductor to that of another, when both conductors are of the same dimensions and tested under similar conditions. The specific resistances of iron and copper are approximately as 6 is to 1. An iron wire has about six times the resistance of a copper wire if the two are of the same dimensions. If it be desired to replace an iron conductor by one of copper of the same length, and retain the same resistance, the copper wire should have only one-sixth the area of cross section of the iron wire.

Resistance Coils.

Resistance is measured by making comparisons with the ohm—the unit of resistance—or multiples of it. For this purpose sets of resistance coils are constructed by means of which comparisons may be readily made. An ordinary set of resistance coils is arranged by fixing a series of brass junction pieces upon a vulcanite slab and connecting the various sections with coils of wire having fixed resistances. By the insertion of conical brass plugs between the junction pieces the coils are cut out of circuit, while the withdrawal of the plugs causes the current to traverse the coils. (Fig. 23.)

The value of a set of resistance coils depends principally upon the constancy of the resistance, the accuracy of adjustment of each coil to its nominal value, and the facility of re-arrangement to cover a large range of resistances.

The resistance of most bodies is affected by temperature. Liquids, and semi-conductors generally, decrease in resistance with a rise in temperature, but the resistance of metals increases if their temperature is raised. The resistance of alloys, however, is practically unaffected by a variation of temperature, and for this reason German silver and platinoid are the metals most frequently employed in the construction of resistance coils. The alloys possess a comparatively high specific resistance. The wire, which is usually covered with two layers of silk saturated with solid paraffin to insure good insulation, is doubly wound upon large hollow bobbins. The object of double winding is to obviate the effects of self-induction. When a current is sent through a coil of wire "extra currents" are set up in the coil by electro-magnetic induction; but when the coil is doubly wound (Fig. 23) the extra current generated in one

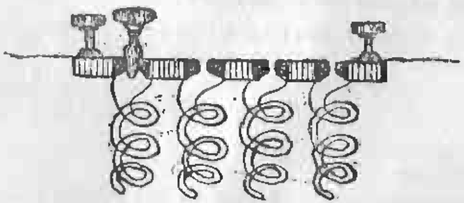

FIG. 23.

section is neutralised by the extra current set up in the opposite direction in the other section of the coil, and the effects of self-induction are consequently eliminated.

The coils required for small resistances should be made of thick wire. If a short wire of small gauge were used the exact value required would be far more difficult to obtain than if a longer wire of greater area of cross section were employed. It is important that the value of each coil should be as accurate as possible, for, although an error in each individual coil may be inappreciable, the accumulated errors of the set may be considerable. When tested each coil should possess a resistance corresponding with the marked value, and the resistance of a series of coils should be equal to the individual resistances added together.

A set of coils by means of which it is possible to obtain resistances varying from 1 ohm to 11,110 ohms is made up of 16 coils, having values of 1, 2, 2, 5; 10, 20, 20, 50; 100, 200, 200, 500; 1,000, 2,000, 2,000, and 5,000 ohms respectively.

Joint Resistance.

When several wires are joined together in *series* the total resistance is the sum of the separate resistances. It is frequently advantageous, however, to join wires in "parallel" or "multiple arc." Circuits joined up in this manner, so as to produce a division of the current at a junction of two or more resistances, are usually termed "divided" circuits, and the resistances of the paths form a "joint" resistance.

In Fig. 24 the resistance of the circuit between the points A and B is the joint resistance of the two wires. If the separate resistances of the two

FIG. 24.

paths are equal, then the joint resistance of the circuit between A and B will be half the resistance of one of the branches.

For example, if the two wires joining the points A and B have each a resistance of 10 ohms, the joint resistance of the two wires will be 5 ohms.

If any number of *equal* resistances be joined in "multiple" their joint resistance will be the resistance of one of them divided by the number employed. The joint resistance in this case is equal to $\frac{R}{N}$

Where R = the resistance of one wire
and N = the number of wires so joined.

The joint resistance of 10 wires, each having 50 ohms resistance, is 5 ohms.

When it is desired to find the joint resistance of two conductors whose resistances are unequal, the product of the resistances should be divided by the resistances added together.

Example 33.—What is the resistance of two wires of 20 and 30 ohms respectively when joined in "multiple arc"?

$$\text{Joint resistance} = \frac{R_1 \times R_2}{R_1 + R_2}$$

where R_1 and R_2 represent the respective resistances of the two wires.

$$\text{Joint resistance} = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12$$

Answer: 12 ohms.

Example 34.—The joint resistance of two wires joined in "multiple arc" is 12 ohms. If one of the wires has a resistance of 20 ohms, what is the resistance of the other?

$$\text{Joint resistance} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$12 = \frac{20 \times R_2}{20 + R_2}$$

$$20\,R_2 = 12\,(20 + R_2)$$

$$= 240 + 12\,R_2$$

$$20\,R_2 - 12\,R_2 = 240$$

$$8\,R_2 = 240$$

$$\therefore R_2 = 30$$

Answer: 30 ohms.

The conductivity of a wire is the reciprocal of its resistance. The joint *conductivity* of any number of wires joined in "multiple arc" is the sum of their separate conductivities. The joint *resistance* of any number of wires joined in "multiple arc" is the reciprocal of their joint conductivity. If three wires have 2 ohms, 4 ohms, and 6 ohms resistance respectively, their conductivities may be expressed as $\frac{1}{2}, \frac{1}{4}, \frac{1}{6}$. The joint conductivity of these three wires will be

$$\frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{11}{12}$$

and their joint resistance

$$\frac{1}{\frac{11}{12}} = \frac{12}{11} = 1\tfrac{1}{11} \text{ ohm.}$$

The joint resistance of any number of wires joined in "multiple arc" will always be less than the smallest individual resistance. The law of joint resistances may be expressed thus: When any number of resistances are joined in "multiple arc," their joint resistance will be the reciprocal of the sum of the reciprocals of the individual resistances, or

$$\text{Joint resistance} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

Example 35.—What is the joint resistance of three wires, the separate resistances of which are 1, 2, and 3 ohms respectively?

$$\text{Joint resistance} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$= \frac{1}{\frac{1}{1} + \frac{1}{2} + \frac{1}{3}}$$

$$= \frac{1}{\frac{11}{6}} = \frac{6}{11}$$

Answer: $\frac{6}{11}$ ohm.

Example 36.—Three wires, whose resistances are respectively 15, 30, and 900 ohms, are joined in "parallel arc." What is the joint resistance?

$$\text{Joint resistance} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$= \frac{1}{\frac{1}{15} + \frac{1}{30} + \frac{1}{900}}$$

$$= \frac{1}{\frac{60 + 30 + 1}{900}}$$

$$= \frac{900}{91} = 9\tfrac{81}{91}$$

Answer: $9\frac{81}{91}$ ohms.

Example 37.—Four conductors, whose resistances are respectively one-third, one-fifth, one-seventh, and one-ninth of an ohm, are joined in "multiple arc." What is their joint resistance?

$$\text{Joint resistance} = \frac{1}{\frac{1}{\frac{1}{3}} + \frac{1}{\frac{1}{5}} + \frac{1}{\frac{1}{7}} + \frac{1}{\frac{1}{9}}}$$

$$= \frac{1}{3 + 5 + 7 + 9} = \frac{1}{24}$$

Answer: $\frac{1}{24}$ ohm.

Example 38.—The joint resistance of three wires joined in "multiple arc" is two ohms. If two of the separate resistances are five and seven ohms respectively, what is the third resistance?

Let x denote the unknown resistance, then

$$2 = \frac{1}{\frac{1}{5} + \frac{1}{7} + \frac{1}{x}}$$

$$\frac{2}{5} + \frac{2}{7} + \frac{2}{x} = 1$$

$$\frac{2}{x} = 1 - \frac{2}{5} - \frac{2}{7}$$

$$\frac{2}{x} = \frac{35 - 14 - 10}{35}$$

$$\frac{2}{x} = \frac{11}{35}$$

$$11x = 70$$

$$\therefore x = 6\tfrac{4}{11}$$

Answer: $6\frac{4}{11}$ ohms.

Divided electro-magnets are used for high speed working. In these the core is divided into two sections, one coil being fitted upon each, and is not continuous as in Fig. 21. With a soft iron strap at the base it was found that, when the armature was attracted at rapid intervals, a closed magnetic circuit was practically formed, and self-induction, to be explained later, became very great. Self-induction most seriously affects the working speed, but is considerably reduced by this slight alteration.

A special kind of electro-magnet (Fig. 22), invented by Professor Hughes,

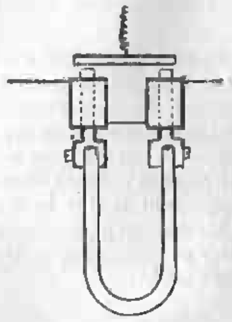

FIG 22

is of great importance in connection with the Hughes' type-printing instrument.

A permanent steel magnet, of the compound or laminated form, is fitted with two soft iron pole pieces, a coil of wire being wound upon each.

The pole pieces or cores are acted upon inductively by the permanent magnet, and these in turn attract an armature of soft iron and hold it in close proximity to the coils.

The incoming current traverses the coils in a direction which tends to reverse the polarity of the cores, the attractive force upon the armature being consequently weakened.

To illustrate the effect, consider the armature to be held by a magnetic force representing 100, and a spring with a force of 91 acting in an opposite direction. If the attractive force be weakened by ten as the effect of the current, the armature would be released and act with the full force of the spring. By the movement of the armature the mechanism of the printing instrument is set in motion, and the coils are short-circuited, and joined to earth. A transient current of sufficient strength will therefore actuate the armature, while a current of comparatively long duration will have no greater effect upon it.

CHAPTER VI.

Resistances.

The resistance of a conductor is directly proportional to the length, and inversely proportional to the area of cross section of such conductor. The resistance of two yards of wire is twice as great as that of one yard of similar wire. If, however, it is desired to compare the resistances of two wires of the same length and material the resistances will be *inversely* proportional to the areas of cross section of the wires. The area of cross section of a circular conductor is *proportional* to the *square* of the diameter. The resistance of a circular conductor is, therefore, *inversely* proportional to the *square* of the diameter of the conductor.

Example 21.—If ten miles of copper wire has a resistance of 80 ohms, what is the resistance of 15 miles of similar wire?

The resistances are in *direct* proportion to the lengths, and calling R_1 and R_2 the respective resistances, and L_1 and L_2 the respective lengths—

$$R_1 : R_2 :: L_1 : L_2$$
$$80 : R_2 :: 10 : 15$$
$$10\,R_2 = 15 \times 80$$
$$R_2 = 120$$

Answer: 120 ohms.

Example 22.—If ten miles of copper wire has a resistance of 80 ohms, what length of similar wire will have a resistance of 120 ohms?

$$R_1 : R_2 :: L_1 : L_2$$
$$80 : 120 :: 10 : L_2$$
$$80\,L_2 = 1200$$
$$\therefore L_2 = \frac{1200}{80} = 15$$

Answer: 1[illegible] miles.

Example 23.—If the resistance of a wi[illegible] 90 mils in diameter is 128 ohms, what is the resistance of an equal length [illegible]f similar wire having a diameter of 80 mils?

Note.—A mil is one-thousandth part of an inch.

respectively, the magnet will tend to turn the needle out of the magnetic meridian. The similar poles of the magnet and the needle are mutually repellent, and the earth's magnetism, which tends to hold the needle in the magnetic meridian, will be opposed by that of the magnet. With the magnet at a certain distance from the needle, the influence of the earth upon the latter will be counterbalanced by the opposing force exerted by the former. At a slightly greater distance the force exerted between the earth and the needle will be greater than that between the magnet and the needle, and consequently the needle will be controlled by the preponderating influence of the earth. It will, in fact, come to rest in the magnetic meridian, but will be held in that position by a weaker force than would be the case if the magnet were removed. It is, therefore, more susceptible to the electro-magnetic influence of a current. The sensitiveness of the needle may be varied by altering the position of the adjusting magnet, and it will be readily seen that by reversing the positions of the poles the magnet will act with the earth and produce opposite effects to those described.

The Astatic Galvanometer.

By using what is termed an "astatic pair" a very sensitive instrument may be constructed. An astatic pair is a combination of two magnetic needles

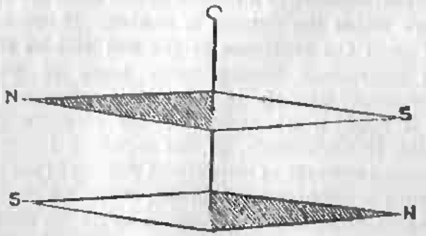

FIG. 25.

of equal strength and size fixed one above the other by means of a light non-magnetic substance. Their axes are parallel and lie in the same vertical plane. (Fig. 25.) Their unlike poles, however, are adjacent, and the earth's force consequently tends to turn the needles in opposite directions. If the above conditions be fulfilled, the pair will be independent of the earth's magnetism. It will come to rest in any position, and the directive influence of the earth will be nullified.

A very sensitive instrument, called an Astatic Galvanometer is constructed upon this principle. The needles are delicately suspended by means of a fibre of unspun silk, and the upper one, which serves as a pointer, rotates above a graduated scale. The frame of the instrument

carries the coil, inside which the lower needle turns. The ends of the coil are attached to two terminals fixed to the base board, and the instrument stands upon three screws, by means of which the coil is brought parallel to the needles. The latter are adjusted to the zero of the scale by a screw which carries the silk suspending thread. This galvanometer is only suitable for measuring or comparing feeble currents. As the needles turn they become oblique to the direction of the force of the magnetic field produced by the current, and consequently are not acted upon to the same advantage as when the force is exerted at right angles. For this reason, when the deflections are large they are not proportional to the strengths of the currents producing them. When, however, the deflections do not exceed 15 degrees they are approximately proportional to the currents producing them. For instance, a current which produces a deflection of 8 degrees is about twice as strong as one which only deflects the needles 4 degrees, but if a deflection of 32 degrees is registered the current is more than double the strength of one which produces a deflection of 16 degrees.

The Tangent Galvanometer.

It is not possible to construct a galvanometer which permits of currents being measured by direct readings in *degrees*. An instrument, however, upon which the tangent of the angle of deflection is proportional to the strength of the current is called the tangent galvanometer, and is very largely used in the British Post Office. Before attempting to describe the construction of this instrument it will be well to consider some of the laws which govern its action.

The total magnetic force of the earth acting upon a magnetic needle is the resultant of two forces, viz., a horizontal force and a vertical force. A magnetic needle which only rotates in a vertical plane will come to rest in a perpendicular position, with its north-seeking pole pointing downwards, if the plane of rotation be east and west; but if the plane of rotation be north and south, the needle (in London) will make an angle of about 67 degrees with the horizon. This angle is called the angle of dip or inclination, and varies in different latitudes. If the needle be so pivoted as to be capable of rotation only in a horizontal plane, then the vertical component of the earth's magnetism will not affect the deflection, but simply tend to depress the needle more firmly upon its pivot, while the horizontal force will turn the needle into the magnetic meridian. The earth's magnetic lines of force are practically uniform over any small space, consequently the forces acting upon the poles of a small magnetic needle are equal and opposite.

The north-seeking pole of the needle will be repelled by the south magnetic pole of the earth, and attracted by the earth's north magnetic pole. The south-seeking pole of the needle will be repelled by the north magnetic pole of the earth, and attracted by the earth's south magnetic pole. The resultant of these two forces acting upon each pole will be the

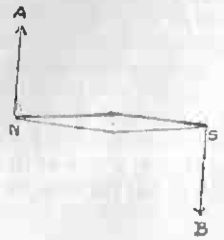

FIG 26

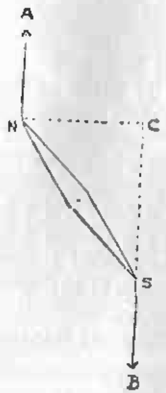

FIG 27

FIG 28

same in strength, but opposite in direction. Further, on account of the great size of the earth, the forces acting upon the poles of the needle are practically parallel.

When two equal and parallel forces act upon the ends of a rigid body in opposite directions so as to turn it upon its centre, the maximum turning effect is produced when the two forces act at right angles to that body. The turning effect gradually diminishes as the body turns, until the latter is in the same straight line as the forces acting upon it, when the turning effect is zero and the body comes to rest. The actual amount of the turning effect is equal to the product of one of the forces into the perpendicular distance between them.

In Figs. 26, 27, and 28 let A and B represent two equal and parallel forces acting at the ends of the magnetic needle NS, then in Fig. 26 the amount of the turning effect will be A (or B) multiplied by the length of NS—the perpendicular distance between the forces.

In Fig. 27 the perpendicular distance between the forces is only NC, consequently the turning effect has been reduced by the rotation of the needle to the position shown. In Fig. 28, where the perpendicular distance is zero, the turning effect is *nil*, and the needle consequently is at rest.

The term *a couple* is applied to a pair of forces acting in this manner. The turning effect is the *moment of the couple*, and the perpendicular distance between them is called the *arm of the couple*.

The force exerted between two magnetic poles is directly proportional to the product of their magnetic strengths and inversely proportional to the square of the distance between them. If, therefore, the horizontal component of the earth's magnetism be represented by **H** and the strength of either pole of a horizontally-suspended magnetic needle by m, the force exerted upon both poles of the magnet is directly proportional to $\mathbf{H} \times m$. The moment of the couple, or the turning effect, however, will depend upon the position of the needle, and will be at a maximum when the needle is pointing east and west and *nil* when the needle is in the magnetic meridian.

A field of force which acts at right angles to the magnetic meridian tends to make the poles of a horizontally-suspended magnetic needle point east and west. Such a condition exists when a wire carrying a current is placed in the magnetic meridian. Further, if it can be arranged for the lines of force developed by the current to be uniform in the space through which the needle turns, the forces acting upon the poles of the needle will be equal, parallel, and in opposite directions. If the wire carrying the current be wound into a circular coil, the diameter of which is relatively large to the length of the needle, the lines of force due to the current will be practically straight at and near the centre of the coil. They will also be equidistant and parallel within the small space through which the needle turns.

Let the strength of the field of force developed by the current be represented by f. The force exerted upon both poles of the needle will be $f \times m$, and it will tend to turn the needle out of the magnetic meridian. This force will oppose at right angles the force due to the earth's magnetism. The directive influence of the latter is to make the magnet set itself with its poles pointing north and south, while that of the former is to deflect the needle from its position in the magnetic meridian. It has been previously shown that the magnetic moment of a couple or the turning effect depends upon the position of the needle. Consequently there will be one position of the needle in which the magnetic moment of the couple produced by the horizontal component of the earth's magnetism will be counterbalanced by that due to the current. The needle will then be at rest.

In Fig. 29 let M M^1 represent the magnetic meridian, and let the needle N S, pivoted at its centre O, be deflected by the action of the current to the position shown. Complete the parallelogram N A S B.

The magnetic moment due to the earth's magnetism is H × m × N A, and that due to the current f × m × A S. But since the needle has

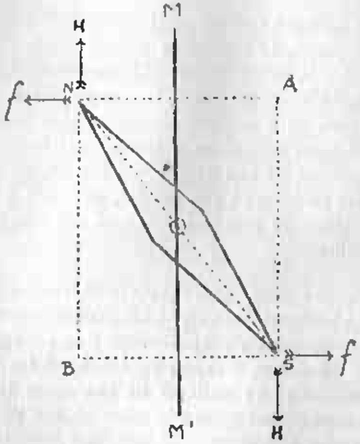

FIG. 29

come to rest the magnetic moments of the two couples are equal:—

$$f \times m \times AS = H \times m \times NA$$

$$\therefore f = H \times \frac{NA}{AS}$$

The angle N S A equals the angle N O M, and since $\frac{NA}{AS}$ is the ratio for the tangent of the angle N S A, f may be said to be proportional to the tangent of the angle of deflection N O M. The strength of the field of force f is proportional to the strength of the current which produces it, and, as H is a constant quantity at any one place, the current may be said to be proportional to the tangent of the angle of deflection.

In the tangent galvanometer used by the Post Office the coil is wound upon a ring-shaped brass bobbin, its diameter being about 6½in. It is differentially wound, each section having a resistance of 160 ohms. Nearly all galvanometer coils are arranged differentially, so that if equal currents pass through the two sections in opposite directions the effect of one section upon the needle neutralises the effect of the other. If the currents are not equal a deflection is produced by virtue of the difference in their strengths, the direction of the deflection being determined by the current having the greater strength. The needle, which is very delicately pivoted at the centre of the coil, is a small magnet ¾in.

in length. A light non-magnetic pointer is fitted at right angles to the centre of the magnet, and rotates horizontally over a scale. If the pointer were not used the scale, of necessity, would be small, as the very short magnet rotates over a limited area, and the scale would be inconveniently close to the pivot upon which the magnet turns. Great care is necessary in attaching the pointer to the magnet. The pointer must be perfectly straight, and fixed so as to cross the magnet exactly at right angles. Any deviation from these rules will result in incorrect readings being registered upon the scale. The adjustment may be verified by sending a current through the coil of sufficient strength to produce a deflection of, say, 100 tangent divisions. An adjustable resistance should be in the path of the current, and should now be arranged so that the *total* resistance is only one-half of what was in circuit when the reading of 100 tangent divisions was taken. If a deflection of 200 divisions is not then registered the pointer is badly set, and requires readjustment to the magnet.

One-half of the scale card is divided into degrees, and upon the other portion are marked graduated divisions which represent the tangents of the degrees. The latter saves reference to a table of tangents. The deflection should be read upon the tangent scale, and the current is then pro-

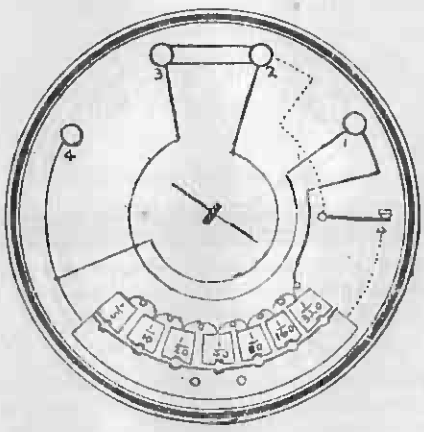

FIG 30

portional to the number of tangent divisions indicated. Two curved slots, into which mirrors are fitted, are arranged in the scale card. The object of the mirrors is to avoid parallax error when the readings are taken. Deflections should not be read upon the scale from an oblique point of view, but the observer should place himself in such a position that the pointer obscures its reflected image in the mirrors. Above the coil a controlling magnet, capable of being raised, lowered, or turned upon its axis, is placed for adjusting purposes. In Fig. 30 the connections of the instrument are shown. Four terminals fitted to the base are marked 1, 2, 3, and 4, the ends of the two sections of the coil being joined to terminals 1 and 3 and 2 and 4 respectively. When terminals 2 and 3 are joined as shown in the diagram, the two sections of the coil are joined in series, and a current entering the instrument at 1 will traverse the whole length of the coil and leave the galvanometer at 4. A simple key is attached to the instrument by means of which the section between terminals 2 and 4 may be short-circuited at will. By momentarily depressing the key when the angle of deflection is increasing in magnitude the swing of the needle is checked. The oscillations are thus considerably reduced and the pointer readily comes to rest.

The ordinary zero of the tangent scale is not generally utilised. There are really two tangent scales, an inner and an outer scale. The former is divided into 100 tangent divisions on either side of the zero, and the direction of the deflection depends upon the direction of the current. The latter, which is called the *skew* scale, is almost invariably used. The zero

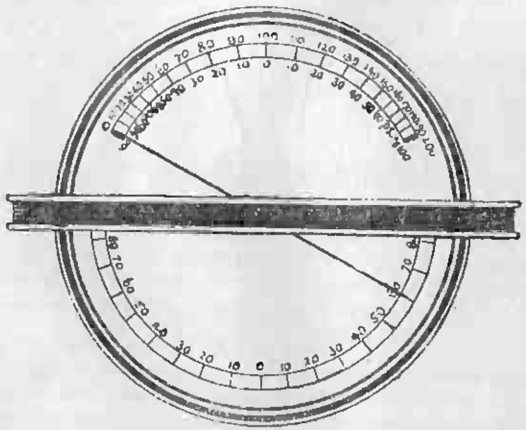

FIG. 31.

is on the extreme left of the scale, and the great advantage of a range of 200 tangent divisions is obtained. The pivoted needle, when not under the influence of the current, remains, of course, in the magnetic meridian,

but in order to bring the pointer to rest at the skew zero the coils and scale are turned to the right through an angle of 60 degrees.

The galvanometer is fitted with a system of shunts, the values of which are $\frac{1}{5}$th, $\frac{1}{10}$th, $\frac{1}{20}$th, $\frac{1}{40}$th, $\frac{1}{80}$th, $\frac{1}{160}$th, and $\frac{1}{320}$th respectively. By this means currents of considerable strength may be readily measured and the practical value of the instrument greatly enhanced. The shunts are arranged between terminals 1 and 4.

To adjust the galvanometer it should be placed at a distance of not less than 3ft. from other instruments, in the construction of which magnets or magnetic substances are employed, and fixed so that the pointer comes to rest at zero on the outer scale. The controlling magnet is then placed upon the stalk in such a position that the pointer again comes to rest at the same zero. A current is then sent through the coils of the galvanometer from a sealed standard dry cell. In circuit with the cell and galvanometer is joined a resistance coil of platinoid wire which has a resistance of about 1,144 ohms. The cell is specially selected, and is of the Leclanché pattern. It has an electro-motive force of about 1·5 volt and a resistance of about 1 ohm. The actual resistance and electro-motive force are marked upon a card attached to the outside of the case containing the cell and the platinoid coil. The number of tangent divisions which should be obtained by using the particular cell supplied is also indicated. This deflection is arrived at by adjusting the controlling magnet upon the stalk. The required sensibility of the instrument thus produced by adjusting to obtain the given deflection is such that a current of one milliampère will produce a deflection of 80 divisions.

The Absolute Galvanometer.

An instrument by means of which the strength of a current may be measured in absolute units is called an absolute galvanometer. The tangent galvanometer may be so employed. The force by which a magnetic needle is deflected is directly proportional to the length of the coil and inversely proportional to the square of the distance between the needle and the coil.

By using an instrument which has a coil of large diameter the length of wire for each convolution is great, but it must be remembered that the greater the diameter of the coil the farther the needle will be away from the wire. The effect of increasing the circumference of the coil is to augment the force acting upon the needle by concentrating a greater number of lines of force into the space through which the needle rotates, and, at the same time, to decrease the force by placing a greater distance between the needle at the centre of the coil and the coil itself.

The circumference of a circle is 3·14159 times its diameter, or, as it is usually written, π d. It may also be stated as $2 \pi r$, where r represents the radius of the circle. The magnetic field developed by the current may therefore be said to exert a force upon the magnet at the centre of the coil proportional to $\frac{2 \pi r}{r^2}$ or $\frac{2 \pi}{r}$

As 2π is an unchangeable quantity the force with which the needle is deflected by any given current is inversely proportional to the radius of the coil. From this it follows that, in order to obtain a given deflection, any increase in the radius of the coil must be compensated for by an increase in the strength of the current. The current producing a given deflection may therefore be said to be proportional to the radius, and, if a number of convolutions of wire, denoted by n, be used, the current producing the deflection will be inversely proportional to $2 \pi n$. The formula $\frac{r}{2 \pi n}$ consequently becomes the *constant* of the instrument, and the current may be read in absolute units on a tangent galvanometer as $C = \frac{r}{2 \pi n} \times H \times \tan. \delta$.

It should, of course, be understood that calculations are made with the radius measured in centimetres, and care should be taken in reading the above to distinguish between *force* and strength of current. If the result obtained in absolute units be multiplied by ten, the value of the current will be in ampères, or practical units.

The Mirror Galvanometer.

The mirror galvanometer is an instrument in which a high degree of sensibility is attained. In all galvanometers used for measuring feeble currents it is a *sine qua non* that the moving parts should be very small and light. In the tangent galvanometer a small delicately pivoted magnet is used, and in order that minute movements may be observed and small deflections accurately measured, a long index or pointer is attached to the needle. The pointer is discarded in the mirror galvanometer, and in its stead a reflected beam of light is employed. The latter has the advantage of being without weight and inertia. In the instrument known as Thomson's Reflecting Mirror Galvanometer two or three pieces of magnetised watch spring about $\frac{3}{8}$ths of an inch in length are used as the needle. They are attached, with their similar poles pointing in the same direction, to the back of a small circular concave mirror, which is suspended by means of a single fibre of unspun silk. The mirror is very light, and its diameter is about the length of the magnets. The coil, which is circular, is wound upon a cylinder, and at its centre the mirror turns. Above the coil an adjustable magnet is placed upon a stalk, and by this means the earth's influence is counteracted. When the magnet is placed at or near

the lower end of the stalk its influence is such that it controls the suspended needle, and by turning the magnet upon its axis the reflected beam of light may be readily projected on to the zero of a scale. The instrument stands upon three feet, which carry adjustable screws for levelling purposes. The scale is placed at a distance of about 3ft. from the galvanometer, and from an ordinary lamp, placed on the side of the scale remote from the galvanometer, a ray of light is projected through an aperture slightly

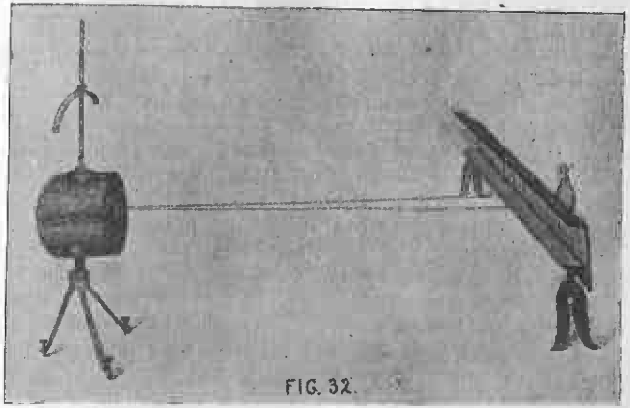

FIG. 32.

below the centre or zero of the scale on to the suspended mirror. (Fig. 32.) The beam of light is reflected to the scale and produces an illuminated spot, which, when no current is passing through the coil, should be on the zero point. When great accuracy is desired a fine wire is stretched perpendicularly across the opening through which the light passes, and readings are taken by the position of its shadow on the scale. As the needle is relatively small to the size of the coil, the tangents of the deflections are approximately proportional to the strength of the currents producing them. Consequently the divisions marked on the straight scale board are equal. The coil is composed of many turns of fine wire, and its resistance is usually about 2,000 ohms. This galvanometer is largely used as a reading instrument upon long submarine cable circuits, combinations of deflections to the right and left producing the characters of the Morse alphabet.

The D'Arsonval Galvanometer.

The D'Arsonval galvanometer is another distinct type of very sensitive instruments. In most galvanometers the current passing through a coil of wire deflects a suspended or pivoted magnetic needle. In the D'Arsonval galvanometer, however, this condition is reversed, the coil itself being turned upon its point of suspension. Between the poles of a powerful laminated horse-shoe magnet the coil of wire is suspended by means of a phosphor-bronze strip, through which the current passes to the coil. The field of force developed by the current opposes the magnetic field of the magnet in the interpolar space, and as a consequence the coil turns. Attached to the coil is an index, which moves horizontally over a graduated scale. In some forms of the instrument the index is not used, but a small mirror and reflected beam of light are employed in conjunction with a scale, as in the mirror galvanometer already described. The chief feature of the D'Arsonval galvanometer is its great sensitiveness. Its *figure of merit*, or the strength of current which will produce a deflection of one division, is ·00008 milliampère, and the instrument is consequently used for testing in connection with high resistances, such as the insulation resistance of cables and accumulator leads. Among the other advantages of the instrument it may be mentioned that the pointer comes to rest with comparatively few oscillations when under the influence of a current, and the galvanometer is, therefore, said to be a *dead beat* instrument. In this connection, however, it should be stated that the swing of the coil is slow, and a few seconds must be allowed to elapse before an observation is made. The powerful magnet also plays an important part, for while rendering a service in making the instrument free from interference by neighbouring magnetic apparatus, it materially affects the readings of other unprotected galvanometers placed in its vicinity. The magnet, being comparatively heavy, also has the disadvantage of making the galvanometer unportable. A system of shunts, to which the term "Universal" has been applied, is generally attached to the instrument. This particular system of shunts is described at the end of this chapter.

Ballistic Galvanometers.

For the purpose of measuring transient currents, or currents which are of short duration, an instrument is used in which the magnet moves sluggishly. This condition is brought about by the employment of a magnetic needle which is relatively long and heavy. The needle is sometimes weighted with lead to produce the necessary slow movement, hence the term ballistic or ballasted galvanometer. A discharge from a condenser may thus be measured, and the sine of half the angle of the first swing is proportional to the quantity of electricity which has passed through the coil. Currents of brief duration which follow each other in rapid succession give sustained impulses to the moving needle until a final steady deflection is attained.

Galvanometer Shunts.

When it is desired to measure a current of considerable strength, it frequently happens that the range of deflection of the galvanometer

employed is not sufficiently large to allow the measurement to be made by a direct reading. When this is the case a definite fraction of the current is allowed to pass through the coil of the galvanometer, and from the deflection observed the strength of the whole current is calculated. The remainder of the current traverses another path, called a shunt, the resistance of which bears a definite ratio to the resistance of the galvanometer coil. Suppose that a galvanometer having a resistance of 90 ohms is employed, and that its range of deflection is not sufficiently large to admit of a current of a certain strength being measured. By joining a resistance of 90 ohms in parallel with the galvanometer coil the current will split equally through the two paths, and the deflection registered upon the galvanometer will be a measure of one-half of the total current flowing in the circuit. The multiplying power of the shunt is said to be 2, and the strength of the current which passes through the galvanometer when a shunt of this value is in operation should be multiplied by that figure in order to ascertain the total current. If the galvanometer be shunted by a resistance of 10 ohms, then by the law of division of current 9-10ths of the whole current would pass through the shunt and 1-10th through the galvanometer. The multiplying power of the shunt in this instance would, therefore, be 10. From these two examples it will be noticed that the relationship existing between the resistance of the shunt and that of the galvanometer plays an important part in determining the value of the shunt. An examination of the figures given in the preceding examples shows that if the resistance of the galvanometer be divided by the resistance of the shunt and unity added to the result, the multiplying power of the shunt will be obtained. This rule holds good in every case, and from it simple formulæ may be deduced which enable the resistance of the galvanometer, the resistance of the shunt, or the multiplying power of the shunt to be readily ascertained, when any two of the three quantities are given:—

Let G = the resistance of the galvanometer.
S = " " shunt.
m = the multiplying power of the shunt.

Then, since $m = \frac{G}{S} + 1$

$$m-1 = \frac{G}{S}$$

$$G = S\,(m-1)$$

and $S = \frac{G}{m-1}$

The formula $m = \frac{G}{S} + 1$ may also be written as $m = \frac{G + S}{S}$

Example 40.—A shunt of 400 ohms resistance is attached to a galvanometer which has a resistance of 2,000 ohms. By what figure must the deflection be multiplied in order that the total current flowing in the circuit may be ascertained?

$$m = \frac{G}{S} + 1$$
$$= \frac{2,000}{400} + 1$$
$$= 6$$

Answer: 6.

From this example it will be seen that if the resistance of the galvanometer be five times that of the shunt the multiplying power of the shunt must be 6. Such a shunt is usually termed a one-sixth shunt.

Example 41.—What is the resistance of a one-fifth shunt upon a galvanometer having 320 ohms resistance?

$$S = \frac{G}{m-1}$$
$$= \frac{320}{5-1}$$
$$= 80$$

Answer: 80 ohms.

Example 42.—If a one-tenth shunt has a resistance of 40 ohms, what is the resistance of the galvanometer?

$$G = S\ (m-1)$$
$$= 40\ (10-1)$$
$$= 360$$

Answer: 360 ohms.

As a joint resistance is formed whenever a shunt is used, the resistance of the shunted galvanometer is less than the actual resistance of the instrument coil. In order, therefore, to keep the resistance of the circuit constant an additional resistance is introduced into the path of the current equal to the difference between the resistance of the galvanometer coil and the joint resistance of the coil and the shunt. Thus the amount of *compensating resistance* necessary to keep the resistance of a circuit constant is

$$G - \frac{G \times S}{G + S}$$

The arrangement of the circuit is shown diagramatically in Fig. 33 in connection with example 43.

Example 43.—What should be the compensating resistance used when a one-fifth shunt is employed in connection with a galvanometer having a resistance of 100 ohms?

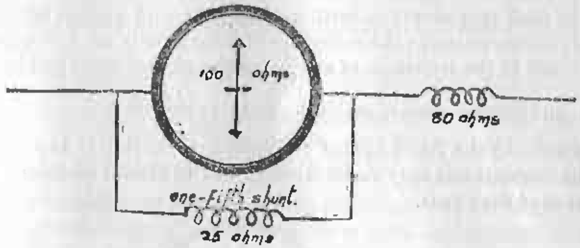

FIG 33.

First find the resistance of the shunt.

$$S = \frac{G}{m - 1}$$
$$= \frac{100}{5 - 1}$$
$$= 25$$

Resistance of shunt = 25 ohms

$$\text{The compensating resistance} = G - \frac{G \times S}{G + S}$$
$$= 100 - \frac{100 \times 25}{100 + 25}$$
$$= 100 - \frac{2500}{125}$$
$$= 80$$

Answer: 80 ohms.

It will be seen that the resistance of the shunted galvanometer (20 ohms) added to the 80 ohms compensating resistance is equal to the resistance of the unshunted galvanometer (100 ohms).

The joint resistance produced by the galvanometer coil and its shunt may be readily ascertained by dividing the resistance of the former by the multiplying power of the latter.

In order to save calculation and the adjustment of the compensating resistance, a set of resistance coils is frequently so arranged that the act of inserting a plug to bring any one of the shunts into operation automatically brings the correct amount of compensating resistance into the circuit.

The "Universal" System of Shunts.—This system is so called because it can be used in connection with galvanometers of various resistances. This is possible owing to the resistance of these shunts not bearing a fixed relationship to the resistance of any particular galvanometer coil.

The multiplying power, m, of a shunt is $\frac{G + S.}{S}$

By arranging the shunt so that the numerator G + S is kept constant and the denominator only varied, then m will be altered according to the resistance of the shunt.

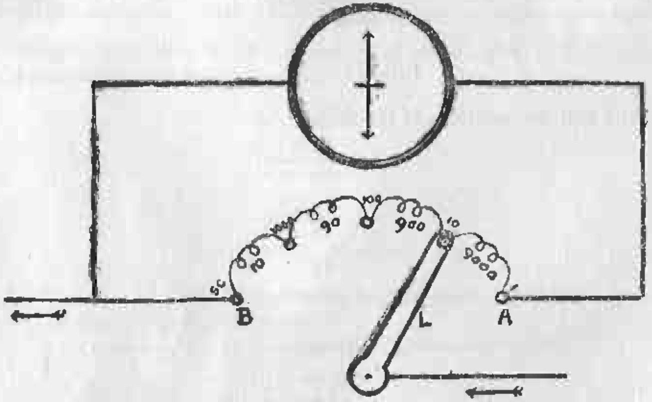

FIG 34.

In Fig. 34, the sliding lever L moves over a number of studs between which resistance coils are fixed. When the lever is in the position marked A, then practically the whole of the current passes through the galvanometer.

Let it be assumed that m in this instance is 1. Obviously when the lever is moved to the position shown in Fig. 34 the 9,000 ohms of the first shunt coil is removed to the galvanometer circuit, and

$$m = \frac{(G + 9{,}000) + S}{S} = \frac{G + 9{,}000 + 1{,}000}{1{,}000} = \frac{G + 10{,}000}{1{,}000}$$

or ten times what it was in the first instance, when

$$m = \frac{G + 10{,}000}{10{,}000}$$

Similarly by placing the lever upon the next stud the resistance of the galvanometer circuit is raised to G + 9,000 + 900, and the resistance of the shunt is reduced to 100. Therefore,

$$m = \frac{(G + 9{,}000 + 900) + S}{S} = \frac{G + 9{,}000 + 900 + 100}{100} = \frac{G + 10{,}000}{100}$$

or 100 times greater than when the lever was upon A.

By moving the lever to the next contact stud it will be seen that m is increased to 1,000, while its removal to the stud B simply produces a short circuit and no current passes through the galvanometer.

It should be remembered that, with the universal system of shunts, the accepted rule that *the joint resistance of a galvanometer and its shunt bears a fixed relation to the reducing power of the shunt* is not applicable.

When wires are joined in "multiple arc" and their resistances are unequal, the current will divide at the junction of the various paths. Each path or section will be traversed by an amount of current in direct proportion to its *conductivity*.

Example 39.—A battery of negligible resistance and an electro-motive force of 3 volts is joined to 3 wires in "multiple arc." The resistances of the wires being 10, 20, and 40 ohms respectively, what current flows through each wire?

First find the joint resistance of the wires.

$$\text{Joint resistance} = \frac{1}{\frac{1}{10} + \frac{1}{20} + \frac{1}{40}}$$

$$= 5\tfrac{4}{7} \text{ ohms.}$$

Next find the current emanating from the battery.

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

$$= \frac{3}{5\frac{4}{7}}$$

$$= \frac{21}{40} \text{ ampère or 525 m.a.}$$

Now, find the joint conductivity of the wires.

$$\text{Joint conductivity} = \frac{1}{10} + \frac{1}{20} + \frac{1}{40}$$

$$= \frac{4 + 2 + 1}{40} = \frac{7}{40}$$

The current may, therefore, be said to split up into seven parts, four of which pass through the path of 10 ohms resistance, two parts through the 20 ohms resistance, and the remaining part through the path having 40 ohms resistance.

$\frac{4}{7}$ of 525 m.a. = 300 m.a. will flow through the wire of 10 ohms.

$\frac{2}{7}$ " = 150 " " " 20 "

$\frac{1}{7}$ " = 75 " " " 40 "

CHAPTER VII.

GALVANOMETERS.

A galvanometer is an instrument used to detect the presence of a current of electricity and to measure its strength. The name clearly signifies its true meaning—a measurer of galvanism. An instrument which merely indicates the presence of a current is termed a galvanoscope.

The fundamental principle of the galvanometer is based upon the fact that a wire carrying a current is surrounded by a magnetic field of force, which is capable of deflecting a suspended or pivoted magnetic needle from its position of rest. A straight wire, unless traversed by a very strong current, however, produces a comparatively weak magnetic field, and, in order to provide for the measurement of feeble currents, methods have been devised for making a magnetic needle susceptible to their influence.

A magnetic field of considerable intensity may be produced by winding the wire carrying the current into a coil, thereby concentrating the lines of force into a small space. Galvanometers are constructed upon this principle. The number of convolutions of wire, however, which may be usefully employed, depends to a certain extent upon the resistance of the circuit through which the current is flowing. If the number of turns used be very great the resistance of the coil will be considerable. If, therefore, an instrument having many turns of wire be used to measure a current flowing in a circuit of *small* resistance, it will produce a marked diminution in the strength of the current. This, of course, is undesirable, as the object of the instrument is to measure the actual strength of the current flowing in the circuit. On the other hand, with a feeble current flowing through a circuit of very high resistance the introduction of a galvanometer having many turns of wire will not materially affect the strength of the current, but the large number of convolutions will increase the intensity of the magnetic field in nearly direct proportion to the length of wire employed. There is, however, always a limit to the dimensions of the coil in order that the outer turns may be effective. Generally speaking, a galvanometer of many convolutions of wire is suitable for measuring currents flowing through circuits of high resistance, but upon circuits of low resistance an instrument having few turns of wire is preferable.

Another method of increasing the sensitiveness of a galvanometer is to reduce the directive force of the earth by using a "compensating" or "adjusting" magnet. If above a magnetic needle, capable of rotating in a horizontal plane, a magnet be placed with its North and South seeking poles pointing to the North and South magnetic poles of the earth

The two limbs are yoked at the base with a soft iron strap. By the effect of the current one pole is made north-seeking and the other south-seeking. A soft iron armature, fixed at right angles to a movable brass lever, is held by adjustable screws in close proximity to the poles, but not actually touching them, and is acted upon inductively by the electro-magnet. An adjustable spiral spring holds the armature away from the cores. Each time the armature is attracted by the passage of a current through the coils an audible sound is emitted, and the acoustic instrument, termed a sounder, is thus formed. A shunt, having a resistance of 500 ohms, is joined across the terminals of the instrument, the reason for which will be seen later.

The direct sounder is in the line circuit, or, in other words, is connected directly with the line wire. This arrangement is in contradistinction to other systems in which a relay is used. As a sounder requires 90 to 100 milliampères of current to produce a workable effect it is only used "direct" on circuits of short lengths where the in-coming currents are fairly strong. It may be mentioned here that the newest sounders in use with relays upon circuits worked by secondary batteries are wound to a resistance of 900 ohms. They are shunted with coils of 9,000 ohms.

The theoretical connections of a direct sounder circuit are shown in Fig. 35. The galvanometer used with this system is not intended as a measurer of the strength of the current received or sent, but simply to indicate that a current is flowing in the circuit. Its resistance is 30 ohms.

The key is a simply devised brass lever fitted with three terminals. Its function is to connect the line with either the battery or the receiving apparatus at will.

"Up" and "Down" Stations.

For the sake of uniformity in joining up apparatus a general rule is followed, viz., that the office nearest London upon any telegraph line is designated an "up station." The positive pole of the battery at an "up" station is invariably joined to the line and the negative pole to earth, whereas at a "down" station the reverse is the case.

At an intermediate station the connections are as shown in Fig. 35. It will be seen that the current sent to the terminal offices is in accordance with the above rule.

"Open" and "Closed" Circuit Working.

In open circuit working, which is that in general use in Great Britain, no current passes to line in the single current system until the key is depressed. When closed working is resorted to, however, there is normally a permanent current in the circuit. This latter system

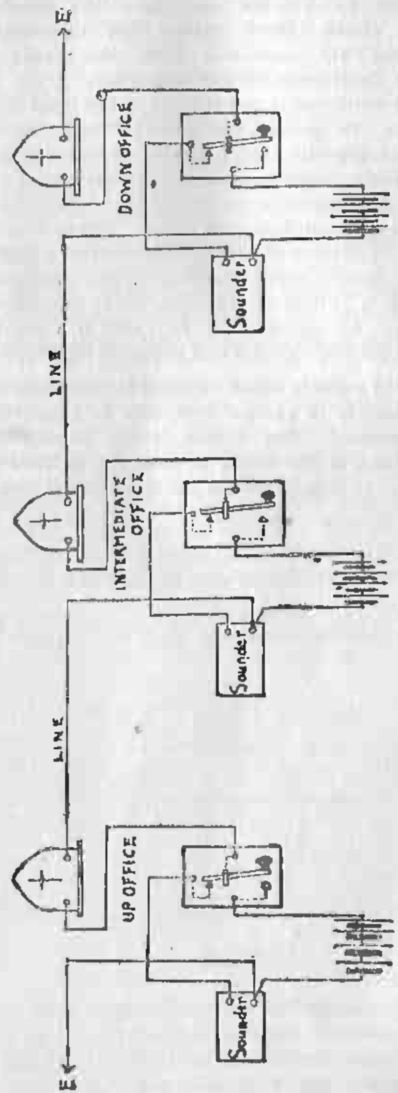

FIG. 35.

CHAPTER VIII.

Telegraph Circuits.

A telegraph circuit is arranged either as a "metallic loop," or as a single line with an "earth return." The former system, as the term implies, necessitates a second length of wire, while in the latter system an earth connection is made at each end to complete the circuit.

The earth may be considered as a vast reservoir of electricity; for all practical purposes it is a huge conductor, the resistance of which is negligible. The capacity of the earth is so immense that its potential is normally uniform, and zero. The potential of all electrified bodies is consequently either above or below that of the earth. A negative potential is said to be below, a positive potential above zero.

There are advantages and disadvantages arising from the use of an earth return. The chief advantages are that a second wire is not necessary, and that the initial cost is therefore considerably reduced. The resistance of a single wire circuit is about one-half that of a metallic loop circuit, and less battery power is consequently needed.

The risk of faults arising is also less when using a single wire than is the case with a metallic loop. The one serious disadvantage, however, upon long lines and cables more especially, is that at times a difference of potential exists between various points of the earth's surface. Earth currents consequent upon this are then observed to flow more or less steadily along the wires and materially affect the working efficiency of the circuits. These earth currents are most troublesome during the prevalence of sun-spots, at times when auroræ displays are exceptionally brilliant, and during "magnetic storms."

Earth currents may be eliminated from a circuit either by substituting a wire for the earth as the return part of the circuit, thus forming a metallic loop, or by working by means of condenser impulses. In the former circumstances the earth is entirely dispensed with, and the difference of potential existing between the two points of the earth's surface is consequently non-effective.

When a knowledge of the action of the condenser has been obtained the student will readily see how the act of charging and discharging it may cause transient currents to be set up and employed as a means of effective signalling.

The introduction of the condenser causes a break in the continuity of the circuit, and earth *currents* by this means are avoided.

When an earth return is used the wire is frequently soldered to an *iron* gas pipe or to the water main. In branch pipes joints are numerous, and these, together with the material used in their making, produce unnecessary resistances and bring about what is known as a "bad earth." When the wires are well soldered to a main pipe, however, a good earth connection is almost invariably insured. Leaden gas pipes must never be used, neither should wires be laid in close proximity to them. Lightning discharges are liable to fuse leaden pipes whilst passing between them and adjacent wires, and the risk of serious consequences by their use is therefore very considerable.

In places where water and gas mains, or other suitable earth connections are not readily accessible, earth plates are employed. They are usually made either of galvanised iron or of copper, having an area of not less than 2½ feet square. The plates are embedded, vertically, in naturally moist soil, and the wires, after having been passed through holes in them to prevent undue straining at the joints, are carefully soldered to the plates. Resin should be used in the soldering, and resin, paint, or tar applied to the joint as a coating to prevent moisture between the solder and the plates and consequent local action. The connecting wires must be of the same material as the plates, and of sufficient thickness to allow for gradual decay. The same kind of metal should be employed at each end of a line to avoid currents from an "earth battery." With dissimilar metals as earth plates, especially upon short lines, these currents may cause a considerable amount of trouble. As several wires are frequently connected to the same plate, it is imperative that all earth plates should be embedded in suitable places to avoid a comparatively high resistance between them and the earth. A moist position, free from rocks, is generally selected, and the resistance offered is not allowed to exceed 10 ohms. If a comparatively high resistance existed the current from one wire, instead of passing to earth, would divide, and a certain amount pass into other wires attached to the same plate. A semblance of contact between the circuits would then ensue. In stony and comparatively dry places it is preferable to sink an earth-plate for each wire at a distance of about 50 yards between the plates, while in the case of very short distances a return wire should be used in the absence of gas or water mains.

The Direct Sounder.

The "direct" sounder circuit is one of the simplest methods of telegraphic signalling, and as the term implies, this system is worked by the direct effect of a current from the distant station. The sounder itself is a simple form of electro-magnet wound to a resistance of 20 ohms. The two coils are wound upon ebonite bobbins, which latter envelop the soft iron cores. The horseshoe pattern of electro-magnet is employed.

produced by self-induction. In Fig. 36 the air space between A B would be easily bridged over by a current of very high potential, and the coil itself left untraversed by the greater portion of the current. It is upon this fact that the principle of lightning protectors is based.

Carbon Protectors.

A very efficient form of lightning protector is constructed by separating two circular discs of carbon by a thin sheet of mica through which three holes are pierced. The line wire is connected to the upper disc, and a continuation of the wire, known as the "instrument lead," is carried to

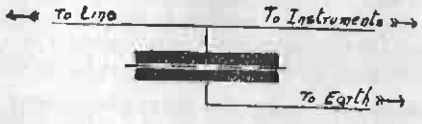

FIG. 37.

the apparatus, while the lower disc is earth-connected. The lightning leaps across the air space between the carbon discs and passes harmlessly to earth. The arrangement is shown theoretically in Fig. 37.

Carbon plates possess a decided advantage over metal plates, inasmuch as they are not fused by the passage of a heavy current through the air space. If brass, or other metal, were used there would be a liability to the plates becoming in metallic contact and the line wire being put direct to earth. Another advantage of carbon is that it is not assailable by oxygen as metals are. A lightning protector in general use at intermediate offices comprises three discs and two sheets of mica, the centre disc being in connection with earth. (Fig. 38.) The "up" and "down" lines respectively are connected to the two outer discs, and the action of this protector is identical with that of the one already described.

Vacuum Protectors.

The "vacuum" protector consists of a glass tube, partly exhausted of air, with metal connections at the ends. Metallic projections, which terminate in points, extend to the interior of the tube. They are in close proximity to each other, but not in actual contact, and the discharge leaps across the space between the points. One end of the tube is in connection with earth, while the other end is joined to the line and instruments. This kind of protector is frequently used at the junction of underground and aerial wires, and is not affected by moisture to any great extent.

A special kind of instrument protector known as a "fuse" is now used upon many circuits. Between the line and instruments a glass tube

fitted with metallic ends is placed, and the circuit is completed by means of a fine platinoid wire which runs through the tube and connects the

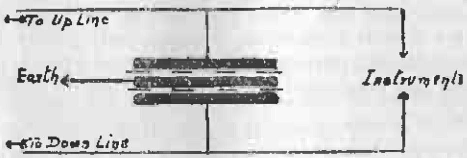

FIG. 38

metallic ends. A current of one ampère is sufficient to fuse the platinoid wire and disconnect the circuit. The instrument coils are consequently saved from the ill effects of an excess current.

A very ingenious arrangement has recently been introduced as a protection against excess currents, and is roughly shown in Fig. 39. The incoming current, after passing through a platinoid fuse, reaches a heat coil of about 10 ohms resistance. A metallic projection at the end of a metallic spring is pressed into one end of the heat coil, and is held in position by means of solder at A. When the current passing through the heat coil is excessive the solder

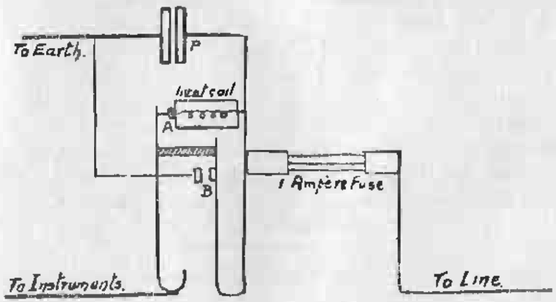

FIG. 39

is melted and the spring released. This action disconnects the instruments, which are connected to the spring, from the line. Another metallic spring arranged between the platinoid fuse and the heat coil is held normally away from an earth-connected contact point by means of an insulating stud. As soon as the first spring is released, the second spring operates in consequence of the withdrawal of the stud, and the connection is largely employed in America and upon the Continent. The advantages of a closed circuit system are numerous in cases where many offices are connected with the same line wire, and little traffic is dealt with at any one office. Upon short lines the battery power is employed at one end only; but upon long lines it is split up into sections. In practice the current from the various sections combines, the result being that a much greater constancy is obtained than if each office supplied a current from a separate source. The labour necessary to keep the battery in order is also concentrated at certain points instead of being required at each office. The various adjustments necessary for differing current strengths from several batteries are also obviated. The single current Morse system is the one usually adopted, and the key is fitted with a switch, which, upon being turned, cuts off the permanent current. An operator at any station, upon turning his switch, can stop the sending operator and request a repetition.

A certain amount of waste is bound to result from a permanent current, and faults which develop in covered wire may be intensified by a continuous flow of current. The system is not popular or generally practicable in England, as the traffic at most offices fitted with Morse apparatus is sufficient to monopolise the use of a separate wire.

CHAPTER IX.

Lightning Protectors.

When two bodies, such as two clouds or the earth and a cloud, are very highly charged with electricity the electrical stress existing between them is frequently sufficient to break down the insulating medium.

The two charges, in the act of recombining to produce equilibrium, cause a disruption of the insulation and a flash, such as that produced by lightning, results. The effect is similar to that produced by the discharge of a Leyden jar. The discharge is oscillatory in action, but the oscillations are so rapid as to cause the flash to appear to be in one direction only.

Lightning discharges frequently take place along telegraph and telephone wires, and if no protection were provided considerable damage to delicate instruments would naturally result. The coils of insulated wire used in the construction of electro-magnets and galvanometers would be rendered useless if the insulation were destroyed by lightning, for each turn of wire would be in direct contact with the next, and the desired effect of the current would not be obtained. The polarity of permanent magnets is also likely to be reversed or destroyed by lightning, and so it becomes imperative to obviate these several deleterious effects.

Fortunately currents of high potentials, such as those produced by lightning discharges, have a propensity for leaping across a

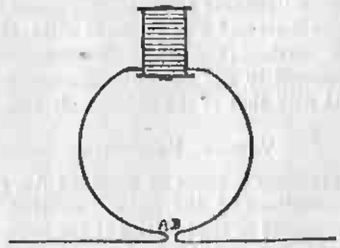

FIG. 36.

small air space, which offers an infinite resistance to the low potential currents used in telegraphy, rather than following the path of a small conductor. If a coil of wire is in the path of the discharge a disruption is practically certain, because of the choking effect of the coils

CITY AND GUILDS
OF
LONDON INSTITUTE.

TELEGRAPHY AND TELEPHONY.

SYLLABUS 1904-5.

The Examination will include questions founded on such subjects as the following:—

ORDINARY GRADE.

1. The fundamental principles of Electricity in their application to the Electrical Engineering industries.

2. Units of Measurement. Standards of resistance, their practical construction and adjustment; electro-motive force and capacity; effects of temperature variation.

3. Galvanometers—principles and manufacture of—(*a*) absolute, (*b*) sensitive, (*c*) dead beat, (*d*) astatic, (*e*) differential. Shunts, ordinary and constant resistance.

4. Resistance coils—construction of; gauge and kind of wire; methods of winding and insulating.

5. Condensers—construction and testing of.

6. Induction coils—construction and principle of employment.

7. Call bells—magneto and battery bells; magneto generators and their construction.

8. Instruments necessary for the equipment of an electrical testing room—(*a*) for land lines, (*b*) for cables; methods of using the apparatus in the simpler forms of testing; apparatus required by linemen.

9. Electrical testing as applied to the inspection of apparatus and to the detection and removal of faults.

10. Faults in land and submarine lines; their nature and the general principle of localisation.

11. Essential qualities of iron and steel for temporary and permanent magnets respectively; methods of making permanent magnets; treatment of iron for electro-magnets; simple calculations as to the effective power of a permanent magnet or an electro-magnet.

12. The construction of telegraph and telephone lines, overhead and underground.

13. Metallic circuit system of working telephones and its advantages; inductive disturbances and methods of overcoming them; theory of such methods.

14. The construction of submarine cables, and the simpler of the phenomena connected with cables.

15. The simpler systems of telegraphy worked by hand, including the double current duplex.

16. Batteries used in telegraphy and telephony; principles, action and construction; methods of grouping; universal battery working; application of secondary batteries to universal working.

17. The principles involved in the electrical transmission of sound and speech; the various systems of telephony and the instruments employed therein, including receivers, transmitters, call bells, and exchange switchboards.

18. Nature and methods of preventing disturbances by earth currents.

19. Testing of materials employed in the construction of lines and apparatus.

20. Methods of protecting circuits and apparatus from lightning and from other extraneous heavy currents.

HONOURS GRADE.

Candidates for Honours must have previously passed in the Ordinary Grade.

In the Honours Examination, which may be either in—I. Telegraphy, or II. Telephony, more difficult questions will be set in the subjects of the Ordinary Grade, and in addition a knowledge will be required of:—

SECTION I.—TELEGRAPHY.

1. The systems of high speed, quadruplex, multiplex, and type-printing telegraphs actually in use in Great Britain.

2. The manufacture, laying, testing, working, and repairing of submarine cables.

3. Practical methods for the supply of current other than by primary batteries.

4. The commercial adaptability of the various systems of telegraphy.

5. Explanation of theory of the Wheatstone Bridge, tangent galvanometer, and reflecting galvanometer.

6. Repeaters—principles and construction; employment and adjustment; for single and double current, simplex and duplex, and high speed circuits.

7. Causes of limiting the speed of automatic telegraph working, and methods of reducing their effect.

8. Daily and other periodical tests in theory and practice.

9. Wireless telegraphy.

SECTION II.—TELEPHONY.

1. Transmitters and Receivers—various forms, construction and special features; adjustment; materials.

2. Translation from single wire to double wire systems and from circuit to circuit by means of condensers and of induction coils.

3. Methods of working telephones and telegraph instruments simultaneously on the same wire; theory of.

4. Conditions which limit the distance to which telephonic transmission is possible; use of iron and copper wires.

5. Individual calls for several stations on one circuit—theory and practical arrangement.

6. Exchange switchboard systems for single and for double wires. Multiple switches.

7. Switches, Intermediate, etc.

8. Automatic Call Boxes.

9. Hughes's Induction Balance.

It should be understood that generally the introduction of suitable illustrative diagrams in answers is to be desired.


Cooperative Printing Society Ltd
Tudor Street, E.C.
Every description of General, Commercial, News & Artistic Printing
Executed by Cooperators and Trade-Unionists
The Pioneer of Cooperative Printers.
And at
Corporation Street and New Mount St Manchester.
Rutherford St Newcastle on Tyne

INDEX.