TELEGRAPHY

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PREFACE

TO

THE NINTH EDITION

SINCE the first edition of this text book appeared in 1876, the progress of Telegraphy has been phenomenal. That progress has been marked by a steadily increasing demand for the exhibition of technical knowledge and skill on the part of the artisans and operators engaged in the engineering and commercial branches of Telegraphy in this country; and we are glad to be able to bear witness to the fact that those concerned have responded to this demand in a way that does them infinite credit. A standard of technical knowledge that was exceptional in the Telegraph Service a few years ago is now the rule, and the time is not distant when we shall look in vain and without regret for the engineering or commercial employé who has no knowledge of the principles of the science. It was in the hope of hastening this desirable consummation that this book was first written, and we venture to hope that this present edition will tend still further in the same direction.

Dealing with so wide a subject in such limited space, the book makes no pretension to a full treatment of each system described. It rather aims at providing such a general introduction to the art and science of Telegraphy as will enable the student to proceed to the study of more advanced works, and give to the operator an intelligible explanation of the apparatus with which he has to deal. Where a system is in actual use in England, the English practice is described—a plan which, while it has an immediate advantage for the English student, is also the most natural, inasmuch as the British Postal Telegraph Administration is distinctly in the forefront, and the British practice is largely followed by the majority of our Colonies.

NEW EDITION (1905).

THE present edition has been thoroughly revised and enlarged, and includes descriptions of the most modern and prominent devices used in telegraphy, in relation to fast-speed recorders, to automatic and translating apparatus for submarine circuits, to Murray's improvements in the Wheatstone Automatic Apparatus, and to the new Telegraph Switching System. The paper-insulated telephone cable, now so largely used, is treated of at length. A chapter upon Wireless Telegraphy, considered theoretically, and also in its most recent practical application, has been added. In the Appendix have been furnished, in so far as they relate to telegraphy, the British Standards for Copper Conductors adopted last year by the Engineering Standards Committee. To afford space for so much new matter, it has been necessary to omit some which, to-day, does not enter within the scope of ordinary practice, and which is not, therefore, of immediate interest to the modern telegraphist.

In the preface to a former edition we had pleasure in acknowledging the valuable assistance afforded us by Mr. J. Gavey (Engineer-in-Chief of the Postal Telegraphs) and by Mr. Arthur J. Stubbs (now Superintending Engineer, Metropolitan North District), and we take this opportunity of again expressing our indebtedness to these gentlemen, and to others—but especially to Mr. E. O. Walker, who has corrected and revised the proofs—who have kindly lent descriptive matter and illustrations for use in the present edition.

March 1905.

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TELEGRAPHY

CHAPTER I.

ELECTRICAL TERMS.

It is not intended that this book shall be a treatise on electricity. It is a Text-book of Telegraphy, dealing with the application of electricity to the conveyance of information to distant points beyond the reach of the ear and the eye. As, however, practical telegraphy is wholly dependent upon electricity, some acquaintance with the elementary principles of that science is essential on the part of the reader if he is to understand telegraphy; and these therefore will be incidentally introduced so as to render the explanations given as much as possible independent of previous knowledge. At the outset it is necessary that the student should have a clear understanding of the meaning of some of the technical terms commonly employed in connection with telegraphy, and accordingly these will be explained in the present chapter; but the question what electricity is, whether it be a fluid or a force, whether it be a form of matter or a form of energy, will not be discussed, the practical application not being dependent on theory.

Electricity is an agent pervading terrestrial and solar space, and is as universal in its effects as are heat and light.

We are cognisant of its existence when we hear the roar of thunder and see the flash of lightning, but we do not know its particular form any more than we know that of sound or that of light. The sound of the thunder and the flash of the lightning affect the ear and the eye—we hear the sound and see the light—but we do not assume the existence either of sound or of light as distinct entities or things. We can speak of the quantity of sound caused by the explosion of a cannon or by the blowing of a penny whistle; the quantity of light emitted by a glow lamp or by a rushlight; the quantity of heat required to melt a pailful of ice or to solder a metal joint, without implying by the term *quantity* a mass or volume of anything actually present. The term implies relative magnitude only. It is the answer to the question 'how much?' It implies the notion of more or less. When we speak of the magnitude of electricity present we speak of its *quantity*. When we read of a church spire destroyed, of trees riven to splinters, of wires fused, or of flocks killed, the damage done is due to the electricity passing, and the amount of that damage is referable to its magnitude or *quantity*. If we take a piece of sealing-wax, a glass rod, or an ebonite comb, and rub it against the coat sleeve, we find it has the property of attracting feathers, straws, and other light bodies. Electricity has been excited upon its surface, and the force of attraction is found to increase with the quantity of electricity present. Equally the force with which bodies are attracted towards each other is an indication of the quantity of electricity excited. So we may say that ELECTRIC QUANTITY *is the magnitude or amount of electricity present.*

We may therefore assume that the electricity on a body has a physical magnitude which, like all other physical magnitudes, is capable of measurement and of reference to some standard. Since quantity implies the notion of more or less, we must be able to answer the question 'more or less than what?' All physical magnitudes need a standard of reference or *unit* with which comparison and therefore calculation can be made. The notion of more or less is supplied by the number of these units which are present. If we wished to express in feet the distance between any two places, we might say 'let the distance between A and B be *f*,' or if we wished to express in gallons the volume of water in a tank, we might say 'let the capacity of the tank be *g*,' *f* and *g* respectively representing '*f*,' feet, and '*g*,' gallons; *f* and *g* standing for any number whatever, and the *foot* and *gallon* being the units or standards of reference taken or understood. So, too, if we wanted to find the quantity of electricity required to effect a certain purpose, we might commence by saying 'let the quantity of electricity be *q*,' by which we should mean an unknown number, '*q*' units of electricity, and our investigation might bring it out ·01 of a unit, or 3 units, or 50 units, or any other number. The unit quantity of electricity in general use has been called a *coulomb*, from one of the great French philosophers. Thus we see that in the literal representation of a physical quantity we assume the existence of a standard or unit to which we give a name, as foot, gallon, coulomb, and we express its value numerically or represent it by the use of a letter.

Whenever electricity has been produced by any means, the bodies which exhibit evidence of its presence are said to be *electrified* or *charged with electricity*, and their condition is said to be one of *electrification*. For instance, a cloud which is capable of discharging itself with a flash of lightning is said to be electrified. A piece of sealing-wax rubbed with flannel or fur becomes electrified. A glass rod rubbed with silk is also electrified. In the two latter cases although both substances have been electrified by friction, yet the character of the electrification in each case is different. The sealing-wax and glass seem to be imbued with exactly opposite qualities: for while two bodies, each electrified by contact with either the sealing-wax or the glass, repel each other, two bodies, one electrified by the glass and the other by the sealing-wax, will attract each other. By an arbitrary convention the electricity excited on glass has been called *positive*, while that excited on sealing-wax has been called *negative*. All electrified bodies are either positively or negatively electrified. A thundercloud, for instance, may at one time be positively and at another time negatively charged. When a cloud charged positively approaches a cloud equally charged negatively and discharge (lightning) takes place between them, complete neutrality, or zero, results. This justifies the use of the opposite terms.

Whenever we walk upstairs or ascend a hill we are conscious of having expended energy. We have, in fact, raised our bodies through a certain height against the influence of the force of gravity. We have done work upon our bodies; and whenever we make an effort against a force of any kind, through any distance, we do work. Thus a horse does work in drawing a load, heat does work in converting water into steam, and thereby driving trains and propelling vessels. Electricity does work when it moves substances against the force of gravity, or when it flows against resistance, and all electrical phenomena are illustrations of energy expended, and are measured by the work done in producing them.

An electrified body acquires a certain quality or condition by which it possesses this power of doing work. In the same way that a poker placed in the fire must acquire a high temperature before it burns the hand, or as water must acquire a high pressure before it bursts the pipe, so an electrified body must acquire a certain condition before it is capable of doing work. The property possessed by such a body, which is analogous to temperature and pressure, is called *potential*.

If it be desired to transfer heat from A to B (fig. 1), it is essential that the temperature at B be lower than that at A; and if it be desired to cause a flow of liquid or gas between two such points, it is equally essential that there be a difference of pressure between them. So if we desire to transfer electricity from A to B either along a conducting wire, such as that of a submarine cable, or through the air, it is imperative that the potential at B be less than at A.

Hence, POTENTIAL *implies that function of electricity which determines its motion from one point to another.*

And, the *difference of potential*, which determines the amount of this motion, is called ELECTRO-MOTIVE FORCE. The unit of electro-motive force is called a *volt.*

The transference of electricity, such as that from a charged cloud to the earth, from a piece of glass rubbed with silk to a piece of ebonite rubbed with flannel, or a signal from Europe to America, may take place in different *times*; the path between A and B offers obstruction to the passage of electricity; the medium through which it passes, whether composed of an air space or of any conducting material, is an obstacle to be overcome. Electricity in motion does work, it excites light, decomposes liquids into their constituent elements, generates heat, produces magnetism, &c.; and the amount of work done in a given time with the same electro-motive force depends on the resistance to be overcome: hence the term RESISTANCE implies *that quality of a conductor in virtue of which it limits the amount of work being done in a given time by a given electro-motive force.*

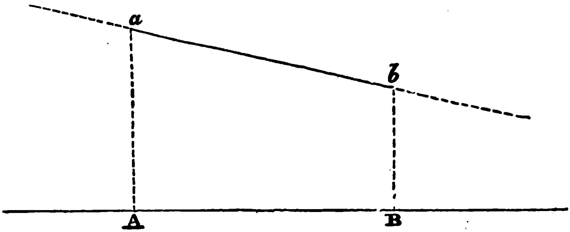

FIG. 1.

The unit of resistance is called the *ohm*, from Ohm, the German physicist, who determined mathematically the laws that regulate the flow of electricity.[1] It is convenient for brevity's sake to use a symbol to represent the ohm as we use ° to represent degrees, and ′ minutes. The symbol in general use is ω, the Greek *omega*. Thus we say that the resistance of a wire between London and Birmingham is $1,200^{\omega}$, and that of one of the Atlantic cables is $6,000^{\omega}$.

Those bodies which offer very great resistance to the passage of electricity through them are called *insulators*; those which offer very little resistance are called *conductors*. The difference between a conductor and an insulator is one of degree only. Thus the resistance of a given volume or mass of metal is very small compared with that of an equal volume of glass, ebonite, or air. The former, therefore, is a conductor, the latter are insulators. The property of matter which determines its resistance is evidently molecular, for it varies with and is dependent upon the physical structure and condition of a body as well as upon its mass. For instance, water, when a liquid, is a conductor; when a solid, an insulator; while some substances are insulators when cold, and conductors when hot.

Under certain conditions conducting bodies have the power of accumulating and retaining a quantity of electricity, and the amount which they can thus retain is termed their CAPACITY. The unit of capacity is the *farad*; but as this is too great for ordinary use, a sub-unit known as the *microfarad*, which is one-millionth part of a farad, has been generally adopted.

The transference of electricity from one point to another is called a CURRENT. A current can flow only between two points *at different potentials separated from each other by a resisting medium*. To produce a continuous current these points must be maintained at different potentials. A current

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[1] For Ohm's Law, *see* Appendix, Section A.

will flow from the higher to the lower potential so long as a difference of potential exists, but when the potentials are equalised it will cease.

Hence we see that what is understood by the term CURRENT *is an apparent transference of electricity from one point to another to produce equalisation of potential.* One current differs from another only in its *strength*—or, in other words, in the quantity of electricity which is transferred by each in equal times. The unit of current is an *ampère*, but as this unit is too great for telegraph purposes, a sub-unit known as the *milliampère* is used by telegraph engineers. The milliampère is one-thousandth part of an ampère.

A current is always supposed to flow from the point of higher potential to that of lower potential. The former point is taken to be positive to the latter; and, *vice versâ*, the lower is taken to be negative to the higher point. The terms positive and negative *currents* are frequently used, but they are misnomers. There is only one current flowing between A and B (fig. 1), and it varies in direction. It is quite correct to apply the term positive or negative to currents *with respect to a given point*, and by those terms to imply direction only, for while stationed at a given place currents may flow *from* or *towards* us; but it is quite incorrect to speak of positive or negative currents without reference to a given point, for what is a positive current at one point is a negative current at another. The current is, however, supposed to flow from the body positively charged to that negatively charged. For the sake of convenience the potential of the earth is always assumed to be *zero*; so that when we speak of the potential of a body, we really speak of the difference between its potential and that of the earth. This does not mean that the earth has *no* potential, for every thunderstorm and every telegraph line tells us that it has, and we shall have to speak of phenomena which show us that different portions of the earth's surface have different potentials at different times; but generally, the tendency of all bodies electrically connected with the earth is to fall or to rise to its potential.

A current can only be *constant* when we have two points separated from each other by an invariable resistance, and *maintained* at the same difference of potential. The material conveying the electricity, whether it be earth, air, water, or matter in any form, separately or conjointly, is called a CIRCUIT, and *the circuit is the whole path along which the electricity is supposed to flow.*

These are the principal terms, independent of all hypotheses, which are used in the science of electricity in its application to telegraphic purposes, and it is upon their clear comprehension that the ease or difficulty of the mastery of the technical details of telegraphy depends. The nature of electricity itself is not known, nor is it necessary to the telegraphist that it should be known by him. He is principally interested in its quantitative measurement and its application to practical purposes. Let him master its elementary principles, its general ideas, its properties and its conditions, and he can well afford to leave to physicists the discussion of its nature, and to mathematicians the determination of its laws.

CHAPTER II.

BATTERIES.

IF two plates of different metals be immersed in acidulated or saline water it is found that a difference of electrical potential is established between them. Let Zn (fig. 2) be a zinc plate and Pt a plate of platinum immersed in acidulated water, then as long as the two metals are kept apart, as shown, no action is observed to take place between them, but immediately they are metallically connected together, either by being brought into actual contact at any point, or by means of a wire (A, fig. 3), and so long as they remain so connected, the zinc is eaten away and the acidulated water is decomposed into its constituent elements, one of which unites with the zinc to form a salt of that metal, while the other—namely, hydrogen—appears at the platinum plate in the form of bubbles, some of which adhere to the plate while others rise to the surface of the liquid.

The wire employed to connect the two plates outside the liquid also appears to become possessed of some very remarkable properties.

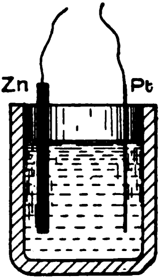


FIG. 2.

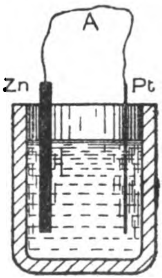


FIG. 3.

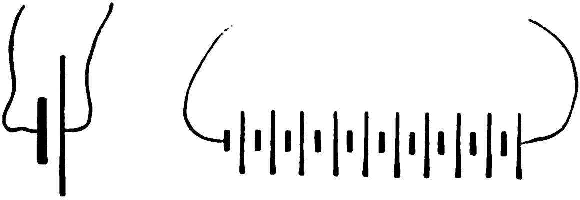
a. If it be wound round a piece of soft iron it will render that iron for the time being magnetic, and almost immediately it is removed the iron will lose all trace of magnetism.

b. If it be placed in the immediate neighbourhood of a freely suspended magnetic needle, the needle will at once exhibit a tendency to place itself at right angles to it.

c. If the wire be broken and the ends immersed in water, the water will be decomposed; oxygen collects at the end of the section proceeding from the platinum plate, and in this *nascent* state forms, as a rule, an oxide of the metal composing the wire. Hydrogen rises from the end of the section coming from the zinc plate.

The other manifestations of the energy which the wire possesses, viz. its generation of heat, its production of light, and its physiological effects, may be passed over, for they are not at present employed in practical telegraphy.

To this combination of two different metals in acidulated water the name of a *cell* is given; and a series of such cells, properly arranged, forms a *galvanic or voltaic battery*. It is convenient to represent a cell symbolically or conventionally by a thick and thin line of different lengths—the former representing the zinc and the latter the platinum plate, as in fig. 4. A battery is similarly represented by a combination of these, as shown in the same figure.



A Cell.

A Battery.

FIG. 4.

The action observed is said to be due to a current which is assumed to start from the chemically attacked zinc plate, to pass through the liquid to the platinum, and thence to return by means of the wire to its starting point. This term 'current' (p. 7) is purely a convention of language, and must not be taken to imply in any way the actual transference of matter from one point to another. The word was introduced in the early days of electricity, when electricity was believed to be a fluid, and it has ever since been retained.

The energy which the wire possesses in virtue of this transference of electricity, or, as we may now call it, the *strength* of the current, varies with the metals which are employed in the cell, as well as with the solution in which they are placed. In water acidulated with sulphuric or nitric acid the maximum effect is obtained when the metals farthest apart in the following list are used : silver, copper, antimony, bismuth, nickel, iron, lead, tin, cadmium, zinc. In water acidulated with hydrochloric acid the above order is modified as follows: antimony, silver, nickel, bismuth, copper, iron, lead, tin, cadmium, zinc.

Various theories have been advanced to account for the determination of the difference of potential resulting in this peculiar action, but they all involve theoretical considerations beyond the scope of this work.

The zinc plate of a cell is named the positive plate or element, the platinum or copper the negative plate or element. These terms positive and negative convey no meaning of themselves ; they are merely intended to denote the relative condition of the two elements. The result in the cell of the flow of current is this: the liquid itself is decomposed ; the hydrogen (H) rising at the copper (Cu) plate leaves it untouched, and the oxygen (O) attacks the zinc (Zn) plate, and gradually eats it away by forming zinc oxide (ZnO). Assuming first that pure water (H_2O) is made use of, the action which takes place may be symbolically represented thus :

Before contact—

$$\mathrm{Zn},\ \overline{\mathrm{H_2O}},\ \overline{\mathrm{H_2O}},\ \overline{\mathrm{H_2O}},\ \mathrm{Cu}.$$

After contact—

$$\overline{\mathrm{ZnO}},\ \overline{\mathrm{H_2O}},\ \overline{\mathrm{H_2O}},\ \mathrm{H_2Cu}.$$

But zinc oxide (ZnO), which is non-conducting, is insoluble in water, and consequently if pure water were used the action would soon cease, because the zinc plate would be speedily covered with an insulating compound. Hence sulphuric acid (H_2SO_4) is added, which instead of zinc oxide deposits the soluble zinc sulphate ($ZnSO_4$), so that the zinc plate is left clear for further action. The addition of H_2SO_4 has also the effect of reducing the resistance offered by the water to the passage of the current. This action is symbolically represented thus :

Before contact—

$$Zn, \overline{H_2SO_4}, \overline{H_2SO_4}, \overline{H_2SO_4}, Cu.$$

After contact—

$$\overline{ZnSO_4}, \overline{H_2SO_4}, \overline{H_2SO_4}, H_2Cu.$$

Although the deposition of hydrogen upon the copper plate is quite harmless so far as the copper itself is concerned, yet it has a very deleterious effect upon the general working of the cell. The working is impeded, and the electromotive force (p. 5) is very sensibly diminished by it. To this obstructive action the name of *galvanic polarisation* has been given. It is due to the fact that the free hydrogen accumulating upon the copper plate behaves with respect to it in a manner almost exactly similar to that of the zinc itself—that is to say, the hydrogen assumes a positive potential relative to the copper. The result is very nearly the same as if two plates of zinc were opposed to each other. If such were the case, no difference of potential could be determined, and consequently no current would be obtained.

It will thus be seen how essentially necessary a matter it becomes to prevent the accumulation of free hydrogen upon the negative plate.

This object has been attained in various ways.

In Smee's battery the deposition of hydrogen on the negative plate was prevented by mechanical means. He coated the plate with finely-divided platinum, and the hydrogen, being readily discharged from its roughened surface, rose in bubbles to the surface of the liquid. This battery is not practically employed in telegraphy now, and may therefore be passed over without further comment.

In 1836 Daniell invented the battery which bears his name, in which he succeeded in completely eliminating polarisation. This battery appears under various modifications, but the principle, which is as follows, is the same in all.

Zinc and copper are employed as the positive and negative plates respectively, but instead of being in the same liquid they are placed in different liquids, which are separated from each other by a porous partition. The liquid surrounding the zinc is diluted sulphuric acid ; that surrounding the copper a solution of copper sulphate ($CuSO_4$). The part played by the latter is the distinguishing feature of Daniell's battery. The instant the two plates are connected with each other action commences ; the zinc plate is attacked, and a salt (zinc sulphate) of that metal is formed ; the hydrogen liberated at the copper plate reduces the copper sulphate, expelling from it the metallic copper, which is thrown down in a perfectly pure state upon the copper plate of the cell. The hydrogen then, by combining with the radicle SO_4, forms sulphuric acid (H_2SO_4), which, finding its way through the porous partition into the zinc cell, maintains the solution there at a constant strength.

The consequence of this is that the positive plate is gradually eaten away, and the liquid surrounding it becomes a solution of the zinc sulphate ; the copper sulphate is reduced, but the negative plate—the main point to be looked after—is kept perfectly clean and bright by the deposition upon it of pure metallic copper thrown down by the hydrogen from the solution of copper sulphate.

The action of a Daniell's battery may be symbolically represented thus :

Before contact—

$$\mathrm{Zn},\ \overline{\mathrm{H_2SO_4}},\ \overline{\mathrm{H_2SO_4}},\ \|\ \overline{\mathrm{CuSO_4}},\ \overline{\mathrm{CuSO_4}},\ \mathrm{Cu}.$$

After contact—

$$\overline{\mathrm{ZnSO_4}},\ \overline{\mathrm{H_2SO_4}},\ \overline{\mathrm{H_2SO_4}},\ \|\ \overline{\mathrm{CuSO_4}},\ \mathrm{Cu}\overline{\mathrm{Cu}}$$

The electro-motive force of a Daniell cell is taken to be 1·079 volt.

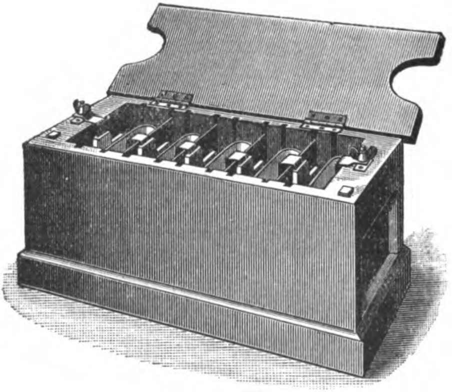


FIG. 5.

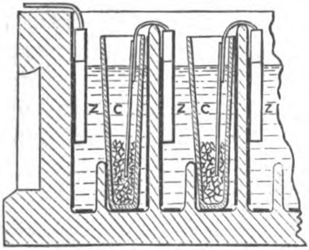


FIG. 6.

One of the most convenient of the various forms of Daniell's battery, and that which has been much employed in the various telegraph systems, is the following :—

A teak trough (teak is selected on account of its durability, and from the fact that it shows little tendency to warp) is divided into five spaces or cells, which are separated from each other by slate partitions (figs. 5 and 6). It is then coated thoughout, including the slate partitions, with marine glue.[1] The object of this is to render the trough perfectly water-tight and prevent any leakage

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[1] Marine glue, patented by Jeffrey in 1842, is formed by dissolving one pound of caoutchouc in four gallons of naphtha, and allowing this

from one cell to another. On the adhesive surface thus formed a glass plate is fixed at the sides and bottom of each cell, as otherwise the materials of the battery would adhere to the cells. At the right of each cell is placed a porous earthenware pot, kept in position by a small ridge running parallel to the sides of the cell, and in which is inserted a thin copper plate four inches square. Opposite the porous pot in each cell is placed the zinc plate, four and a half inches wide and two and a half inches deep.

The porous cells are then filled to about one third of their height with crystals of copper sulphate, and pure water is poured in up to the level of the top of the zinc plate. A short time is allowed for this solution to force the air from and to saturate the porous earthenware, after which the zinc divisions are filled with pure water to within a quarter of an inch of the top of the zinc plates. The copper plate of one cell is connected with the zinc of the succeeding cell by a copper strap passing over the slate partition. The plates, in fact, are permanently connected with each other, and are issued in pairs. One end of a copper strap is fastened to the copper plate by means of a copper rivet, and the other end, after being well tinned for about $\frac{3}{4}$ inch so as to insure good metallic connection, is cast into the zinc plate.

The last copper and the last zinc are each connected to a brass binding screw or terminal, which become respectively the positive and negative poles of the battery.[2]

In setting up a Daniell's battery there are various points to which special attention must be given, a disregard of any one of which will more or less mar its action.

a. The copper sulphate, which is manufactured by dissolving either pure copper or scales of cupric oxide in

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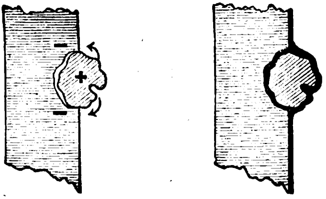
to stand for ten or twelve days. Two parts of shellac are then added to one part of this mixture, and the compound thus obtained is cooled on marble slabs.

[2] Note that the connection at the *negative plate* is the *positive pole* and that at the *positive plate* the *negative pole.*

sulphuric acid, must be of the purest possible description. The foreign ingredient mainly to be found in it is iron, whose presence may be ascertained by the following test :—The copper sulphate, like all the copper salts, forms with excess of ammonia a deep blue solution, whilst the iron sulphate, under similar circumstances, is precipitated as a dirty-brown powder. If, therefore, to a solution of copper sulphate ammonia be added until this deep blue colour is obtained, the amount of iron present, provided there really is any, can be readily known. In good copper sulphate it should never exceed ·55 per cent.

b. The metals, but more especially the zinc, should be as pure as can possibly be obtained. This applies to the metals not only for Daniell's battery, but for every other species of battery as well. For, if any foreign ingredients make their appearance the action of the battery is seriously interfered with ; the effect is the same as though a number of small plates of different metals were opposed to each other. Local currents are generated, the plates are needlessly attacked, and the general condition of the battery is impaired. Let fig. 7 represent a portion of a zinc plate containing several particles of iron, tin, or lead, which are the usual impurities to be met with in it. The contact of either of these metals (say lead) with zinc causes the latter to have a positive potential relatively to the former, and if the impurity be on the surface of the plate, a liquid arc intervenes so that, all the required conditions being present, a current starts from the zinc to the lead through the liquid (fig. 7 A). Owing to the *local action* which is thus commenced, the zinc plate is eaten away to no purpose, the liquid is decomposed, and the hydrogen which is liberated



A FIG. 7 B

partially polarises the zinc plate (p. 12). The consequence is that the resultant[3] current may be materially weakened, at the same time that the battery is proportionately injured.

The possibility of anything like this occurring is prevented in various ways. Pure zinc, on account of its expense, cannot be employed. The object, however, is attained either by covering the zinc with mercury—a process called *amalgamation*, or by employing a solution of zinc sulphate in place of acidulated water in the zinc cells.

Mercury possesses the power of combining with several of the other metals, and forming alloys, which are known as amalgams. Zinc may be amalgamated by being first cleaned with hydrochloric or sulphuric acid and then rubbed over with mercury. The ordinary liquid arc can then no longer intervene between the various impurities in the plate—a mercurial metallic arc takes its place (fig. 7 B). Consequently the conditions for a local current are destroyed, and no local action on the surface of the plate can take place; at the same time a perfectly homogeneous surface is presented for the general working of the battery.

Amalgamation, however, is not adopted in the Daniell's battery employed in telegraphy; it has been found more advantageous in every respect to adopt the suggestion (first made by Mr. Fuller in 1853), to employ a solution of the zinc sulphate if the battery is to be brought at once into use. But it will be seen (p. 13) that zinc sulphate is spontaneously formed in the action of the battery. Consequently if the action be allowed to go on for some time, say forty-eight hours, before the battery is actually required, it becomes unnecessary to use at the outset anything more than water in the zinc cell.

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[3] The term *resultant* implies the ultimate effect of a series of actions which may be similar or opposite in their character. There may be several causes present to determine currents in the same or different directions, and the *resultant current* is the final result or algebraic sum of the currents arising from all those causes.

c. The copper sulphate used must be in the form of crystals, and not a powder. In the latter state it dissolves slowly, and in time adheres so tenaciously to the cell that it can with difficulty be removed.

d. Care must be taken that the zinc plate does not touch the porous cell. Should it do so a local action commences at once, due to the fact that some of the copper sulphate makes its way through the porous partition into the zinc division, and may come in contact with the zinc plate. Now the compound radicle SO_4 (which together with Cu makes up copper sulphate) has a far greater affinity for zinc than for copper, it consequently leaves the latter which is precipitated in a metallic state on the side of the porous partition or upon the zinc plate as a black spongy deposit.

Batteries such as those described, in which these precautions have been taken, will remain in constant action for some weeks without requiring any attention whatever. At the expiration of a month it becomes necessary to refresh them, and the following points must then be seen to:

a. The solution in the zinc cell should not be supersaturated with the zinc sulphate. The result of this would be the deposition of crystals on the zinc plate, the copper strap, and along the edges of the cell, whereby the liquid would be carried off by capillary action, and short-circuits formed between the cells. Should this occur, the crystals must be removed, a portion of the liquid drawn off, and the cell refilled with water. The solution is in the best possible state when it is semi-saturated with the zinc sulphate; its conducting power is then at a maximum.

b. The zinc plate should be examined, and if there be any quantity of what at first sight appears to be black mud upon it, this should be scraped off and carefully laid aside. The 'black mud' contains the purest copper, and its presence on the zinc plate is thus accounted for:—Liquids differing in specific gravity and separated from each other either by gravity alone or by a porous diaphragm, possess the power of gradually diffusing into each other, and in time forming a mechanical mixture. As the specific gravities of a solution of the zinc sulphate and of a solution of the copper sulphate are different, they mingle with each other in course of time through the porous partition; but no sooner does the copper sulphate enter the zinc cell than the radicle SO_4 leaves it and unites with the zinc, for which, as has been already observed (p. 18, *d*), it has a more decided affinity. The copper of the copper sulphate is thus set free and deposited on the zinc plate. The action of the battery is thereby gradually weakened, until eventually, when the zinc plate is covered with copper, the current entirely ceases to flow. It is just in effect as if two plates of the same metal were employed, between which no difference of potential can of course be determined. The copper, on account of the finely-divided state in which it is precipitated from its sulphate, speedily becomes oxidised and loses its bright metallic lustre.

c. The copper cell should be examined, and if the crystals of copper sulphate are nearly exhausted a fresh supply should be added, and water poured in to supply the place of that which may have been carried off by evaporation.

d. Special care should be taken that the connecting straps and the terminal binding screws are kept bright and clean.

The battery, at the end of two months, if it has been in constant use, and three months if it has been but moderately worked, should be thoroughly cleaned throughout. The solution in the zinc cell is first drawn off by means of a syringe and placed for further use in a vessel, into which it is advisable to throw a few scraps of zinc, for any copper which may be held in solution will thus be thrown down and only the zinc sulphate left. The liquid in the copper cell is drawn off in the same manner, any crystals which may remain being taken out. The plates are next removed, well scraped and cleaned, the 'mud' obtained from the zinc being carefully preserved in a box provided for the purpose.

The porous cells are then cleared of the copper with which they have become partially encrusted. The presence of copper on them cannot well be prevented; it is one of the results of a local action which owes its origin partly to the intermingling of the zinc sulphate and the copper sulphate, and partly to the impurities which, in the shape of metallic dust or small pieces of carbon, are occasionally to be met with in the porous cell itself. This deposition is prevented to some extent by the plan adopted with a view to check the diffusion of the copper sulphate solution into the zinc cell, which is the saturation of the porous cell with melted paraffin wax, except at the part immediately opposite the zinc plate. The cells themselves must be well rinsed out, the metal deposited in them scraped off, and every particle of foreign matter removed.

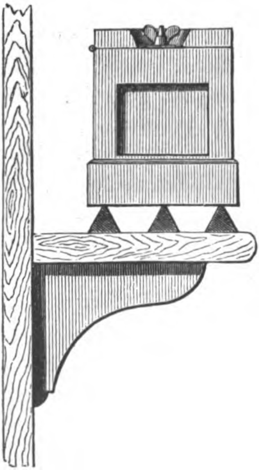

FIG. 8. ⅛th real size.

The battery is re-charged in the same way as it was originally charged. The porous pots are replaced, the plates refitted, new ones being substituted for any which are found to be imperfect; the porous cells are charged with copper sulphate crystals and filled to the right level with pure water, and the solution drawn off from the zinc cells is diluted with pure water and replaced.

It is essential that the battery shall be placed in a dry position, free alike from the extremes of heat and cold, and be protected as far as possible against the accumulation of dust upon it. If it rests on damp ground it is worked unnecessarily and its force is consequently reduced, for the damp ground more or less short-circuits the battery. To prevent this the batteries are sometimes placed upon wooden racks, the boards of which should be of a triangular section, as shown in fig. 8.

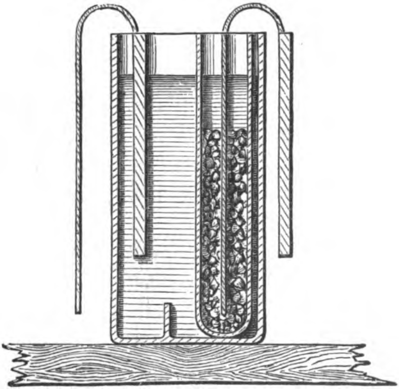

FIG. 9. ⅓rd real size.

The various forms and sizes of Daniell's battery are devised chiefly with reference to the conditions under which they are ordinarily used. One, which has been employed to a considerable extent in Great Britain, is the 'Chamber' form, introduced by Muirhead about 1858. Into a vessel of glazed porcelain or of ebonite a flat porous earthenware pot, as shown in fig. 9, is placed, the pot having been previously saturated, except at the part opposite the zinc plate, with melted paraffin wax. This porous pot contains the copper plate with the solution and crystals of the copper sulphate ; the zinc is placed in the porcelain vessel, which is filled up as before with water. The action as well as the mode of treatment is exactly similar to that which has been already described. At a large station, where every facility is afforded for cleaning batteries, the 'Chamber' cells can be more easily handled than those of the trough ; whilst if it be found necessary to employ increased battery power, a few of these cells can be very conveniently added to those previously in use.

The conditions to be fulfilled by a good working battery for ordinary practical purposes are :

1st. That the electro-motive force and internal resistance shall be constant.

2nd. That the materials used in the construction and maintenance of it shall not be expensive.

3rd. That when the battery is not being worked there shall be no waste of the materials employed ; in other words, there shall be no local action.

The Daniell battery fulfils the first condition as satisfactorily as any battery which has yet been invented.

Local action, causing a variation in the strength of the current, does take place, as was pointed out at p. 16, *b* ; but if the precautions indicated above to prevent this are taken, the variation is so slight as to be imperceptible in practical working, and no inconvenience is felt from it.

In point of cheapness, both in construction and maintenance, the Daniell contrasts favourably with its rivals. A battery of five cells similar to that which has been described above, charged and ready for use, costs 15*s.* ; in the course of twelve months, if the battery has been fairly worked, ten pounds of sulphate of copper are used ; and, including the labour of refreshing and cleaning out, the annual cost of the maintenance of it may be set down at 7*s.* 6*d.*

It does not fulfil the third condition. Even when Daniell's battery is at rest there is a waste of the materials employed. By reason of the action to which reference has been made (p. 16, *b*), the liquids diffuse into each other through the porous cell, and the copper sulphate is gradually reduced.

On account of this the porous cells of a Daniell battery which is required only for occasional use are made considerably thicker than those already described ; in this way the mixture of the two solutions is retarded, but at the same time the resistance to the current as it passes from plate to plate is increased.

Several modifications of the Daniell's battery, to which reference will be made hereafter, have been introduced with a view to prevent as far as possible the diffusion of the liquids.

Next to Daniell's, the battery which of late years has obtained most favour in Great Britain is that invented by the late M. Leclanché, of the Eastern Railway of France, in 1866.

Zinc is employed in this cell as the positive element, and carbon as the negative element. The depolarising agent is manganese dioxide (MnO_2), the pyrolusite of mineralogists. This mineral is to be found in Germany, France, Hungary, Brazil, Cornwall, Devon, &c., and is one of the main sources of supply of oxygen. For use in the battery it is broken up into coarse grains and carefully sifted; in this way all that exists in the form of a powder is got rid of. It is mixed with an equal volume of carbon crushed to about the same state as the dioxide of manganese itself. An earthenware porous pot, into which a plate of carbon has been placed, is then filled with this mixture. The zinc, which is in the shape of a rod, is surrounded by a solution of chloride of ammonium (NH_4Cl), the ordinary sal-ammoniac; and when it is connected with the carbon plate the following action takes place:—The zinc is attacked by the chlorine; chloride of zinc is formed, and dissolved in the liquid. The other constituent of the sal-ammoniac besides chlorine, namely, ammonium (NH_4), is immediately, on being set free, oxidised by the dioxide of manganese, and ammonia and water are thereby formed. So long as this simple action goes on unimpeded by any other, galvanic polarisation is prevented, and the strength of current obtained from this combination remains constant. The manganese dioxide is reduced to a lower oxide known as the sesquioxide (Mn_2O_3). What actually takes place may be symbolically represented as follows:

Before contact—

$$Zn + 2NH_4Cl \parallel 2MnO_2 + C.$$

After contact—

$$ZnCl_2 + 2NH_3 + H_2O \parallel Mn_2O_3 + C.$$

The results of the action are, the formation of chloride of zinc, free ammonia, and water, and the reduction of the dioxide of manganese to the sesquioxide.

Three sizes of cells are made, the form generally adopted being that shown in fig. 10. Into a glass vessel containing a solution of sal-ammoniac a zinc rod is placed; the porous pot containing the carbon plate and the mixture of pounded carbon and dioxide of manganese is next inserted into it. This carbon plate is fitted with a lead top, into which a binding screw is fixed for the purpose of connecting it with the wire proceeding from the neighbouring zinc. Lead is employed in preference to any other metal, chiefly on account of its stability, and it is of great importance that good contact should be insured between it and the carbon.

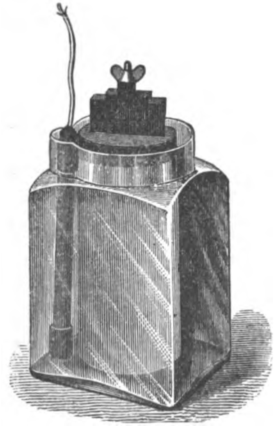

FIG. 10.

In setting up a Leclanché's battery the following points must be carefully attended to:

a. A strong solution of sal-ammoniac should be used (not crystals with a supply of water); and care should be taken that none be spilt on the edges of the cell or on the porous pot, as this is apt to give rise to capillary and subsequent chemical action. In the action of the battery double salts—oxychlorides of zinc and zinc-ammonic-chlorides—are formed. They are the result of a secondary action which makes its appearance after the battery has been kept steadily at work for a short time, and which seriously interferes with its constancy. So long as chlorine only is set free at the positive plate and ammonium liberated at the negative, so long is galvanic polarisation averted; but as soon as oxygen arises at the zinc and hydrogen unconsumed accumulates on the carbon—which actually does occur after continued working for a few minutes—galvanic polarisation ensues, a counter current is generated, and the resultant strength of current obtained from the battery is reduced. This galvanic polarisation, along with every trace of secondary action, speedily disappears if the battery be left to itself; and it is not observable at all if the battery is called into play only at intervals.

b. The porous cell should stand not more than two-thirds its height in the solution, as the latter tends to creep up the pot by capillary action, and when the water has evaporated, a crust of the salt is formed in the neck of the vessel which may short-circuit the cell.

c. The connecting wires from the carbons to the succeeding zincs must be carefully protected. This is done by covering them with paint, tar, gutta-percha, Chatterton's compound,[4] or any other substance of a similar nature. India-rubber has been found to answer the purpose as well as anything. The object of this is to prevent the free ammonia given off in the action of the battery from reaching the metallic wire; if the wire is exposed to the smallest

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[4] Chatterton's compound is a mixture of resin, Stockholm tar, and gutta-percha, in the following proportions:—

1 pound of resin.
1 ,, ,, Stockholm tar.
3 pounds of gutta-percha.

extent, the ammonia attacks it and gradually eats it through. The result is that the circuit is broken, and the battery is for the time rendered perfectly useless.

d. The dioxide of manganese which is used is of the form known as needle manganese. All the dust should be carefully removed from the coarse powder into which this is broken up. Leclanché found the presence of a small amount of fine powder in the porous pot to be not only injurious to the action of the battery, but also to interfere greatly with its constancy.

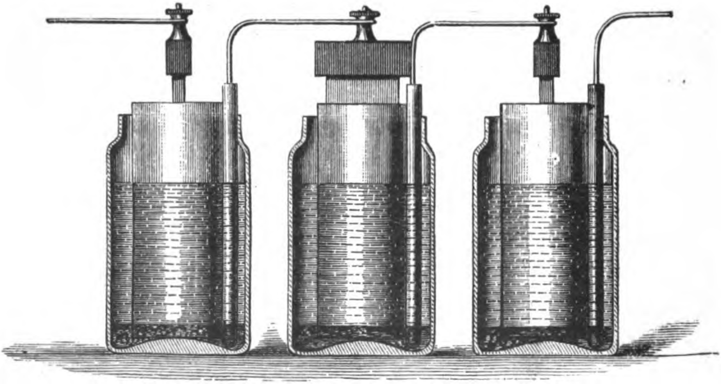

FIG. 11. ¼th real size.

The top of the carbon pot is covered with marine glue, or an asphalte composition. Care has to be taken, however, to leave a hole in the same so as to allow the air to escape when the pot is placed in the solution. The cells of a Leclanché's battery are joined up in the usual way to form a series. Fig. 11 shows how three of these cells are so connected.

A Leclanché's battery thus set up will remain in good condition for a period varying according to the amount of work which it is called upon to do. If it be required only for occasional use, such as the ringing of bells for either signalling or domestic purposes, or if it be employed upon a speaking circuit along which comparatively little traffic passes, it is really difficult to say how long the battery would last, provided the precaution be taken to add every now and then a little water to the liquid in the cells to compensate for evaporation, and if need be cleaning the zincs. On busy circuits, however, it cannot be relied upon to anything like the same extent as the Daniell, because (unless the current is very weak) the hydrogen is liberated at the surface of the carbon faster than the MnO_2 can be deoxidised, and polarisation ensues. The zinc salts which are formed do not admit of being readily dissolved by the solution of sal-ammoniac; the secondary action already alluded to makes itself felt; the strength of the current consequently varies, and constancy is lost. And not only this; the porous pots crack in considerable numbers; the glass cells occasionally break from no apparent external cause, and the connecting wires, if exposed to the slightest extent, are very liable to be eaten through by the free ammonia given off. A local action, too, is observed to take place between the connecting wire, the brass binding screw, and the lead top of the carbon plate. Salts of lead are there formed, causing disconnections in the circuit. An attempt was made to get rid of this local action by welding or soldering the wire on to the lead top of the carbon plate, and issuing the elements in pairs, as in the case of the form of Daniell's battery which has been described (p. 15); but this is not convenient. White lead is also apt to form in considerable quantities at the junction of the carbon with the lead.

In the conditions to be fulfilled by a good working battery, Leclanché's battery possesses one decided advantage over Daniell's, and that is, that there is no waste of materials when the battery is not actually at work, for the diffusion which takes place in Daniell's battery cannot exist with the single fluid in Leclanché's. In point of cheapness, however, as well as constancy, the Daniell's battery holds its own. A five-cell Leclanché, of the form described, would cost 17*s.* 6*d.*; the cost of maintenance, like the constancy, will vary according to the purpose for which it is employed.

Leclanché dispensed with the porous pot by agglomerating into one mass under hydraulic pressure a mixture of 40 parts manganese dioxide, 55 parts powdered carbon, and 5 parts gum lac resin. Solid blocks are thus formed, which are placed against the carbon plate and held there by india-rubber bands. The durability of the battery is thus considerably increased, and its internal resistance reduced.

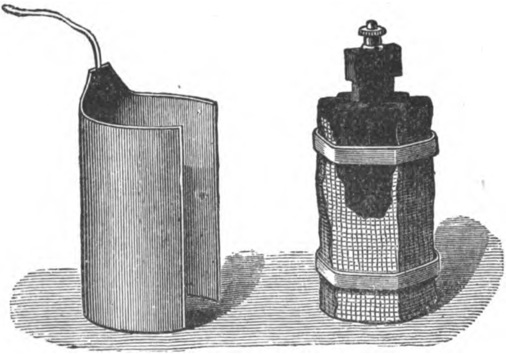

FIG. 12.

In one form of the Agglomerate Leclanché, as they are called, a flat carbon plate has a block on each side of it, and the zinc is the usual rod. This, however, perhaps owing to some defect in manufacture, is not entirely satisfactory; but another form, shown in fig. 12, and known as the Six-block Agglomerate, is extremely good. It consists of a central carbon block grooved to take six agglomerate cylindrical rods which are placed around it; the combination is wrapped round with a piece of canvas and kept together by rubber rings. In this case the zinc element is in the form of a cylinder, which almost completely surrounds the agglomerate combination and so further tends to reduce the resistance of the cell. In the figure the two elements are shown separate, and part of the canvas covering is removed from the agglomerate combination.[5]

The electro-motive force of the Leclanché cell at its best may be 1·6 volt, but in practice it cannot be relied upon to give more than 1·4 volt.

The so-called dry cells have recently been so much improved that they are fast coming into more general use, but as a rule the electromotive force of this type of cell diminishes very rapidly after a comparatively short time, while its internal resistance increases abnormally, frequently amounting to hundreds of ohms. These cells have, however, the advantage of extreme portability, and in the best forms of dry cell this advantage may outweigh the disadvantages due to the above-mentioned defects. One other important point is that after once being set up they require no further attention until renewal is necessary.

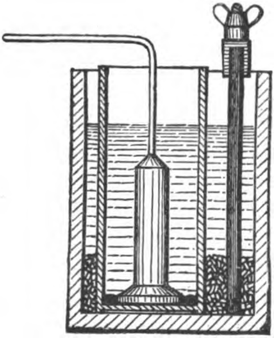

FIG. 13.

Fuller's mercury-bichromate battery (fig. 13) is very extensively employed. The zinc rod, which is of the form shown, cast on a copper wire, is placed in a porous pot, with two ounces of mercury, by which the zinc is kept self-amalgamated (p. 17). The carbon plate and porous pot are then inserted in a quart-size earthenware jar, into which are

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[5] In a later form the end of the zinc is cut off at an angle, and the zinc is suspended clear of the bottom of the cell.

placed four ounces of bichromate of potash. The outer jar is then filled up to within two inches of the top with water and four ounces of sulphuric acid; water and a quarter of an ounce of sulphuric acid being added in the porous pot.

The battery is ready for work as soon as it is charged, but its full strength is not attained for some hours. Polarisation takes place in this as in most other batteries; its effect when working through low resistance is to vary the strength of the current, but when working through a high resistance the variation, even if it occurs, is not perceptible.

The electro-motive force, which is the main consideration in all batteries, is equal to 2·14 volts per cell—about twice that of the Daniell cell. By varying the thickness of the porous pot and the strength of the solution, the internal resistance may be made to range from half an ohm up to four ohms, according to the work which the battery is called upon to perform.

The maintenance of this battery is inexpensive, and the labour required to keep the cells in good working order is not considerable. So long as the solution in the earthenware jar remains of a deep orange colour no attention is required; but when it assumes a bluish tint a portion should be withdrawn, and a further supply of bichromate of potash, sulphuric acid, and water added; at the same time it may be necessary to withdraw a part of the solution from the porous cell, replacing it by water.

The zinc should remain bright and silvery in appearance when it is raised out of the solution. If it be dull or black it shows that there is not sufficient mercury. Care should be taken to use the full quantity—two ounces for a quart-size cell.

Other forms of constant batteries occasionally (but now very rarely) employed for practical purposes in England are Grove's and Bunsen's. A Grove's cell consists of a plate of zinc as the positive element, in dilute sulphuric acid, separated by means of a porous partition from a plate of platinum (Pt), the negative element, which is immersed in concentrated nitric acid (HNO_3). When the circuit is completed the zinc is attacked, the soluble sulphate of zinc is formed, and the liberated hydrogen passing through the porous pot decomposes the nitric acid, forming water and nitrogen peroxide (N_2O_4), which, unlike hydrogen, is incapable of adhering to the platinum plate, and rises in the form of a dark brown poisonous vapour.

The action which takes place may be symbolically represented thus :

Before contact—

$$Zn + H_2SO_4 \parallel 2HNO_3 + Pt.$$

After contact—

$$ZnSO_4 \parallel 2H_2O + N_2O_4 + Pt.$$

The low resistance of the Grove's battery combined with its high EMF. makes it well adapted for experimental purposes where a considerable current is required through a circuit of low resistance. For such purposes, however, secondary cells (p. 36) are now more generally employed.

Bunsen's battery is similar to Grove's, with the exception of the negative element. The expensive platinum employed in Grove's battery is replaced in Bunsen's by carbon specially prepared for the purpose.

It has been already mentioned that two liquids varying in specific gravity possess the power of diffusing into each other, and ultimately forming one mechanical mixture. Graham showed that this process of diffusion was an extremely slow one, and Fick advanced the now universally accepted theory that the rate of diffusion among different liquids varies inversely as the square root of their specific gravities. Advantage has been taken of these facts in the arrangement of galvanic batteries, in which the porous partition is dispensed with altogether, and the liquids are kept apart by gravity alone. A copper plate is placed at the bottom of the vessel (fig. 14), and over it is poured a saturated solution of copper sulphate. A less dense solution of zinc sulphate in which the zinc plate is immersed is placed over this. The connecting wire leading to each succeeding cell is covered with india-rubber or gutta-percha, to protect it from the free acid formed in the action of the battery.

Such is the principle of all the gravity batteries. Unless aided by some mechanical contrivance they have not proved a success. Absolute rest, so that the liquids may not be shaken up together, is indispensable for their working: and even when this condition is fulfilled, the waste of zinc and copper sulphate which takes place is far greater than in the case of the ordinary Daniell battery.

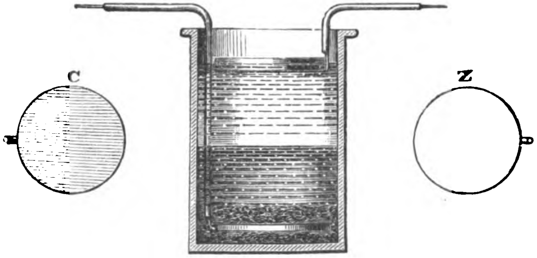

Fig. 14.

The Minotto is one of the earliest and perhaps the best known of all forms of gravity battery.

It consists of a round glazed earthenware jar, in the bottom of which is placed a circular copper disc with three holes perforated in it, as shown at c in fig. 15. Into these holes is slipped the conductor of an insulated copper wire, which has been stripped of its covering for a distance of about 2½ inches. This is well hammered into the copper plate so as to insure perfect metallic contact without the employment of solder, which is liable to introduce a danger of local action. If solder is used instead of the threading through, the joint has to be very carefully insulated. Over the copper plate is packed from eight to twelve ounces of copper sulphate, and above this is placed a piece of linen or blotting-paper. Next comes a layer of moistened sawdust, or, in the event of sawdust not being procurable, of clean river sand, which is to be preferred to the sea sand. This is likewise covered with a piece of blotting-paper, upon which finally rests the zinc plate, fitted with a brass terminal, as shown in fig. 15. The insulated wire, the end of which has been firmly welded into the copper plate, is led up through the copper sulphate and the layer of sawdust or sand, which is tightly pressed down, and is attached to the zinc of the succeeding cell. The whole is filled up with clean water to a height of about an eighth of an inch above the level of the zinc plate.

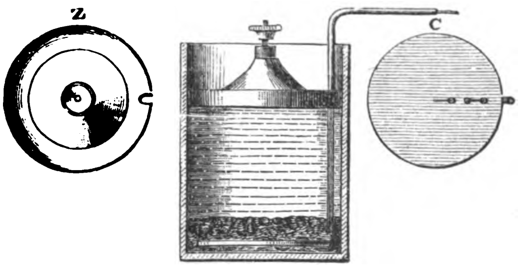

FIG. 15. ⅙th real size.

The connecting wire should be very carefully examined, and rejected if the trace of a flaw in the insulating covering is detected. No covering of tape should ever be employed, for the moisture spreading in time wholly over it, plays the part of a return wire, and places the cell on 'short circuit.'[6] To prevent local action between the zinc plate and the brass

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[6] A cell is said to be on 'short circuit' when the plates are directly connected by means of a conductor of no resistance.

terminal, it is necessary to apply a coating of coal tar and resin on each side of their junction.

This form of battery has been employed for many years in India, and has given every satisfaction; the number of cells in use at almost all the offices is comparatively so limited that they can all receive daily attention; and if the froth generated in the action be then drawn off and replaced by a little pure water, the cells will continue at work for a very long period. From eighteen to twenty months is the average life assigned to them. It is stated that even upon important lines they sometimes last for two years; and upon local lines, where little work is done, for as long as thirty to thirty-two months. No other form of battery is used in India for telegraph circuits. None but some other modification of the Daniell could successfully compete with it; for the means of transit are generally so slow and expensive that considerable inconvenience might arise were any materials employed in the battery which did not form a portion of the general stock-in-trade of the country. The copper sulphate possesses this advantage in being an article of commerce; it is manufactured amongst the natives, by whom it is largely employed for medicinal purposes, and it can be procured at very short notice whenever the necessity arises.

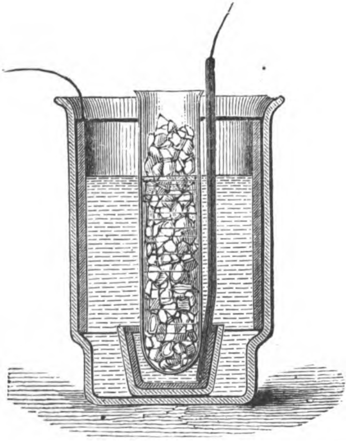

Fig. 16. ⅛th real size.

Another form of gravity battery is the Meidinger, which is extensively used in Germany. It consists of a glass cell of the shape shown in fig. 16, with a smaller glass vessel inside it and resting on its bottom. Into the latter a copper cylinder is placed; to this a copper wire covered with guttà-percha is attached, and thence passes to the next cell. Into the cell a zinc cylinder is inserted, and is supported upon the projecting ledge. A wooden lid covers the whole, and through an aperture cut in its centre a glass vessel in the form of a test tube with a few holes perforated in the bottom is suspended, and reaches about halfway down into the smaller vessel.

This cell is set up by filling the test tube with crystals of the copper sulphate, and the vessel, up to within about a quarter of an inch of the top of the zinc plate, with a solution of the magnesia sulphate ($MgSO_4$. Epsom salts). The copper sulphate, after dissolving, passes through the holes in the test tube, and from its greater specific gravity settles at the bottom of the vessel. The zinc and magnesia sulphates, being specifically lighter, remain on the surface until, by diffusion, they gradually mingle with the copper sulphate; it then becomes necessary to recharge the cell. In this, however, as in every other form of gravity battery, it is essential that the solutions shall remain undisturbed, and that every precaution be taken against their being shaken up and thereby mixed with each other.

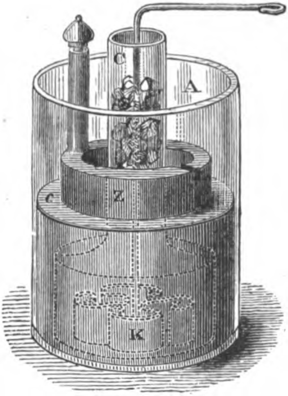

FIG. 17. ⅛th real size.

In Siemens and Halske's form of Daniell's battery (which is also a German pattern) the main point is the substitution of specially prepared paper pulp in place of the porous earthenware or unglazed porcelain partition of the ordinary form. One of these cells is shown in fig. 17. A is a glass vessel, at the bottom of which a cross of sheet copper of the form K is placed; over this stands a tube, C, of unglazed porcelain, having its lower part widened out bell fashion. Into this tube a supply of crystals of the copper sulphate is placed and water filled in. The glass vessel is packed as far as *c* with the paper pulp, which in its preparation has been treated with sulphuric acid, and worked up into a homogeneous glutinous mass. This is well pressed down, and over it stands the zinc cylinder Z surrounded with water. A copper wire, covered with gutta-percha, proceeds from the copper plate K through the sulphate of copper solution to the next cell, where it is attached to a neck cast in the zinc plate similar to that shown in the figure.

The various batteries already described generate electricity by chemical action without the aid of a current from another source, and are therefore called *primary* batteries. When, however, plates of similar metal are immersed in a proper solution, and a current is passed through them, decomposition of the liquid follows,[7] gases adhere to the plates, 'polarisation' ensues and a battery is formed. This is a '*secondary*,' '*accumulator*,' or '*storage*' battery: it accumulates or stores energy under the influence of a primary current. When the energy is being stored the battery is said to be 'charging,' and when the accumulated energy is being liberated to be 'discharging.' If two platinum wires were immersed in dilute sulphuric acid and thus polarised by the liberated gases, the return of electric energy would be momentary and small, but if the wires were replaced by large lead plates and the current allowed to act upon them and the acid for some considerable time, then a much greater supply of energy could afterwards be stored. The production of a secondary current in this way was discovered in 1801, but no practical use was made of the fact until Planté in 1860 introduced batteries of remarkable power constructed of two sheets of lead rolled together, and separated by a strip of insulating material. The plates

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[7] This is called 'electrolysis.'

were placed in a solution of dilute sulphuric acid and subjected to electrolysis. The oxygen set free at one of the two plates formed peroxide of lead (PbO_2) upon its surface, while the hydrogen evolved against the opposite plate left there pure soft metallic lead. As peroxide of lead is a conductor of electricity, it follows that two dissimilar electrodes [8] were obtained, and conditions established analogous to those of an ordinary voltaic battery.

The amount of peroxide of lead formed, or the quantity of energy stored, determines the capacity of the battery for doing external work. Theoretically an equivalent supply of electrical energy to that put in ought to be given out, but this cannot be attained in practice. The Planté method of producing useful plates was slow and tedious. Faure in 1881 much increased the capacity of secondary cells and expedited their formation by coating the lead plates with a mixture or paste of red lead or minium (Pb_3O_4) and sulphuric acid (H_2SO_4). This results in the formation of lead sulphate ($PbSO_4$). When a current is sent through such a cell for the purpose of 'charging,' the paste upon the negative electrode (the *positive* plate of the cell) is converted into lead peroxide (PbO_2), and the paste upon the positive electrode (*negative* plate) is reduced to spongy lead. The chemical action, though really of a more complex nature than is shown below, may nevertheless be symbolically represented in its first and last stages thus:

Before charging—

$$PbSO_4 + 2H_2O + H_2SO_4 + PbSO_4.$$

After charging—

$$PbO_2,\ \overline{H_2SO_4},\ \overline{H_2SO_4},\ \overline{H_2SO_4},\ \overline{Pb}.$$

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[8] An *electrolyte* is any compound substance which in solution is capable of being decomposed into its constituent elements by the passage of a current of electricity. The poles—the conductors by which the current enters or leaves the electrolyte—are called *electrodes*; that by which the current enters is the *anode* or positive pole; that by which it leaves, the *cathode* or negative pole.

It will thus be seen that in the process of 'charging' the solution becomes more and more acid, since (as shown above) the H_2O is displaced by H_2SO_4; the density of the liquid in consequence gradually increases. The cell is said to be fully 'charged' when as much as possible of one plate has been converted into red peroxide of lead, of the other into grey spongy metallic lead, and the liquid has acquired its greatest density. The density of the liquid, when measured by a hydrometer, should show, when charged, 1·25 and when discharged 1·18. The hydrometer is a good indicator of the condition of the cell, and it is a good plan to provide one for each cell. It is easy to tell when a cell is fully charged by the hydrometer and by a voltmeter; the former will show 1·25 and the latter 2·5 volts. The liquid becomes milky through the gases that are evolved when the plates are saturated.

Modern practice varies very considerably. Some manufacturers coat the positive plate (*i.e.* that plate in connection with the *negative pole* of the charging dynamo) with a paste of PbO (litharge, or monoxide of lead) and acid. Others use minium, lead sulphate, and litharge mixed; but in all cases the ultimate action is as though one plate consisted of lead peroxide and the other of lead.

It is important to notice that the lead exchanges the radicle SO_4 for the oxygen contained in two molecules of water, and thus liberates four atoms of hydrogen, two of which combine with the SO_4 (liberated from the $PbSO_4$) to form H_2SO_4, and the remainder unite with the O of the PbO to form H_2O, leaving the lead itself in a grey spongy condition. In this, therefore, as in the former case, the solution becomes more and more acid and therefore denser during the charging process.

The secondary or return current produced in discharging the cell practically reverses the chemical action. The reactions which occur are of a very complex nature, and can only be represented in outline. In the first part of the reaction only the acid in the cell is involved, but for the sake of symmetry we will include the water in the representation. The condition of the cell after charging is :—

$$PbO_2 + 2H_2SO_4 + H_2O + Pb;$$

and during discharge this first becomes—

$$PbO + H_2SO_4 + H_2O + H_2O + PbSO_4.$$

But here a secondary reaction occurs, due to the fact that lead monoxide is decomposed by sulphuric acid, forming lead sulphate and water, thus :—

$$PbO + H_2SO_4 = PbSO_4 + H_2O.$$

Hence, bearing in mind that the reaction occurs in two stages, we may represent the first and last conditions thus :

Commencement of discharge—

$$PbO_2 + 2H_2SO_4 + H_2O + Pb.$$

End of discharge—

$$PbSO_4 + H_2O + H_2O + H_2O + PbSO_4.$$

In practice the discharge is never allowed to become so complete as is represented by the last formula ; the cells are always re-charged before they are completely exhausted, so that the negative plate always contains some spongy lead and the positive plate some lead peroxide. In the process of discharging, the excess of acid is absorbed by the plates and the solution returns to its normal condition. The charging current should always have a definite density per square inch of positive plate. This is usually in Faure cells ·025 ampère. Thus by knowing the surface exposed it is easy to calculate the current required to charge the cells properly. If less current is used the cells become in time sulphated or coated with a white salt. A freshly made solution having a density of 1·20, during the first making-up of the cell falls to about 1·16, due to the conversion of H_2SO_4 into $PbSO_4$, but when the cell becomes fully charged the density rises to 1·25. During the process of discharge the density of the solution should never be allowed to fall below 1·18; in fact re-charging should commence when it falls to 1·20. Since the liquid contains more acid when the cell is charged than when it is discharged, its resistance will be less in the former than in the latter case. The variation may amount to 20 per cent.

Manifestly the capacity of a cell depends upon the amount of material (paste or lead) available for oxidisation in the one case, and reduction in the other; hence the greater the mass of material and the surface of the opposing plates the greater will be the amount of energy which it is possible to store.

Secondary cells may be divided into two main types, one being known as the Planté cell, the other as the Faure or pasted cell. The main difference between these types being that in the one case the plates are of solid lead cast so as to give as great a surface as possible; in the other type the plates consist of a light framework or grid which is filled to its utmost capacity with paste. Figs. 18 and 18A show standard plates of these two characters. Some few manufacturers combine these types, using Planté negatives and pasted positives.

It is generally supposed that the Planté plate has a longer life than a pasted plate. It also has a slight advantage as being capable of withstanding greater discharge currents without disintegration. On the other hand the pasted plates are decidedly lighter and cost somewhat less.

The internal resistance of an ordinary secondary cell is very small, being about $0{\cdot}0015^{\omega}$.

The use of these cells for telegraph and telephone purposes is being considerably extended, and where facilities exist for recharging them, such as where there is an electric-light system, their introduction is a distinct advantage, since a great number of circuits may be worked on the universal principle (see p. 121) from one set of those cells.

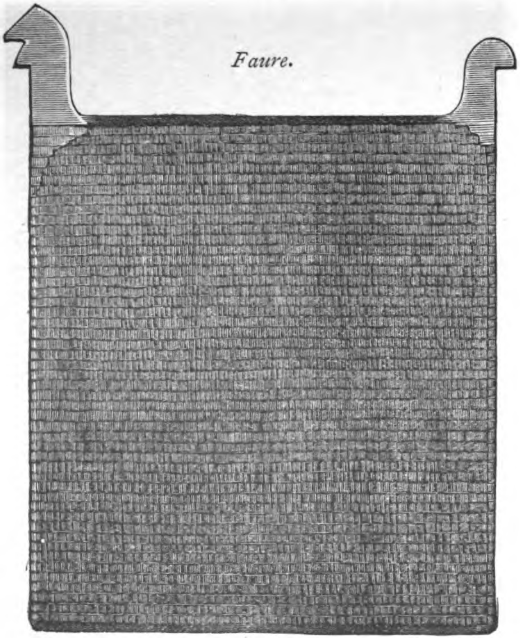
Faure.

FIG. 18

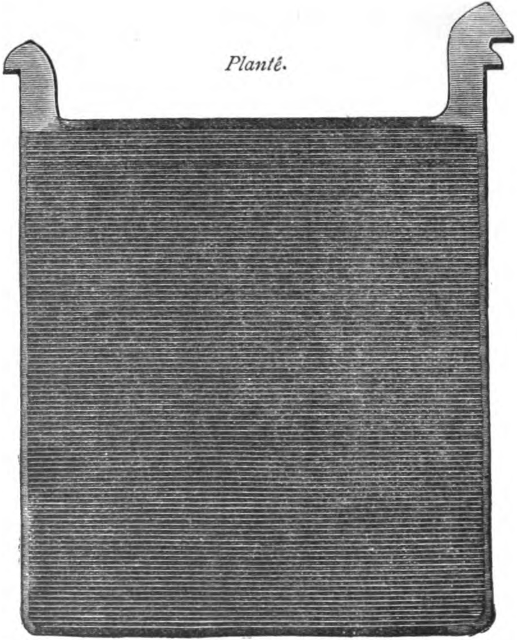
Planté.

FIG. 18A.

CHAPTER III.

SIGNALLING INSTRUMENTS.

TELEGRAPHY is the art of conveying to distant points the first elements of language—either letters or numerals—by certain preconcerted signals or sounds; and the formation of these signals, by means of the action of currents of electricity upon permanent magnets, upon soft iron, and upon electrolytes,[1] forms the next portion of our subject.

Telegraphic signals are either *visible* or *audible.*

Visible signals, again, are either *permanent* or *transient*; in other words, they are either *recording* or *non-recording*; and they differ from each other either in form or position.

Audible signals, on the other hand, are always *transient* or *non-recording*; they differ from each other either in tone or duration.

Hence we have different systems of telegraphy in which the signals are registered in different ways, and the currents do their work by different methods.

A.—THE NEEDLE SYSTEM.

The needle is a visible system with transient or non-recording signals. It takes its name from the fact that the alphabet is formed by the vibration of a small pointer or *needle*, movable between two fixed stops. N S (fig. 19) is such a needle, movable in the plane of the paper about its centre C, the distance of its motion being restricted by the stops *a* and *b*. This needle is capable of receiving two distinct motions, the one to *a* and back, and the other to *b* and back. Its normal position is vertical. In the earliest needle system five of these movable pointers were

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[1] See footnote, p. 37.

employed; the number was afterwards reduced to two, and this has been gradually superseded by a needle system where only one pointer is employed, and which therefore goes by the name of the Single-Needle System.

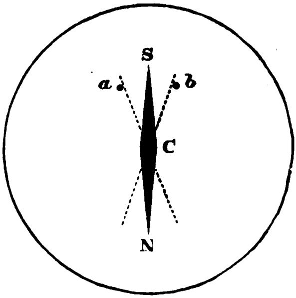

Fig. 19.

Since we have a motion to the right and a motion to the left as well, we can combine these two motions in any order or number we please, and so form a series of preconcerted signals which shall represent the alphabet. Thus, taking those letters which are most frequently used—viz. e and t—one motion to the left is the letter e, one motion to the right the letter t; and, taking those letters least used —viz. x and z—one motion to the right, two motions to the left, and one motion to the right represent x; two motions to the right and two to the left represent z. All the other letters are similarly formed of two, three, or four combinations; and thus, by a series of combinations, not exceeding four movements of the needle, the whole of the alphabet can be formed. The manner in which the alphabet is made is shown by the above diagram (fig. 20), the little stroke ˎ representing a motion to the left and the longer stroke / a motion to the right.

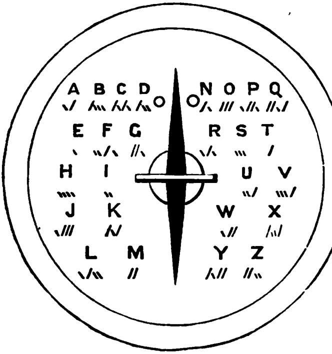

Fig. 20.

The motions of the needle are produced by the mutual action of currents and magnets. Electricity and magnetism are so intimately related to each other that they may be considered to be only different phases of the same agency. Thus the motion of a magnet always produces electricity; the transference of electricity always produces magnetism. The neighbourhood of a current is, in virtue of this fact, a *magnetic field*—a term introduced by Faraday to denote the entire space through which a magnet diffuses its influence —and a magnet or a piece of soft iron placed there is influenced by the magnetism of that field.

Thus, if the wire A B (fig. 21) be traversed by a current in the direction shown by the arrow, it is surrounded along its whole length by a magnetic field. If a freely suspended magnet be placed in this field, it will itself move in a certain direction, which direction is dependent on the polarity of the field. If in fig. 22 the wire A were conceived to be surrounded by a ring of little magnets, all freely suspended by their centres at any distance A *a*, they would assume the positions shown in the figure, with all their N poles turned in one direction and all their S poles in the opposite direction. If their N poles were free, they would move in a circular path or orbit around the wire, in the direction shown. Hence we may conceive a wire conveying a current to be surrounded by a series of concentric tubes of magnetised matter, each formed by a series of concentric rings of magnetised molecules whose poles are all tangential, or at right angles to a radius of the

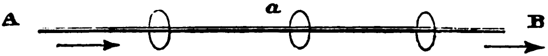

FIG. 21.

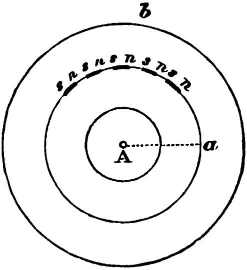

FIG. 22.

ring. Such a series is shown in fig. 22. Thus, if a magnet be brought within the neighbourhood of the wire, it will be acted upon by the directive power of these imaginary magnetised molecules and tend to place itself at right angles to the wire, and always, under the same circumstances, in the direction shown by the molecules in fig. 22. We have conceived the current flowing in one direction ; if it flow in the reverse direction, the polarity of the field will be reversed. Hence a current in one direction will cause a magnet suspended above it to deflect to one side and a current in the opposite direction to the other side (fig. 23), and whenever the magnet is placed in the direction of the wire, it will always tend to form a tangent to a circle having that wire for a centre. There is no difficulty in remembering this direction of deflection. Taking the face of a watch and conceiving the current as going *from* you,

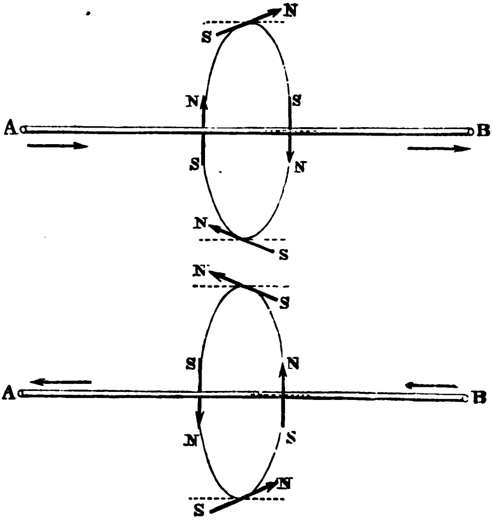

FIG. 23.

the N poles will all be '*N*egatively rotated,' or moved to the *right*, like the hands of a watch (fig. 22). The energy of this action between a current and a magnet depends upon the strength of the current passing, upon the strength of the poles of the magnet, upon its shape and weight, and upon the distance between the magnet and the wire.

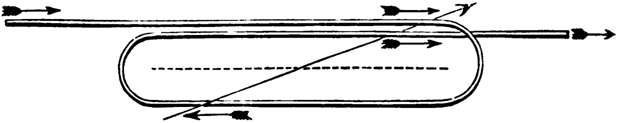

FIG. 24.

The strength of the current acting upon the magnet can practically be multiplied at will. If the wire take a turn round the magnet, as shown in fig. 24, it will be evident, on a little consideration, that the directive action of the current as it passes above the magnet is the same as, and is added to, that of the current as it passes below: the effect of the current below the magnet is, in fact, duplicated by the additional turn. Hence the effect is triplicated in fig. 24. Thus, by multiplying the number of turns we multiply the effective action of the current upon the magnet. In this way we have the means of rendering sensible the presence

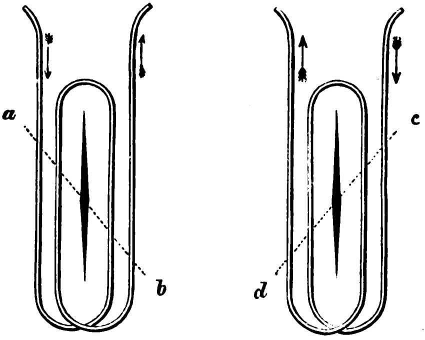

FIG. 25.

of the weakest possible current, and we can, by varying the direction of the current, vary its directive influence upon a magnet suspended along its length, so as to make it move either to *a b* or to *c d* (fig. 25).

The single-needle instrument is based upon these fundamental facts.

There are two forms of the single-needle instrument in general use, viz. the drop-handle and the pedal or tapper form. The essential principles of each are precisely the same; the only difference between them lies in the mechanism of the manipulator or sending portion of the instrument.

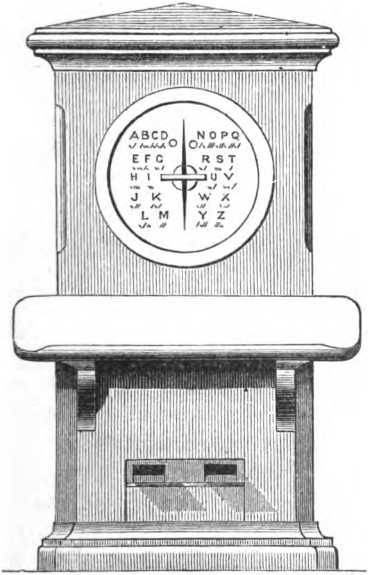

FIG. 26.

⅛th real size.

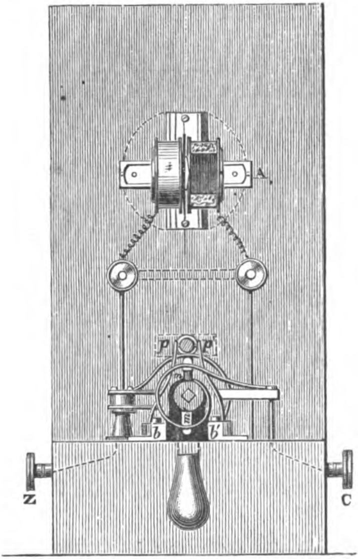

FIG. 27.

Fig. 26 gives a view of a tapper form of instrument, and fig. 27 of a drop-handle single needle from which the case and dial have been removed. A (fig. 27) is the receiving portion of the apparatus. It consists of two ivory bobbins wound with fine silk-covered copper wire, and placed symmetrically with respect to a small magnetic needle free to move inside them (see p. 52 and figs. 32 and 33). Fixed upon the same axis as this small magnetic needle is an indicator moving over the outside of the dial (fig. 26). The motion of this indicator is limited by two small ivory stops placed upon the dial, which is so constructed as to be capable of rotating upon its centre. The presence of earth currents (see p. 175), by deflecting the indicator, would stop the working of the circuit if this provision were not made for rotating the dial. By this means the dial can be placed in such a position that the average earth-current deflection places the needle in position midway between the stop-pins.

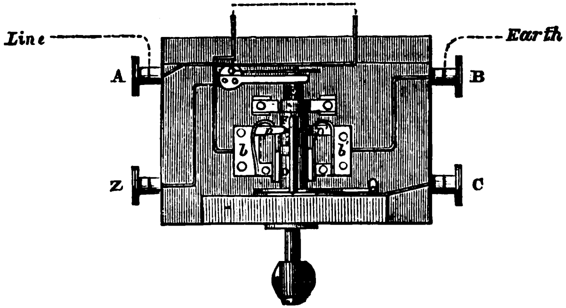

FIG. 28. ⅙th real size.

If now a current of electricity pass through the coils, the magnetic needle and the indicator will be deflected. The direction of this deflection will depend upon the direction in which the current is passing. The two coils are wound quite distinct from each other, but one end of each is soldered to the brass frame and they thus act as if they formed one continuous coil. The advantage of this arrangement is that should the wire in either get broken or fused—as may happen by lightning—the instrument will still work, provided the wire be carried over to either of the screws. All, therefore, that is necessary to enable communication to be effected by this instrument, is an arrangement by means of which the magnetic needle can be deflected to right or left at will; in other words, an arrangement by which the direction of the current passing through the coils can be reversed when desired. An investigation of the mechanism of the commutator, or sending portion of the instrument, will show how this is carried out (figs. 28 and 29).

The wire from the positive pole of the battery is attached to the terminal marked C, that from the negative to the terminal Z. The line-wire is led to A, and a wire from earth is connected to B. The arbor of the handle consists of two parts, D and F, formed of gun-metal, and separated by some insulating material: ebonite or, more frequently, boxwood is employed. To D a wire leading to terminal C is attached, to F a wire leading to terminal Z. *p*, *p'* are two steel springs, each of which is connected with separate brass bars, *b* and *b'*, on the base of the instrument; by this means *p* is connected with terminal A through the coils, and *p'* is connected with terminal B by means of the other portion of brass-work *b'*. These two springs press against the 'bridge' shown at F, thus maintaining the continuity of the line. The section F of the arbor carries over

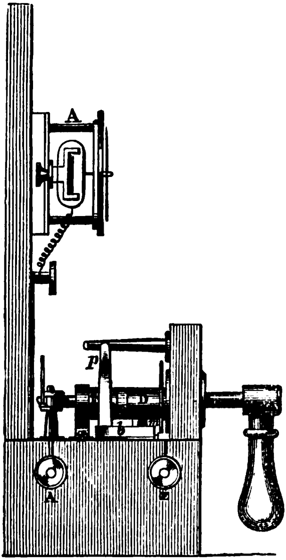

FIG. 29. ⅙th real size

it a metallic pin or projection *m*, which when the arbor is at rest remains between the two springs *p* and *p'* without touching either; whilst D is similarly fitted beneath with a pin or projection *m'*, which when the arbor is at rest remains between the two pieces of brass-work *b* and *b'*.

Let now the handle be moved to the left: the projection *m'* of the section D moves to the left, and pressing against the brass-work *b*—which along with the spring *p* is in connection with A—brings the positive pole of the battery on to the line-wire; at the same moment the projection *m* of section F is thrown to the right, and pressing against the spring *p'*—which with the brass-work *b'* is in connection with B—breaks its connection with the bridge and puts the negative pole to earth. In this way a positive current is sent along the line, through the receiving apparatus at the distant station, deflecting the needle there, and returning by means of the earth to B and thence to the negative pole of the battery.

Let the handle be next turned to the right. Everything is reversed: the projection *m'* is now thrown into contact with *b'*, and thereby puts the positive to earth; *m* is meanwhile pressed against spring *p*, and thus brings the negative to line. The current may now be regarded as passing along the earth through the coils at the receiving station, deflecting the needle in the opposite direction to what it previously did, and returning along the wire to A and thence to the negative pole of the battery.

The principle of the sending portion of the 'pedal' or 'tapper' form of single needle is as follows:

C and Z (fig. 30) are two strips of metal to which the positive and negative poles of the battery are respectively brought. E and L represent two metallic springs which are in connection with the 'earth' and line respectively, and which, when at rest, press against Z. If now L be depressed and brought into contact with C the circuit is completed, and the current starting from C traverses the line wire and the coils of the receiving instrument at the distant station, returning by means of the earth to E, and so to the battery. If, on the other hand, E be depressed while L retains its normal position, the direction of the current is reversed, for the positive pole of the battery is now to earth and the negative to line; consequently the needle at the distant station is deflected in the opposite direction.

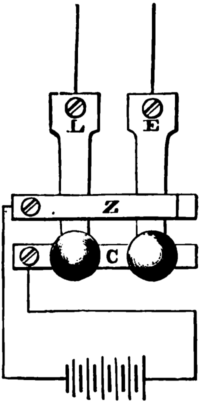

FIG. 30.

The mechanical details of the pedal commutator are such as cannot be clearly shown in a small diagram, but if the principle stated above is clearly understood, its electrical functions will be apparent upon consideration of fig. 31, which shows the normal electrical connections of the latest form of this instrument.

The single needle is essentially an English instrument; it was invented and is still largely employed in England, especially upon the railways, where no other form of instrument has ever been able to compete with it. The adjustment of the receiving portion of the apparatus is of the simplest possible character; in fact, when once at work no adjustment whatever is required. Any reasonable number can be joined up in circuit upon the same wire without fear of a complaint as to their working, unless it may be that of weak signals; and this can be readily obviated by the employment of additional battery power. The main defect in the older form of instrument was the liability of the small magnet inside the receiving coils to be partially, sometimes entirely, demagnetised, and even reversed in polarity by lightning. Mr. S. A. Varley, however, in 1866 entirely removed this defect by the introduction of needles which are maintained in an invariable magnetic condition by induction from large permanent magnets. Instead of the small permanent magnet, a soft iron needle of the shape shown in fig. 32, *n s*, is employed. This owes its magnetism to the influence of two permanent bar magnets, N S and N′ S′, whose like poles are adjacent to each other, and which are fixed to a slip of soft iron let

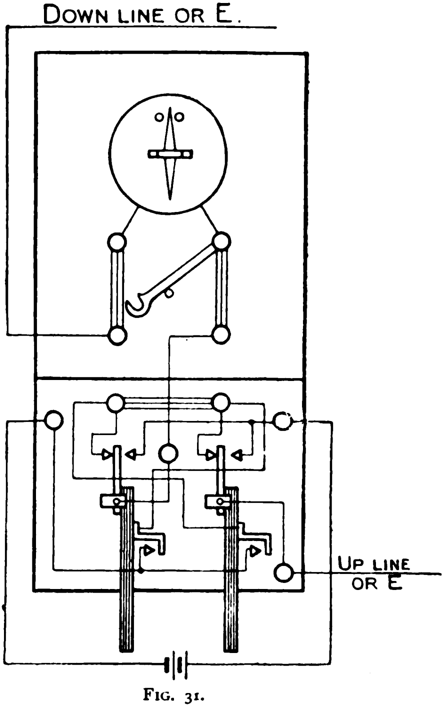

FIG. 31.

into the inner cheek of each bobbin. These bar magnets are very seldom demagnetised by lightning, except during storms of exceptional violence. They, however, like all permanent magnets, lose their magnetism after a time, and require remagnetisation.

Another arrangement of induced needle, devised by

Mr. C. E. Spagnoletti, is shown in fig. 33. In this case the permanent magnets are of horseshoe form, one being placed above and the other below the axis of the needle. The induced soft iron needle is in two sections, and of the form indicated, they are separated magnetically by being brazed together with a layer of spelter between them. The axle is of soft iron in two sections, the front part being extended to form the lower half of the needle, and the back part of it continued into the upper half. The like poles of the

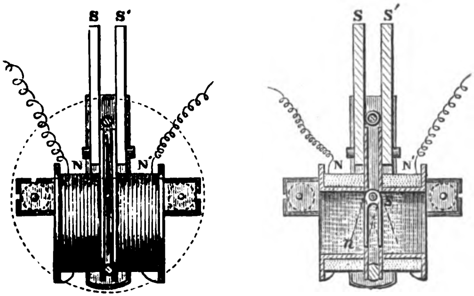

Fig. 32.

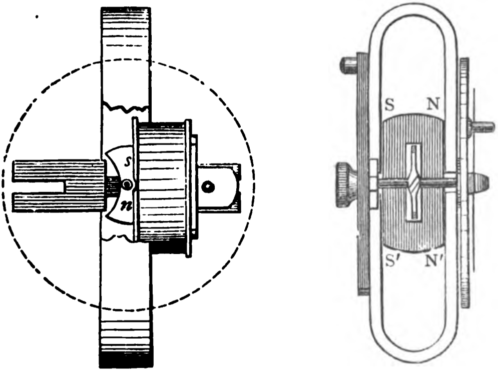

Fig. 33.

permanent magnets are adjacent, and thus the upper end of the central needle is induced with S polarity, and the lower end with N polarity.

This form of induced needle gives a rather firmer impact than the Varley needle with the same strength of current.

A simple but very important addition to the single-needle dial has been introduced of late years in the form of *tin sounders*. One pattern of tin sounder is shown in fig. 34. It consists of a small tin plate cut and bent as shown, and so fitted that each time the needle is deflected it strikes either one or the other of the two tin sounders. These sounders can be easily arranged to give sufficiently distinctive sounds for the two signals to be distinguished, and by this means the operator is enabled to read off the deflections by sound. Other metals have been tried, but commercial tin (that is, tinned sheet iron) seems to give distinctly the best result for this purpose. A later form provides for fixing the sounders independently of the bridge, which is preferable.

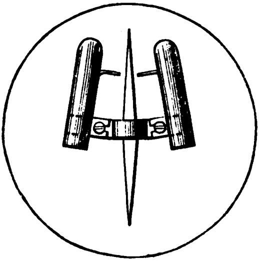

FIG. 34.

B.—THE ACOUSTIC SYSTEM.

The acoustic system is, like the needle, a transient or non-recording system, but differs from it, as its name implies, in the fact that the ear is made use of instead of the eye to interpret the signals sent. There are two types of instrument employed in working this system, viz. the *Sounder* and the *Bell*.

Both these instruments are based upon the electro-magnetic effects of the current. Inasmuch as the neighbourhood of a current is a magnetic field, and filings of iron placed in that field acquire magnetic properties (p. 44), it follows that if we envelope a mass of iron filings—or even better, a piece of iron itself—with a ring of wire conveying a current, every filing or molecule of iron within this circle will be similarly magnetised ; that is, it will be so magnetised that similar poles lie in similar directions. Let A B (fig. 35) be such a wire, conveying a current in the direction shown, and S a flat disc of soft iron. Now inasmuch as every molecule constituting the soft iron disc lies in the magnetic field of that current, it will be polarised in the direction shown in fig. 36 ; and as all these molecules have their polarities in the same direction, the resultant effect is as though there were one magnet whose N pole was above and S pole was below the disc. Moreover, if instead of one ring of wire we were to surround the disc with several rings, the current flowing in the same direction in each ring, as shown by fig. 37, the effect would be magnified ; and if we were to

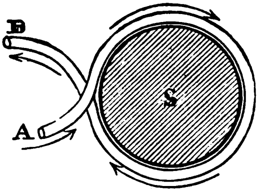

FIG. 35.

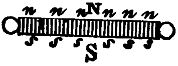

FIG. 36.

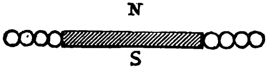

FIG. 37.

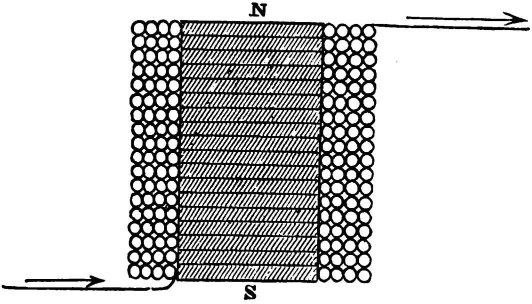

FIG. 38.

superpose several discs, as in fig. 38, thus surrounded with rings in all of which the current flowed in the same direction, the effect would be still further magnified, and we should have a powerful bar magnet, N S. Precisely this effect is produced by winding a helix of wire around an iron bar or core. By combining two such iron bars (fig. 39) by a cross piece of soft iron *p*, and surrounding each bar with a coil of silk-covered wire, we construct an *electro-magnet* which is powerfully magnetised every time a current flows, and which therefore exerts attraction upon a bar of soft iron or *armature* (*a*) placed in front of it. The power which this electro-magnet exerts depends upon the strength of the current flowing, upon the number of turns the wire takes around the core, and upon the size of this core. Thus a very powerful current requires but a few turns of wire to produce a considerable effect, while a very weak current requires a great number of turns to produce any effect at all.[2]

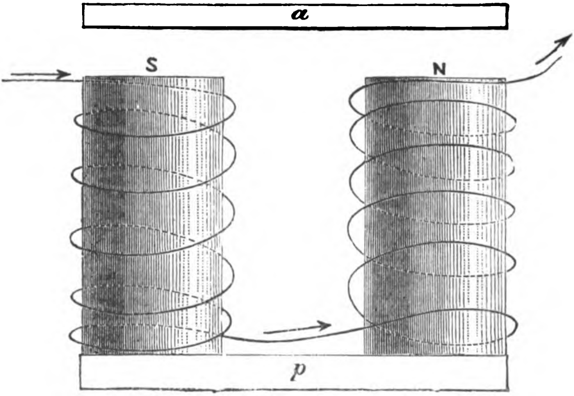

FIG. 39.

The direction of the poles of the magnet is dependent

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[2] See Appendix, Section D, with regard to the Winding of Electro-magnets.

upon the direction of the current and upon the direction in which the helix is wound. Electro-magnets are almost invariably wound with the right-handed helix, shown symbolically by fig. 40, and the polarity due to the different directions of the current is shown by *a* and *b*. Thus, if the current flows around the iron core in the direction of the hands of a watch whose face is held before the eyes, the N pole is away from us.

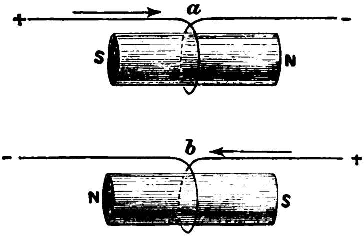

FIG. 40.

We can fix the armature of the electro-magnet at the end of a lever *a b* (fig. 41), pivotted at C, and limit its play by the two screws *d* and *e*. We can also maintain the lever in its normal position pressing against *e* by means of the antagonistic spring S, and then whenever a current of sufficient strength passes through the coil, whatever its direction may be, the attraction of the magnetised core will overcome the tension of the spring, and cause the end *b* of the lever to make a sharp blow against the adjusting piece *d*, and take up the position shown in the figure. When the current ceases, the

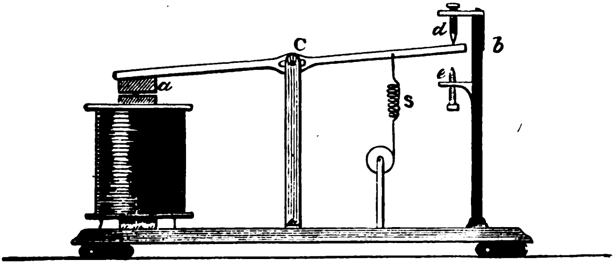

FIG. 41.

attraction also instantly ceases, and the lever is pulled smartly back into its normal position against *e* by the action of the spring s. The blows made by the lever against *d* and *e* emit distinct and clear sounds, which are taken advantage of to convey to the ear the letters of the alphabet and other preconcerted signals. This is the principle of the Sounder.

1. *The Sounder.*

How can we convert the sound made by the contact of the lever against the two limiting stops into an alphabet? We have shown (p. 43) how two motions, a motion to the right and a motion to the left, of a vertical needle are applied to the communication of preconcerted signals through the eye; and we have seen that, by means for instance of tin sounders, we can do the same thing through the ear if we make one kind of sound to represent the motion to the left and another kind of sound to represent the motion to the right. This, however, requires the comparatively complicated two-lever mechanism of the commutator, as well as that the receiving instrument shall be polarised, and that there be three possible positions of the indicator. In the sounder we have still two sounds, but one—that against the stop *d*—is always produced when a current is sent, no matter in which direction; and the other is produced only on the cessation of the current. We are, therefore, obliged to obtain our two signals, not by the direction in which the current is sent, but by regulating the time during which it flows.

The lever striking *d* gives the commencement of the signal, and striking *e* the end of the signal. The *time elapsing between these two sounds* determines the kind of signal. Representing the one signal by a dot (·), and the other by a dash (—), we have the dot and dash alphabet of Morse.

It will be seen that in this alphabet we have introduced *duration* as an element of signalling. It is really duration of *silence* rather than duration of *sound.* The signals are formed of short or long intervals of silence between the sounds produced by the lever striking first *d* and then *e*, forming *dots* and *dashes* ; separated by *spaces*, which are the intervals between the two sounds made by the lever as it strikes *e* and *d* successively. There are three kinds of spaces : the space separating the elements of a letter, that separating the letters of a word, and that separating the words themselves. Thus sound reading and sending is a method by which time is divided into accurate multiples of some arbitrary standard or unit, viz. the dot.

1. A dash is equal to *three dots.*
2. The space between the elements of a letter is equal to *one dot.*
3. The space between the letters of a word is equal to *three dots.*
4. The space between two words is equal to *six dots.*

The basis of the alphabet therefore is the dot

· representing the letter .... e

and the dash

— representing the letter.................... t

Placing a dot before each of these elementary characters, we have

· · i

·— .... a

Placing a dash before each elementary signal, we have

—· .... n

—— .... m

Now prefixing each of the above four signals with first a dot and then a dash, we have

· · ·	s
· · —	u
· — ·	r
· — —	w
— · ·	d
— · —	k
— — ·	g
— — —	o

Pursuing the same system with these eight characters, we have

· · · ·	h
· · · —	v
· · — ·	f
· · — —	(German) ü
· — · ·	l
· — · —	(German) ä
· — — ·	p
· — — —	j
— · · ·	b
— · · —	x
— · — ·	c
— · — —	y
— — · ·	z
— — · —	q
— — — ·	(German) ö
— — — —	ch

There is also the French accented è · · — · ·, but with this exception no letter exceeds four signals.

A combination of five signals is employed to represent the numerals and cypher.

1	· — — — —
2	· · — — —
3	· · · — —
4	· · · · —
5	· · · · ·
6	— · · · ·
7	— — · · ·
8	— — — · ·
9	— — — — ·
0	— — — — —

The stops and other signs of punctuation are made by a combination of six signals.

Period or full stop	·· ·· ··
Repetition or ?	· · — — · ·
Horizontal stroke, or the divisional bar of a fraction	— — — — — —
Hyphen	— · · · · —
Apostrophe	· — — — — ·
Note of exclamation !	— — · · — —

There are many other signals in use, such as ... ... for the vertical stroke of a fraction, and some of those indicated above are rarely employed in England. *Ch*, for instance, has been abandoned because it is so much like '*to*.'

Fig. 42 represents a simple sounder arranged for the conveyance of the above signals to the receiving clerk, and is the one which is at present generally employed in England. The sounder is in every respect the simplest of all the signalling apparatus in use, and simplicity in construction is a great consideration when technically unskilled operators are employed. The ends of the wire of the electro-magnet are connected to brass terminals fixed on the wooden base, and to these terminals the line and earth-wires are brought. One end of the antagonistic spiral spring is attached to a vertical arm projecting from the lever and the other to an adjusting screw (shown to the left in the figure), by means of which its tension may be increased or decreased at pleasure so as to compensate for the variation in the strength of the line current. The adjustable stop which passes through the lever strikes against the angular bridge-piece when the armature is attracted, and the other forms the banking stop for the lever in its position of rest.

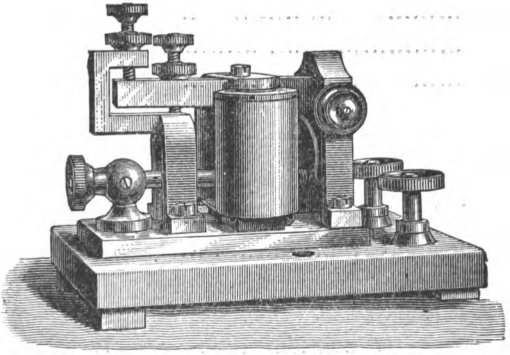

FIG. 42.

The Key.—How are these currents of varying duration sent by the sending station? The apparatus for doing so, called a *key*, is much simpler than that required in the needle system, because no reversals are needed, currents in only one direction being required. The key (fig. 43) consists of a simple brass lever, which is in connection with the line wire, and which is pivotted so as to be movable about its centre on a brass piece fixed upon a wooden base. It is maintained in its normal position by a spiral spring, causing the back of the lever to be held in contact with the back stop, which is in connection with earth through the receiving instrument, thus preserving the continuity of the line. One pole of the battery is placed in connection with the front contact piece, the other pole being put to earth. Thus, whenever the key is depressed the lever is brought into contact with the front stop and the current flows to line. The moment the key is released the contact is broken and the current ceases. The duration of the current thus evidently depends upon the duration of this contact. These currents pass through the receiving instrument at the distant station and operate the sounder in the manner described at p. 57. Hence to send dots and dashes by this key it is only necessary to tap or move it as one would the key of a piano in order to produce crotchets and quavers.

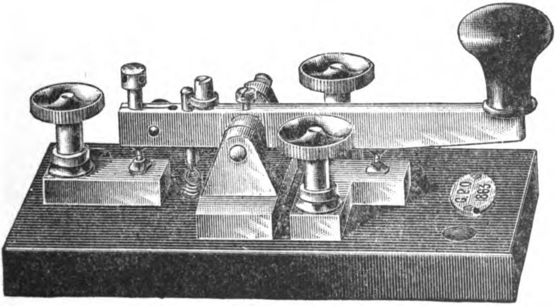

FIG. 43.

Such is the sounder in its simplest form, though it is not always possible to work it in this simple form except for very short distances. When other systems have been described a comparison will be drawn between the advantages and disadvantages of the different plans in use, and an indication given as to why the sounder is so very generally preferred to other forms of signalling apparatus.

The Relay.—But as we have said, it is not always possible to work it in this simple form. As the lines increase in length, and consequently in resistance, and the effects of imperfect insulation make themselves felt, the battery power would have to be increased beyond practicable limits in order to produce audible signals upon our sounders. Some method is then needed by which the inaudible weak line currents shall bring in fresh currents which will make the signals audible. This is the function of the *relay*, by which a local battery is brought into play which works the receiving sounder in the same way as the line current would have done had it been of the requisite strength.

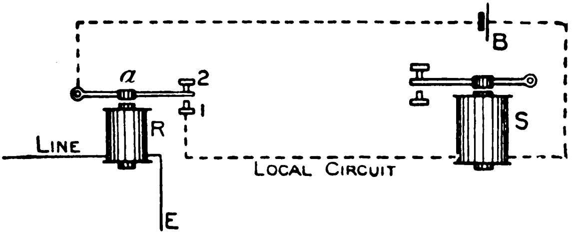

FIG. 44.

The relay is, in fact, nothing more nor less than a more delicate form of the electro-magnet and lever employed in the sounder previously described. It is wound with a finer and longer wire, and all its parts are more delicately constructed, so that a very weak current will cause the armature to move. However long a line may be, and however badly it may be insulated, if any currents at all can get through, so long can relays be constructed to move with those currents. The principle of operation is given by fig. 44. S is the electro-magnet of the ordinary sounder wound with thick wire, but requiring to work it a stronger current than can be sent from the distant station. R is the electro-magnet of the relay, wound with very fine wire and worked by the line current. B is a *local battery* whose positive pole is attached to one end of the coil of the sounder, and whose negative pole is connected with the lever of the relay. The other end of the coil of the sounder is connected with the lower contact I of the relay. When a line current passes through R it attracts the armature *a* and brings the lever in contact with I, so completing the *local circuit.* The local current therefore works the sounder, whose armature remains attracted just as long as does that of the relay, and thus every movement of the relay is repeated on the sounder.

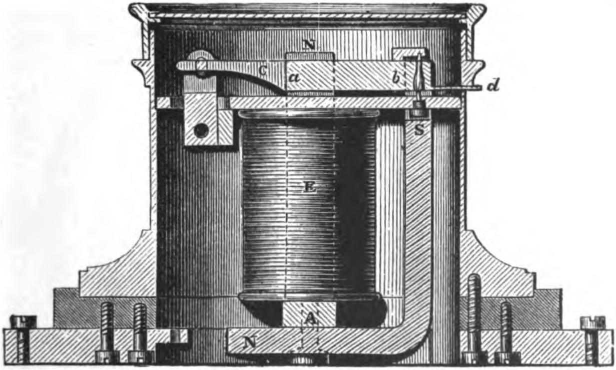

FIG. 45.

There are many different forms of relay. Such a one as that just indicated is called a *non-polarised* relay, but it is not much used in England for such a purpose. The forms of relay more largely used are called *polarised*, because their armatures are maintained in a magnetised condition by permanent magnets. They differ principally from the non-polarised relay in that they are affected by the direction of the current, and under certain circumstances they are far more sensitive.

Siemens' Relay.—A sectional view of this apparatus is shown by fig. 45, and a plan of the top by fig. 46.

N S (fig. 45) is a hard steel permanent magnet, into a slit in the upper or S end of which is pivotted a soft iron armature *a b*, capable of motion in a horizontal plane about the centre *b*, and having a small German silver tongue C fixed to its free end ; on the lower or N end of N S rests an iron bar A, which supports the two soft iron cores of the electro-magnet E ; the further extremities of these are terminated in the pole pieces P and P_1 (fig. 46), which are fixed by screws and can be moved to and fro at will. D and D′ are two contact points whose position can be varied by means

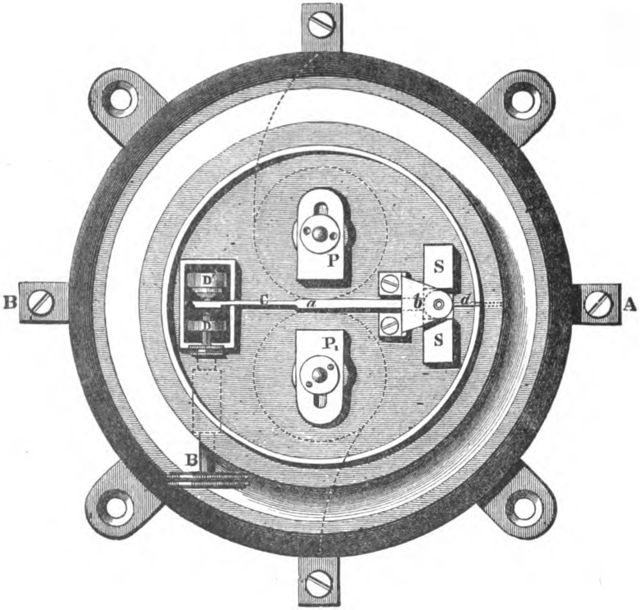

FIG. 46. ½ real size.

of the adjusting screw B. When the tongue C presses against the former, the local circuit is completed; when drawn against the latter, which terminates in an insulating point, it is broken. The coil wires of the electro-magnet are attached to two of the terminals as shown; and the other two terminals (A and B) are electrically connected to the tongue C and the contact point D respectively.

The action of the relay is as follows:

The end N of the permanent magnet N S induces S polarity in the bar A and the ends of the cores next to it, but N polarity in the upper ends remote from it and terminating in P P_1, both of which are therefore N poles. The end S, on the other hand, induces N polarity in that portion of the armature *a b* next to it, and S polarity in the further extremity moving between P and P_1 (C being a non-magnetic metal is not affected). When, therefore, *a b* is equidistant from P and P_1, it is equally attracted by both, and may be supposed to touch neither D nor D′. If the pole P be approached nearer to *ab*, it obeys its influence and is attracted to the point D′. This is the position of the armature when the relay is at rest.

As soon, however, as the line current enters the coils in the proper direction the electro-magnet is thereby polarised, so that P, P_1 tend to become respectively south and north poles; the pre-existing north polar magnetism of P_1 is consequently increased, while that of P is correspondingly diminished, and, according to the strength of the line current, this diminution may extend to complete neutralisation or even reversal. The result is that under the influence of a more powerfully attracting force, C is drawn from D′ to D, and remains there so long as the line current is flowing, returning to D′ when this ceases. In this way the local circuit is completed, and the sounder or other instrument worked in exactly the same manner as though a line current of equal strength to that of the local current had been the cause.

The adjustment of the Siemens' relay is extremely simple, and the only objection that is urged against it is that on account of the comparative weight of the moving parts and the presence of electro-magnetic inertia in the coils it is scarcely sensitive or light enough for very long lines, rapid sending, and extremely weak currents. Fast-speed telegraphy has necessitated other relays of greater delicacy and better adapted for long circuits and for the improved mode of working that will be described. The most generally used of these—the Post Office Standard Relay—will be explained in the Chapter on Repeaters (Chap. VIII.)

2. *The Bell.*

With any sensitive form of relay sounders can be worked at any distance and through any weather in England. The sounder was introduced in America and it has there

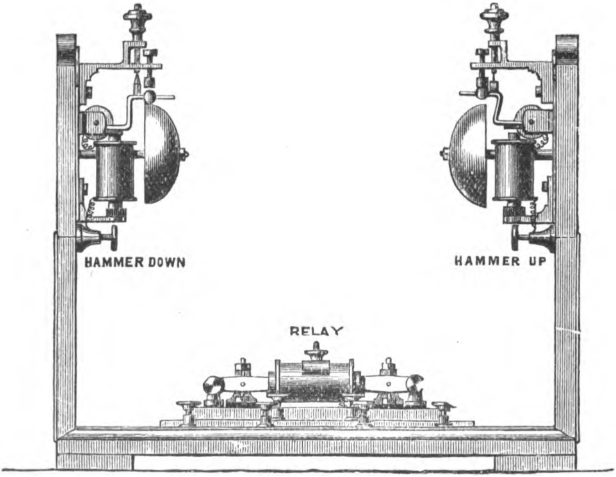

FIG. 47. ⅙th real size.

supplanted all other forms of apparatus. It is also almost universally employed in India. But the earliest form of acoustic instrument that was used in England was Bright's Bell. Two bells or plates of different tone are used, the hammer of one being actuated by currents in one direction, and that of the other by currents in the other direction. The sound of one bell corresponds to dots, and that of the other bell to dashes. The sending apparatus is the same as in the pedal single needle, and relays and local currents are needed. Its general construction is shown by figs. 47 and 48, the former giving a back view of the relay. The relay here shown is being replaced by the Post Office Standard.

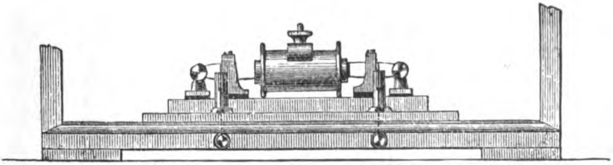

FIG. 48. ⅛th real size.

3. *The Double Plate Sounder.*

A modification of the Bright's Bell instrument is shown in fig 49. It is called the Double Plate Sounder, and consists of two sounders similar in arrangement to those of the Bright's Bell, which are mounted, together with a relay, in a screen which is useful in concentrating and directing the sound. The relay used in this case is the Post Office Standard. Instead of having two tongues, as in the case of the relay for Bright's Bell, it has only one, which is normally held, by means of a thin flat spring, between two contact points, and is capable of being moved against one or the other according to the direction of the current through the coils, and so closing the local circuit of one or other of the sounders.

In a later form the galvanometer is in the screen, and the relay is placed on the table, where it is more accessible for adjustment.

4. *Neale's Acoustic Dial.*

The Neale's Acoustic Dial (fig. 50) is an elegant and most useful form of needle instrument. As its name suggests, it is really a sound-reading instrument, but the needle in front makes it equally available for reading by sight.

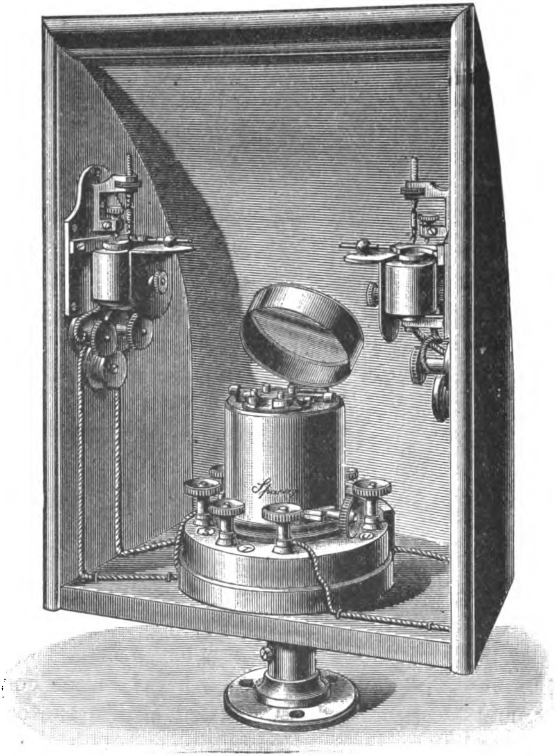

FIG. 49.

The upper part of the needle $n\ n'$ is polarised by means of the permanent magnet M, and is arranged to strike against the pins *e e′*, which are fixed to the two sounding-tubes *t t′* upon the dial-plate D. The two tubes are made of different thickness so that they may give different notes. Instead of passing through simple coils of wire, as in the case of the single needle, the line current traverses a complete electro-magnet which is fixed vertically behind the dial-plate, and the two pole-pieces of which are so shaped that their extremities project through the plate as shown at *a*, *b*. The upper end *n* of the needle is therefore within the magnetic influence of the electro-magnet, and consequently, whenever a current of sufficient strength passes through the coils, *n* will be attracted towards *a* or *b* according to the direction of the current, and will strike against *e* or *e′*, causing the corresponding tube to emit its characteristic sound.

Attached to the axle of the needle behind the plate is a small hook, between which and a similar hook at the upper end of the screw *k* a spiral spring is fitted. The screw *k* passes through the carriage *d* in such a way that it can be raised or lowered by the milled-edged nut s^2, so that by this means the tension of the spiral can be regulated, thus providing that the needle can be adjusted to be brought back to its normal position after being acted upon by the current. This normal position for reading as a needle instrument is of course vertical, so that the needle may be exactly midway between the two pins *e e′*; and any tendency of the needle to hang over to either side

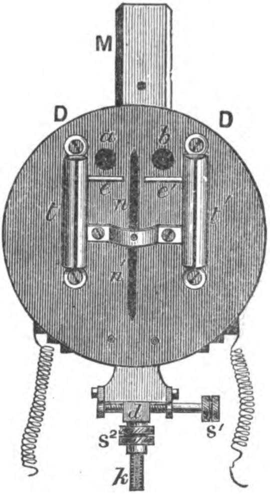

FIG. 50.

can be corrected by means of the screw s^1, upon the threaded portion of which the carriage *d* is fitted in such a way that it is adjustable from side to side.

When properly adjusted this instrument is nearly as sensitive as the needle itself; and, owing to its having an electro-magnet instead of simple coils, the impact of the needle when deflected—and consequently the sound emitted—is much greater than could be the case with the ordinary instrument.

In the instruments which have been described the signals are transient, and leave behind them no permanent record for reference. We have now to deal with recording instruments, in which the signals are permanent.

The simplest and earliest of all is the 'Morse' recording instrument, so called from its inventor.

C.—THE MORSE SYSTEM.

The Embosser.—The first form of Morse recorder was the Embosser, shown by fig. 51.

The radical principle is exactly the same as that of the sounder, which has been already described. The recording arrangement is purely mechanical, and is as follows:

E E are the coils of the electro-magnet, *o* the armature. The latter is attached to a lever movable about an axis, and carrying at its further end a small steel style S. When the armature is attracted, so that that end of the lever is drawn down, this style is thrown upwards and pressed against a strip of paper *p*. This strip of paper is unwound from the roll above by being passed between two friction rollers W W′, which are set in motion by the action of clockwork. In the centre of the upper roller just over the style is a small groove, into which the paper is pressed so long as the armature is attracted. A mark is thus embossed on the upper surface of the paper, which will appear in the form of either a dot or a dash according to the time that the armature has been held down and the style elevated; these, it will be seen, correspond to the short or long sounds in the simple sounder.

The Ink-writer.—The reading of the signals made by the embosser is so fatiguing to the eye, that the instrument was very soon entirely supplanted by the more modern form of recorder, viz., the Ink-writer. The first instrument of this description was invented by Thomas John, an Austrian engineer, in 1854. The main object which he had in view was to reduce as far as possible the force which was required to drive the style on to the paper before the marks could be distinctly recorded in the embosser. He succeeded in doing this by substituting for the embossing style a small metallic disc, which was kept constantly revolving in an ink-well, and which was raised against the paper as it passed above it, making a distinct ink-mark instead of the mere depression. All the ink-writers which have been brought out since 1854 have been simple modifications of this idea, and the most perfect instrument which is now in use is only a mechanical improvement upon John's original principle.

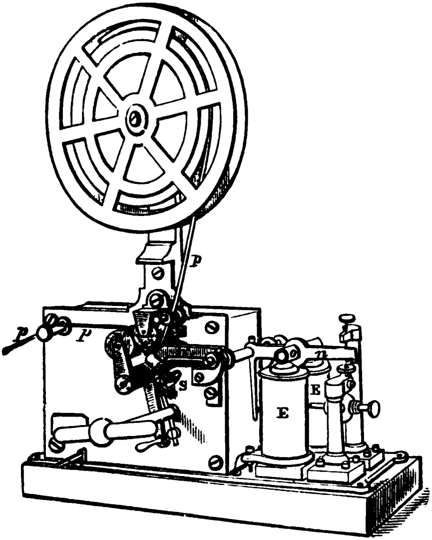

FIG. 51.

Various arrangements have been tried for the purpose of increasing as far as possible the delicacy of the apparatus. The best for hand-working is that introduced by Messrs. Siemens and Halske, which is the type now almost universally employed wherever recording instruments of this class are in use.

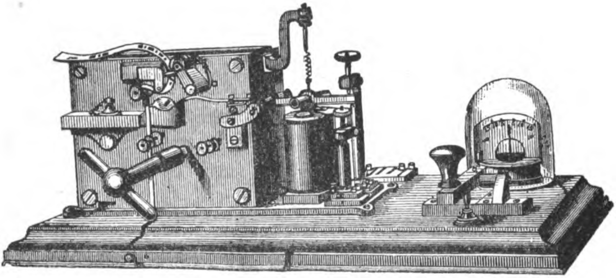

FIG. 52.

Fig. 52 shows one of the latest forms of these, and fig. 53 shows the details of the electrical portion of the receiving apparatus.

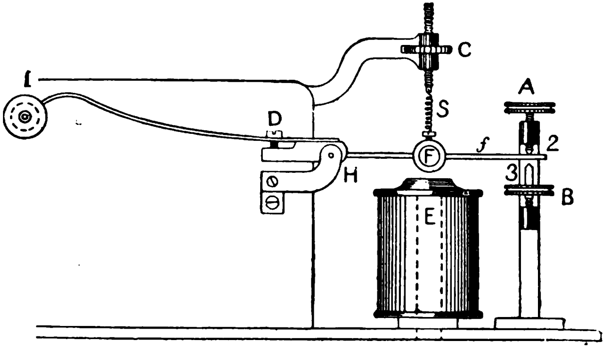

FIG. 53. ¼th real size.

E (fig. 53) is the electro-magnet, which is worked in the same way as the sounder, already described; F is the armature; S is the antagonistic spring, whose tension may be increased or diminished at will by means of the screw C. F is attached to the lever *f*, which is movable upon the axis at H and carries the small disc I at one end, whilst the other end moves between the two points marked 2 and 3: either of these two points may be raised or lowered at will by the adjusting screws A and B: the disc I dips into a reservoir of ink. The paper is wound upon a roller fixed in a drawer in the base-board of the instrument, and its path is indicated in fig. 52. It passes between two friction rollers, which are set in motion by means of an ordinary clockwork train enclosed in the case. This clockwork is liberated by the movement of a lever.

In addition to moving the friction rollers the clockwork also causes the disc I to revolve in the ink-well in the opposite direction to that in which the paper runs, and in this way the periphery of I is kept constantly wet with ink so long as it is required. When, therefore, F is kept down for a short space of time, I is correspondingly held up against the paper strip and records a dot upon it: a dash in like manner is recorded if F be kept down for a longer time.

The paper which is employed is slightly coloured, and is in continuous rolls of slip three-eighths of an inch in width: the ink is a kind of printer's ink of good quality, diluted with olive-oil.

This instrument has three distinct and separate adjustments:

1. Screws A and B, which regulate the play up and down of the armature F, and therefore of the inking disc I.

2. Screw C, which regulates the tension of the antagonistic spring S, tightening or slackening it as may be required.

3. Screw D, which regulates the position of the inking disc with respect to the paper and armature.

It is regulated for working thus:

(*a*) The screw B is first adjusted, so that the disc 1 gently touches the paper without pressing it too hard when the end of the lever *f* banks against the stud 3.

If the disc presses the paper too hard, it makes thick and indistinct signals; if it presses too lightly it causes the disc to jump and signals to split: thus — (t), may become .— (a), —. (n), or . . (i).

(*b*) The electro-magnet is then raised by turning the screw D to the right, so that when the lever *f* rests upon the lower stud 3, the poles *just* clear the armature *without actually touching it.* A thin streak of light should be seen between the armature and the poles of the electro-magnet.

(*c*) The screw A is next adjusted so that the lever *f* may be free to move through a space of about $\frac{1}{16}$ of an inch. A and B together so regulate the play of the inking disc that while it just dips into the ink-well it also *gently* presses against the paper, so as to mark it clearly.

If, when a station is working, a continuous mark is made upon the paper, or signals run into each other, screw B should be raised. If marks should still run together when the coils are well clear of the armature, then the antagonistic spring must be tightened up.

As a rule, the screw C is found sufficient to meet all the requirements of adjustment; and when once A, B, and D have been fixed they rarely require alteration.

C, however, requires to be altered very frequently, and where several stations exist in the same circuit a different adjustment is often required for each.

(*a*) The ink-reservoir should never be too full, otherwise the apparatus is apt to become clogged with ink—a condition that indicates great carelessness.

(*b*) The communication between the ink-reservoir and well frequently becomes choked with coagulated ink after disuse. This should be cleared with a piece of wire.

(*c*) The ink-reservoir must be frequently cleaned out, and the ink never left in for any length of time.

(*d*) When the day's work is over the paper should be taken from between the friction rollers, and the instrument should be allowed to run down, to prevent the weakening of the main-spring.

D.—BAIN'S CHEMICAL MARKING SYSTEM.

In the recording instruments described above the signals are recorded by means of electro-magnetism; but Bain, in 1846, devised an instrument by which the same thing was done through the electrolytic effects of the current. Whenever a current passes through an electrolyte, that is, a liquid capable of being decomposed into its constituent parts, the acid element appears at the one pole, and the alkali element at the other. If the liquid be coloured with any vegetable product, such as red cabbage, its colour will be changed at the two poles. If a piece of paper be soaked in a solution of potassium iodide in water, iodine will appear at the positive pole and potassium hydrate at the negative pole. The former produces a brown stain upon the paper. If paper so soaked be drawn between a platinum point and another conducting surface, and thus be made part of a circuit in which a current can flow, so long as a current flows a brown line will be marked upon the paper. Thus we can form marks by the current and spaces by the absence of the current. Bain did this in the following way (fig. 54). A is a brass drum whose circumference is tinned, and B is a smaller wooden roller pressing the paper *p* against it; motion is imparted to the drum by clockwork, so that the paper passing over it is drawn beneath the piece of wire or style 3, which is held in position by the clip O. The metal point is in connection with the line wire, and the brass drum A is in connection with the earth, so that when the current flows from the line to the earth, iodine appears at the point and leaves a brown line upon the paper. Dots and dashes can thus be made, and we have all the requirements of a recording telegraph. The following is a sensitive and useful solution :

1 part potassium iodide,
20 parts starch paste,
40 ,, water.

The solution usually employed in practice is composed of one volume of a saturated solution of potassium ferrocyanide (prussiate of potash), one volume of a saturated solution of ammonium nitrate, and two volumes of water. The ammonium nitrate is a deliquescent salt,[3] and is used to keep the paper damp. The style (3) is of iron or steel wire. When a current flows from the line through paper soaked in this solution it decomposes the electrolyte, the acid radicle unites with the iron, and forms *Prussian blue.* Thus dots and dashes can be formed in bright clear blue.

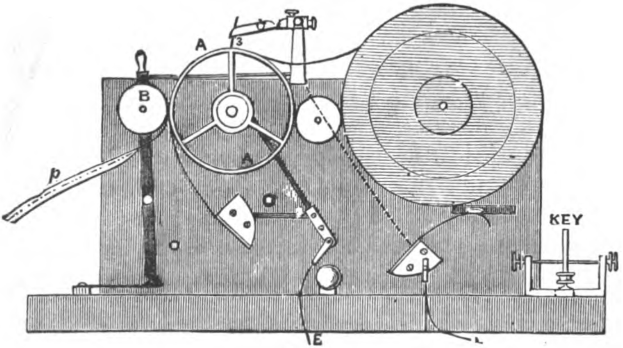

FIG. 54.

The instrument is worked by a key in precisely the same

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[3] A deliquescent salt is one which is capable of attracting moisture from the atmosphere and so becoming liquid.

way as that described for the sounder (p. 62), but it is essential that the direction of the current be attended to, for if it flows in the opposite direction the marks are made upon the under side of the paper. Hence a Bain's instrument must always be worked with the current passing from the style through the paper to the roller.

Although relays have been used in connection with this apparatus, the solution can be made sufficiently delicate to be decomposed by the weakest currents. It is not now in practical use excepting for experimental purposes, for which it is invaluable, because it is very sensitive to weak currents and can register its signals with marvellous rapidity, being independent of electro-magnetic inertia and self-induction. It was at one time the only form of recording instrument in use in England, but was supplanted by the Morse recorder which is less liable to get out of order and also avoids the troublesome operation of preparing paper chemically. In Bain's original instrument a sheet of the paper was fixed on a flat horizontal rotating disc of metal, and the metal point moved from the centre to the circumference, so that the dots and dashes were made in a spiral curve. Many ingenious applications of this principle have been attempted by Bakewell, Bonelli, Caselli, and others, but descriptions of such apparatus do not come within the scope of this book.

The *vibrating sounder*, which has been extensively used of late years, especially for military purposes, was invented by Major Cardew, R.E., in 1881. Where other instruments fail from weak signals through faults of insulation on the lines, the vibrating sounder has proved eminently successful. It has been worked through sixteen miles of bare wire laid upon the ground in England, and through over twenty-three miles in Egypt, even when the conductor was in contact with stay wires and railway fences. It was used largely in the Egyptain and South African campaigns, as well as during the frontier expeditions in India, and on the badly-insulated jungle lines of that country, Ceylon, and West Africa. The instrument is illustrated diagrammatically in figs. 54A and 54B, which show two rather different arrangements, either of which may be used. In the former an induction coil is used; in the latter the coil is single wound for the sake of simplicity and cheapness. Both work well, but the latter is the more common.

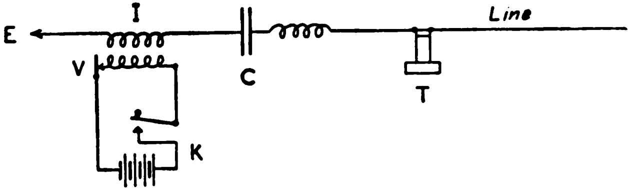

FIG. 54A.

The telephone is the receiving instrument, and it has the advantage that it will emit notes of any pitch that are audible by human ears without adjustment. A practised signaller is able to distinguish the notes which emanate from different offices, and can eliminate one message from another when his instrument is affected by inductive

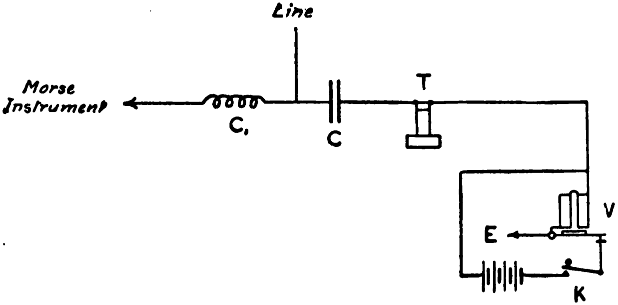

FIG. 54B.

disturbances. The coils of the 'buzzer' are wound to a resistance of 20 ohms each. The spring armature vibrates, when a current is caused to pass, similarly to the hammer of an electric bell. The extra currents thus engendered have a derived circuit in the line and through the distant telephone. The battery consists usually of four Leclanché or dry cells put up conveniently in a box with strap for portable purposes, and, with such a battery, it has been found possible to communicate over 300 miles of line.

With the aid of a 'separator,' consisting of a small condenser of $\frac{1}{3}$ microfarad capacity, and a coil with an iron core wound inductively to 200 ohms resistance, and joined to the line as shown in fig. 54B, it is possible to work the vibrating sounder on an ordinary Morse circuit without interference. The condenser prevents the signals from the Morse instrument from leaking into the vibrator circuit, and the choking coil softens the clicks from the Morse instruments in the telephone, making it easier for the operator to read the notes from the distant 'buzzer.' It is not, of course, necessary to use the separator when the circuit is worked exclusively with the vibrating sounder.

E.—THE A B C SYSTEM.

This system, like the needle, is transient or non-recording, but it conveys its signals directly to the receiver by indicating with a pointer the letters of the alphabet arranged consecutively upon a dial. It is the simplest of all forms of telegraphic apparatus for reading messages, but its construction is complicated. The apparatus of this kind in general use in England is Wheatstone's, but there are many other dial forms in use in other countries, such as Siemens', Breguet's, &c.

Wheatstone's A B C dispenses with the use of a battery, as the currents which are employed to move the indicator are produced by the application of magneto-electricity—one of Faraday's most brilliant discoveries—by which currents are produced through the relative movements of magnets and wires.

We have stated (p. 44) that when a current is flowing through a conductor, the neighbourhood of that conductor is converted into a magnetic field. The converse of this is also true, viz., that when a magnetic field is projected through or traverses a conductor, or when a conductor traverses a magnetic field, that is to say, whenever the relative positions of the magnetic field and the conductor are altered, a current is produced. Thus to produce these effects motion is necessary, and their magnitude is dependent on the length of conductor in the field, the strength of the magnetic field, and the velocity of the conductor across it.

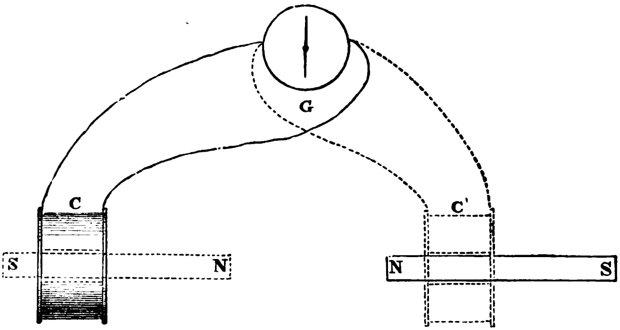

FIG. 55.

Let N S (fig. 55) be a powerful fixed bar magnet and C a movable hollow coil wound with a quantity of fine silk-covered wire, whose ends are attached to the coil of a galvanometer G. Let the coil C be rapidly moved over the pole N into the dotted position C′—a powerful momentary current will traverse the galvanometer. Let the coil be restored rapidly to its original position C—a current of equal strength, but in the reverse direction, will traverse the galvanometer. Now let the magnet be reversed, and the same movements be repeated, the same effects will be produced, but in the opposite direction. Again, let the coil be fixed and the magnet be movable. If the N pole of the magnet be inserted within the coil, a powerful current will traverse the galvanometer; and the same will occur, but in the reverse direction, when the magnet is removed. Reverse currents are generated when the poles are reversed. The currents produced by the motion of the coil over the N pole and towards the S pole, or by the insertion of the N pole into the coil, are in the same direction, as are also those produced by similar action between the S pole and the coil.

The actual direction in which the induced current will flow in each case is determined by a law first formulated by Lenz, and hence called *Lenz's Law*. It may be enunciated thus:

A current induced in a conductor by the relative movement of the conductor and a magnet, or of the conductor and another conductor in which a current is flowing, will flow in a direction the effect of which will be to oppose the originating motion.

For instance, in moving C to C′ (fig. 55), as C approaches N the current induced will make the right-hand end of C of N polarity, so that the pole N and the approaching coil will tend to repel; but in moving from C′ to C the induced current would give a S polarity to the right-hand end of the coil.

If the magnet, instead of being a bar magnet, be of the ordinary horseshoe form, and if the coil instead of passing over the end of the magnet simply passes in front of its poles, the same effects occur though in a somewhat diminished degree; but if the inside of the coil be filled with an iron core this loss is greatly compensated for, because the field is thereby strengthened. Let the coil be moved from

C (fig. 56) to C′; as it approaches N a current is induced in one direction, as it leaves N a current is induced in the reverse direction; as it approaches S a current is induced in the same direction as the last, and as it leaves S a current is induced in the same direction as the first.

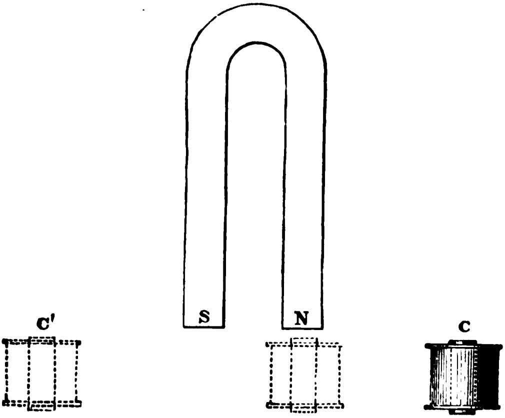

FIG. 56.

Let us take two coils wound like an electro-magnet, the two cores connected by a piece of soft iron, *a b*, and arranged to rotate about their centre *c*, as shown in fig. 57; then, if the coils are made to take one quarter revolution, so that *ab* stands at right angles to N S, a current in a certain direction will be induced in each; and if the coil-ends are properly connected to each other and to the line-wires, the currents induced in each will strengthen one another, and a current of double strength will be obtained. If now the coils be rotated a further quarter revolution, the

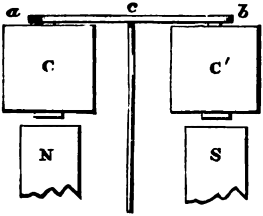

FIG. 57.

induced currents will be in the same direction as before (see last paragraph); so that a half revolution of the coils across the magnet will practically produce a single continuous current, strongest at its commencement and at its end. For the next half revolution a similar current but in the reverse direction will be induced; for, as already seen, the current obtained in receding is reverse to that obtained in approaching, and in the same direction as that induced when approaching an opposite pole. Thus by every complete revolution of the coils two distinct currents are produced, one in each direction. It may be noticed that these currents are obtained without in any way disturbing the continuity of the circuit.

Now instead of making the coils of wire and their iron cores (which are heavy) movable, let us fix the cores and coils to the poles of the permanent magnet, and simply cause the light piece of soft iron, *a b*, to revolve (fig. 58). This somewhat alters the conditions. The coils are now constantly under magnetic influence of the same polarity, but when the armature *a b* is across the pole pieces *a′ b′* the strength of the magnetic field is concentrated upon it directly through the coils; if now the armature be moved to the position shown, then the magnetic field is disturbed and the lines of force are diffused, and this has the same effect upon the coils as if the magnet had been withdrawn, that is, it will induce a current (say a positive current) in them. Let *a b* be rotated another quarter revolution to take up the position *b′ a′*; this restores the original condition of the magnetic field, and has the same effect upon the coils as causing the magnet to approach—this is, to induce in them a current in the reverse direction (say negative). Thus by this arrangement *four* currents, alternately positive and

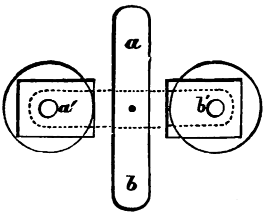

FIG. 58.

negative, are induced in the coils for each revolution of the armature.

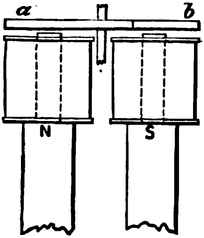

FIG. 59.

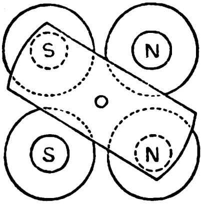

FIG. 60.

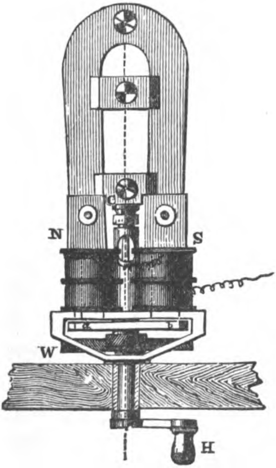

FIG. 61. Plan from below—¼th real size.

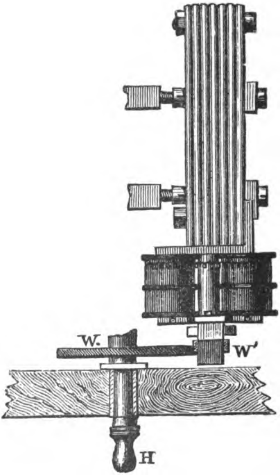

FIG. 62. Side elevation—¼th real size.

The most effective portion of each induced current is just when the armature takes up its position across the cores or leaves that position, so that the four currents due to one revolution are not produced at equal intervals ; but by attaching to each pole of the permanent magnet two soft iron cores fitted with coils, as shown in plan by fig. 59 and in elevation by fig. 60, the cross piece is approaching one core while it is leaving the other, and the irregularity is by this means eliminated.

We are now able to comprehend Wheatstone's magneto-electric A B C apparatus. A plan and side elevation of the sending portion, called the *communicator*, is shown by figs. 61 and 62. It is mainly encased in a wooden box, which is not shown in either of these figures.

N S is a compound permanent horseshoe magnet, usually formed of seven simple magnets placed with their like poles together. By means of this arrangement not only is greater magnetism obtained from the same mass of metal, but it is moreover longer retained. To each pole of the magnet two soft iron cores wound with insulated wire are fixed, as explained above. These are placed symmetrically with respect to an axis which carries a soft iron armature *a b*, whose breadth is rather more than the distance between two adjacent cores as shown in fig. 60, and which

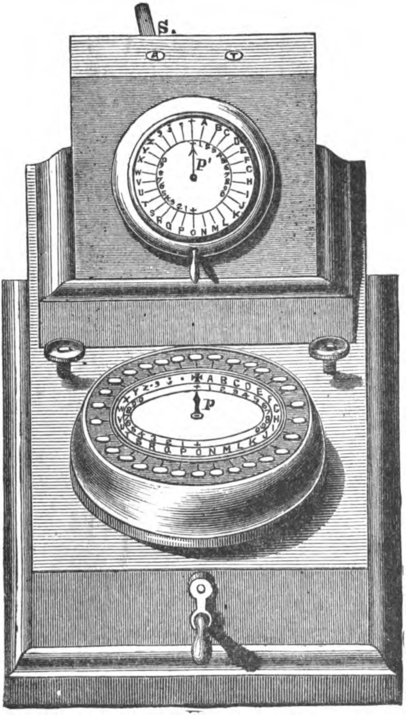

FIG. 63.

is made to revolve by means of the 'gearing' or driving wheels W W′ turned by the handle H. Above this electrical mechanism is a dial, over which is a pointer *p* (fig. 63), the end of which traverses the circumference of the dial. This dial is divided into thirty equal spaces, upon which are marked the twenty-six letters of the alphabet, the three points of punctuation , ; . and a + known as the *zero* stop: inside these are placed, on each side, the numerals, with the cypher and a +. Opposite to each of the spaces is fixed a key similar to that shown by fig. 64, which can be depressed at will. These keys are placed outside an endless chain, held in position by being passed round a series of small pulleys (fig. 65), and so arranged that only one key can be depressed at a time. One effect of depressing a key is to press in the chain at that point as shown at C C; when another key is depressed the chain is straightened and the first key thereby thrown up into its normal position.

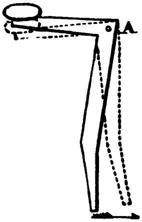

FIG. 64. ½ real size.

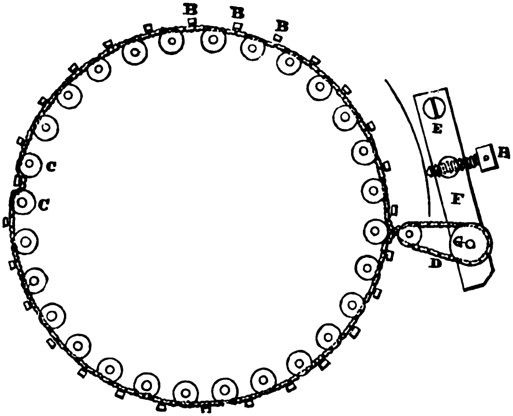

FIG. 65.

If now the handle be turned and the armature sent through one complete revolution in front of the four cores, four separate currents differing alternately in direction are generated. The motion is so adjusted that for each of these currents the pointer moves through one space, and thus for an entire revolution of the armature the pointer goes through four spaces, and four distinct currents are sent in succession along the line to the distant station. When a key is depressed, the motion of the pointer is arrested on coming opposite to it; and the currents, instead of going to line, are cut off. This is effected by means of a carrier arm fixed 'spring-tight' on an axle, which revolves conjointly with the pointer, but which is thrown out of gear immediately the pointer is arrested by the depressed key: it remains so until this key is raised by the depression of another, and, supposing the handle to be continuously turned, the pointer and carrier arm then resume their movement until again stopped when brought into contact with the latter key. The contact maker K is shown in fig. 66: L is a spiral spring holding it against the stop M in its normal position of rest. As soon as the handle is turned and a key depressed to admit of the carrier arm revolving, K is drawn against N, which is in connection with the line and so held until the carrier arm is again stopped.

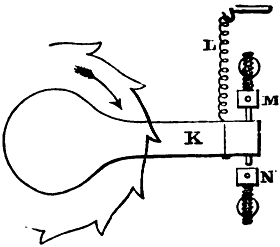

FIG. 66.

It occasionally happens that the endless chain in the communicator, by means of which the motion of the keys is regulated, is either stretched to such an extent that more than one key can be depressed at the same time, or (by repair, for instance) it may be so shortened as to prevent even one key from being depressed. In the first case the chain requires to be tightened, and in the second to be slackened. Provision is made for effecting this by means of an arrangement which will be understood on reference to fig 65.

The endless chain is passed around an additional pulley G, fixed upon a lever F, pivotted at E. In connection with this lever is an adjusting screw H. By screwing H in, the lever is drawn outwards, and, a greater portion of the chain being thus taken up in the section D, there is less slack left. By unscrewing H, on the other hand, a portion of the chain is released and the length available for the action of the keys may be thereby increased to whatever extent is desired.

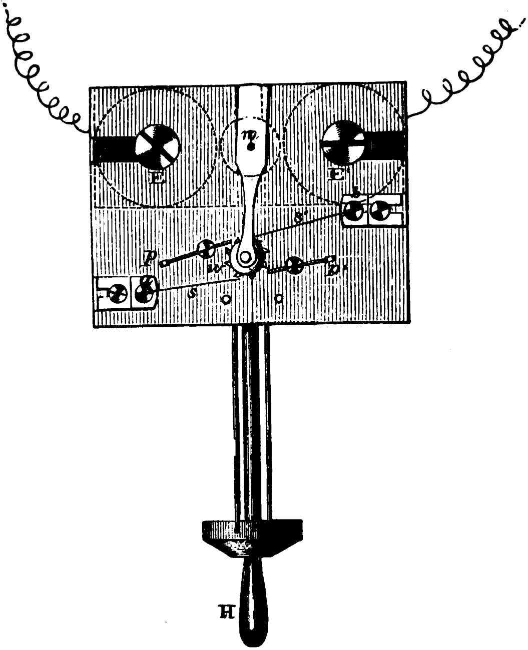

FIG. 67. Full size.

The Indicator.—The dial of the indicator is divided and marked in exactly the same manner as that of the transmitter. Movable upon an axis in its centre is a small pointer p' (fig. 63) which indicates whatever letters are sent. The motion of this pointer is regulated by a small escape-wheel w (fig. 67), which is propelled by the electro-magnetic arrangement shown in plan in fig. 67 and in section in fig. 68. E, E' are two separate electro-magnets, the cores not being joined across by a piece of soft iron as is ordinarily done. The coils are so connected up that the unlike poles of this pair of electro-magnets are adjacent, and between the coils, and lying parallel to the cores, are two small magnets $n\,s$ and $n'\,s'$ (fig. 68) fixed to an axis $m\,m'$. Upon this axis is fixed an arm which carries the ratchet or escape-wheel w, which thereby moves to and fro with it. The mutual attraction and repulsion between the cores when magnetised by the alternating currents that are sent and these magnets gives an oscillatory motion to the arm, which causes the escape-wheel to rotate in the following manner. The wheel has fifteen teeth cut on its circumference; its play is regulated by two small pallets $p\,p'$ (fig. 67), and two small steel pallet-springs $s\,s'$. Each motion to or fro of the magnets forces a tooth against one of the pallet-springs, which propels the escape-wheel forward through a distance equal to half a tooth, and causes the pointer on the dial to move through one space. A complete revolution, therefore, of the armature in the sender, which, as already remarked, generates four currents,

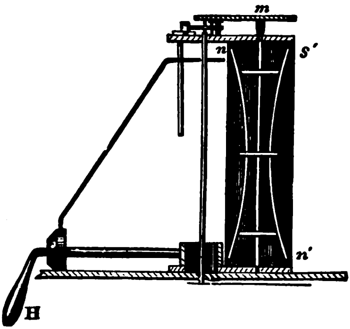

FIG. 68. ½ real size.

would carry the escape-wheel two teeth forward by four movements, and move the pointer through four spaces. H (figs. 67 and 68) is an adjusting handle which works the pointer on the dial in the same way as is done by the currents passing through the electro-magnet, so that the position of *p* and *p′* may be made to correspond.

When two stations are placed in communication with each other, and the apparatus at each is perfectly adjusted, the pointer on the communicator at the sending station moves synchronously with that on the indicator at the receiving station. When at rest both should point to zero, and in these circumstances the zero key must be always kept depressed.

When there are only two stations in circuit Wheatstone's A B C is found to work very satisfactorily indeed. The addition of every intermediate station introduces an element of irregularity, and complicates to a great extent the adjustment of the apparatus. Four stations fitted with these instruments upon the same wire may be accepted as the limit of safety: only under quite exceptional circumstances should five be tried. As these instruments are invariably employed either upon circuits over which comparatively little work passes or for private wires, an alarum bell is used in connection with them for the purpose of drawing attention when any communication is to be sent. This bell can be cut out of circuit by the movement of the switch S, the top of which is shown in fig. 63. When this switch is at A the alarum and indicator are both in circuit, when turned to T the coils of the alarum are short-circuited, and the indicator only is in circuit.

The adjustment, more especially of the indicator, is a delicate matter, and requires a considerable amount of skill and training before it can be undertaken with safety. If the pointer in the indicator jumps, or moves on in advance of the letters sent, the currents are either too strong or the pointer is too lightly adjusted. Either the armature in the communicator should then be moved farther back from the cores, or the play of the escape-wheel in the indicator should be lessened by adjusting the small screws and springs. The screws *p p'* are provided with split heads in the usual way: the screws *a* and *b* (fig. 67) are for regulating the tension of the springs.

If on the other hand the indicator pointer lags behind and drops letters, the currents sent are too weak, or the springs are too stiffly adjusted. Either the armature should then be approached to the cores in the communicator, or the play of the ratchet-wheel in the receiver should be assisted by easing the studs and springs.

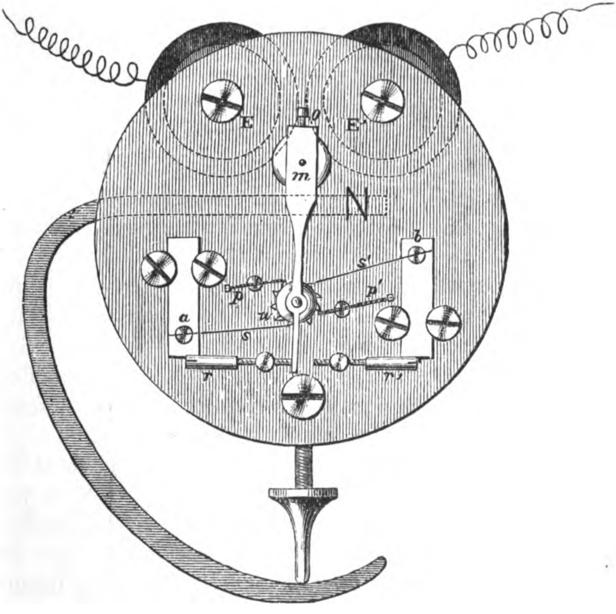

FIG. 69. Full size.

The main difficulties experienced with these instruments are due to atmospheric electricity. Lightning frequently deranges them to a great extent. Not only does it readily fuse the coils, on account of the wire with which they are wound being necessarily so fine, but by demagnetising or even reversing the polarity of the small magnets in the indicator, it interferes with their action and renders a fresh adjustment or remagnetisation necessary. This latter danger has been overcome to a great extent in the form of indicator which is now issued by adopting the principle which was introduced into the coils for needle instruments (p. 53), that is to say, by employing induced instead of permanent magnets. Fig. 69 shows in plan the latest form of indicator. The escape-wheel and its adjustment are almost exactly the same as in the earlier issue : two additional screws *r* and *r'* are added by means of which the play of the arm can be better regulated. The compound magnet shown in fig. 68 is dispensed with, and in its place two soft iron armatures connected by a small axle pivotted at *m* are employed. The upper of these is indicated at O. These soft iron armatures are kept in a magnetised condition by means of the large bent horseshoe magnet N S partly shown in the figure : the S pole is at the lower end of the coils. The same beneficial results attend this arrangement as have been already referred to in connection with the single-needle instrument.

Occasionally, too, in the case of a heavy thunderstorm, the large permanent magnets in the sender have their magnetism reduced, so that the currents generated by them are too weak for the adjustment to which the apparatus has been set : indeed, instances have occurred, even in England, where the lightning has removed every trace of magnetism from these large magnets.

F.—TYPE-PRINTING INSTRUMENTS.

These are instruments which record the messages sent in bold, clear Roman type. Many ingenious forms of

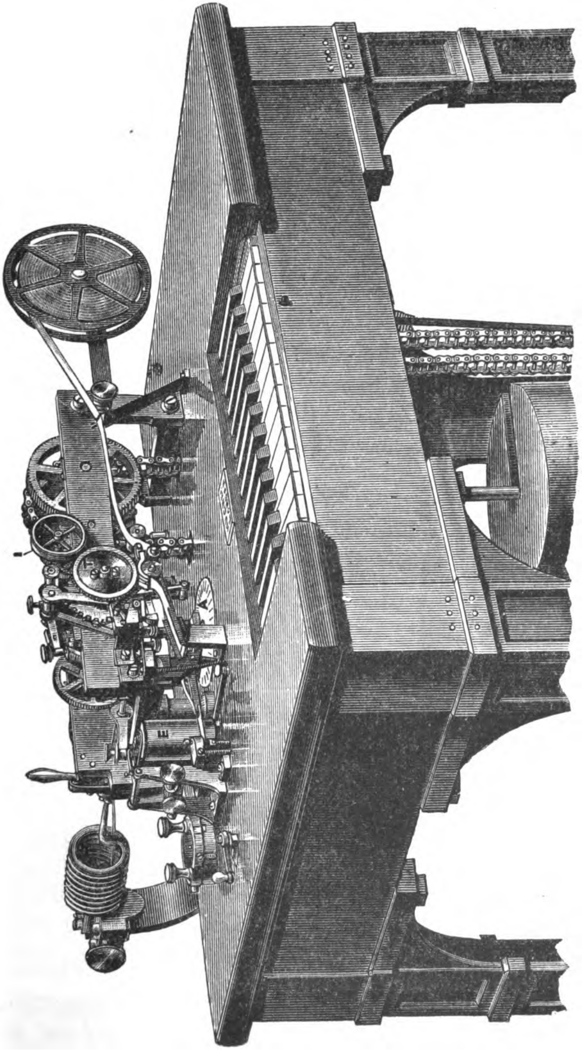

FIG. 70.

apparatus have been devised and practically used for this purpose, but only two have attained any considerable employment in ordinary telegraphy, namely the Hughes and the Baudot.*

(1) *The Hughes Type-printer.*

This instrument, shown by fig. 70, differs from all others of its class in being principally mechanical; only one current of short duration being employed to register each letter. The instruments at the sending and the receiving stations are identical in construction and movement. Their type-wheels (T, fig. 70), having the letters of the alphabet raised on their peripheries, and attendant apparatus are kept rotating synchronously and simultaneously. The sending apparatus is like a piano key-board, with the letters of the alphabet and any other signals needed engraved on the keys; when one of these keys is depressed a pin is raised on the plate marked A, which just catches a '*chariot*' rotating with the type-wheel, and thereby sends a current through the electro-magnet E to the distant station. This current causes the paper at both stations to be lifted at the same time into contact with the type-wheels. The wheels, having their circumferences coated with printing ink by means of the inking roller, I, and rotating in unison, each print the letter corresponding to the pin raised at the sending station. The same movement causes the paper to be moved forward one space ready for the next signal. In this way, by touching each key required successively, words and sentences are spelt out and properly re-

FIG. 71.

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* This is used on the Continent, but not in England except on two London-Paris circuits.

corded at both stations simultaneously. Fig. 71 gives a sample of a short sentence so printed.

The mechanical construction of the apparatus is exceedingly ingenious and perfect; but as it is in use only to a limited extent in England, a full description of it does not fall within the scope of this work.

The electrical arrangement also is very simple, and very sensitive. The current which is sent does not *attract* an armature, but it temporarily weakens the polarity of a permanent magnet so as to cause it to *release* an armature, which is then pulled away by the tension of a powerful antagonistic spring. The armature is restored to its normal position by the mechanical action of the instrument. This electrical arrangement is indicated by the following figure (fig. 72). N S is a powerful permanent magnet, having two soft iron pole pieces, to which two soft iron cores are permanently attached, surrounded with coils of wire which form part of the line wire : *a* is a movable soft iron armature and *s* an antagonistic spring. When this armature is placed upon the pole pieces, it is held there by the magnetism induced in the pole pieces by the permanent magnet N S, and it will bear a considerable tension of the spring *s* before it will be torn off; but if a current passes through the coils in such a direction as to induce in the cores a polarity the reverse of that induced by the magnet, the armature will be released and it will fly back with the full force of the tension of the spring. The instrument is thus actuated by exceedingly delicate currents but it records its signals with the full mechanical force of a trainwork driven by a

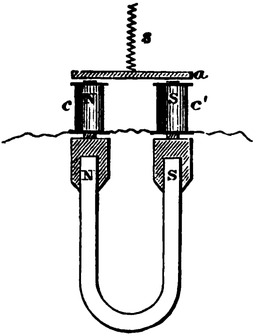

FIG. 72.

heavy weight, the printing portion of which trainwork is brought into gear by the action of the spring *s* when the armature is released.

Although the Hughes instrument is very extensively used in France and other continental countries, its use in this country has hitherto been restricted to the working of foreign cables. Its expense, which is very considerable both in initial cost and in working, has been the prime factor against its employment.

(2) *The Exchange Company's Type-printer.*

Although the Hughes instrument is the only form of type-printing instrument in general use for ordinary telegraph business in England, there are other requirements for which such an instrument would be quite unsuited. Thus the delivery of general and other news to many different points simultaneously by one operation, without reference to attention being given at those points, would be quite impracticable by the Hughes system. The general principle of the kind of intrument used for the transmission of news in this way will be clear from a consideration of the instrument used by the Exchange Telegraph Company of London.

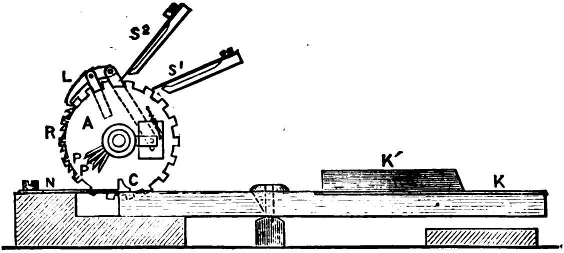

FIG. 73.

The transmitting instrument consists essentially of a series of finger keys for determining the letter or sign that is to be recorded, as in the Hughes instrument. Two of these finger keys, K, K′, are shown in fig. 73. The inner end of each key is beneath a small catch C, which, on being raised by the depression of the key, comes in contact with one of a series of pins, P, P′, upon a revolving barrel. These pins are arranged spirally around the barrel corresponding in number and position with the finger keys, and the barrel revolves continuously except when stopped by one of the pins coming against a catch on the depression of a key. Attached to the barrel by an ingenious friction arrangement is a contact-wheel A, with half the number of contact projections that there are letters and signs, and these projections come alternately beneath the two independent contact springs S^1 and S^2.

A ratchet-wheel R is driven continuously by an electric or other motor, and when running normally the pawl L, which is pivotted on a bracket attached to the hinder face of the contact-wheel A, engages with the ratchet-wheel R so that the pin-barrel and the contact-wheel are carried round by the motor. By the action of any of the pins P P′ stopping the barrel when a key is depressed, the pawl is raised and the motor left to continue its revolution, although the barrel is stationary. On the release of the key the barrel again takes up the motion of the motor.

Such a transmitter as this may be used to work an almost unlimited number of recording instruments placed upon any number of lines. In connection with each line is a set of three relays, say R_1, R_2, and R_3. The tongue of R_3 is used to join up the line to the contacts of R_1 and R_2, the tongues of which are connected respectively to the positive and negative poles of two powerful batteries, the other poles being joined direct to earth. Relays R_1 and R_2 are actuated respectively on the completion of the circuit of a battery through S^1 and S^2 (fig. 73), and R_3 may be considered to be kept closed so long as messages are being sent. Hence, as the pin-barrel and contact-wheel revolve powerful alternate currents are sent to each line.

This explains the general principle of working of the transmitting arrangement, but there are other electrical and mechanical details to which reference need not here be made. Switches are provided for joining up the batteries and for starting and stopping the motor. Provision is also made for preventing sparking at the contacts of the relays from the powerful currents that are required for working.

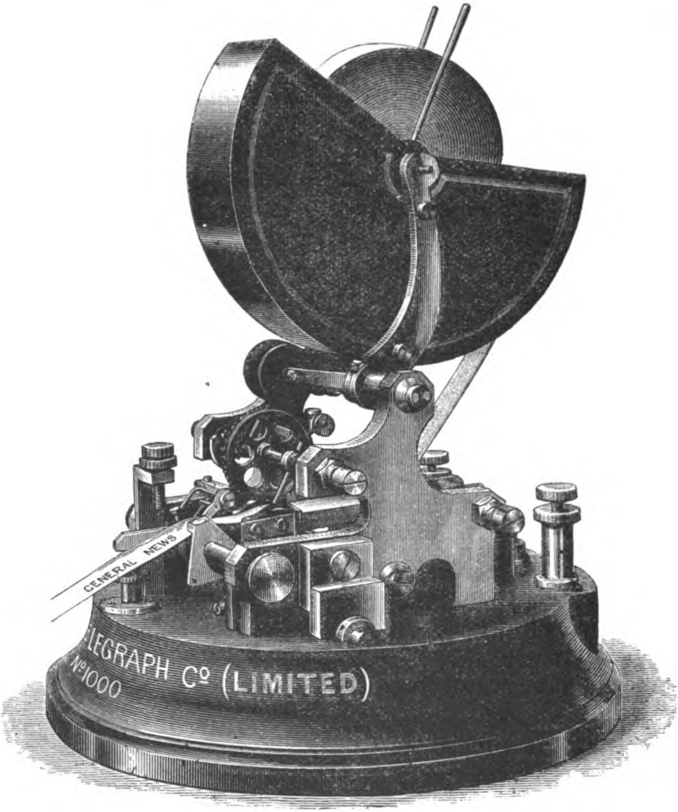

FIG. 74.

A general view of one form of recording instrument is given in fig. 74, and fig. 75 shows some of the electrical details.

The apparatus consists of a powerfully magnetised armature A, oscillating between the poles of two electro-magnets M_1 and M_2. A forked lever upon the armature axle carries pallets p_1, p_2, which are arranged to engage with the teeth of a ratchet-wheel R on the type-wheel axle in such a manner that when A is attracted towards M_1 the type-wheel is propelled by p_1, and when A is attracted towards M_2 the type-wheel is propelled by p_2. These pallets are also so shaped that, when the armature is attracted either way, the type-wheel is held quite steady by their means. This is important in order to secure clear printing.

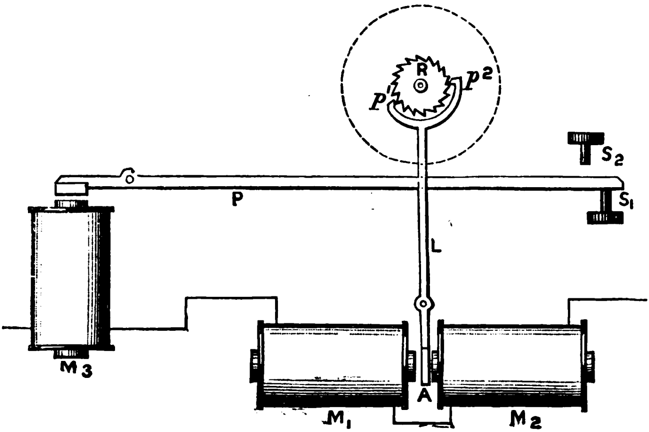

FIG. 75.

M_3 is the printing electro-magnet, the armature of which is attached to the lever P, whose motion can be regulated by the two stops S_1 and S_2. The paper slip upon which the record is made is carried by this lever, so that when M_3 attracts its armature the lever raises the paper into contact with the type-wheel (shown by a dotted circle), and the lowest letter or sign upon the wheel is recorded upon the paper.

The commencement of the movement of the printing lever effects the forward movement of the paper slip by one space.

The printing and type-rotating magnets are in the same circuit, but the alternate currents from the transmitter which propel the type-wheel are too short in duration to overcome the inertia of the printing lever; when, however, by the depression of a finger key, the contact-wheel is brought to rest for a short time, the current is prolonged, and, while the type-wheel is held firmly as described by one of the pallets p_1, p_2, the lever P effects the forward movement of the paper slip and then raises it against the type-wheel.

In a certain position of the type-wheel axle—which can be secured for every instrument in the several circuits by two complete revolutions of the transmitter contact-wheel —the type-wheel is locked until the printing lever is actuated. By this means the operator at the transmitter is enabled from time to time to set every recording instrument in his charge to zero, thus providing against any considerable loss of news in the event of any instrument happening to miss one or more of the alternate currents.

The speed of manipulation with a skilful operator reaches as much as forty words per minute.

There are many different forms of recorder designed to meet the various services required; for instance, that employed for Stock Exchange quotations requires sixty characters, and these are disposed upon two type-wheels carried on a common axis, either of which can, at the will of the operator, be brought into position with great facility. Another instrument is arranged to print in column form instead of in one long line.

For working at great speed or to long distances the motive power for the recorder is supplied by a spring or weight through a train of wheels, instead of directly by the transmitting station by means of the electro-magnets.

Another type-printing telegraph instrument which of late years has been gaining popularity is that of Steljes, who uses the Wheatstone A B C transmitter in conjunction with a tape recorder driven by weights. The apparatus is shown

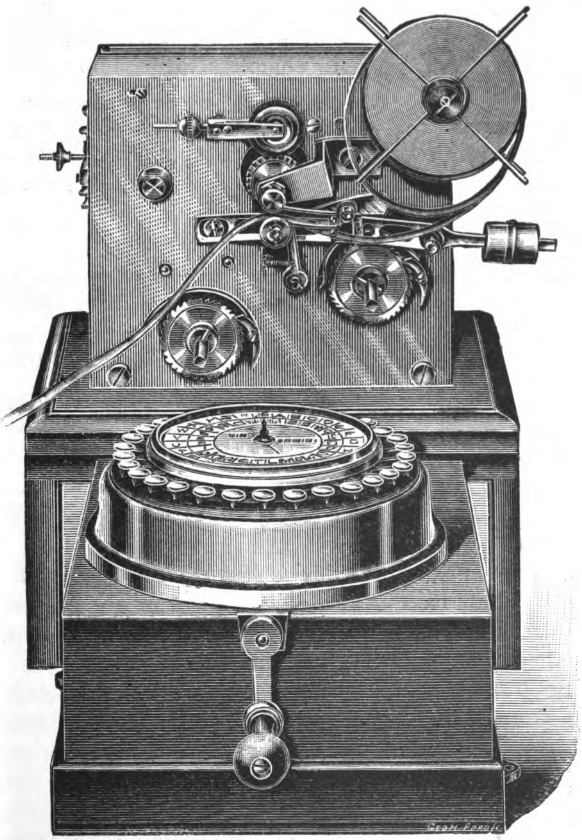

FIG. 75A.

in fig. 75A. The transmitter may be driven either by one hand, the other being used to manipulate the keys, or both hands may be free by adopting a motor or treadle drive. This instrument is used in conjunction with telephones, as shown in fig. 75B, in which case two 'bridging' coils of resistance and self-induction suitable for the circuit are connected so as to separate the telephone from the printer, which is joined to earth to complete the circuit. A condenser may be inserted in the earth circuit to prevent metallic connection between line and earth. The starting and stopping of the recorders are automatic, so that a message can be received during the absence of an attendant, the instrument case being locked if desired to secure privacy.

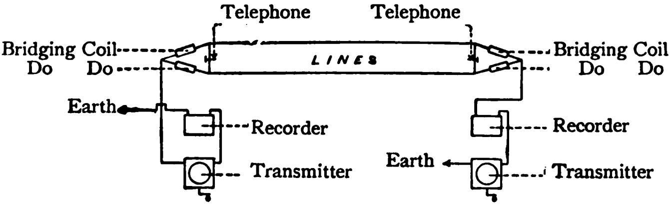

FIG. 75B.

A somewhat similar device has been brought out by Siemens and Halske in Berlin. This system is worked with accumulators at low voltage, which has the advantage that the induction in neighbouring circuits is small.

Both the above type-printers are used with advantage in connection with central exchanges and plug switchboards for a number of subscribers.

G.—A COMPARISON.

The instruments which have been described in the previous pages have shaken themselves out as it were from a mass of beautiful apparatus of the same species, which have been practically tried in England; and each has in its own sphere proved itself to be the best adapted to the purposes which it was intended to serve. This struggle for existence is, however, still progressing, and it is quite impossible to say that each is an example of the survival of the fittest, for the probability is that one or other of the forms now in use will eventually be jostled out of employment by some more perfect competitor.

The Hughes is employed in England only for Continental traffic. The Bain, as already stated, is never used, and the Bell is gradually being replaced by the Sounder or the Needle. In drawing a comparison of the relative advantages of the different instruments used, these three instruments, the Hughes, the Bain, and the Bell, will therefore not be considered.

For the purposes of comparison we will consider the simplicity in construction and working, the rate of working, and the special adaptability for the purposes the several instruments are each peculiarly qualified to fulfil.

1. *Simplicity in Construction.*

Simplicity in construction is a great desideratum, especially when the operators are unskilled or ill-educated. Of all the different instruments described, the direct Sounder is unquestionably the simplest in construction; but when it has the relay added to it, it is difficult to say whether it is simpler than the Needle. The Needle has this advantage over the Sounder or any other form of instrument: it has no points requiring delicate adjustment, and though the arrangement of the sending portion of the apparatus is more complicated than the simple key of the Morse and Sounder, the receiving portion is much more simple than either. The Morse involves a complicated and expensive trainwork of mechanism, including a governor to maintain the paper in uniform motion, and a special contrivance to keep up the supply of ink, besides which both Sounder and Morse have galvanometers which are themselves equivalent to a single-needle dial.

The A B C is both complicated and costly in its construction, and in the simplicity of its parts cannot compare with its competitors.

Hence, on the whole, the Sounder is probably the simplest form of apparatus constructed for telegraphic purposes.

2. *Simplicity in Working.*

The A B C involves no technical skill in sending and receiving messages. An hour's practice will enable any child or old person to send or receive a message by its means. It is only necessary to watch the movements and pauses of the indicator to read, and to follow the letters of the alphabet to send. The Needle instrument requires no special skill with the hands to send, though rapidity of sending is acquired with practice only ; but the Morse recorder and Sounder involve technical skill, long practice, and experience both to read and to send. In the case of the Sounder, however, if once a person learn to read by sound, sending becomes not only comparatively easy, but remarkably accurate. The A B C instrument is therefore the simplest in working, and the Sounder is the most difficult ; the Needle and Morse may be bracketted together. The Sounder has this immense advantage over the Needle, that it allows the receiver to concentrate his eye upon the form on which he writes the message he is receiving, while the needle-clerk has to glance alternately at the needle and the paper, thus performing two operations to one performed on the Sounder. This difference, however, is considerably modified by the application of tin sounding plates to the

Needle (see p. 54), or the employment of Neale's Dial (p. 70) or the recently introduced 'Polarised Sounder.'

Where several Sounders are in use it is necessary to enclose each in a screen, to concentrate the sound; and a disadvantage inherent to all sound-reading instruments is that they are liable to be abused by eavesdroppers.

3. *Rate of Working.*

The useful speed of a non-recording telegraph instrument is in reality limited by the rate at which a clerk can write; but in recording instruments this is not so, because if one clerk cannot write as fast as the instrument records, a second clerk can be appointed to assist him. All these instruments which have been described are, however, limited in speed by the rate at which a clerk can send or manipulate his key. The Single Needle in expert hands frequently attains 30 words per minute; and the average rate at which an ordinary needle circuit works is 20 words per minute. The Morse ink-writer, under the same circumstances, attains 35 words per minute, while the average rate at which such a circuit works is 30 words per minute. Very expert manipulators sometimes attain as many as 20 words per minute on the A B C, but the ordinary rate of working with this form of instrument rarely reaches 10 words, and the average does not exceed 5 words per minute.

The Sounder attains the same speed as the Morse, and practically can be read faster than any clerk can write; but there is no advantage in exceeding this speed except in conversation, and therefore for all ordinary purposes the Sounder attains a rate of working in experienced hands of from 30 to 40 words per minute. But the number of words per minute which an instrument can transmit is really not a criterion of its value as a fast-working apparatus, because the nature of business in England is such that the greater part of the messages are sent between the hours of ten A.M. and one P.M., and it is essential that between these hours the wires shall not be overcrowded with messages. Hence it becomes a question of the suitability of the instruments for use on busy circuits rather than of the working speed per minute. The following table may be taken as giving a fair average of the number of messages which each instrument transmits in an hour and in a day:

	Hour	Day[4]
Sounder	60	300
Morse	45	200
Needle	30	150
A B C	15	75

Thus the Sounder is by far the fastest instrument, and a day's work on a Sounder will exceed that on any other instrument similarly worked. Of course this rate of working depends upon the number of words which each message contains. In England the average is 17 words, including the ordinary service signals, and each word averages five letters. The reason why the Sounder is so much quicker than any other instrument is that, as both stations are equally ready to send and receive, corrections are made at once, the receiving clerk keeps up with the sender, and there is never any waiting for repetitions or acknowledgments. A clerk receiving a message by means of the Sounder confines his eye to what he commits to paper—his mind is free to follow the sense of the message. He is simply in the position of being addressed by a clerk, perhaps hundreds of miles away, who dictates each word, not as it is spoken, but as it is spelt. The ear does not tire like the eye, hence the clerk can maintain the rate of working for longer periods than with the Recorder or Needle.

4. *Special Adaptability.*

Telegraph instruments are required for many different purposes, and are placed in many different situations. They are required for the transaction of the ordinary business

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[4] This does not indicate what the instruments *can* do, but what they actually do in a day with English telegrams when so arranged that they shall not be unduly overcrowded at busy times.

wants of the country and of the domestic relations of the community. The transmission of that enormous mass of news that now forms such a large portion of ordinary newspapers has to be performed by them. They are necessary for the various purposes of the railway companies in regulating the traffic and moving the trains upon their railways. They are employed between the mansion and the stables, between the merchant and his counting-office, between the shop and the parlour. They are worked by highly-trained and well-paid manipulators, by inexperienced and insufficiently paid boys and girls, by the assistants of the flourishing tradesman, and by the superannuated village grocer or his wife. There is thus a sphere for many forms of instrument.

The A B C is especially adapted for private wires and for small village post-offices, where messages are few and far between and where skilled and trained labour can neither be found nor paid for.

The Needle is specially adapted for linking together several towns on one wire, neither of which singly does much work, but where all together can fairly occupy a wire. No instrument that has ever been devised so fully meets the requirements of a railway. Its manipulation is easily learnt and not easily forgotten ; the apparatus never wants attention and is always in order. Many more stations can be placed in circuit on one wire with it than with any other form of instrument.

The Morse and Sounder are specially adapted for ordinary commercial purposes where the amount of business is sufficient to justify the employment of skilled labour ; and of these two the Sounder is unquestionably the superior and is rapidly displacing the other.

Special apparatus—Automatic Fast Speed, Duplex, &c. —cannot properly be included in this comparison ; and the Telephone, which is so peculiarly adapted for untrained operators, is only just beginning to take a place in England for ordinary telegraph purposes, although in some continental systems it is very extensively employed. The considerations that it cannot be satisfactorily worked except with two wires, that it must be fixed in a 'silence box' or a private room, and that transmission by actual word of mouth is so liable to abuse, sufficiently indicate the reasons which militate against its general adoption in the public telegraph service.

CHAPTER IV.

CIRCUITS.

We have defined the circuit (p. 8) to be the whole path along which the electricity is supposed to flow; and we may consider two cases, (*a*) that in which a current is flowing, (*b*) that in which it is not flowing. If we erect a wire between A and B (fig 76), the end at each place being connected with the earth, then the circuit consists of the whole path from A to B along the wire, and back again from B to A through the earth; and this circuit may either have a current flowing through it, or it may be free from all current. In the latter case the circuit is said to be *open*, in the former case to be *closed*.

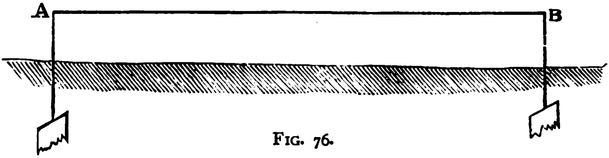

Fig. 76.

These two conditions of the circuit are shown in figs. 77 and 78 respectively.

The earth is considered simply as a part of the circuit, offering a certain resistance to the flow of electricity through it; but, owing to its infinite dimensions, this resistance is practically nothing. Hence the earth may be said to allow currents to flow through it in any direction, and without any obstruction or interference when considered as a whole ; but in some sorts of dry and rocky formations and for limited distances it does offer resistance, especially at the earth plate. This resistance can be measured, and introduces peculiar disturbances which have to be eliminated or allowed for.

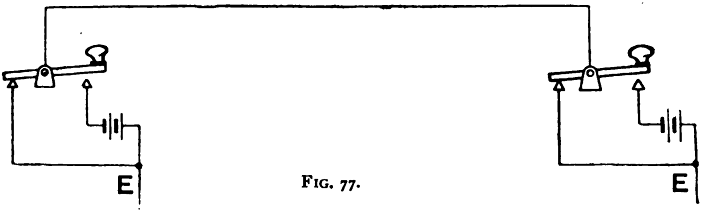

FIG. 77.

The battery which generates the current, and the apparatus which renders it evident to the senses, are essential and important parts of the circuit, and their resistances are material in determining its working conditions.

Thus we see that whatever is in the path of the current —whether it be in the battery itself, in the apparatus, in the line wire, or in the earth—whatever, in fact, offers any resistance to the passage of the electricity, is the *circuit*, and this circuit, for telegraphic purposes, may be either open or closed.

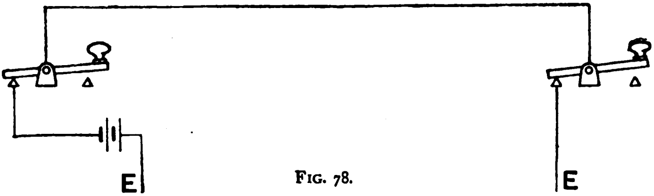

FIG. 78.

The needle instrument is invariably worked on the open-circuit system. The normal position of the needle when at rest being vertical implies the absence of current, and the motions to the right and left, due to the reversal of currents, imply some rearrangement of the circuit resulting in the flow of current in one direction or the other. K and K′ (fig. 79) are the commutators, B and B′ are the batteries, A and B are the coils and needles. The action of the commutator is described at p. 51. When *r* of K is depressed the current flows from station A through the line to station B in one direction; when *l* is depressed the current flows in the reverse direction. The needle deflects in the direction of the current. Thus from A we can deflect the needle at B to the left by depressing *l*, or to the right by depressing *r*; and similarly from B we can make the needle at A deflect in either direction at will.

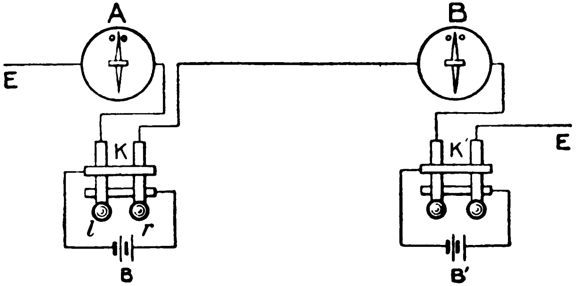

FIG. 79.

The Morse or Sounder system is also in England invariably worked on the open-circuit system, but it is worked with or without a relay. Open-circuit working without a relay is called *direct working*. It is shown in fig. 80.. B, B′ are the batteries, and the instrument connections are so arranged that the current in the line always flows in the same direction, whichever station is sending. This is effected by reversing the line and earth connections at the down station. It is a conventional arrangement made for convenience, and not essential to the working of the apparatus. K is the key described on p. 62, which on depression at A permits the current to flow. G is a galvanometer which indicates the existence of the current, and M is the recorder or sounder worked by the current received from the distant station. Now when station A wishes to communicate with station B, he depresses his key K, which brings the battery B into action, and sends a current which causes the needle of the galvanometer G, as well as that of G′ at B, to deflect, and works the recorder M′ at B, his own recorder not being affected. Thus the attention of B is attracted by the sound or motion of the recorder, or by the galvanometer, and A knows by his own galvanometer whether his current is going properly to line or not.

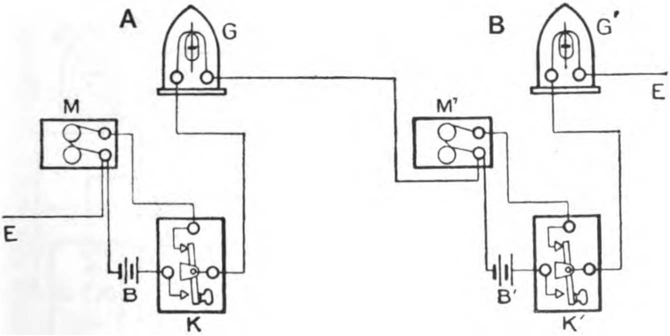

FIG. 80.

Direct working is used only for comparatively short lines, for if the length of line be considerable the electro-motive force required in order to obtain a current of sufficient strength to work a Direct Writer or a Sounder is so great that the cost of maintaining the battery becomes excessive. Where, therefore, the distance exceeds 20 miles, where the insulation of the wires is indifferent, and where abnormal resistance is introduced through the insertion into the circuit of intermediate stations, relays become necessary. We then work by *local currents*. M (fig. 81) is the recorder or sounder, L B a local battery, and R the relay which takes the place of the sounder in fig. 80; all the other connections are the same. When the key K at station A is depressed, a current flows from the battery B through K, G, R′, K′, G′, to earth and back to the battery at A. In flowing through R′ it moves the tongue of the relay, which completes the local circuit by which the local current flows from L B′ through M′, and records its signals.

Allusion has been made to the effect of the introduction of intermediate instruments. The introduction of such apparatus in no way affects the theoretical working of the circuit. If in either of the above two cases the earth wire at B, instead of being carried direct to earth, were attached to another line wire extending beyond it, it will be seen that the circuit would still remain whole and open, and that when any one station worked every other station would be affected. The theoretical connections at an intermediate station on a circuit working with local currents are shown in fig. 82. It is evident that while the apparatus is idle the continuity of the circuit is maintained through the key, and that when the key is depressed the currents flow through

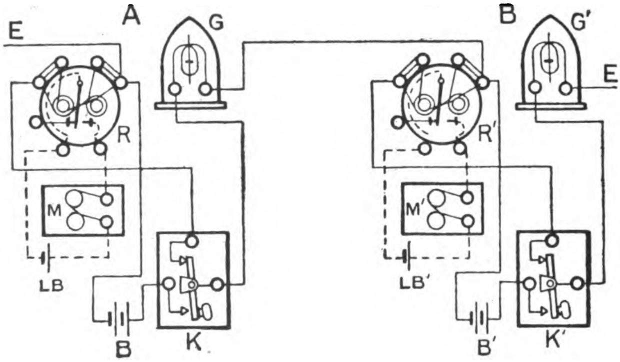

FIG. 81.

both the up and down line without affecting the sounder at the intermediate station itself, but operating those at the other stations. If simple sounder working be in use it is only necessary to replace R by M alone, and remove L B.

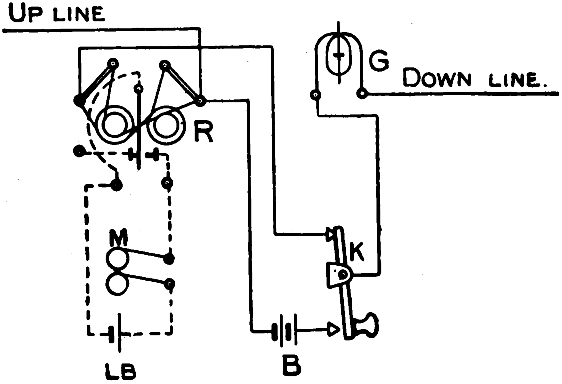

FIG. 82.

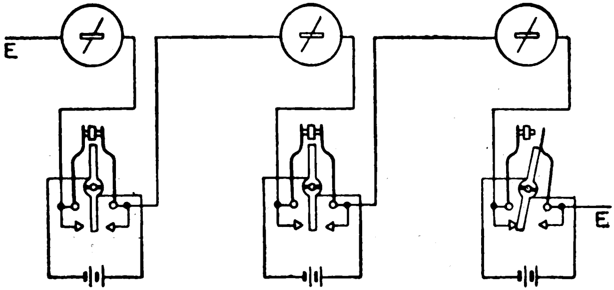

FIG. 83.

The mode of connecting up a needle instrument intermediate is symbolically shown in fig. 83, where, for variety, drop-handle instruments are shown.

The closed-circuit system has never been a favourite in

England; it has been frequently tried, but the experience of its use has been sufficiently unfavourable to warrant its withdrawal. One important consideration has been the increased cost arising from the greater consumption of materials, owing to the much longer time during which the current is passing. It is shown in its simplest form in fig. 84. M is the recorder or sounder, K the key, B the battery, as before; but there is a battery at only one station, and not at each station, as in open-circuit working. The key K has a movable handle or *switch*, as it is called, which normally is closed, as shown in K at station B, and connects the battery to line, so that even when the circuit is idle the current is flowing. If A wishes to communicate with B this switch is pushed aside, the current ceases to flow, the circuit is open, and A works as in the open-circuit system, closing the switch when he has done working. If B wishes to communicate with A he also opens the switch; but when he depresses his key he does so simply to complete the circuit for A's battery, and therefore he works the circuit by means of that battery. A large number of intermediate stations can be inserted on such a circuit, and it is evident that if they all keep their switches closed the current flows throughout the whole circuit; and any station, by opening his switch, can break in and operate every instrument upon

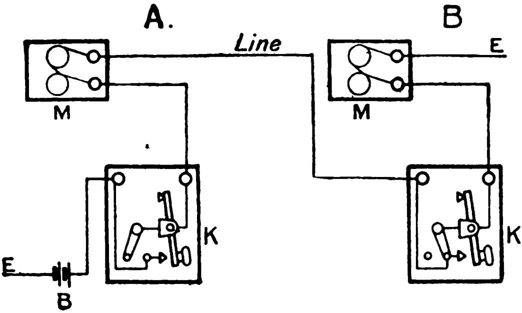

FIG. 84.

the circuit by opening and closing the circuit of the one battery fixed at one of the terminal stations.

Closed-circuit working is very generally adopted in Australia and other colonies, as well as in America. It is also much used in Germany, where some circuits have as many as fourteen stations upon them. As, however, owing to leakage, the current from a battery at one end of a long circuit becomes gradually weaker according to the distance of the different stations, each station is sometimes provided with a part of the battery, which forms part of the circuit. This is shown in skeleton form in fig. 85.

There is another mode of working a closed circuit, which was originally introduced in America, has been used on the Hanoverian lines, and is now applied to the State Railways of India. Instead of breaking the closed circuit by a switch, and converting it really into an open circuit with the key worked at any point, the instruments are caused to work by the interruption of the current. Relays are used which are held in their normal position of rest by the current, and which are caused to complete the local circuit by the interruption or cessation of the current. It is not much used.

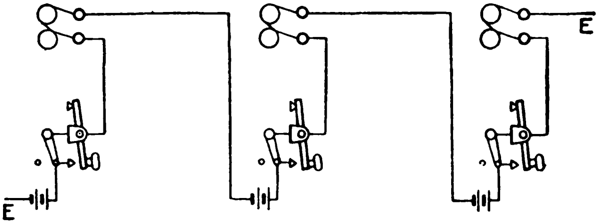

FIG. 85.

There can be no doubt that where many intermediate stations are fixed on one wire worked on the Morse principle, the closed-circuit system offers considerable advantages over the open-circuit system ; for the inconveniences arising from the difficulty in maintaining the accurate adjustment of the apparatus, when receiving from different stations at different distances, owing to the variations in the current, are to a considerable extent avoided. The current at the same station is constant. But in England we never do use the Morse on such circuits. The Needle is far preferable, and in that system no adjustment whatever is needed. It is an exceedingly rare thing to fix more than four stations on one Morse circuit, for the simple reason that it is almost impossible to group four Morse stations together without filling the wire—that is, without obtaining a sufficient number of messages to wholly occupy the wire during the busy parts of the day. If there is not enough work to fill the wire, the needle instrument, from its simplicity, economy, and certainty, is used in preference. These facts are mentioned because surprise is often expressed by colonists and Americans that the closed-circuit system is not used in England. Every country has developed its own system, and the conditions which have rendered the closed-circuit necessary in America do not exist in England. It should be remarked, however, that the introduction of secondary cells for telegraphic use materially alters the aspect of the case, and it is not impossible that a development in this direction may take place in the near future.

When any length of gutta-percha covered wire, either in a submarine cable or in underground pipes, forms part of a circuit, it tends to diminish the speed of working by accumulating upon the surface of the wire, in virtue of its electrostatic capacity (p. 138), a portion of the current which otherwise would proceed to the distant station to record or register its marks. A similar effect, but on a smaller scale, occurs on overground wires. When, however, such lines are very long, the effect of this *electrostatic induction*, as it is called, becomes evident. To overcome this distortion of the signals, more deliberate sending is necessary. The key must be held down longer to allow a dot to be made, for the short and smart dots made upon a short aerial line are entirely lost on an underground, a submarine or a long overground circuit. This loss of speed is to a large entent remedied by ***double-current*** working. A second current, reverse in direction to the first current, and sent immediately after it, not only hastens the discharge or the clearance of the wire of the charge accumulated upon it, but it enables the relays to be worked in their most sensitive and, therefore, their most rapid position. This method of working is shown by fig. 86.

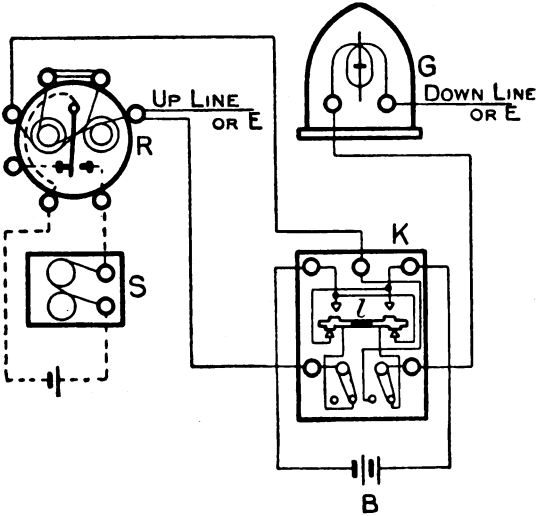

Fig. 86.

G is the galvanometer, K the key, R the relay, S the sounder, and B the battery. The lever *l* of the key consists of two brass pieces rigidly fixed together, but insulated from each other by a strip of ebonite. At the back of the key (as shown in side elevation in fig. 134) each brass piece plays between two contact springs. The function of the switch shown at the lower part of the key is to connect the battery or the receiving instruments to line at will. In the diagram the switch is shown in the sending position, and it will be seen that the negative pole of the battery is joined to the down line and the positive pole to the up line. If the key be depressed, the back end makes contact with the upper springs and the battery connections are reversed. When, therefore, it is desired to send, the switch is placed in the position shown, and while the key is at rest the current sent out will pass through the relay at the distant station and hold the tongue away from its contact point. Hence all antagonistic springs or other forces may be dispensed with, and the relay kept in the most sensitive condition for responding to any change in the current. When the key is depressed this current ceases, and a reverse current is sent to the line, which moves the tongue of the relay in the proper direction, and 'marks' are made. Thus there is always a current flowing when the switch is turned for sending, and it is the reversal of this current which works the apparatus. It will be seen that when the switch is turned to receive, the line is joined through the key to the relay.

The double-current system of working not only expedites the rate of working on submarine, subterranean, and long overground circuits, but it frequently enables the working of the circuits to be continued in the face of considerable interferences and disturbances inherent to overground wires. It destroys in relays all the effects of residual magnetism ; it allows circuits to be worked with less powerful currents because the relay tongues may be adjusted to their most sensitive position, and consequently it enables them to be worked to much greater distances.

It is objected to this system of working that messages once commenced cannot be interrupted for corrections or inquiry, but general experience shows that the objection is only theoretical.

The difficulties of adjustment inherent to open-circuit working with single currents, owing to the variations in the strength of the currents received from different stations, are entirely overcome in double-current working; for whatever be the variations in the prime current the reversing current is equally and similarly affected, and thus the moving force and the antagonistic force vary together and are self-adjusting. Double-current working is therefore almost invariably adopted on Morse and Sounder circuits having intermediate stations upon them, or which exceed twenty-five miles in length.

We have seen that in the closed-circuit system one battery may be made to work all the stations on one circuit; but there is another plan, by means of which it is possible with one battery to transmit on several circuits from one station, each circuit being independent of the others. This is known as the *universal battery* system. If several equal resistances be joined across the poles of a battery of comparatively low resistance, a current of equal strength will flow in each, and this current will be practically equal to the current which would flow through one of the resistances if it alone were in the circuit. This fact is the basis of the universal battery system. Several circuits (usually not more than five) whose resistances do not vary more than 25 per cent. between the highest and lowest, are grouped on one battery, one pole of which is connected to earth. If any circuit which is to be placed in a group is below the required resistance, then an equalising resistance coil is joined in the battery lead of that circuit.

It is necessary for satisfactory working that the resistance of the battery shall be less than one-half of the joint resistance[1] of the several circuits worked from it.

It is clear that for this system the battery must not be worked double current, as, if one circuit were sending a positive current and another were simultaneously sending a negative current, *both* poles of the battery would be to earth, that is, the battery would be short-circuited. For double-current working, therefore, two batteries with opposite poles

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[1] See Appendix, Section C.

to earth are required, and a single-current key provided with a switch is sufficient for sending. Fig. 102, p. 147, shows the actual connections of a double-current circuit on the universal battery system arranged for either simplex or duplex working. Similarly, single-needle circuits require a double battery, and the commutators also need slight alteration. Accumulators, owing to their low resistance and the ease with which they can be kept at a normal electromotive force, are peculiarly suitable for universal work. Almost any number of circuits can be supplied with current from one set of cells; at one office batteries with a voltage of nearly 6,000 volts were replaced by 250 secondary cells, half of which were 'spare.' The one serious objection to any very extensive application of the universal system is the fact that a failure in the battery involves the stoppage of all the circuits in the group affected, and in the case of a very large group the consequent delay might be very inconvenient. Hence the provision of a complete spare set of accumulators.

The electro-motive force required to record the signals with the different forms of instrument used and on circuits of various lengths is a very important matter. It depends upon so many conditions of climate, country, size and age of wire, character of insulation, &c., that no definite rule can be laid down. The unit current is called the *ampère*, but for telegraph purposes we consider only the thousandth part of this, or the *milliampère*,[2] and the currents which are provided for the different instruments will be seen from the following table:

Needle	15	milliampères.
Direct Writer . . .	20	,,
Direct Sounder . . .	35	,,
Relays	15	,,

Therefore the electro-motive force must be regulated to give the strength of current indicated above. Now, one Daniell

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[2] See Appendix, Section B.

cell through one thousand ohms (1,000$^{\omega}$) gives approximately one milliampère. For instance: a line 16 miles long, giving a resistance of 25$^{\omega}$ per mile and having one intermediate station, is to be fitted with single-needle apparatus (resistance 200$^{\omega}$ each), and worked by Daniell batteries; how many cells will be required? Here the total resistance in circuit is 1,000$^{\omega}$, consequently the current given by 1 cell will be 1 milliampère; but the instruments require 15 milliampères; therefore, theoretically, 15 cells will be required at each office. Twenty cells, however, would be fixed, to allow for leakage along the line in wet weather and for the internal resistance and the deterioration of the battery.

We can scarcely conclude this brief description of the mode of joining up instruments in circuit without referring to the circuit arrangements required to serve a portion of the country. We will take the Isle of Wight. The diagram (fig. 87) shows how all the villages and towns were connected together, and with their great centres of communication, Southampton and London. It illustrates also the way in which the different instruments are employed. Thus little places like Brighstone, Carisbrook, St. Helens, which are mere sub-offices under larger head post-offices, Newport and Ryde, are amply served by the A B C. East Cowes, Totland Bay, School Green, communicate with their head offices by means of Needle circuits, because the amount of work will not justify the employment of a trained telegraphist. On the contrary, the traffic between Southampton and Osborne, Ventnor, Ryde, Newport, and Cowes, justifies the employment of skilled operators, and they are served by Morse circuits; and the amount of business done at Ventnor and Ryde is such as to require communication with London as well as with Southampton. In some cases, as at Ryde, the business with London is such that only quadruplex (see Chapter IX.) will meet it, and even this is sometimes insufficient, and additional facilities have to be afforded.

A direct wire, with only the terminal offices upon it, and fitted with Sounders, is the most perfect hand-worked telegraph arrangement we can devise. The insertion of intermediate stations at once reduces its efficiency, principally by

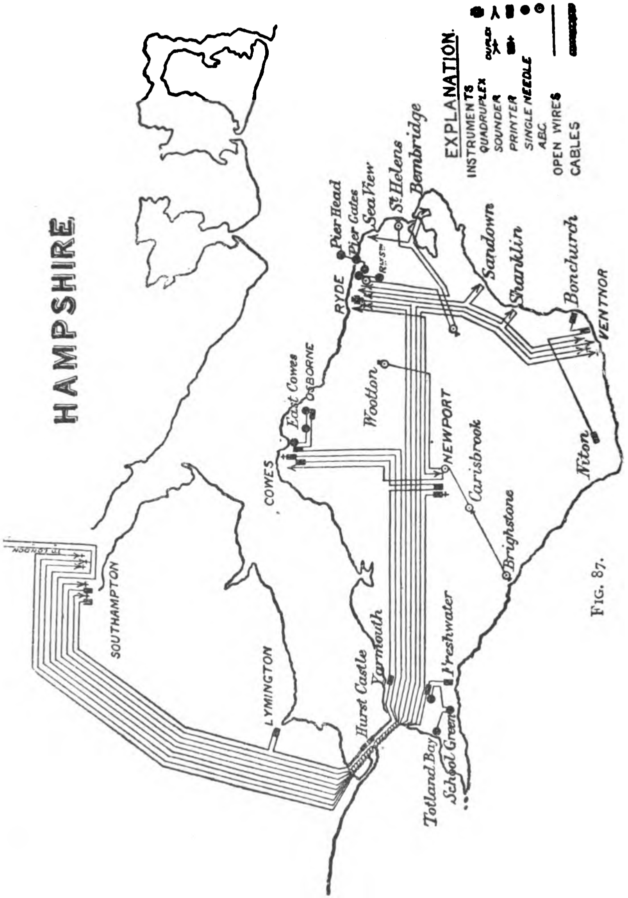

Fig. 87.

blocking the wire with local messages. But even a direct wire must, where possible, be supplemented by a second means of communication in case of failure or accident. Thus Ryde has a sounder duplex circuit to Southampton which, in case of need, could be joined through to London. Telegraphic circuits, even when of the simplest and most perfect character, are singularly liable to failure from causes which will be described; and occasionally periods of pressure arise from political, special, and local causes, such as elections, races, assizes, &c. It is imperative that a well-organised system shall be prepared for such emergencies.

CHAPTER V.

DUPLEX TELEGRAPHY.

THE rapid increase in the business of telegraphy has called forth the exercise of the ingenuity of telegraph engineers to increase the capacity of a single wire for the transmission of messages. Duplex telegraphy is one way by which this has been effected. By this system messages can be sent on one line *in both directions at the same time*, thus practically doubling the carrying capacity of the wire, because station A can transmit a message to station B, while B is sending another message to A. Under ordinary circumstances, when A is working to B on the open circuit principle (fig. 80) any interference on the part of B disconnects his receiving instrument and so prevents A's signals from being recorded. If now it can be arranged that the receiving instruments at both stations can be always in circuit, yet affected only by the currents sent from their own station when these currents interfere with the currents sent from the other station, then duplex telegraphy becomes possible. There are several modes of doing this, but we shall confine ourselves to a description of two methods which are in practical use, and which may be designated respectively the *Differential* and the *Bridge* methods of duplex working.

1. *The Differential Principle.*

If two circuits of precisely equal resistance be open to a current, it will divide itself equally between the two, and the currents in each wire will be exactly equal. If, for instance, the wire Z *l* E (fig. 88) offers the same resistance as the wire Z *r* E, the current in *l* will have precisely the same strength as the current in *r*.

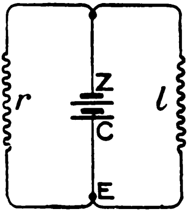

Fig. 88.

Now let the electro-magnet M (fig. 89) be similarly wound with two wires of equal length, one of which is in connection with *l*, and the other in connection with *r*. If the current through *l* traverse the electro-magnet in the *reverse* direction to that through *r*, and if the currents be equal, it is evident that the polarity induced by the one current must be exactly neutralised by that induced by the other current, for the effects are equal and opposite, and there will be no magnetism excited. Thus, as long as the two circuits are intact the currents which flow will not affect the electro-magnet; but if the currents in *r* be interrupted, those in *l* will excite the electro-magnet, and if those in *l* be interrupted, the currents in *r* will excite the electro-magnet.

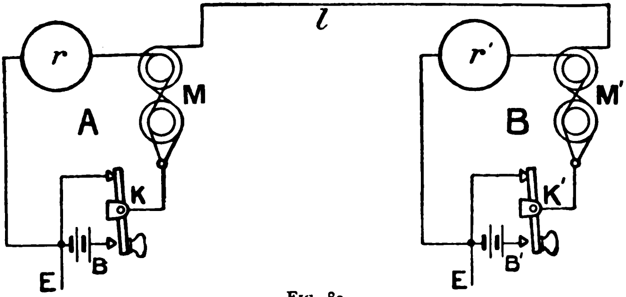

Fig. 89.

Assume A and B (fig. 89) to be two stations connected together by the line wire *l*. Let M be an electro-magnet at A, wound as just described, and M′ a similar one at B ; K a key, and B a battery. Let *r* and *r*′ represent resistance coils or artificial lines, each giving a resistance equal to the line circuit. Now let us in the first place assume A alone to be working to B; every time the key K at A is depressed a current is sent from A's battery. This current divides at M, the one half going through the coil in connection with *l* in M, through *l*, and at B, through the coil in connection with *l* in M′, through the key K′ at B to earth and thence back to the battery. This is called the *line current.* The other half, which is called the *compensation current*, passes around the electro-magnet M through the coil in connection with *r*, through *r* and back to the battery. As these two currents are equal, their effect on M is *nil*, but the line current passing through one coil only of M′ operates it and causes signals to be given. Thus while A telegraphs to B its own instrument is not affected, but that at B is actuated. Similarly, when B alone is working to A its own instrument is not affected, but that at A is actuated. But when B is working to A at the same time that A is working to B, what happens? Every line current that leaves A at the same time that a line current leaves B is neutralised. The compensation current at A is now able to excite the electro-magnet, and the armature is moved *in precisely the same way as if* B's *currents were received.* In the same way B's line currents are neutralised, and its compensation currents move the armature of M′ in precisely the same way as if A's currents were received. Thus M and M′ continue to be worked by their respective stations, regardless of the fact that the line currents are being continually neutralised so that practically no current flows between A and B, and that they are operated sometimes by the line current and sometimes by the compensation current. Thus, while A sends messages to B, B can be sending messages to A upon the same wire and at the same time.

We assumed that the line current received at A from B was exactly equal to that proceeding from A to B, and that therefore they were exactly neutralised, but it is not so in practice, for owing to the effects of bad insulation the incoming line current is always weaker than the outgoing one. Hence the current received at A from B does not neutralise the whole of the current sent from A to B, but only a portion of it. It so weakens A's current to line that the compensation current preponderates over this resultant current, and the signals are registered by the preponderance. The *difference* in the strength of these two currents when both stations are working is very nearly equal to the strength of the current received at A when B alone works, so that the marks, whether made by the received line current or by the preponderating compensation current, are practically the same.

We have shown in the diagram that the same poles of the battery are to line, and that therefore the line currents flow in opposite directions; but the same effects occur if the opposite poles are to line, and the currents flow in the same direction. If the current from B flows in the same direction as that from A, the effect, when the two stations work simultaneously, is not to weaken the resultant current, but to strengthen it, and therefore to produce a preponderance of the current in coil *l* over that in coil *r* of relay M, and consequently to register signals; but in this case the marks made at A when both stations are working simultaneously are not made by the preponderance of the compensation current over the line current, but by the excess of the resultant line current over the compensation current.

As shown in fig. 89, the keys K and K′ put the line to earth through the back contact, but there is an interval while the keys are being depressed when this connection is broken. In fact there are three positions which the key takes up during the operation of sending, viz., 1st, when resting upon the back contact; 2nd, when resting upon the front contact; 3rd, when disconnected from both contacts. The line circuit is not, however, in either case interrupted. The first and second cases are clear, but consider the third: take the key K (fig. 90) and depress it to the intermediate position; then the received current, when it arrives at the bridge of the key, instead of going to earth through the back contact stop, passes through the compensation coil of the electro-magnet and through the resistance R to earth. This continues the effect of the line current upon the electro-magnet; for though the resistance to the line current is twice as great and the current consequently reduced one-half, as it passes through *both* coils of the relay in the proper direction to actuate the armature, there is a double effect of a current of half strength, the influence of which is equal to the original current. In fact, it is possible to dispense with the back contact altogether, but it introduces irregularities due to electro-magnetic inertia (p. 164), which tend to diminish accuracy and speed of working. For accurate duplex working the total resistance of the circuits should be disturbed as little as possible, so that even the portion of the circuit from the back contact of the key to the earth should be made equal in resistance to that of the battery by the insertion of a resistance coil *r*; then the resistance is not altered whether the key is up or down. Theoretically the best form of key is one which does not break the back contact until the front contact is made.

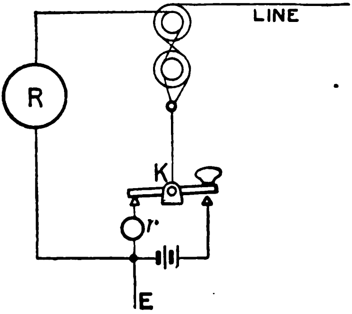

FIG. 90.

This is the principle of the system, which may be applied to any form of instrument, whether it be a direct ink-writer, a single needle, or a relay. As most circuits are worked with relays, we will illustrate such a system. This is done in simple form by fig. 91.

P is an ordinary polarised relay whose tongue moves be-

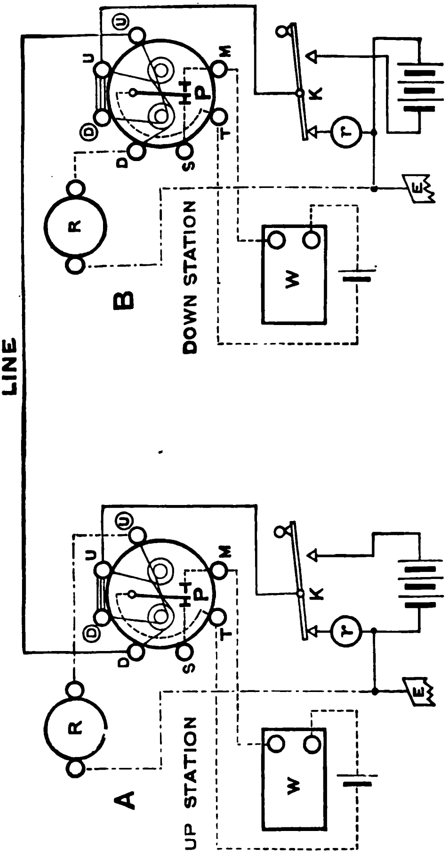

Fig. 91.

tween the two points in connection with terminals S and M. Its normal position is against S. The line current moves it against M, and thus works the local circuit in which is placed the sounder or writer, W. Each bobbin of the electro-magnet is similarly wound with two wires of equal length and resistance, and the inner ends on one bobbin are then joined to the outer ends on the other, so that there are thus two circuits, each comprising one wire on both bobbins, and making an equal number of convolutions round the electro-magnet. The ends of the one wire are brought to the terminals D and U, and the ends of the other wire to the terminals Ⓓ and Ⓤ. If now, while a current is traversing the circuit U to D in a direction to actuate the tongue, a second current of exactly equal strength is flowing between Ⓓ and Ⓤ in the opposite direction, the effect on the tongue of the relay must be *nil.* The line wire at the Up Station is attached to terminal D, and the compensation wire to terminal Ⓤ. Terminals Ⓓ and U are connected together by a brass strap and connected to the lever of the key K, which in its position of rest joins these two terminals to earth through the back contact. The other end of the line wire of course makes earth through the apparatus at the Down Station, which is similarly connected up, except that the line wire is attached to Ⓤ and the compensation circuit to D.[1] The other extremity of the compensation circuit makes earth at E through the resistance coils R, which can be varied at will.

Now let the key at the Up Station be depressed; a current flows and divides at Ⓓ U, one portion passing through the coils of the relay from U to D and so out to the line, thence to earth at the Down Station by way of the relay coil Ⓤ Ⓓ, the key and the resistance coil *r*. This

[1] This reversal of the relay connections would not be necessary if the receiving instruments were not polarised. The connections might then be precisely alike at both stations, and the arrangement would work properly.

portion of the current tends to move the tongue of the Up Station relay against the stop M. The other portion passes through the compensation coil Ⓓ Ⓤ of the relay, through the resistance coils R, to earth at E, tending to hold the tongue of the relay against the stop S. If these two currents are of equal strength they will not influence the tongue of the relay, because they tend to move it with equal force in opposite directions. But if they be of unequal strength, then the tongue of the relay will be moved in the direction of the stronger current, and by a force equivalent to that of a current equal to the difference between the two currents. Let us at first insert in the adjustable resistance R, a resistance large compared with that of the line, then the current passing through the compensating circuit will be considerably less than that passing through the line circuit. Every time the key K is depressed the relay will work, and will cause signals to be made. By gradually decreasing the resistance in R the difference in strength between the two currents will be diminished, until at last a point is attained where their strength is equal, and where the tongue of the relay will be unaffected by the movement of the key. The artificial resistance R is now equal to that of the line circuit beyond terminal D.

The line currents which are received at the Up Station from the Down enter at terminal D, pass through the coil D U of the relay, and so to earth through the back contact of the key, moving the tongue against the stop M, and recording signals in the usual way. Now, it is evident that when A alone works to B, A's relay remains unaffected while B's relay records the signals sent from A. When, under similar circumstances, B alone works to A, B's relay remains unaffected while A's relay records the signals sent by B. But when B works to A at the same time that A is working to B, the outgoing line current from each station is increased in strength by an amount equal to the strength of the incoming line current at each place; this, therefore, preponderates over the compensation current at each place to an extent precisely equal to the normal current received. Hence marks continue to be recorded with the same force and regularity when the stations work to each other simultaneously as when they work to each other separately and independently.

On p. 124 it was shown that in connection with the theoretical arrangement indicated by fig. 89, it is immaterial whether similar or opposite poles of the batteries at the two stations were to line; this, however, does not apply in the case of the receiving instruments which are *polarised*, as then one portion of the current—say that through the compensation circuit—tends to hold over the relay tongue to the 'spacing' or non-recording stop s, and therefore if the current from the other station reduced instead of augmenting the other current, no signal could be recorded; similarly, if it were the line circuit portion of the current which tended to hold the tongue to spacing, an increase of that current by the other station would not record signals. This consideration at once shows the possibility of duplex working on the double-current system; and in practice double-current duplex working is found to be so much superior to single current, that in England only the most unimportant duplexed circuits are worked single current.

There are certain irregularities in the working of such a system in actual practice which have to be provided against, due to variations in the resistance and in the electrostatic capacity of the line. Telegraph wires, in fact, are in a constant state of change. If A and B be connected together by an aerial wire supported at intervals of about 80 yards upon earthenware insulators, then the current which arrives at B from A must necessarily be less than that which leaves A, because at each pole a small portion of the current escapes or leaks to earth. No earthenware support is an absolute insulator. Moisture is deposited upon its surface. The amount of this moisture continually varies, and the resistance of the insulator to the leakage of the current varies with it. Hence the difference between the current leaving A and that arriving at B is constantly varying, and the effect upon the current leaving A is precisely the same as though the resistance of the line varied. If moisture be abundant more current leaves A, and the effect at the sending end is the same as though the resistance of the line wire were reduced, but of course the increased current is not received at the other end. If the insulators become dry, less current leaves A, and the effect is the same as though the resistance of the line were increased. In fact, the resistance of the circuit does vary with the amount of moisture deposited on the insulators, and with the amount of dirt which necessarily adheres to them. Rain, fog, dew, and mist affect it. Lines exposed to the spray of the sea or the smoke of manufactories are peculiarly liable to this variation.

The resistance varies also with alterations in the physical condition of the mass of the wire due to heat. As the temperature of a metal increases or diminishes, so does its resistance. Iron wire increases in resistance 0·21 per cent. for each degree of temperature (Fahr.) through which it is raised. The diurnal variations of temperature in this climate are not great : in summer the greatest range is about 30°. This would practically not affect the comparatively short circuits used in England; but in India and America, where the circuits are much longer, and the daily variation is much greater, considerable difference is observable in the resistance of the wire between midday and midnight.

The amount of variation also largely depends upon the character of the country through which the line passes. The resistance of some lines varies in bad weather as much as 50 per cent. in one day, but remains constant in fine weather. Short lines, as a rule, are little disturbed by variations of short duration, but long lines of 200 miles and upwards are subject to constant variations due to atmospheric changes at different points. A thunderstorm here, a shower there, excessive radiation at one point, condensation at another—all tell their tale.

Other causes also introduce irregularities which interfere with the constancy of a line. The wires are constantly subject to accidents of various kinds, many of which tend to produce variable resistance.

Now what effect has this variation of the resistance of the line wire upon duplex working, and how is it provided for? Clearly it disturbs the equality of the line and compensating currents, and causes the one to preponderate over the other; and if no means were adopted to compensate for this variation, duplex telegraphy would be impossible. The resistance, therefore, in the compensation circuit is not made a fixed quantity, but consists of a series of resistance coils by which the resistance of the compensation circuit can be varied in consonance with the variation of the line circuit. This instrument is called a *Rheostat.*

The rheostat shown in fig. 92 is a box of resistance coils, each coil being 'double wound' (as described on p. 409) so as to eliminate the effects of self-induction, and the whole is so arranged that the resistance can be adjusted by the motion of the arms over the dial. The figures over which these move indicate the number of ohms resistance which will be inserted in the circuit according to the position of the handles. The arrangement is such that each handle can move over only one-half of the dial; the range of one being by gradations of 40 ohms from 0 to 400, and that of the other being by gradations of 400 ohms from 0 to 4,000. Thus the maximum resistance which can be inserted in the circuit by these arms is 4400$^{\omega}$. But in addition to this a coil offering a resistance of 4000$^{\omega}$ is placed in connection with a switch at the side of the main box, and this can be cut out of the circuit or inserted in it at will by means of a plug. Further, as the arms do not permit of a smaller variation than 40$^{\omega}$ being made, two other coils of 10$^{\omega}$ and 20$^{\omega}$ are also included, so that the range of the rheostat is really from *nil* to 8430$^{\omega}$, by variations of 10$^{\omega}$.

What plan can be adopted for the adjustment of this compensation circuit? In the early days of duplex working the adjustment had to depend upon the actual sending and receiving of working signals; but the general introduction of *differential galvanometers* has had the effect of greatly facilitating the adjustment.

The most approved form of differential galvanometer (shown in fig. 93) is virtually an induced single-needle coil of Varley's pattern, but with each coil wound with two wires of precisely the same length, and joined up to form two independent circuits in the same way as the coils of the relay (as described at p. 131). If a current be sent through either of these circuits the needle will deflect to right or left, according to the direction of the current; and therefore if equal and opposite currents be sent through the two circuits no deflection at all will take place. If the currents are not

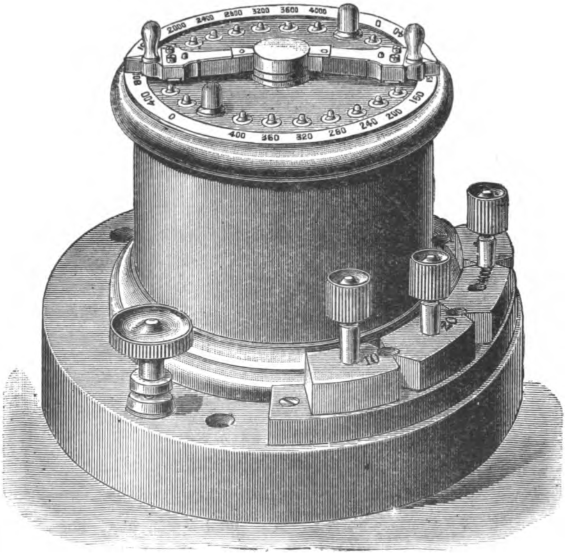

FIG. 92.

of equal strength, then the stronger will be partially effective to produce a deflection to the extent of its excess. Such a galvanometer, then, is fitted at each end of a duplex circuit, one coil being in the line circuit and one in the compensation circuit. The needle is to show any *difference* of current flowing in the two circuits. Now, the sending of a current from (say) station A should vary the current in both circuits

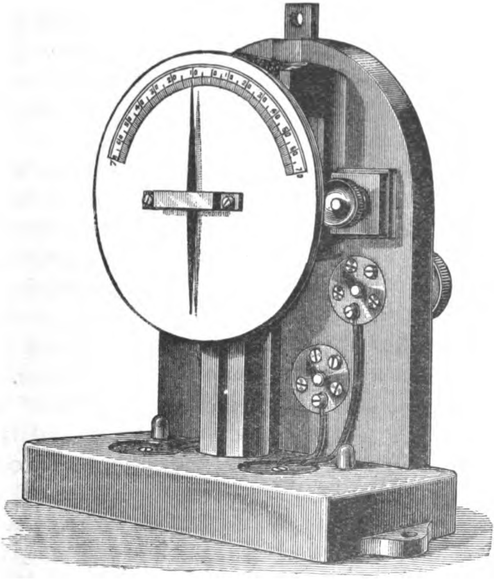

FIG. 93.

of A's galvanometer equally—that is, A's sending should not cause any variation of the difference between the currents in the line and compensation circuits. Hence, if when the key at A is manipulated the position of the needle changes, then the resistance of the rheostat must be increased or decreased until no such change takes place. In double-current working there is always a current—either positive or negative—being received from the other station, and consequently there is always a deflection on the galvanometer. Assuming that A is balancing, and that B is sending the ordinary 'spacing' current, then, if when A's key is depressed—that is, when A sends a 'marking' current—the deflection is increased, it shows that A's previous spacing current was stronger in the compensation circuit than in the line circuit, and the rheostat resistance should therefore be increased; if, on the other hand, depressing the key decreases the deflection, then the resistance in the rheostat should be decreased. The deflection should be steady when the key is alternately depressed and released. Thus can the varying resistance of the line be provided for in the compensation circuit.

When a quantity of electricity flows through a line in the form of a current, the first portion of the current is retained or accumulated upon the surface of the wire, in the same way that a charge is retained or accumulated upon the surface of a Leyden jar.[2] The quantity accumulated depends (1) upon the length and diameter of the wire, (2) upon its distance from the earth and earth-connected bodies, (3) upon the insulating medium surrounding the conductor. Thus, in the case of a submarine cable, the conductor of which is insulated with gutta-percha or india-rubber, and is maintained in very close proximity to the earth, a very considerable charge is held by the wire. An overground wire is insulated in air, and though it is maintained at a considerable distance from the earth, yet it is in close proximity to other wires, or to buildings or trees which are in connection with the earth, and it also retains a charge. In fact it is found, in England, that the charge retained by twenty miles of ordinary line wire is about equal to that retained by one mile of a cable of average dimensions. This power of retaining a charge is called the ELECTROSTATIC CAPACITY of the circuit.

Now what are the effects of this electrostatic capacity?

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[2] See Appendix, Section F, Condensers.

In the first place, it absorbs all the electricity of a short momentary current and prevents the appearance of any current at the distant station. And as it absorbs the first portion of every current sent, it has the same effect as if it *retarded* or delayed the first appearance of the current at the distant end. Thus the apparent velocity of the current is diminished more or less in proportion to the capacity of the circuit. In a circuit of very low capacity the current appears practically instantaneously at the distant end; but on a long or a submarine circuit there is sure to be considerable capacity and consequent retardation. Thus between Europe and America, on an Atlantic cable, the current is retarded four-tenths of a second.

In the second place, when a current has been sent through the circuit, the whole of this charge upon the wire must either be withdrawn or neutralised before a second charge of opposite sign can be accumulated upon it. This discharge may occur as a current flowing out at each end to earth, in which case one part of the current—called the *return current*—flows back to the sending station, and the other flows out at the receiving station so *prolonging* the primary current. If one end of the wire, say the sending end, be disconnected, all the charge flows out at the distant end and the prolongation of the current is increased. Again, the charge may be neutralised by a reverse current, which may be sent from the receiving as well as the sending end.

Thus it is seen that the effect of electrostatic capacity is to produce *retardation* at the commencement of a current and *prolongation* at the end.

Again, the electrostatic capacity of a line is unequally distributed, and its working conditions are naturally affected by this distribution. A circuit may be made up of overground wires, underground wires and cables. Since cables have the largest capacity, it is their position which most materially influences the working.

We see then that the working condition of a line is dependent not only upon its quality of resistance but that this other quality of electrostatic capacity must also be considered ; and, for duplex working to be satisfactory, the compensation circuit must be arranged to represent the electrostatic or inductive condition of the line as well as that of its electrical resistance. The electrostatic capacity can be represented by a *Condenser.*

'Condenser' is a term applied to an apparatus composed of alternate layers of tinfoil and paraffined paper (or mica) so arranged as to form a flat Leyden jar of large surface, and constructed to give any capacity that may be required within a certain range. a, a_1, a_2, b, b_1, b_2 (fig. 94) are square pieces of tinfoil separated by sheets of thin paper steeped in melted paraffin wax. The series a, a_1, a_2 are connected together, and so are the series b, b_1, b_2. A and B thus become connected with what may be regarded as the inside and outside coatings of a Leyden jar ; and by putting one pole of a battery to A, and the other pole to B, we can communicate a charge to the plates the quantity of which will depend (1) directly upon the electro-motive force of the cells used, (2) directly upon the total surface of each series of conducting plates opposed to each other, (3) inversely as the distance between each pair of plates, and (4) upon the nature of the insulating material used to separate the conducting plates. Insulating material so used is commonly known as a *dielectric.*[3] Thus we can construct condensers of any capacity,

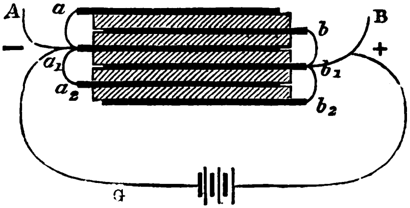

FIG. 94.

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[3] For further details as to Condensers, see Appendix, Section F.

giving a charge varying from that accumulated upon a short length of overground wire up to that accumulated upon an Atlantic cable. The unit, or standard of reference by which capacity is known, is called the *microfarad*, and it is equivalent to the charge retained by about three miles of cable. (See p. 6.)

Condensers are conventionally represented by parallel lines as shown in fig. 95, A and B being opposite plates. If a galvanometer be joined in circuit with the battery, say at G (fig. 94), and the battery (with galvanometer) be connected to A and B as shown, there will be a momentary deflection of the galvanometer needle in one direction to an extent dependent upon the capacity of the condenser and the electro-motive force of the battery; and if then the battery be cut out of circuit, there will be an equal (or nearly equal) deflection on the galvanometer in the other direction. These two deflections represent the *charge* and *discharge* of the condenser.

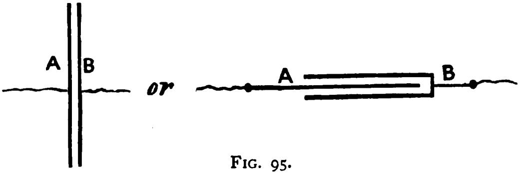


FIG. 95.

It will be seen that this charge and discharge are precisely analogous to the electrostatic condition of a telegraph line which has been described. If the line between A and B (fig. 89) has electrostatic capacity and A is working to B alone, the return current will flow back through M and record signals; but if there be inserted in the compensation circuit a condenser whose capacity is such as to exactly represent the electrostatic condition of the line, then A's initial current will charge both the line and the condenser, and the return current from the line passing through one wire of the electro-magnet will be opposed by a precisely similar discharge current from the compensation condenser through the other wire, and so the effects of the electrostatic capacity will be eliminated.

But the discharge due to the electrostatic capacity of the line varies. It is greater in dry weather than in wet. The condensers used are, therefore, made adjustable to permit of compensation for this variation, in the same way as the resistance coils of the compensation circuit; and since, as was pointed out on p. 139, the capacity of a line may be unequally distributed, the condensers are commonly made in two or more distinct sections, so that they may be inserted at more or less corresponding points of the compensation circuit.

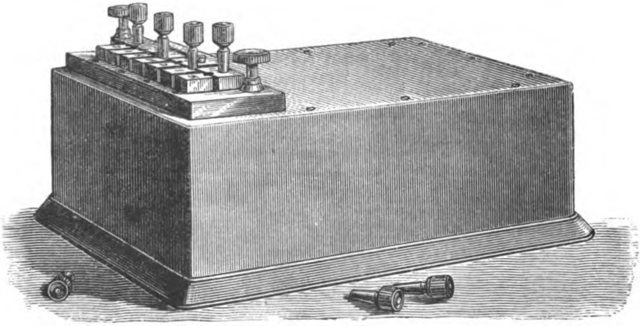


FIG. 96.

A condenser with two sections is shown in fig. 96. In one section the total capacity is 3·75 microfarads, adjustable by gradations of ·25, while the capacity of the second section is 3·5 microfarads, adjustable by gradations of ·5. It may be observed that, whereas in resistance coils the resistance is usually inserted by *removing* the pegs, the capacity of condensers is inserted by *inserting* the pegs.

The method of applying condensers in the compensation circuit is shown by a theoretical diagram in fig. 97. In this arrangement the current in passing to earth through the compensation resistance (rheostat) R charges the condenser C_1 to an extent which can be regulated by the adjustable resistance R_1; and C_2 is also charged to a degree which is still further modified by the resistance (sometimes adjustable) R_2. The discharge from C_1 then takes place through R_1, while that from C_2 has to pass through the additional resistance R_2. Thus C_2 really represents the capacity of the further sections of the line. It should be noticed that the discharge has two paths, one through R and the other through the relay, and it is only that portion which takes the latter course that has an influence on the balance.

The compensation for capacity may be adjusted by aid of the differential galvanometer, but as a rule it is found better to adjust by the passage of working signals. If the adjustment be not right a dot will be formed at the sending station, when the key is depressed if the capacity of the condenser be not large enough, and when the key is raised if it be too large. Received signals also are broken when the key is working, while they are unaffected when the key is at rest. If a marking current be sent from the distant station an unbroken line or signal will appear when the key is worked if the adjustment be right, but if it be wrong the signal will be broken.

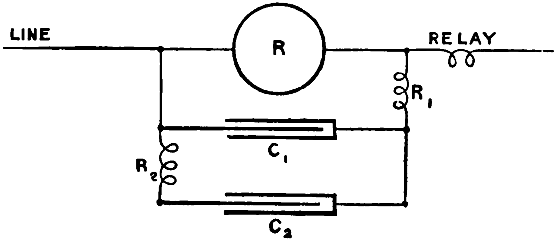


FIG. 97.

The effects of electro-magnetic inertia at the sending office do not introduce any irregularity in the working of the differential system. They tend only to reduce speed of working. The effects of one wire are exactly compensated by those of the other wire, so that no disturbance of signals results.

In practical telegraphy it generally happens that, although the requirements of business in connection with a circuit demand the application of duplex apparatus, it is not always necessary to work it as duplex ; and it occasionally happens that from line variations, &c., duplex working proves temporarily impracticable. In such cases it is desirable to have a means of reverting to ordinary single working, still using the same apparatus. This is provided for by a switch so arranged that when in one position the connections of the

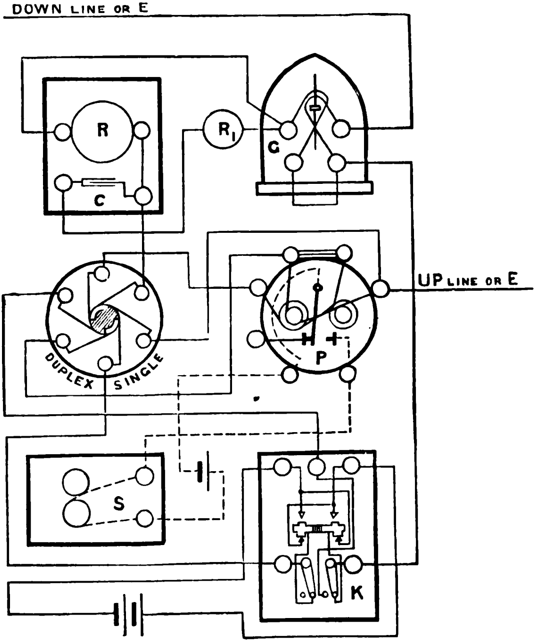


Fig. 98.

apparatus are right for 'duplex,' but when the handle of the switch is turned the connections are so altered as to be suitable for 'single' or 'simplex' working.

The full connections of such a set of apparatus for one station are shown in fig. 98, where, besides the switch, R represents the rheostat; R_1 the retardation coil; C the condenser; G the differential galvanometer; P the relay; S the sounder, worked by the local circuit of the relay; and K the double-current key.

The switch has six terminals, and the connections in the respective positions 'duplex' and 'single' are shown in fig. 99. It will be noticed that the centre line of the lever in each position crosses between the two pairs of terminals connected.

It will be remembered that a switch is used in connection with the double-current key, having one position to 'send' and another to 'receive.' This is shown on the key in fig. 98. For duplex working the switch must, of course, be permanently to 'send,' in which case the connections of the key when the lever is up and when it is depressed are shown in fig. 100. When the switch is turned to 'receive,' the centre terminal at the back is joined to the front right hand terminal and the other terminals are disconnected.

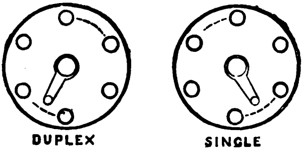


FIG. 99.

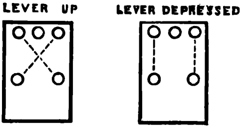


FIG. 100.

On analysing fig. 98, the fact will be noticed that there are two paths for the current to take not only at the relay, but also at the galvanometer. Fig. 101 is a diagram in which the connections for duplex only are shown in a similar simple manner to those of fig. 91. From an inspection of this figure, in which only a conventional arrangement of 'double current' is indicated, it will be clear by tracing the current from the centre of the double battery shown (one-half only of which is in use in either position of the key), that it passes in reverse direction through the two coils of the relay; one part goes through the rheostat and one coil of the galvanometer back to the other pole of the battery, while the other part goes to earth. It may then be assumed to traverse the earth to the other station, enter the line, and so back through the line coil of the galvanometer (in the reverse direction from that of the compensation circuit portion) to the battery. Hence the 'double split,' as it is called, does not affect the working.

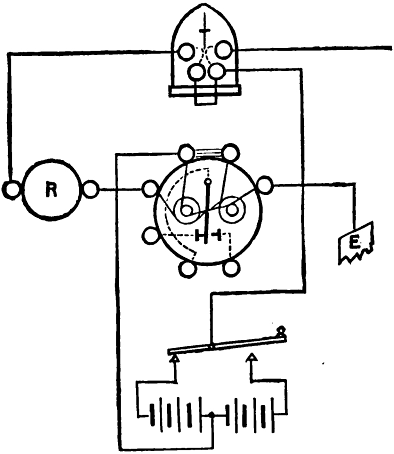


FIG. 101.

Fig. 98 shows 'down line or E' and 'up line or E.' This signifies that if the apparatus is fixed at an 'up' station the former connection is taken as line and the latter as earth; while the reverse, without any further change, is correct for the other end or the 'down' station. With the single split system of connections, the adoption of this principle would make the instruments at one end of the circuit double split.

'Up' and 'down' are useful conventional terms which are adopted to prevent confusion in connecting up polarised instruments.

Fig. 102 shows the up station connections of a set of apparatus for double-current working on the universal system, the function of the switch (see page 145) being to change the connections so that simplex or duplex working may be resorted to at will. The only special piece of apparatus used is the key. This is of the single-current pattern, provided with a switch by means of which the line may be disconnected from the lever of the key and joined through to the relay. The back contact is joined to one pole of the battery and the front contact to the other, hence

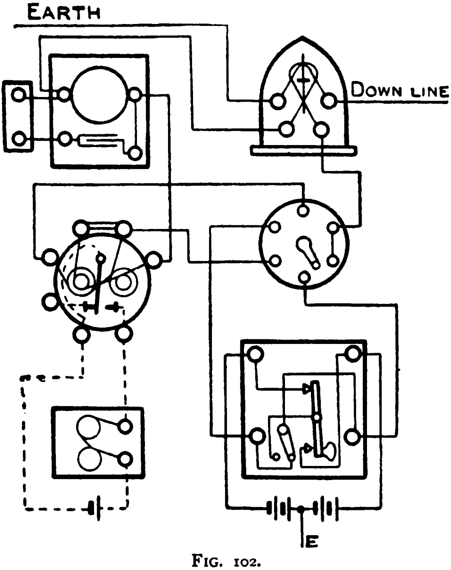


FIG. 102.

when one is joined to line the other is disconnected. If a short-circuit occurred in any one set joined up on this principle, all the other sets connected to the same battery would be left without current; furthermore, since the internal resistance of the battery is very low indeed, an abnormally strong current would flow through the short-circuit and cause damage by the heat generated. To provide against interruptions consequent upon such a fault, a fuse-wire is placed in each battery lead, so that in the event of the current strength exceeding one ampère the fuse melts and disconnects the faulty set from the battery. As a further precaution against short-circuiting during adjustment of the key, the adjustable contact screw is made of such length that the back and front contacts cannot be connected together through the lever.

It will be noticed that the arrangement is what is known in practice as the 'single split,' for when the switch is to 'duplex' the current divides only at the split of the galvanometer. At a 'down' station fitted with a similar set of apparatus the battery connections and the relay connections must be reversed.

2. *The Bridge Method.*

We have entered so fully into the working of the differential system, that little remains to be said on the bridge method. The differential principle is dependent on producing an *equality of currents*, whereas the bridge principle depends on producing an *equality of potentials*. Fig. 103 shows the arrangement at two stations A and B. C C′ is the line wire, R is the rheostat, whose resistance is equal to line. *a* C and *a c* are two artificial resistances equal to each other. The key K is connected up with the battery in the usual way. The relay P is fixed between C and *c*. The recorder or sounder, which is worked in the ordinary way by the relay, is for the sake of simplicity not shown in the figure.

The apparatus at B is precisely the same as that at A. When A depresses his key K a current is sent, and this current splits at *a*; one portion passes through the line wire to B, making earth through the apparatus at that station, and the other passes through the rheostat R to earth at A. These two currents are equal because the resistances of the two circuits from *a* are equal, and as the points C and *c* are electrically equidistant from *a* their potentials are the same, and therefore no current can pass between them. Hence the relay P is not affected when A alone is sending to B. The same exactly occurs at B when it alone is working to A, so that we are able to send currents to a distant station without affecting our own apparatus.

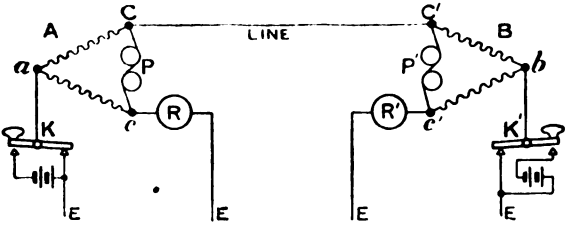


FIG. 103.

The apparatus at B duly registers the marks when A is sending, for the line current on reaching C′ has two paths open to it—the one through C′ *c*′, the other through C′ *b*. That through C′ *c*′ works the relay, and causes signals to be recorded. The strength of this current will depend upon the relative resistances of the two circuits C′ *b* through key to E, and C′ *c*′ to earth through the combined resistance of *c*′ *b* and R′. We have assumed the branches C′ *b*, *c*′ *b* to be equal in resistance to each other, but it is not necessary for these resistances to be equal; they may bear any ratio to each other provided the same ratio is maintained between the resistance in R′ and that of the line circuit. By making the resistance of *c*′ *b* small compared with C′ *b*, we obviously increase the strength of current passing through C′ *c*′. If we make the resistance of *c*′ *b* *nil*, nearly the whole of the current will pass through C′ *c*′ if only the resistance of C′ *c*′ is small compared with that of C′ *b*; or, again, if the resistance of the branch R′ be made *nil*, nearly the whole of the current will pass through C′ *c*′. But in either of these cases duplex working would be impossible, for the balance of potentials which is necessary for it depends upon the ratio of the resistance in *c*′ *b* to that of R′ being the same as the ratio between the resistance in C′ *b* to that of the line circuit. To maintain duplex working we must establish a balance; that is to say, we must keep the potentials at the points C′ and *c*′ equal when B is working to A; hence as we vary the resistance in *c*′ *b*, we must likewise vary that of R′ in the same proportion if the ratio of C′ *b* to the line remains constant.

But the effect which the reduction of the combined resistances in *c*′ *b* and R′ has upon the outgoing current, that is, the current which B sends to A, must not be overlooked. The smaller this resistance is made the smaller is the amount of current which will pass along the line to A, as the greater portion will take the circuit *b* *c*′ E. A similar result would of course follow at A if the same thing were done there. Hence it is evident that the resistance of all the branches must bear a given ratio to each other in order to produce the maximum effect upon the relay at each station, and that this ratio will vary with every circuit of different resistance. Generally it may be said that the smaller the internal resistance of the battery the more we can afford to reduce the resistance of the branches *b* *c*′ and R′, and therefore the greater will be the proportion of the current passing through the relay in C′ *c*′; and the larger we can make the resistance of C′ *b*, compared with that of C′ *c*′, the greater will be the difference of potential between C′ and *c*′, and, consequently, the stronger the current passing through the relay.

The best practical results are obtained when the resistance of *c'* *b* is half that of C' *b*—the latter being about half that of the line. The resistance of the battery should be made as small as possible, and therefore large-sized cells should be used.

The balance may be adjusted by altering the branch *c'* *b* or R', or by varying both together by means of what is called a *slide*, but in practice it is found better and simpler to alter only that of R'.

It will thus be seen that when A is working to B alone, or B is working to A alone, the apparatus at the sending station is not affected, and marks are duly recorded at B or A, as the case may be. When A is sending to B at the same time as B is sending to A, with the resistance in the various branches at A and B duly proportioned, the equality of the potentials at the points C *c* and at the points C' *c'* is disturbed; they vary, currents therefore pass, and these currents are in the same direction and of the same strength as the ordinary currents when one station alone is working. For, looking first at station B when K' is depressed, the potentials at C' and *c'* are equal; but K having also been depressed, a certain portion of the reverse current from A reaches C'; the potential of C' is therefore altered with regard to that of *c'*, and a current flows through C' *c'*, whose strength depends upon this difference of potential, and is manifestly the same as when K' is at rest and no current is flowing from B's battery. Exactly the same reasoning will apply to A, and thus we see that while A is sending messages to B, B can also simultaneously send messages to A upon the same wire.

The chief point of this method which characterises it from that already described is that *it is independent of the character of the apparatus* used for receiving messages. It will work as well with the delicate mirror apparatus as with the roughest Morse recorder: by means of this arrangement the simple Sounder can be manipulated as well as the rapid Wheatstone automatic instrument. No special apparatus is required for its introduction except a supply of resistance coils. This duplex working is applicable to every species of instrument, and it is even possible to work one form of instrument at one station and another form at the other station. For instance, Stearns, to whom is due the application of condensers for compensation purposes, once worked the Morse at one end of a line and the Hughes at the other.

The effects of a variation in the resistance of the circuit or in its electrostatic capacity are felt in the bridge method of duplex working as much as in the differential method, and exactly the same steps are taken to obviate these in the former case as have been already described in the latter. As at present arranged, the two systems are about equally efficient, and the all but universal use of the differential in preference to the bridge method is to be attributed to the fact that it is more economical as regards battery power required.

CHAPTER VI.

AUTOMATIC TELEGRAPHY.

All the different kinds of apparatus which have been described in the foregoing pages are manipulated by the hand, and though in the A B C and Needle systems little skill is needed to work the sending portion of the instruments, yet in the other systems not only skill but practice and endurance are required to keep up the constant subdivision of time into dots and dashes. The operators tire, and as a consequence not only is the speed of working reduced, but errors are made leading to repetitions and delay. The limit of speed with which the hand can work the key of the Morse instrument is soon reached. It is impossible to maintain by hand the maximum useful power of the system. Signals can be made to follow each other on the simple

Morse apparatus far quicker than clerks can send or even write. The muscular motion of the wrist and the directive action of the mind have their limits, both as regards speed and endurance. They cannot reach the recording speed of a Morse receiver on a short circuit. Moreover the sending of a clerk after a time loses clearness and legibility, and health, both of mind and body, affects his speed of working. But if the manipulation of the human agent be replaced by the precision and regularity of a suitably arranged machine, not only can we attain, but far exceed, the highest speed of the ordinary Morse or Sounder. Hence early efforts were made to replace the hand-worked key by some mechanical contrivance which would remove the defects inherent to manual labour and would secure precision in the formation of the characters, accuracy in the despatch of messages, and speed in transmission. Bain in the year 1846 was the first to propose this. He punched broad dots and dashes in paper ribbon which was drawn with uniform velocity over a metal roller and beneath styles or brushes of wire. This device replaced the key, for whenever a hole occurred a current was sent by the brushes coming in contact with the roller. The recording instrument was his chemical marker (p. 77). The speed at which messages were transmitted at experimental trials was enormous ; 400 messages per hour were easily sent ; but when to the defects in the machinery were added the disturbances on the line from causes which were then unknown, it failed to commend itself. Perhaps the real reason for its not being persevered with was that it was really not wanted ; but now that telegraphic business has increased so enormously that extra wires are needed in every direction, apparatus which increases the capacity of the wires, by sending through them a greater number of messages in a given time, have become a necessity.

Wheatstone's system of automatic telegraphy is that which is used in England. Bain's method of punching has been considerably modified, and the messages are recorded on an exceedingly delicate form of direct ink-writer.

The apparatus consists of three parts; the *Perforator*, by which the message is prepared by punching holes in a paper ribbon; the *Transmitter*, which sends the message under the control of the punched paper; and the *Receiver*, which records the message at the distant station when thus sent by the Transmitter.

The *Perforator*, which is shown in perspective by fig. 104, and in plan and front elevation by figs. 105 and 106,

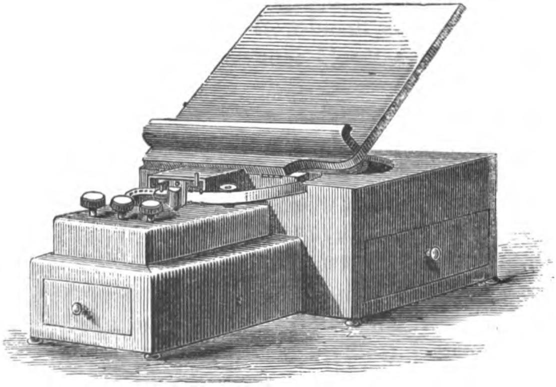


FIG. 104.

consists of three levers or keys, five punches, and a groove and a feed arrangement to guide and move forward the paper as it is punched. The paper $p\,p'$ (figs. 105 and 106) is of a white description dipped in olive oil. *a b c* are the three keys which, on being depressed, actuate and drive the punches or perforators through the paper, cutting or punching out clean round holes. 1, 2, 3, 4, 5 (fig. 106) are the punches which perforate these holes in the paper. Key *a* causes 1, 2 and 3 to perforate the paper in
o
one vertical line thus : o ; *b* causes 2 only to punch, thus : o ;
o

and *c* causes 1, 2, 4 and 5 to perforate the paper, thus :
○
∘ ∘ . *a* corresponds with dots, *b* with spaces, *c* with dashes.
 ○

The holes made by 2 and 4 are in the centre of the paper, and are smaller than the upper and lower ones made by the other three punches. They admit the teeth of a little star wheel, which is turned through a small space whenever one of the keys is depressed, and which thus moves the paper forward a certain distance for each depression of either key by a species of rack and pinion movement. The space through which the paper is moved by *c* for a dash is twice the length of that through which it is moved by either of the other keys. In fact, two central holes, 2 and 4, are punched for each dash required, and the star wheel is made to turn two teeth instead of one as in the case of the other two keys. If *a*, *c*, and *b* be struck or depressed in succession we have the

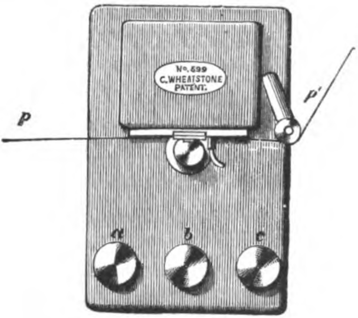


FIG. 105. ¼th real size.

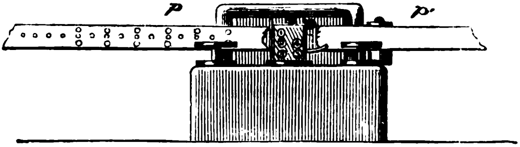


FIG. 106. ¼th real size.

paper prepared for the letter A; if *c*, *a*, *a*, *a*, and *b* be struck, as indicated by the repetition of the letters, we have the paper prepared for the letter B; and if *c*, *a*, *c*, *a*, and *b* be struck, we have the letter C prepared upon the paper. The word *Paris* thus prepared is indicated by fig. 107.

Mr. Willmot has introduced a punch with a hollow recess at its end, having no centre on which a deposit of oil can take place, and giving a clean perforation. The cutting edge being free from accumulation of paper is better preserved, and is more easily ground when required than the solid punch.

It is difficult to indicate these movements by means of a diagram. Their ingenuity, simplicity, and mechanical perfection are best comprehended by an examination of the perforator itself. The keys are usually struck by small india-rubber-faced mallets grasped by the hands, but at the Central Telegraph Station in London and in other large towns the air-pressure employed to work the pneumatic tubes is used for the performance of this work. Three piano keys, easily depressed by the fingers, open valves which admit the compressed air into little cylinders fitted with pistons which, when forced down, depress the keys *a*, *b*, *c* (fig. 105). The labour of punching with the mallets is considerable, and this application of air-pressure is very beneficial and is much liked. The power at command is so large that four or even eight ribbons are frequently punched simultaneously at the rate of forty words per minute. An expert operator can punch at the rate of about forty-five words per minute on either plan, but the average rarely exceeds thirty.

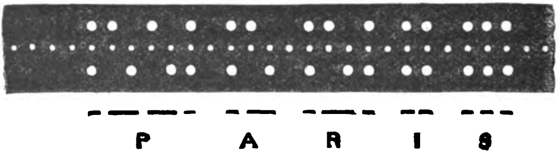


Fig. 107.

The *Transmitter* replaces the key of the ordinary apparatus, and it sends the currents by mechanical means under the control of the punched paper. Hence the name of the system—the *AUTOMATIC.* The arrangement of the portion of the apparatus which sends the reverse currents is shown in figs. 108 and 109. The contact points, marked c^d, c^u, and those marked z^d, z^u, are connected respectively to the positive and negative poles of the transmitting battery. Between these contacts plays the compound lever D U, the two parts of which, D and U, are insulated from each other and connected respectively to 'down line' and 'earth.' The lever is so pivotted and the contacts are so arranged that when D makes contact with z^d, U is in contact with c^u; and when D moves against c^d, U is changed over to z^u. Thus reverse currents are sent to line. So long as the upper part of D U is to the left (as in fig. 109), a 'spacing' current is sent to line; and when it is to the right (as in the other figure) a 'marking' current is being sent. If, therefore, the lever be made to vibrate between the position shown in fig. 108 and that shown in fig. 109, regularly and

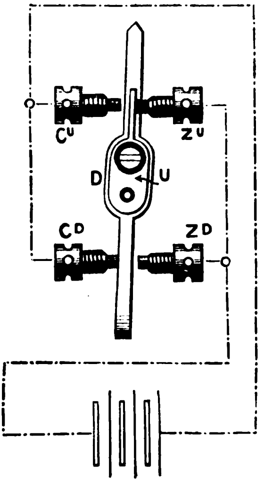


FIG. 108.

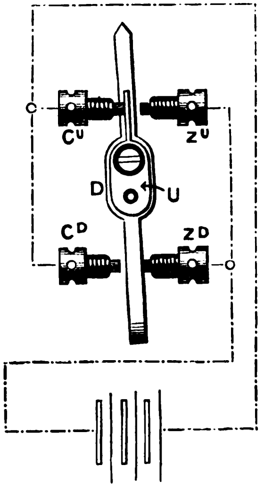


FIG. 109.

continuously, a succession of reversals will pass to the line; and if a Receiver be fixed at the distant end of the line a succession of dots will be recorded by it. If, however, the lever remains as in fig. 108 during a sufficient interval a reversal will be missed, and a *dash* will be recorded at the distant station instead of *two dots*. The function of the punched paper is to so regulate the motion of the Transmitter as to produce this effect when required, and thus cause the currents to flow in such a way as to form dots and dashes.

The perforated slip (fig. 110) is carried forward, from right to left, by a little star wheel, W, similar to that which moves it in the perforator, by gearing in the central row of holes. Two rods, S and M, are fixed to the horizontal ends of the levers, A and A′, which are pivotted on the front of the instrument, and are maintained at a constant upward pressure by means of the spiral springs s_3 and s_4. The two rods M and S play one opposite each of the two lines of larger holes in the punched paper, so that their ends would project through if there were holes, or would be checked by the paper if there were no holes. The rod S projects through the holes in the lower row on the slip, and the rod M through those in the upper row, and the adjustable studs

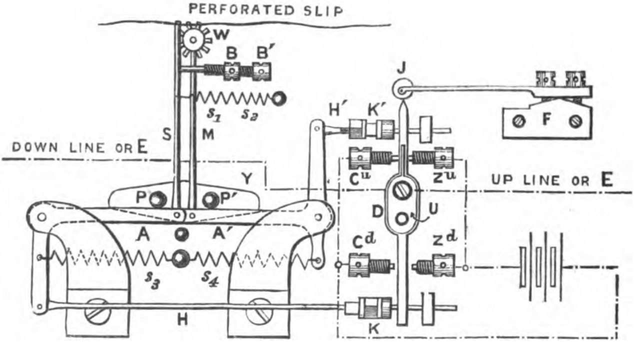


FIG. 110.

B, B′ and the spiral springs s_1, s_2 are for keeping the rods in position. Y is a beam which is pivotted at its centre and which can be maintained in a condition of constant equable vibration by means of a small crank driven by the clockwork. Projecting from Y are two steel pins P, P′, against which the bell-crank levers A, A′ are normally maintained by the action of the springs s_3, s_4, so that the levers are kept rocking in unison with Y. The lever A has at its lower end a rod H fixed to it, and the lever A′ has a similar rod H′. The free ends of these rods pass freely through holes in the lever D and work in brass bearings, shown to the right of the lever, so that they do not interfere with the action of the lever. Upon the rods, but insulated from them, are screwed adjustable collets K, K′.

The star wheel W is so geared that the upward movement of the rods S, M, if properly adjusted, takes place when the perforations in the paper slip come exactly opposite the ends of the rods.

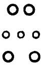
The exact positions of the rods are regulated by the screws B, B′. Each of the rods should be so adjusted that it commences to enter a perforation in the slip when the left-hand edge of the perforation is sufficiently clear of the left-hand edge of the rod to allow it to pass through freely. If the screws B, B′ are screwed too much either way out of their correct position, the rods will catch against the edges of the perforation, and the mechanism will not act properly.

The springs s_1 and s_2 pull the rods S, M back against the screws B, B′ when they have become sufficiently withdrawn to be just clear of the slip. These springs, although very light, must be strong enough to cause the rods to return to their normal positions promptly.

When the transmitter trainwork is started, the rocking beam Y is set into vibration, and the pins P, P′ move alternately up and down. When P rises, the horizontal arm of A is free to rise also, and the spring s_3 causes it to do so. The rod H is thereby moved towards the right, and the collet K therefore pushes the lower end of the lever D U towards the right also. The pin P′ simultaneously descends, pressing A′ down, and moving the collet K′ clear of the compound lever. The pressure of the jockey wheel J ensures smart and decided action of D U, which in practice cannot maintain the intermediate position shown in the figure (fig. 110). When pin P′ rises in its turn, the reverse action takes place ; H is moved to the left, so that K is clear of the lower end of the lever, and H′ is moved to the right, so that K′ pushes the upper end of the lever smartly to the right.

When the transmitter is running without slip this alternate motion (which, as has been already indicated, reverses the current sent to line) takes place regularly without interruption, and simple, rapid reversals take place, because the bell-crank levers and the rods attached are free to follow the alternate motion of the pins P, P′.

When unpunched paper is inserted, both the rods S, M are pressed downwards, and the pins P, P′ in their motion do not actuate the bell-crank levers A, A′ ; the lever D U, consequently, does not move, and a permanent current is therefore sent to line.

If slip, perforated (say) with the letter  (*a*) be now inserted ; then when rod M rises it will be free to pass through the first upper hole, and the lever D U will be moved to send a 'marking' current ; when the reverse movement of the rocking beam Y takes place, rod S will be free to pass through the first lower hole, and the current sent by D U will be reversed : a *dot* will therefore have been sent. On the next movement of the rocking beam, M will be free to pass through the second upper hole, and the length of the 'spacing' current is consequently precisely equal to that of the previous 'marking' current (*dot*). The marking current being now on, when the rocking beam leaves S free to rise it is prevented from so doing by the paper, which is not perforated below the second upper hole. In this case, therefore, the marking current is kept on until the rod S is again free to rise, which it can do through the second lower hole, and the current is then reversed. It will be seen that the marking current is therefore kept on during movements equal to two dots and the space between, and this is the recognised length of a dash. It is thus clear that when a properly perforated slip is run through the transmitter, any required Morse signals—dots, dashes, and spaces—can be automatically sent to the line.

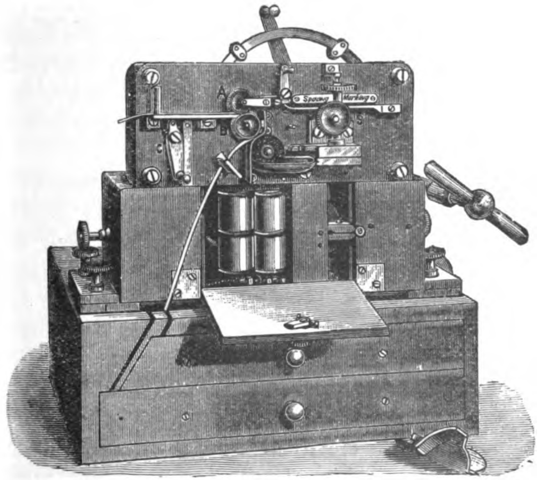


FIG. 111.

The lever D U and its contacts form in reality a double-current key, worked automatically by the moving rods, under the control of the punched paper, which takes the place of the hand or fingers. An improvement has been effected in the apparatus of the British Post Office by Mr. Willmot, in the substitution of a permanent magnet for the spring and jockey roller J. This entirely removes the downward pressure of the spring and greatly increases the holding-over force operating upon the contact lever, thereby causing more perfect impact between the contact points.

The lubrication of the roller is also dispensed with and the consequent liability of the oil getting between the contact points is removed.

The *Receiver*, by means of which the signals sent by the transmitter are recorded, is a direct ink-writer of a very sensitive character. The latest form is shown in perspective by fig. 111. The paper is drawn forward between the two rollers A and B by means of a train of wheels driven by a large weight. Before passing between the rollers the slip is brought near to a small inking disc which is rotated when the clock-work is in motion. The instrument is regulated by a fly to maintain uniform speed, and this fly is so arranged that, by means of the lever seen above the clock-work, the speed of slip can be adjusted to suit recording at any speed between 20 and 450 words per minute.

The light marking disc is fixed to an axle geared with the clock-work, and rotates close to the periphery of a larger disc that moves, in the reverse direction, in a well of ink. This latter disc takes up the ink and feeds the marking disc by capillary attraction without introducing friction. In the figure the cover of the ink-well is removed and the marking and inking discs can be seen.

The starting and stopping of the clock-work is effected by the lever C.

Passing now to the electrical arrangement of the Receiver, the electro-magnets which work the recording armature can be seen in fig. 111, as the hinged front is shown open. They consist of two bobbins of fine silk-covered copper wire, having cores of carefully annealed soft iron. If these cores were provided with a cross-piece, they would form what is generally known as a horseshoe-shaped electro-magnet; but less electro-magnetic inertia and greater rapidity of action are obtained by dispensing with the cross-piece and providing a second armature at the lower end of the axle, polarised in the opposite direction to the upper armature by means of the other pole of the inducing magnet. The arrangement of the armatures and inducing magnet is shown by fig. 112. Near the top of the axle H, a long bent tongue J is fixed in a similar direction to the armatures N′ S′. In the bent end of J there is a gap in which the axle A revolves, being kept in position by means of the flat spring F, one end of which is screwed to J near the axle H. The marking disc *m* is fixed at the forward end of the axle A.

The adjustment of the receiver towards 'marking' or 'spacing' is effected by altering the position of the electro-magnets with respect to the armatures. This is done by turning the upper edge of the screw S (fig. 111) to the left for a spacing and to the right for a marking bias. Turning to the left moves the electro-magnets in that direction, so bringing the armatures more under the influence of the right-hand electro-magnet and tending to hold over the inking disc to the right, which is the spacing position; while turning to the right tends to bring the armatures more under the influence of the left-hand electro-magnet and so gives a marking bias. The most sensitive position of the instrument is when the electro-magnets are so adjusted with respect to the armatures that when once a current, however short in duration, has passed through the coils, the armatures remain as placed until they are restored to the other position by a current sent in the reverse direction. A dot is made by sending a current in the proper direction to move the marking disc to the left, and immediately afterwards another current in the reverse direction to bring it back. A dash is made by sending the marking current for a longer time before the reverse current is sent. Normally

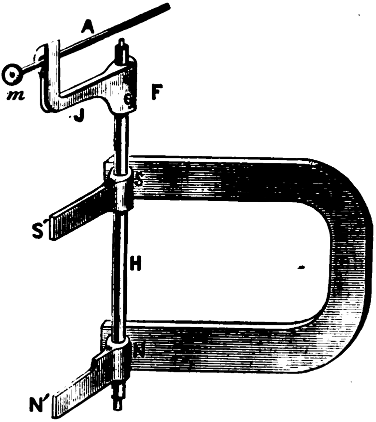


FIG. 112.

the spacing current is flowing to line as in the ordinary double-current system, and it has been already explained how the passing of the perforated slip through the transmitter determines the relative duration of the signals which it is required to send.

It will be seen that the working speed of the system is dependent upon the receiver as well as upon the transmitter. The latest transmitter is capable of working up to a speed of 600 words per minute; but in practice there are other factors which help to determine the speed of transmission, one of which is the rate at which the receiver itself can record.

This rate is limited not only by the mechanical inertia of the moving parts of the instrument, but also by what may be called the magnetic inertia of its electro-magnets. An electro-magnet cannot be magnetised and demagnetised with infinite rapidity. The iron core takes time to magnetise and to demagnetise, and each operation induces an extra current in the coils in a direction opposing the effect required. Thus, when a current passes through the coils tending to magnetise the core, the act of bringing the core from a neutral to a magnetic state has the effect of inducing an extra current in the coils which is opposed in direction to the originating current. This *self-induction* or *inductance* is important in its bearing upon high rates of speed, but, by the application of a small condenser joined across a resistance coil in circuit with the receiver (fig. 113), it can be practically eliminated.

The extra current really results from an opposing electromotive force, the value of which depends (1) upon the mass and continuity of iron in the core, (2) the strength of the originating current, and (3) the number of convolutions of wire in the coils. The strength of this electro-motive force for the same coil is invariable for any given primary current, but the extra current varies with the external resistance. Hence, it is found that, other things being equal, a high-speed instrument will give better results with a certain current working through a high resistance than with the same current working through a low resistance. The explanation of this is that while the strength of the primary current is fixed, the opposing extra current is weaker through the high than it is through the low resistance.

The effect of the shunted condenser will be understood from fig. 113. R represents the receiver coils, K being the condenser, *R* the non-inductive resistance, both being adjustable. If a current be sent through the coils, the condenser will be charged to an extent dependent upon the resistance *R*, and this may be so adjusted that when the primary current ceases the discharge current *k* from the condenser may exactly equal the extra current *l* from the receiver.

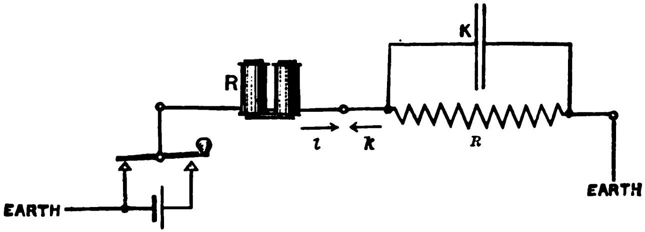


FIG. 113.

It is not, however, only in connection with the receiver electro-magnets that this disturbing influence is felt; it arises also, although in a less degree, from the coils of the galvanometer, and in this case a different device is applied for its elimination. This consists in providing another path of discharge, through a simple resistance coil placed as a shunt across each coil of the differential galvanometer. The resistance of the galvanometer coil being 50ω and that of the shunt 300ω the reduced effect upon the galvanometer of the working currents is not considerable,[2] while the extra currents from the galvanometer coils circulate much more

[2] See Appendix. Section D.

readily through the non-inductive shunt coils than through the much higher resistance and self-induction of the receiving circuit.

In the local circuit also of receivers and relays, where the primary current is strong and the resistance of the circuit low, the extra current arising from the discharge of the sounder electro-magnet is very considerable; and as the path of this current is across the contact points of the relay or receiver, and sparks oxidise or dirty them, it is necessary to shunt the coils of the sounder.

With no further special provision the fast-speed apparatus as described can send at the rate of 600 words per minute so long as it is working only on a short line, but it has been already shown (p. 138) that as the length, or rather, as the resistance, inductance, and capacity of the line are increased, so the rate at which it will allow separate distinct signals to pass is diminished.

The effect of electrostatic capacity upon the recording of signals may be best studied by means of Bain's chemical recorder (p. 77), for the whole time during which a current is flowing is there indicated, and the result of retardation and prolongation beautifully shown. Fig. 114 represents the effect which would be observed with dots, (1) on lines of little electrostatic capacity, (2) on lines of moderate capacity—say 300 miles of overground wire, and (3) on long cables. While 20 dots can be firmly and clearly recorded in the first case, 10 can be recorded in the same time in the second case, and

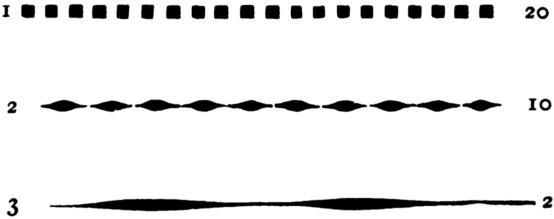


FIG. 114.

only 2 in the third. If a higher rate of speed were adopted in the two latter cases the marks would run together and become illegible—on a Wheatstone receiver they would form a continuous line.

If dashes be sent instead of dots the effect upon the speed of working is still more marked. With dots the current from the sending end may be so regulated in duration as to allow just sufficient current to appear at the distant end to record the signal and no more; then the sending of the reverse spacing current immediately afterwards will almost exactly neutralise the charge. But with dashes the line will get more fully charged, and the charge will not be neutralised ordinarily by the spacing current.

In the practical working of automatic circuits every condition of signal is to be met with. In the case of a dot followed by a simple space, or a dash followed by a letter space, the discharge would be properly neutralised, but with other conditions, the effects of retardation and prolongation result in the distortion of the marks at the distant end either by the loss of dots, by the running together of the signals, or by the conversion of dashes into dots and dots into dashes. Letters are thus deformed and even converted into other letters. A dot entering a neutral line becomes a dash from prolongation; a dot following a dash may be lost because its current is entirely occupied in neutralising the return charge of the dash, or it may be only shortened, which may also be the case with a dash. Signals following each other too rapidly will run together because there is no time for discharge and reversal.

These defects cannot be entirely remedied, because they are inherent to the principle of working, but their effect can be considerably diminished by the application of condensers in a suitable way. The need for this arises, however, principally in the case of circuits which include a cable, and the method of applying condensers for this purpose will, therefore, be dealt with in the next Chapter (see p. 188).

Fig. 115 shows the connections of a complete set of the apparatus required for working high speed on a simple circuit.

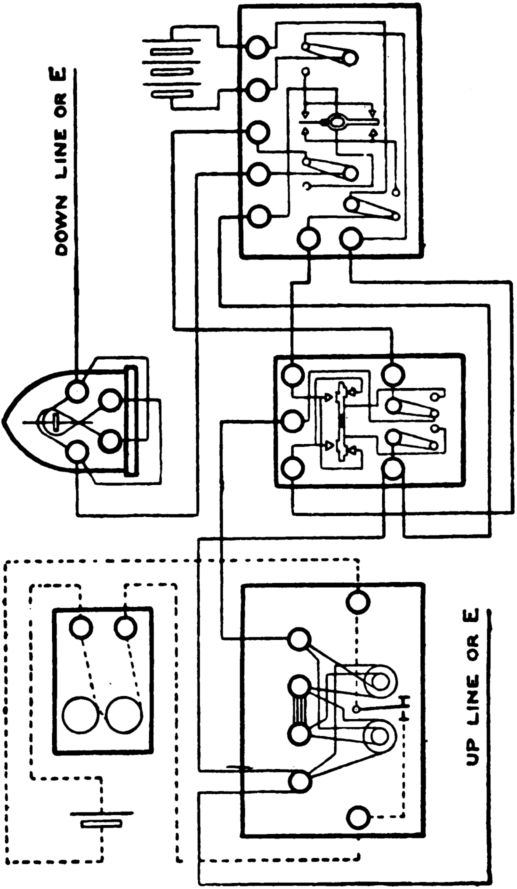


Fig. 115.

Beneath the transmitter base there is a triple switch which is actuated by the stopping and starting lever of the trainwork. The three levers are shown in the position of rest of the instrument, in which case the poles of the battery are joined across to the two left-hand terminals, which are connected to the battery terminals of the double-current key, and the down line wire also passes, by way of the galvanometer and the transmitter, to the key, and thence through the receiver to earth. Hence in this position the operator is able to communicate by means of the key.

When the transmitter is started the switch levers join up the battery to the transmitter contacts and connect the down line to one section of the transmitter lever. The other section of the lever is permanently connected to the up line or earth.

The receiver is arranged to act as a relay for a local circuit, in which is placed a sounder, which is used for calling attention and also for reading from when the line is being worked by key.

Automatic instruments are employed on nearly all long circuits in England, not only because they increase the capacity of the wires for the conveyance of messages, but because they are so specially adapted for the conveyance of news, which is such a distinctive feature of the English system of telegraphy. One batch of news is often sent to a great many different places, and as four or even eight slips can be prepared at one operation, and one slip can be used several times, the labour of preparing for transmission is very much reduced. In fact, without this system it would be simply impossible to transmit the enormous amount of intelligence sent telegraphically all over the country. One million words are sometimes sent on one night. There are many news circuits radiating from the Central Telegraph Station, having three and four intermediate stations upon them, one or more of which repeat or translate onward to three or four more stations. Thus one punched slip disseminates the news to many places.

It is of course evident that, apart from its extreme accuracy, the chief value of the automatic system is its increased speed of working. It may be said to increase the capacity of wires eightfold. The average rate of automatic working in England, due to the length of circuit, to the amount of self-induction and electrostatic capacity present, and to the various causes that have been enumerated, is about 100 words per minute. A speed of 300 words is, however, often attained. Thus one wire fitted with the automatic apparatus can do the work of eight fitted with the ordinary apparatus. But the former involves additional expense in working and additional delay to each individual message. When a wire is kept going at its full speed, five punchers, one operator in charge of the sending and receiving apparatus, and six writers are required, that is, eleven additional clerks are wanted at each station. The messages are punched and transmitted in batches of five or six. Thus a message has to wait to be punched, and to take its turn in its batch. This involves delay. For these reasons it is not economical to introduce automatic working on short circuits, except for special occasions and for break-downs, and hence it has been confined principally to long circuits.

The automatic system is invaluable when a sudden glut of work is handed in at a station, or when communication is interrupted through storms and accidents. Once, when four out of the five wires then working between London and Birmingham were broken down, the remaining wire, working automatically, did the work of all, but of course with some delay.

The Murray Printing Telegraph.

The Murray Printing Telegraph is a high speed automatic system which prints the messages in Roman type. The electrically controlled perforator for punching the paper ribbon can be worked by an ordinary typist at the rate of thirty words per minute, and four such, continuously in operation, can feed the transmitter when the latter is working at its highest speed. Between Edinburgh and London a speed of 120 words per minute has been achieved. The keyboard perforator consists of a typewriter keyboard with thirty-two keys operating a group of selecting bars which control the combinations of punches employed to punch the message holes in the paper tape. The work of punching and feeding the tape forward is performed by an electro-magnet, the circuit of which is closed by the depression of any of the keys. The punching takes place on the front stroke and the feeding of the tape on the back stroke of the armature of the electro-magnet. There are five punches and a die-block, and the tape is fed forward by a small sprocket-wheel. A back-spacing lever is provided to pull the tape back letter by letter in the event of error. Depressing a special key then punches the tape full of holes. This obliterates the error in such a way that no trace of the correction, not even a blank space, appears in the printed message at the other end of the line.

The transmitter is of a similar character to the Wheatstone, with this peculiarity, that the clockwork is operated by a motor or phonic wheel, which receives its energy, in the form of electrical pulsations from a vibrator which is actuated as follows: on either side of an iron reed is fitted an electro-magnet, the circuit of each being alternately connected and broken by the break-and-make contact springs on either side of the reed. One of the magnets is connected with one side of the transmitting motor and the other with the opposite side of this motor, so that alternate pulsations are given to each, thereby maintaining the phonic wheel, which is pivoted centrally between them, in steady and constant rotation, and, as the axle of this wheel transmits its power to the clockwork inside, a perfectly uniform speed is secured for the transmitter.

At the receiving end is a vibrating reed which can be adjusted by a weight movable on its free end. It is set to vibrate at a speed a little in advance of the transmitting one. Flexible contact springs, one on either side of the reed, are connected respectively with the spacing and punching electro-magnets of the recorder. The amplitude of the vibration of the reed is limited by two resilient or buffer springs, one on either side of the free end of the reed. The effect of these buffer-springs is to make the reed very sensitive to variations of current, thus enabling the rate of vibration of the reed to be controlled by the arriving signals. The recorder is arranged, by aid of the spacing and paper-feeding magnets and a tape previously furnished with centre holes, to punch electro-magnetically perforations precisely similar to those originated at the sending station. The contact spring on one side of the vibrating reed, a local battery, the spacing electro-magnet, and a shunt-wound motor combine to give the proper feed for the paper tape.

The method adopted by Murray to produce a type-printed page from the record perforated on the tape is a mechanical arrangement like an ordinary typewriter of the Barlock pattern. The keyboard is retained for filling in any letters that may have been accidentally dropped, or for making necessary corrections. The received paper tape is passed over a wheel, the teeth of which engage in the centre holes and lead the paper over the face of a die-plate having five holes, corresponding in size and in distance apart to any five possible combinations of perforations in the tape. Facing these holes are the points of five longitudinal rods capable of penetrating through the holes in the die-plate by the action of a motor-driven cam. These rods have teeth cut out of their front edges like those of a comb, and are designed to engage, in certain combinations, with the key-connected levers so as to operate any particular letter key. As the paper passes over the die-plate it presents to the points of these five reciprocating rods a certain number of perforated and unperforated spaces, according to the specific letter. The former admit the passage of certain rods through the die-plate, while the latter block the passages of others. The rods, therefore, take up a certain position for each and every symbol, and the particular alignment of their teeth at any time determines the action on the printing levers and the letters connected therewith. This mechanical device can attain a speed of 150 words per minute. The great advantage of the Murray system is that it replaces human writers by automatic Roman-type printing, which is economical to the Post Office and convenient to the receivers of messages. Accuracy and economy of labour are of more value than speed of transmission ; 1,000 words per minute are easily transmitted electrically, but the handling of messages containing so many words at each end without delay is a difficult and expensive process.

The Pollak-Virag Writing Telegraph.

The Pollak-Virag Writing Telegraph was brought out in 1899, and has since been perfected. It is essentially a high-speed system, with a photographic record in written characters. It is not in everyday use as a commercial system, but has features which possess peculiar interest and which are full of promise. The apparatus consists of two telephones connected to a double line. One telephone is looped in, the other is between the loop and earth. Rods are attached to the diaphragms of the telephones, which move when currents circulate, and cause oscillation in a small concave mirror supported upon one fixed point and two movable points. One telephone moves the mirror about a horizontal axis, the other about a vertical axis, so that, acting simultaneously, the telephones can cause the reflected spot of light to trace any desired curve. The source of light is a stationary glowing filament, surrounded by a metal mantle in which a helical slit is cut, the helix having one complete turn. In consequence, when the mantle is turned about its axis, the source of light falling on the mirror moves in effect uniformly from right to left, and the spot of light on the paper from left to right by reflection. The mantle and the sensitised paper strip are automatically started at the commencement of a message. A perforated strip is used in the transmitting station, five slip rings connected to batteries and two brushes connected to the line. The strip is so perforated as to allow of currents passing which will suitably operate the telephones at the distant end, and cause them to supply through the mirror and reflected spot of light the vertical and horizontal components necessary for the closed curves of written characters. For producing the vertical movements a positive current and an equal negative current, and a positive current of double their voltage serve; for the horizontal motion a positive current and a negative current of approximately equal voltages are required. The exposed strip is carried forward by clockwork into a developing bath and then into a fixing bath, when it is ready for delivery. When tried between Pressburg and Budapest a message of 250 words was transmitted with this apparatus in only fifteen seconds, and between Berlin and Königsberg a speed of over 600 words per minute has been attained.

FIG. 115A.

The above is a facsimile of the writing reproduced on the photographic slip at the receiving end of the line.

CHAPTER VII.

SUBMARINE TELEGRAPHY.

SUBMARINE cables of considerable length, such as those connecting Europe and America, or those forming the great chain connecting the Mother Country with the Antipodes, have to be worked by methods specially devised with a view to obtain the maximum possible speed of working. Relays or other forms of apparatus whose action is dependent upon electro-magnetism are inadmissible for various reasons: 1st, they require stronger currents to influence them than can with safety be transmitted through long submarine cables. 2nd, they aggravate the effects of retardation, the causes of which in such cases have been sufficiently dwelt upon (p. 164). But there are other causes of embarrassment which have also to be provided against. Different portions of the earth, from causes which are not yet known, are frequently at different potentials. When these portions at different potentials are connected together by wire, we have currents in the wire which are called *earth currents.* The currents vary in strength and duration during different periods of the day and year, and at certain seasons they acquire such magnitude as to be called 'electric storms.' They then interrupt the circuits to such an extent as to render working difficult and even impracticable. On long cables they are specially prevalent, and sometimes become of such strength as to endanger the safety of the cable. They are to be guarded against in two ways: 1st, by dispensing with the earth and using a second wire as the return wire, working, as it is called, with *metalic circuit*; 2nd, by using *condensers* and working with a broken or interrupted circuit, so that the cable wire does not present a continuous conductor connecting the two distant points of the earth.

The first method is used chiefly on land lines because it can be easily and rapidly resorted to on the comparatively rare occasions when it is needed; but the second method is that which is principally used on cables, and it is very effective. It was invented by C. F. Varley.

Let A B (fig. 116) be a wire connecting Europe and America; K an ordinary key, and B a battery at A; C a condenser inserted in that wire, and G a galvanometer at B. Now, if the circuit be so arranged, it is evident that as it is broken at C, no continuous current can pass from A to B, and thus earth or other extraneous currents are prevented from flowing through the galvanometer. But how can we affect the galvanometer G at B? In this way: when we depress the key K, a current flows into the cable to charge it; one side *a* of the condenser is thus connected with one pole of the battery, its potential is raised, and it is charged, say, negatively. The negative charge accumulated on *a* attracts across the dielectric a positive charge on *b*, and repels a negative charge. This positive charge apparently passes from earth at B through the galvanometer in the form of a short current or pulsation. When K is released and falls back to its normal position the cable is discharged, and the potential of *a* is again reduced. The positive charge on *b* is released, and it flows to earth through G in the reverse direction to that of the previous current. Thus whenever we depress the key at A and release it, we reverse the galvanometer at B.

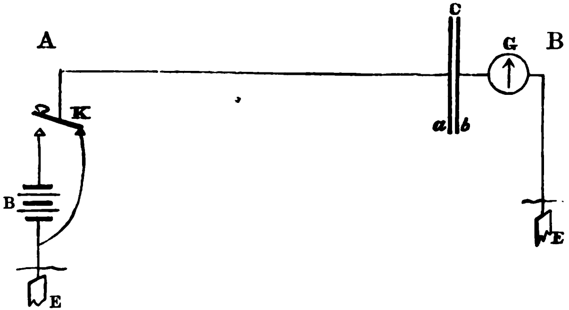


FIG. 116.

The condenser might equally well be placed at the sending end, but it is better to employ condensers at each end, as shown in fig. 117. The arrangement for working a submarine cable by means of condensers is there symbolically represented. B and B′ are the batteries, K and K′ commutators of the 'tapper' type, G and G′ reflecting galvanometers, *c* and *c′* condensers, and *s* and *s′* two-way switches, by means of which the cable may be joined to the sending or receiving apparatus. *s* is shown in the sending position and s' in the receiving. If it be required that the condenser shall be in use at the receiving end only, it must be placed between the switch and the galvanometer or between the galvanometer and 'earth' at each station; but the signals from the latter position will be reverse as compared with those from the former. In actual practice it is found that when both condensers are in circuit as shown in the diagram, the speed of working is thirty per cent. greater than when a condenser is employed at the receiving end only. There is the additional advantage that the cable is completely isolated, since it is disconnected at each end, and therefore the presence of earth currents will be less evident than in the case where one condenser only is employed.

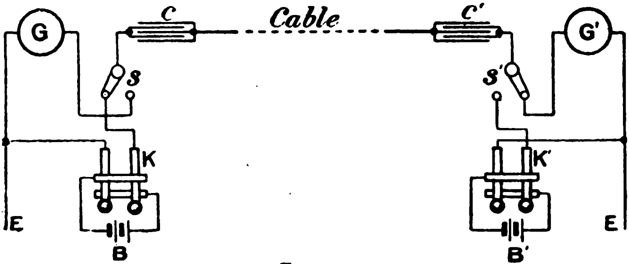


FIG. 117.

It must be remembered that the evil effects due to the difference in the potential of the earth at each end of the cable are not entirely eliminated by the use of condensers, for as the potential at either end varies, so will the potential of the plates of the condenser, a gradual increase or decrease in the charge will take place and affect the receiving apparatus. The earth's potential, however, changes very slowly under normal conditions, the current produced is therefore very weak and affects the instruments very slightly.

Now, by using galvanometers or other receiving apparatus of the most sensitive character, which will be actuated by the first appearance of the current, we are able to work cables with the smallest possible electro-motive force. This not only conduces to the safety of the cable, but adds to the speed of working.

Thus, by suitably determining the size of the condenser, the electro-motive force of the battery and the delicacy of the galvanometer, it is possible to transmit signals which shall represent the maximum speed with the minimum expenditure of power, and, while effectually counteracting the ill effects of earth currents, to reduce to the lowest possible point the retarding influence of induction.

The condensers used have a capacity of 30 microfarads, which is equivalent to the capacity of about 100 knots of cable. Storage batteries are now much used for cable signalling when facilities exist for charging them, but, otherwise, the bichromate or the Daniell cell is employed.

The galvanometer is Thomson's reflecting galvanometer —the most delicate and perfect instrument of its kind ever invented, without which long cables could scarcely have been made commercially successful. The needle consists simply of one or more pieces of watch-spring ⅜ inch in length, cemented upon a small circular flat mirror of silvered glass, which is suspended by a short thread of cocoon silk without torsion. It weighs only 1½ grain. This needle is suspended in the centre of a coil of very fine wire, giving a resistance of about 2,000$^{\omega}$. Above the coil is a bar magnet, which can be raised and lowered, or turned upon its centre by means of a screw. This exerts a directive force on the needle, and is so adjusted as to cause the mirror to reflect a beam of light passed through a small slit on to the centre of a scale. It also controls the vibrations of the needle so as to make its movements almost 'dead beat'; indeed they are sometimes so sudden and short as only to broaden the spot of light.

Fig. 118 represents conventionally the arrangement of the apparatus at one end of a long submarine cable. G is the galvanometer, one terminal of which is attached to the resistance coil R, by means of which adjustments may be made

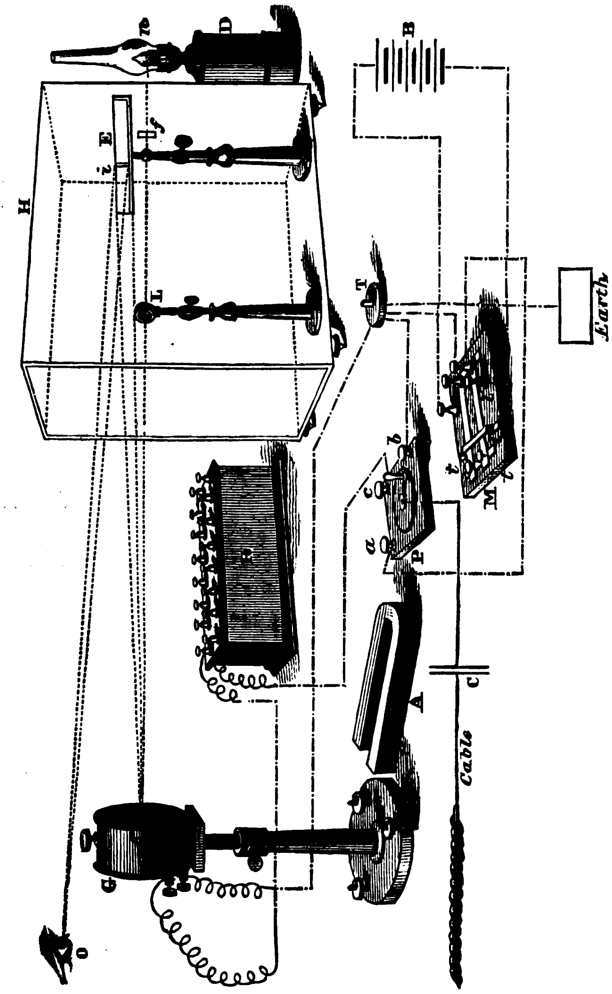


FIG 118.

to suit the varying conditions of the cable and the strength of the currents; and the other galvanometer terminal is connected to earth by means of the earth switch T. B is the battery, which is connected to M, the transmitting portion of the apparatus, which is similar in every respect to the pedals of the single-needle instrument already described. The condenser C is joined on the one side to the cable and on the other to the switch P, by means of which the cable (through the condenser) may be put direct to earth, or placed in connection with either the galvanometer G or the commutator M, according as it is desired to receive or to send. The directing magnet is shown at A, separate from the instrument, but it is in practice fixed and adjustable.

The beam of light proceeding from the lamp D, through the slit *f*, is concentrated, by means of a lens L, on to the mirror *m*, whence it is reflected back to the scale E as shown at *i*. By means of the movements of this reflected beam of light to the right or left the alphabet is formed, in precisely the same way as by the motion of the pointer on the dial of the single needle. H is a large box which acts as a species of darkened chamber, and enables the movements of the spot of light to be discerned with ease.

A glance at fig. 118 will serve to show the electrical connections which are required. The cable is brought through the condenser to the switch P. When signals are to be received the switch-bar is placed in connection with *c*, and in this way the cable is connected through the resistance coils R to earth through the galvanometer G. If, again, signals are to be sent, the switch bar is carried to *a*; to which the commutator M is connected, and in this way the signal's are sent direct to the cable without influencing the galvanometer G.

If the ordinary apparatus used for land telegraphy, such as the Morse or Sounder, were used on the old Atlantic cables, a word a minute could scarcely be obtained; with the mirror instrument fifteen words are easily sent in the same time, and twenty-four have been obtained. The mirror is really a single-needle instrument, whose index is a spot of light; but apart from its excessive delicacy, it has this advantage over the vertical needle, that in place of having a fixed ***zero*** or ***neutral*** line, to the right or left of which the needle vibrates to impart its signals, the zero line moves with the spot of light and wanders all over the scale, the signals being made by the pulsations or vibrations of the spot, and being read by their direction and not by their position or amplitude. Thus signals need not be read by separate distinct currents, as in land lines, but by the increment or decrement of one continuous current, the strength of which (from the great capacity of the cable not permitting its being fully discharged between the signals) is varied by the reversals made at the sending end.

The use of condensers, as shown in fig. 117, tends to fix the zero line of the mirror, for it is evident that there will not be a continuous current now; but still the capacity of the cable will have effect and the condenser will only respond to the changes of potential of the current in pulsations corresponding to those imparted to *c*.

In 1867 Lord Kelvin, then Sir William Thomson, invented an instrument which records the signals by spurting ink upon a moving paper ribbon from a fine glass syphon, which is moved to the right and left by these reversals. The paper moves in a horizontal plane, and the short leg of the syphon dips into an ink reservoir; its long leg is directed obliquely downwards, with the end close to the paper. Originally the ink was electrified to make it flow, and much trouble was sometimes experienced in securing the proper electrification. This has now been replaced by a mechanical device which causes the ink to be impressed

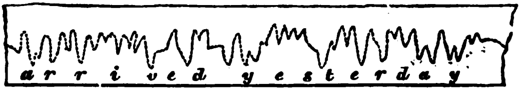


FIG. 119.

upon the paper by rapid vibrations imparted to the tube. A sentence sent by this *Syphon Recorder*, as it is called, is shown by the dotted line in fig. 119.

The essential parts of the syphon recorder which is now most generally used in long cables are illustrated in fig. 119 A. The plan of the connections is the same as that shown for the mirror galvanometer. The moving part of the instrument is a suspended coil A, oscillating in a strong magnetic field. The received current passes through this coil from terminals B and C, and the coil moves right or left according to the direction of the current. Fibres fastened to the two upper corners of the coil are connected to the carrier of a very fine glass tube bent into the form of a syphon, as shown at D, so that when the coil moves, the syphon makes corresponding oscillations. The syphon is suspended from a stretched wire, which is kept in constant vibration by means of an intermittent current sent through electromagnet E, and the ink is by this means afforded free course

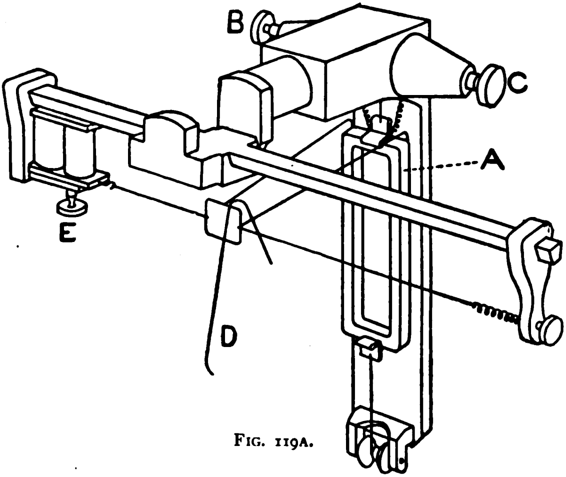
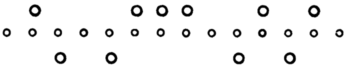


FIG. 119A.

through the fine bore of the glass tube. The tape is arranged suitably to travel underneath the point of the syphon, and a continuous line is inscribed upon the tape. From the sinuosities of this line, as exhibited in fig. 119, the letters are read. The coil of the recorder is furnished with an adjustable shunt, by which the amplitude of its oscillations may be controlled. The suspension is so finely effected, and the electro-magnetic reaction so quick, when a current traverses the coil, that legible signals are produced by one-twentieth of a milliampère. Through a cable 2,000 miles in length a speed of fifty words per minute has been attained when working simplex and sending automatically, and in duplex a speed of forty-five words each way. This must, however, not be considered to be other than an exceptional rate.

The principal cables, such as those connecting Europe with America are, under normal conditions, worked duplex on the bridge system. The sending is done automatically by a transmitter constructed on similar lines to that shown on page 157. Perforated slip is drawn forward by a star wheel engaging in the centre row of holes, and levers pass up through the holes on either side as described on page 158. The signalling currents are, however, of equal duration, being in one direction for a dot and in the reverse direction for a dash. The lower row of holes in the perforated ribbon correspond to the dashes, and the upper row to the dots; thus the letters *a*, *b*, and *c*, would be punched as follows:



The electrostatic capacity of a long cable is so great that if steps were not taken to neutralise, or hasten the discharge from the cable, the signals would become so distorted as to be quite unreadable. It is therefore arranged, by means of levers and cams included in the trainwork of the transmitter, that immediately after each signal is sent, a current in the reverse direction is made to flow through the cable in order to hasten the dissipation of the electrostatic charge. The duration of this *curbing* current, as it is called, will depend upon the speed of working; the higher the speed the more nearly must the curbing current equal in duration the signalling current; as a general rule the former is applied for a length of time equal to four-fifths of that occupied by the signal. Between each curbing current and the following signalling current, the cable is automatically connected to earth by means of the same lever and cam which sends the curbing current, which further tends to clear the cable of any remaining charge. The receiver consists of a syphon recorder placed in the position occupied by P in fig. 103, which shows the theoretical connections of a circuit worked duplex on the bridge principle.

Improvements in automatic transmission have been introduced by Dr. A. Muirhead in regard to the intervals of application of positive current, earth, and negative current. An adjustable contact is furnished with his automatic transmitter by which these intervals can be adjusted to suit the peculiar condition of each cable. The suitability of such a device is evidenced by the fact that an increased speed of 30 per cent. has resulted from its adoption. Fig. 119B illustrates the appliance, and its mode of operation is as follows: L_2, L_2 are two levers connected to 'line' and 'earth,' resting normally on the contacts Y, Y, which are joined together in the same manner as in an ordinary cable signalling-key, and connected to the upright lever L_3, which by the action of the revolving cam C upon the pawl G_3 makes connection alternately with the upright and fixed contacts K_1 and K_2, to which are joined the opposite poles of the batteries B_1 and B_2; X, X are the two other contacts joined together in the same manner as the lower contacts of an ordinary cable signalling-key, and connected to the junction of B_1 and B_2, the 'signalling' and 'curbing' batteries respectively. Referring to fig. 119C, the relative duration of contact between the lever L_3 and the contacts

K_1 and K_2 respectively is determined by the position of the pawl G_3 upon the surface of the cam C; the ebonite platform, carrying the pawl, the lever L_3, and the upright fixed contacts K_1 and K_2, is made adjustable in a direction parallel to the axis of cam C by means of a screw T. By turning a milled head, attached to this screw, to the left, the platform, together with the pawl, lever, and contacts, is moved bodily in the direction of the arrow, and the pawl G_3 can thus be made to bear upon the surface of the cam C at any point along its entire length as required.

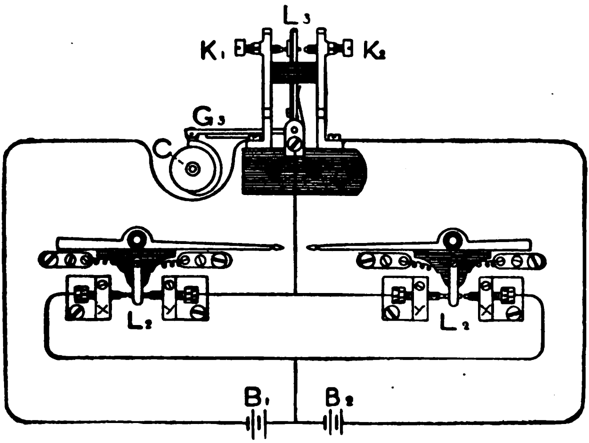


FIG. 119B.

Referring again to fig. 103, the transmitter takes the place of the key K, and a condenser is placed in each of the arms *a c*, *a* C, and C *c*; the condensers in the 'ratio' arms of the bridge are known as sending or signalling condensers, and that in the recorder circuit is termed the receiving condenser. Instead of the simple rheostat R in the compensation circuit, a *grid condenser* or *artificial cable* is substituted. The peculiarity of this instrument is that it constitutes an artificial resistance as well as a condenser.

It is made as follows :—A sheet of tinfoil is cut into the form of a grid, each limb of the grid being slightly more than an inch in width, and presenting altogether the appearance of a continuous zigzag ribbon of tinfoil: this forms one plate of the condenser. The second plate, which is separated from the first by paraffined paper, consists merely of a plain sheet of tinfoil. These differently shaped plates alternate throughout the whole condenser, the zigzag ones being joined in series and the plain ones connected to earth, each plate being separated from the next in the manner described. Now, although the tinfoil strip is somewhat broad, it is also very thin, consequently when several of the zigzag plates are joined in series they offer considerable resistance, and it is this resistance which is utilised in balancing that of the conductor in the cable. The capacity of the tinfoil strip is also made to balance the capacity of the cable. Since the resistance and the electrostatic capacity of the compensation circuit are thus evenly distributed (for they both vary directly as the length of the strip used) it is evident that

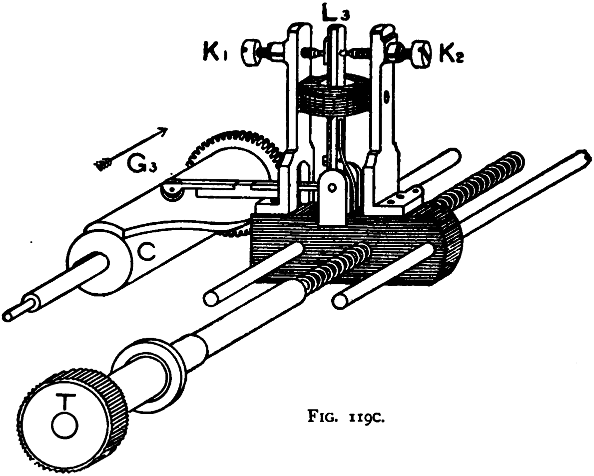


FIG. 119C.

the actual condition of the cable may be more truly reproduced than it could be by means of separate condensers and resistance coils. The thickness and the breadth of the strip are so arranged that the ratio between the resistance and capacity per unit of length of the tinfoil strip shall be approximately equal to the ratio of resistance to capacity in the cable itself. Suitable means are also provided for bringing into use any desired portion of the whole artificial cable, and 'leaks' are placed in the compensation circuit to correspond as nearly as possible with defective insulation of the cable: those of course being varied in magnitude and position from time to time as necessity arises.

On consideration it will be clear that short cables may be dealt with in the same way as long overground lines, and hence the cables connecting various points in the British Islands and those between England and the Continent are not worked in the same way as are the long Atlantic and other sub-oceanic cables. The Hughes Printing Instrument, for instance, is used very extensively on Continental lines, and consequently that system is also at present employed in working the cables which connect us with the European system. The Morse system, again, meets the general requirements of working of the less important local British cables, while the Dublin to Nevin and other important cables demand the application of the automatic system. This latter requirement, however, necessitates a special provision to enable signals to be recorded at the requisite speed.

The effects of electrostatic capacity upon the speed of working have been described with sufficient fulness in the previous chapter; and, as is there stated, they are felt more upon cables than upon overground wires, since one mile of ordinary cable has a capacity equal to about twenty miles of open line.[1]

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[1] The speed of working actually varies inversely as the product of the *capacity of the line multiplied into the resistance* (KR), but as the *resistance* of the average cable used is about equal to that of the overhead wire used for important lines on the English system, it is practically the relative *capacities* which determine the relative speeds.

For automatic working, then, it becomes necessary to make such an arrangement of condensers with resistance coils at each end of the circuit that the discharge from the condensers at the sending end will approximately correspond with the discharge of the cable. The theoretical method of compensation for automatic duplex working is shown in fig. 120, where Rheostat and R_1, R_2, R_3, C_1, C_2, C_3 represent the ordinary compensation circuit for duplex, except that the condenser is of large capacity and in three sections, with retardation coils to correspond; R C shows the shunted condenser, the discharge from which tends to neutralise the extra currents of the receiver coils (see p. 164), and S C_1, S C_2 show the special signalling condenser with its coils S_1 and S_2, by means of which the return current from the cable is practically neutralised. If anything, the presence of this signalling condenser has a disadvantageous effect upon the *received* signals, but this may practically be compensated for by extra capacity in the receiving condenser R C.

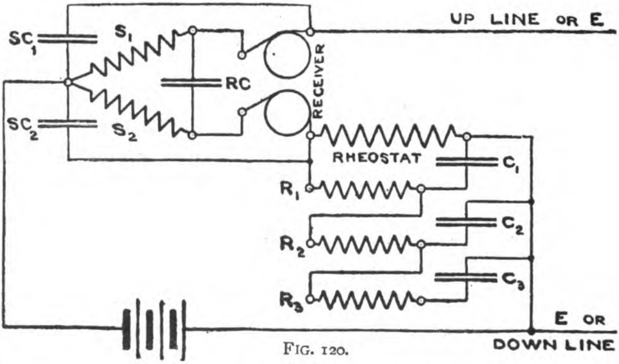

Fig. 120.

Not only does the capacity of a line affect its possible speed of working, but the distribution of the capacity in the circuit has an influence. Thus, generally, a long open wire at the receiving end of a cable circuit, by favouring discharge to earth through leakage, reduces the effect of the discharge current upon the receiving apparatus. This effect of unequal distribution of capacity may be well illustrated by the following facts. Between London and Amsterdam there are about 130 miles of open wire on the Great Eastern Railway, then a cable 130 miles long and then 20 miles of land line. When working direct London can send to Amsterdam only 48 words per minute, while Amsterdam can send 68 words to London. Between London and Dublin there are 266 miles of land wire in England, 66 miles of cable, and ten miles of land wire in Ireland. When working direct Dublin can send to London 80 words per minute, while London can send to Dublin only 40 words.

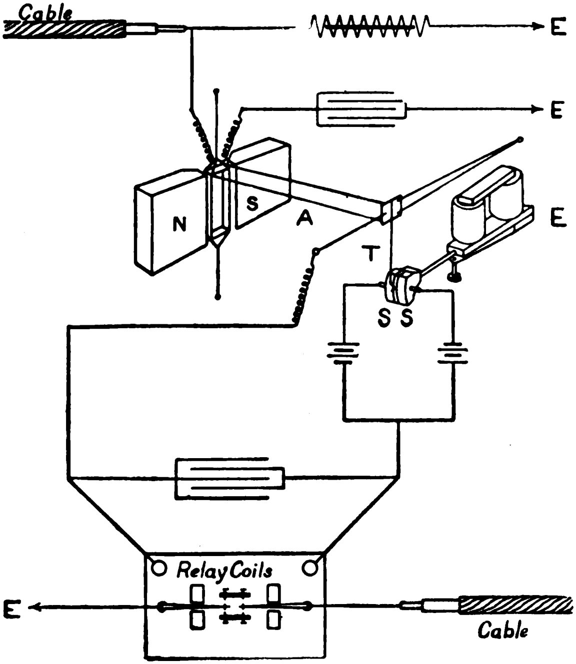

FIG. 120A.

Having the same working conditions, but applying the signalling condenser compensations described above, the possible speed at each end is practically equalised, and for the Amsterdam circuit becomes 116 words per minute either way, and for the Dublin circuit 120 words. (See p. 195.)

Until lately messages through long lines were received and retransmitted at intermediate stations by hand, so as to cut up the circuits into lengths convenient for reasonable speed. The speed of working is the speed of the longest section. Repeating relays invented by Muirhead, Brown, and Gulstadt have now enabled messages to be automatically repeated, and have rendered it possible to work directly a circuit of a length of 2,500 miles, as from Waterville *viâ* Canso to New York. In Muirhead's relay (shown in fig. 120A) the moving coil of a syphon recorder is connected, as shown at A, to a tight wire, carrying a light contact maker or tongue instead of a syphon, whose end plays upon the silver plates S, S. These are slightly convex, mounted side by side on a flat spring, and insulated from each other by mica; they are vibrated up and down by the electro-magnet E. The tongue or trailer T rests normally on a centre ring of silver insulated from the two plates. Evidently, when currents traverse the coil, the tongue will move to the one plate or the other, and, as the figure shows, can be made capable of transmitting fresh signals to another line or cable.

Mr. S. G. Brown, in his cable relay (fig. 120 B), which is also of the moving coil type, causes the tongue or trailer to bear upon the surface of a rotating drum, the latter being divided into insulated sections, which are in circuit with relays. The tongue consists of a fine syphon tube carrying a bronze wire (*p*) tipped with iridium (*d''*). The drum D revolves about 150 times per minute. This relay depends for its efficiency upon the elimination of friction to the lateral movements of the tongue, due to the tangential motion at the surface. If the drum be stopped, the tongue also stops, the cable currents being too feeble to overcome the statical friction between the tongue and surface which now supervenes. For automatic work, when successive impulses of the same sign follow each other in the course of transmission, the signals are apt to run together or to be dropped. Brown employs what he names an 'interpolator' to reproduce the original impulses. An electro-magnet, worked from one of the relays in connection with the drum and tongue, is caused to release a catch from a clutch sleeve, which then mechanically revolves and moves a lever which is suitably arranged for connecting a battery to line. A crank pin is also caused to revolve,

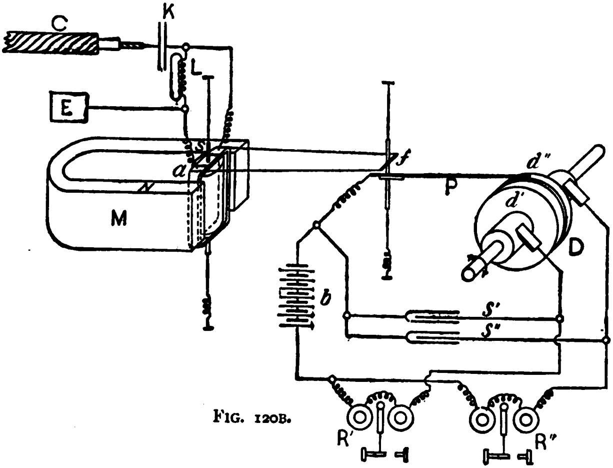

FIG. 120B.

and at stated times reverses the battery, acting as a curb to the first battery current. Thus a long contact at the drum relay due to the running together of two or more dots is split up by the 'interpolator' into its component parts and retransmitted in a restored form.

For methods employed for the localisation of faults in submarine cables the reader is referred to works specially treating of this subject, but graphic methods which have been usefully employed when the copper wire is exposed are exhibited in Appendix, Section G (1).

CHAPTER VIII.

REPEATERS.

THE strength of the current received as compared with that sent on a telegraph circuit decreases with the length of the circuit not only in consequence of the additional resistance, but also from the effects of weather upon the wire and its supports. Of course an increase of battery power will overcome these latter effects to some extent, but it is undesirable to be dependent upon such a condition with every variation of weather, and there is necessarily a limit to such an increase. In England the conditions are such that it is difficult to maintain uninterrupted communication for distances of over 400 miles. In dry climates, and where purely aerial wires are used, much greater distances are possible; but in all countries a distance is at last reached where direct working is impossible, and where it becomes necessary at some intermediate point either to take off the messages and repeat them by clerks, or to introduce a *repeater* or *translator* which, worked by the original currents, will automatically repeat stronger currents similar in direction to, and of equal duration with, those which are passed through it. It is, in fact, an extension of the principle of the ordinary relay, and is introduced into the circuit for a similar reason—the relay is placed in circuit that it may be actuated by currents which would not work the sounder or Morse writer direct, and completes a local circuit in which the receiving apparatus is placed; the repeater is also arranged to relay similar currents to those which actuate it, but, while the relay as ordinarily used is required to work an instrument in the same office, the prime function of the repeater is to retransmit the signals along an extension of the original line. By this means it is possible to work to any distance. Thus the Indo-European line from London to Teheran, a distance of

3,800 miles, is worked with only two retransmissions by means of eight repeaters.

The theoretical connections of a repeater are shown in fig. 121.

The principle consists simply in converting the lever of the recorder or sounder M or M′ into a key which is moved by the attraction of its armature between two contact points corresponding to the front and back contact points of the key. The electro-magnet of the recorder thus replaces the hands, and the motions of the key at the distant sending station are thus repeated at the translating station. This automatic key brings into play a fresh line battery B, which sends on a fresh current to the distant receiving station. Let us fix ourselves at the repeating station, where there are two sets of identically similar apparatus, as shown in the diagram, and assume that the up station A is sending to the down station B. The currents from the up line enter the lever *t′* of the recorder M′, and pass by 1 to R, the relay of the up set of apparatus, which they work; they then pass to the

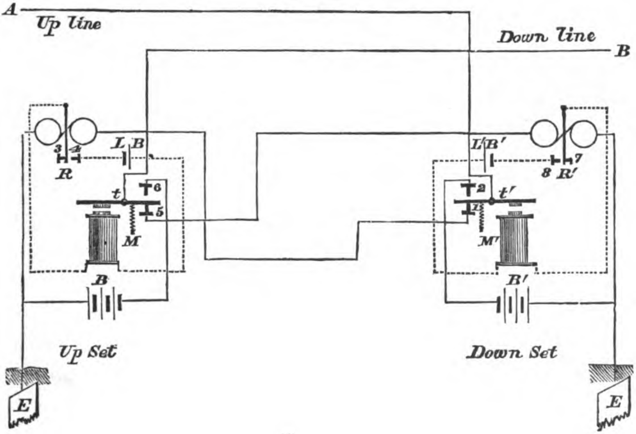

FIG. 121.

earth plate E, and return by the earth to A. The tongue of the relay R moves from 3 to 4; it thus completes the local circuit of the local battery L B, the armature of the recorder M is attracted, the lever rises from 5 to 6, and the battery B sends currents viâ 6 and *t* to the down line. These currents correspond precisely with those received from A.

Next let us assume that the down station B is working to the up station A. The currents from the down line enter the lever *t* of the recorder M, and pass by 5 to R′, the relay of the down set of apparatus, which they work, pass to the earth plate E, and return by the earth to B. The tongue of the relay R′ moves from 7 to 8; it thus completes the local circuit of the local battery L′ B′, the armature of the recorder M′ is attracted, the lever rises from 1 to 2, and the battery B′ sends currents viâ 2 and *t*′ to the up line which correspond with those received from B.

In practice the connections are not so simple as those shown in fig. 121. Galvanometers are used on each line wire to show if the currents pass correctly. Also, hand keys are used, which can be thrown into both up and down circuits by means of switches, so that the circuit can be divided, and the repeating station can work independently, either to A or to B.

Varley introduced repeaters at Amsterdam to translate the English double-current system of working into the Continental single-current system in 1858, but in England the Post Office has introduced them to increase the rate of working. There is, however, a limit to the number of repeaters which can be employed on one line. The motion, friction, and inertia, both magnetic and mechanical, of the moving parts and the introduction of disturbing electrical causes, prevent the duration of the contact of the tongue of the relay from being the exact counterpart of that of the sending key. It is of less duration. Retardation therefore takes place, and the rate of working is reduced with each relay added. In few cases in England do we introduce more than one repeater, but by means of that an actual and decided increase of speed is obtained, due to the fact that the speed of working of the whole circuit is that of its worst section alone. Their value may perhaps be best demonstrated by stating that we have now, in the *Fast Duplex Repeater*, an instrument which will mechanically retransmit messages, at the rate of 300 words per minute, simultaneously in both directions, on circuits exceeding 400 miles in length; and by referring to p. 177, where it is stated that the highest speed attainable without repeater upon the London-Amsterdam wire is 116, as compared with a speed of 400 words with a repeater at Lowestoft, while the London-Dublin circuit without repeater will give only 120 words and with a repeater at Nevin a possible 450. The latter figure, too, represents the highest possible speed, not of the line but of the present form of instrument.

The present chapter will be devoted to a development of the principle and an explanation of the actual method of working of fast speed repeaters.

The rapid growth of the postal telegraph business in England rendered the introduction of a means of rapid transmission absolutely necessary, and this want was naturally most felt on the longest circuits, where the cost of the erection of lines becomes a very important consideration.

The Wheatstone automatic apparatus, working direct, provides only for the fast transmission of messages over circuits which do not much exceed 200 miles in length, but the difficulty experienced in keeping up speed increases in proportion to the increasing length of the line, even though proportionate battery power be used; and, as already pointed out, there is a limit of power beyond which for several reasons it is not safe to go, for a high power fuses the contact points of the apparatus by the sparks which pass on breaking contact, damages the underground lines by the high potential tending to discharge to earth through the dielectric, and is very apt to fuse the coils of the instruments.

The perfection to which rapid repeating has attained has been due not so much to the introduction of any new principle or to the application of any electrical law which had not previously been practically applied, as to the close observation of, and careful attention to, the requirements of the working, and the systematic elimination or neutralisation as far as practicable of all disturbing causes.

The theoretical repeater, shown in fig. 121, provides only for single-current working, but it will be readily understood that double-current working is essential for fast speed. It is therefore of the first consideration that a fast speed repeater should be worked by means of reversals. This has accordingly been provided for.

The retardation due to the motion, friction, and inertia inherent to the moving parts of all apparatus has been minimised: (1) by making the motion as small as possible—the tongue of the relay which is used describes an arc of only one-quarter of a degree (·25°) in passing from one contact point to the other; (2) by making the moving parts light, and giving special attention to the proper burnishing of their pivots and the bearings in which they move; and (3) by arranging that the necessary weight of the moving parts shall be as far as possible balanced upon the pivots.

The first consideration in adopting double-current working, as was seen at p. 119, is to find means of putting the line either in connection with the battery or with the receiving (or in this case *repeating*) instrument. This is arranged for in fig. 86 by the switch S; and for repeaters provision must be made to do mechanically under the control of the terminal offices what is in that case done by hand. An instrument called the *automatic* or *electro-magnetic switch* is arranged to meet this requirement. The function of this instrument has already been explained; briefly and specifically it is this. In its normal position it must place the line in connection with the repeating instrument, so that the currents from that line may be 'repeated' along the other line; and, when it is required to transmit to the wire to which it is joined, the switch (controlled by the currents sent from the other line) must disconnect its repeating instrument, and join up the batteries, maintaining these connections so long as a message is being sent.

The form of switch which is now generally adopted for this purpose is shown in figs. 122 and 123. The former is an elevation which shows the actual construction of the instrument; the latter gives the electrical connections.

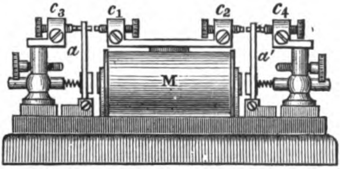

FIG. 122. ¼th real size.

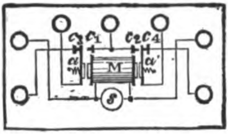

FIG. 123.

There are two complete electromagnets placed side by side, one only of which (M) is shown; at each end of the magnets is an armature fixed upon a contact lever which plays between two contact points. These levers, *a a'*, are normally kept against the contacts c_3 c_4 by spiral springs; but when a current is passed through the coils in either direction the armatures are attracted, and the levers make contact with c_1 c_2, which are generally connected together and to the middle terminal; in some instruments, however, c_1 c_2 are connected to two separate terminals.

If, therefore, the line be connected to the lever *a'*; the battery (i.e. that part of the repeater which corresponds to the contacts of the double-current key, fig. 86) to the contact points c_1 c_2; and the repeating instrument to the point c_4; and if also provision be made for the armatures to be attracted when it is required to send currents to the line, the required conditions will be satisfied. The use of the contacts c_1 and c_3 and of the lever *a* will be understood when we come to consider the connections of the repeater itself.

A top and a side view of the form of relay known as the Post Office Standard Relay—which is employed for fast speed working not only in England but almost universally—are shown in figs. 124 and 125. The principle of its electrical arrangement is the same as that of the Wheatstone receiver.

M M′ are two complete electromagnets, double-wound on the differential principle, and so connected that when a current is passed through their coils their opposite poles are adjacent. M′, together with some other parts, is omitted in fig. 125, in order to show the arrangement more clearly. Upon the axle *a* are fixed two soft iron tongues or armatures, *n*, *s*, which play between the soft iron pole-pieces of the electromagnets, and are kept permanently magnetised by means of the magnet N S. Upon the same axle *a* is fixed the German silver tongue *t*, which therefore moves with the armatures *n*, *s*, and whose end makes contact with *c* or c_1

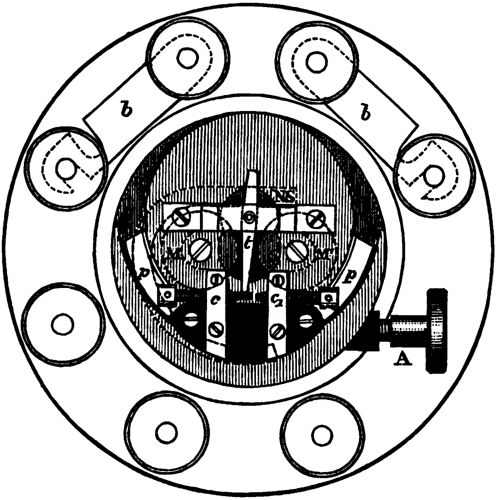

FIG. 124. ½ real size.

according to the direction of the current through the coils or to the 'bias' which is given to the tongue. The 'bias' is given by means of the screw A, by which the position of the contact points, which are fixed upon the movable piece *p*, is regulated. The screw A, which is fixed on the base *b* (fig. 125), banks against the end of a lever pivotted at its centre, whose other end works in a slot in the curved piece *p*, which is concentric with *a*; when, therefore, A is screwed inwards the contact points are moved to the right, and (the end of the lever being held against A by means of a spring) when A is unscrewed they are moved to the left. Almost any degree of sensitiveness of adjustment can by this means be obtained. The brass straps *b b* are for the purpose of joining the coils of the relay in 'multiple' or 'series' at will. When the straps are as shown in fig. 124 the coils are joined in multiple; when required in series both straps are joined across the two back terminals. The electrical connections of the relay are shown by fig. 126.

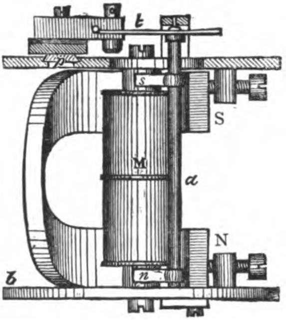

FIG. 125. ½ real size.

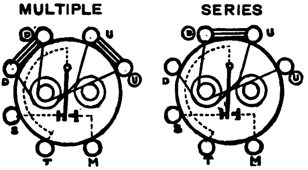

FIG. 126.

Having thus glanced at that part of the apparatus which calls for special attention, we may proceed to consider the connections of an ordinary *Fast Speed Repeater*. The general principle upon which the working of such an instrument is based is shown by fig. 127.

T_1 and T_2, called the 'transmitting relays,' are ordinary Post Office Standard Relays. One end of the coils of T_1 is connected through a lever of the automatic switch A_2 to the 'down' line, and one end of the coils of T_2 is connected through A$_1$ to the 'up' line. The other ends of these coils are connected respectively with the relays S$_1$ and S$_2$.

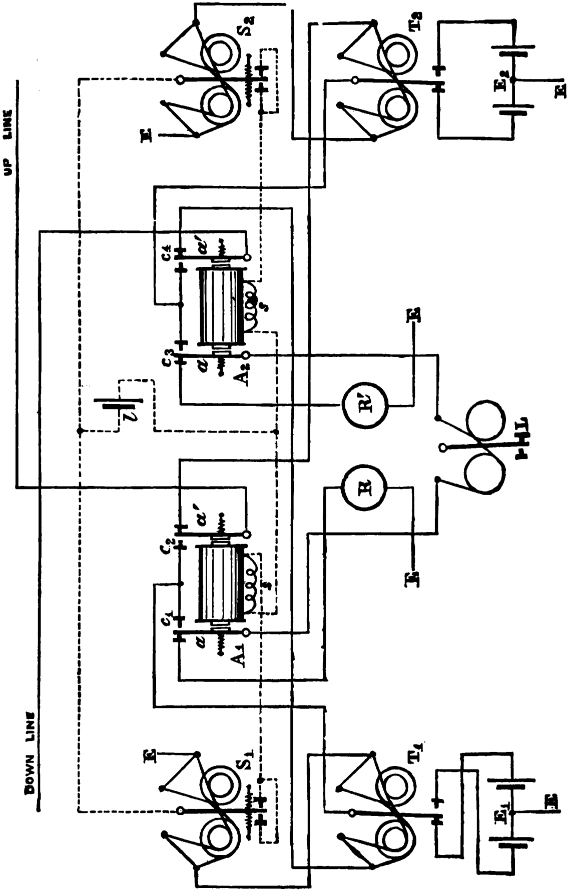

FIG. 127.

These relays (S$_1$ and S$_2$) are known as the 'automatic switch relays.' Their tongues are fitted with adjustable springs by means of which they are kept in an intermediate position between the contact points, being clear of both. When the tongue of S_1 is moved in either direction the circuit of the battery *l* is completed through the coils of the automatic switch A_1 ; when that of S_2 is actuated the battery circuit is completed through the coils of A_2.

This being premised, we are in a position to trace the effect produced by a series of currents coming from (say) the 'down' line. The currents pass through the coils of the relays T_1 and S_1 to earth, thus actuating both relays. Now, when S_1 works, the local circuit of *l* being completed through the coils of the switch A_1, the armatures are attracted and the levers a a' make contact with the inner points c_1 and c_2 respectively. It is obvious, however, that, although the circuit of *l* through A_1 is completed whether the tongue of S_1 be attracted either to the right or to the left, it must be momentarily broken while the tongue is passing from side to side. In order to prevent the levers a a' from breaking contact with the points c_1 c_2 while the circuit of *l* is thus interrupted, the ends of the coils of the switch are connected through a shunt, *s* (figs. 123 and 127), which helps to form a circuit in which the current of self-induction due to the demagnetisation of the electromagnets can circulate (p. 164). This induced current holds over the armatures for a few seconds, so that if an automatic transmitter at the down terminal office is causing the tongue of S_1 to vibrate, the levers of the switch A_1 will be continuously held against c_1 and c_2 by the combined action of the currents from the battery *l* and those induced by the interruption of the same. Thus is utilised an effect which in the case of apparatus which is required for rapid action it is of the first importance to neutralise. The resistance of the shunt (*s*) is made equal to that of the coils.

While the levers of A_1 are thus held over, the tongue of T_1 is vibrating between its contact points in response to the currents sent from the down office, and thus currents, the direction and duration of which are regulated by the direction and duration of those sent from the down line, are retransmitted to the up line from the battery E_1, through c_2 and the right-hand lever of the switch A_1.

It is necessary, however, that the clerk who has charge of the repeater shall know how it is working. This is provided for by means of a 'leak' circuit, which takes its current direct from the repeating battery and the transmitting relay tongue through a receiver, L, and a resistance R or R′, to earth. The resistance, R or R′, in the leak circuit is such that the current passing is just sufficient to work the receiver and does not, of course, affect the current flowing to the line. In fact, the two branches are worked on the universal battery principle, and consequently, as was explained at p. 121, if the circuits are not very dissimilar they do not affect each other. Thus, when the down station transmits, currents in the same direction and of the same duration are repeated on to the up station and simultaneously recorded (when desired) at the repeating office.

The ends of the receiver coils are so connected, as will be seen, with the levers *a* of A_1 and A_2 that, when A_1 works, the receiver is put on the up leak, the circuit being completed through *a* of A_1, through the receiver to the lever *a* of A_2, and through R′ to earth; while, when A_2 works, the receiver is placed in the down leak, the circuit being through *a* of A_2, the receiver, *a* of A_1, and R to earth.

The effect of the transmission of a series of currents from the down office has been traced, and it is evident that the same description applies to currents coming from the up office. They pass by means of the lever *a′* of A_1, through the coils of T_2 and S_2 to earth. The armatures of A_2 are attracted, and the tongue of the relay T_2 transmits similar currents to the down line at the same time working the leak circuit, as has been explained above.

In effect, we may look upon the relays T_1 and S_1 and the automatic switch A_1 as a transmitter controlled by the clerk at the down station, and the parts T_2, S_2, and A_2 as a transmitter controlled from the up station. The automatic switch corresponds to the switch of the transmitter, the tongue of the transmitting relay takes the place of the electro-mechanical portion of that instrument, while the currents sent through the coils of the relays represent the starting and motive power.

It is evident that the clerk at the repeating station should not only be able to watch the communication between, but should himself be able to communicate with, the terminal offices, not to transmit messages but to carry on the ordinary service communication of a circuit. In practice this is provided for by keys, one of which is placed in each line.

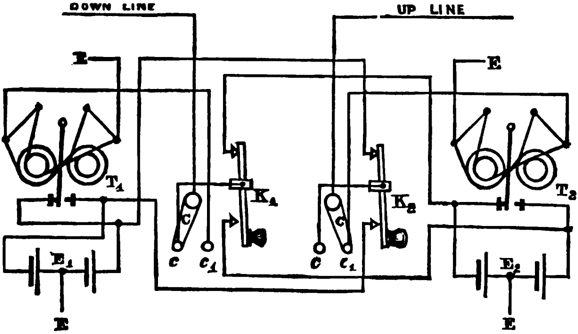

FIG. 128.

The key is brought into circuit by means of a switch placed on its base, and the connections are shown in fig. 128, from which, to simplify the connections, the automatic switches are omitted.

The lever C of the switch is normally connected to the contact c_1, so that the key itself is cut out of circuit. When it is wished to communicate (say) with the down station, the switch of K_1 is turned to c, and currents can thus be sent to the down line from the battery E_2, by which it is ordinarily worked. The working of the lever of the key K_1

therefore imitates the action of the tongue of the relay T_2, but, as it is not desirable when the repeater clerk is communicating that he should work his own receiving instrument, the communication is effected without the intervention of the automatic switch. K_2 in the same way works the up line, using the battery E_1.

In addition to the instruments to which reference has been made, both up and down lines are provided with galvanometers to show whether the currents are passing properly.

Hitherto we have considered the repetition of messages when being sent only in one direction at one time, but it is obvious that this arrangement might be duplexed.

The principle of duplex working is fully explained on p. 126 and following pages. We have therefore only to show the method of applying that principle to a fast repeater.

In the first place, it may be observed that on a double current duplex circuit the switch of the key is kept permanently to 'send.' On the duplex repeater, therefore, the automatic switch and its controlling relay, which were found of such great importance on the ordinary fast repeater, may be dispensed with.

Again, as there will be messages being sent in two directions at the same time, and the repeater clerk requires to know the state of working in both ways, there must be two receiving instruments on the repeater board, i.e. there must be two leak circuits, one for the up and the other for the down messages.

After these preliminary considerations, if the student has thoroughly mastered the differential duplex principle referred to above, he will be in a position to understand the *Fast Duplex Repeater*, the theoretical connections of which are shown in fig. 129.

T_1 and T_2 are, as before, the transmitting relays; R_1, R_2 are the rheostats, in connection with which are placed the condensers C_1 and C_2, and the adjustable retardation coils

R_3 and R_4. The rheostats and condensers are to represent the artificial line, and the function of the coils R_3 and R_4 is, as their name implies, to so retard the discharge of the condensers that the effect may more nearly represent that produced by the discharge of a long line. L' is a standard relay of the ordinary pattern, which works a sounder; it is placed in a leak circuit in connection with the down line: and L is a Wheatstone receiver placed in the other leak circuit, which is connected with the up line.

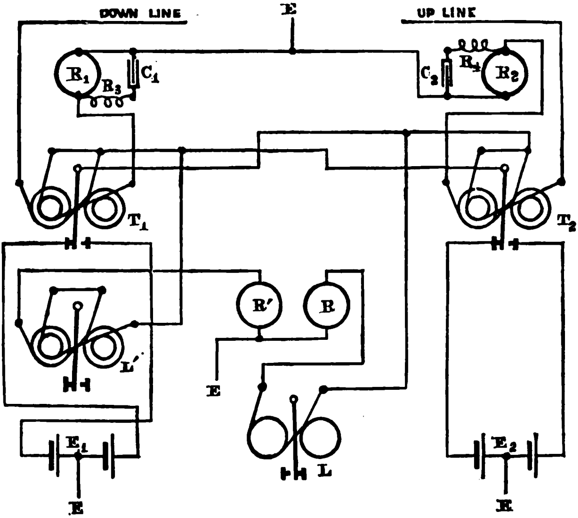

FIG. 129.

Although it is not necessary that the repeater clerk should be able to read at high speed on both sides at one time, it is necessary that he be able to do so on either side at will. A switch (not shown in the figure) is therefore provided, by which the receiver can be placed either in the up or down leak, the relay with sounder being at the same time placed in the other.

The tongue of the relay T_1 acts as an automatic transmitter worked at the down office, sending currents from E_1, which divide through the coils of the relay T_2 (therefore pro-

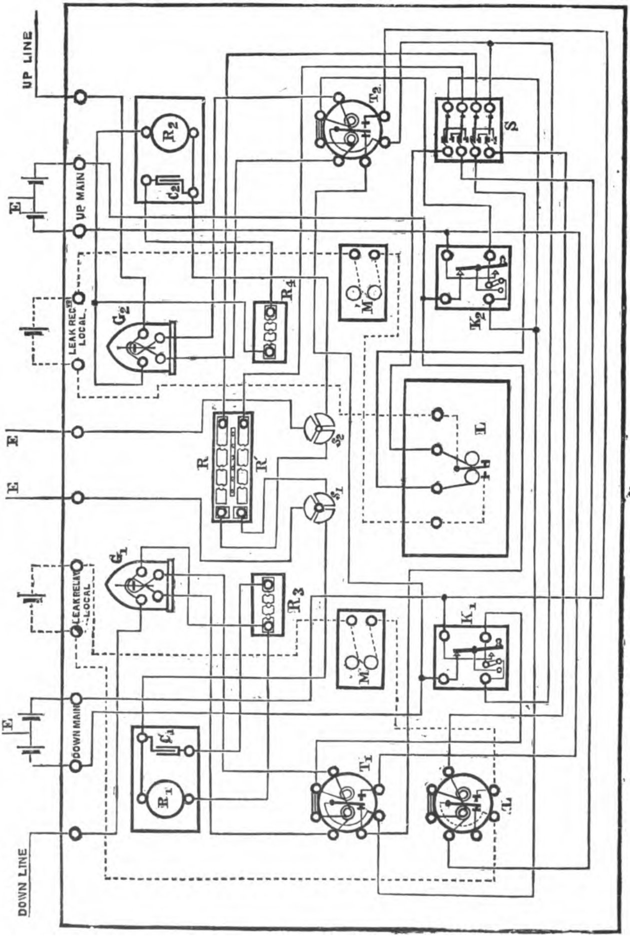

FIG. 130.

ducing no effect upon it), one-half going through the rheostat R_2 to earth, while the other half goes to the up line.

In the same way T_2 acts as a transmitter worked from the up station; and we may again look upon the transmitting relays T_1 and T_2 as actual transmitters (working the up and down lines respectively), manipulated from the terminal offices.

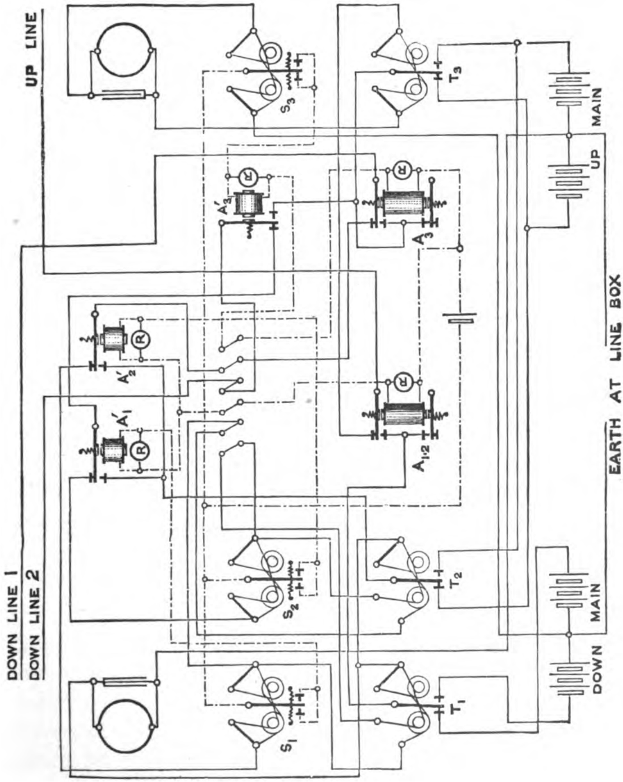

FIG. 131.

Fig. 130 shows the complete connections of a fast duplex repeater, and gives the various instruments on the repeater board in the relative positions which are found most convenient in practice. The several instruments are marked as in fig. 129, and will be easily recognised. G_1 and G_2 are differential galvanometers, placed respectively in the down and up lines, and it will be noticed that the resistances R and R′ are combined as one instrument.

M, M′ are sounders worked by the leak-receiver and leak-relay respectively, and S is the switch, to which reference has been made, for placing the receiver either in the up or down leaks. The receiver is shown in the up leak, the relay being in the down, but by moving the bars of the switch to their lower contacts these positions are reversed.

The switches S_1 S_2 are for disconnecting the batteries from earth when the repeater is not in use. This is effected by removing the pegs from the centre holes.

Many other forms of repeater are in constant use, each arranged to meet some special requirement. One, for instance, provides that by means of a switch the apparatus may be worked either as fast ordinary or fast duplex repeater at will. Another, the theoretical connections of which are shown in fig. 131, is arranged for the transmission of 'news' from one station to two other stations at once through the repeater, provision being made that when either station is sending the other two shall each be able to read, and a special key on the repeater (not shown) works all three lines simultaneously.

CHAPTER IX.

QUADRUPLEX TELEGRAPHY.

DUPLEX telegraphy, as was seen in Chapter V., means the transmission *on the same wire* of a message from (say) station A to station B while B is sending another message to A. If A be able to send two messages to B at the same time on the same wire we have *diplex* telegraphy, and if the two systems—duplex and diplex—be combined, we have four messages being sent at the same time on the same wire, and this is *quadruplex* telegraphy.

Quadruplex working had been suggested by Stark of Vienna, and Bosscha of Leyden, in 1855, but it was not rendered practical until Edison solved the problem in 1874.

His principle of working is based upon the fact that currents of electricity differ from each other in their strength and in their direction. If we have one instrument which works with change of strength only, and another which works with change of direction only, then it should be possible to work the two together if we can alter the strength of the currents without affecting their direction, or change their direction without affecting their strength. This is accomplished by combining double-current and single-current working in such a way that one relay works by the one system of currents and the other relay by the other system of currents. A current is constantly flowing through the line : a change in its direction operates one relay ; a change in its strength operates the other. The first relay is a simple polarised relay, deprived of any antagonistic adjustment, and responding to the reversal of the current, whatever its strength ; and the second relay is a non-polarised relay, adjusted by an antagonistic spring, so as to fail to respond to the current, whatever its direction, unless it is considerably strengthened. Thus the two relays are perfectly independent of each other. They actuate separate sounders, and each is under the control of its own receiving operator, who can therefore adjust for himself.

In the early days of quadruplex it was found difficult in practice to get the non-polarised relay to work, especially on long circuits, the reversal of the current producing breaks or 'kicks.' This defect, however, Mr. Gerritt Smith remedied in 1876 by introducing the pole-changer and compound relay. The fault, however, lay as much with the instruments used as in the principle, and with improved apparatus it has been found possible to revert to a non-polarised relay; but the uprighting sounder is still used (p. 215). The principle

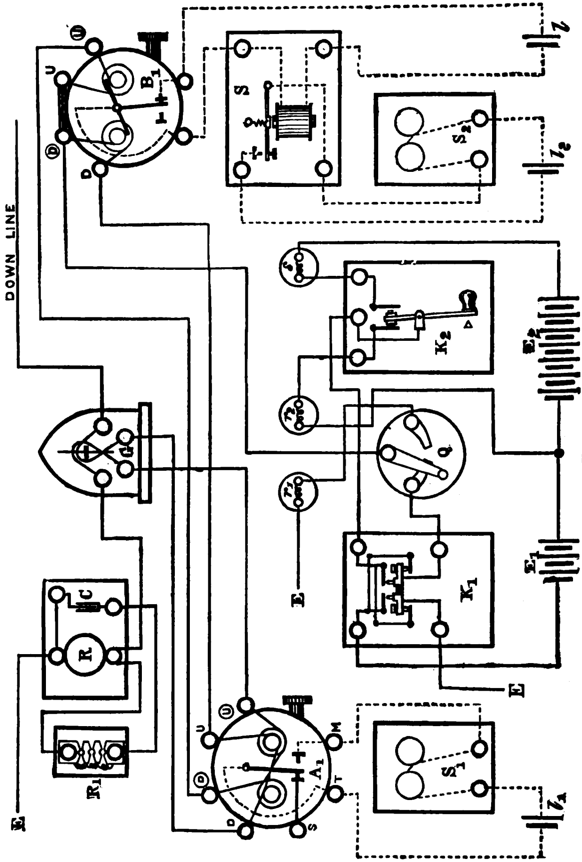

FIG. 132.

of the compound relay was to so arrange a compound tongue and its contact stops that whichever way the tongue moved the local circuit was interrupted.

The arrangement of the apparatus and their connections for terminal offices is shown by fig. 132. Sufficient table room is provided to seat four clerks. The apparatus is arranged for the two senders to sit together in the centre, the messages to be forwarded being placed between them. The section on the left of the switch Q is known as the 'A' side, that on the right as the 'B' side of the apparatus.

K_1 (fig. 132), the *reversing key*, reverses the direction of the current in the manner shown in fig. 133. The springs, which are shown to the side, are actually in the same position relatively to their contact points as are those in fig. 134. The positive pole of the battery Z C is connected to the two springs c and c_1, the negative pole to the two springs z and z_1. The lever of the key is divided into two parts, insulated from each other, the one, L, connected to line, and the other, E, to earth. L is arranged to touch c_1 before it leaves z, and E to touch z_1 before it leaves c; the battery Z C is therefore momentarily short-circuited. s s are two adjusting screws by which the duration of this short-circuit between the reversal is regulated so as to reduce it to a minimum. The figure shows the negative pole to line and the positive pole to earth; but when the handle of the lever is depressed the positive pole is connected to line and the negative to earth, the current being thus reversed.

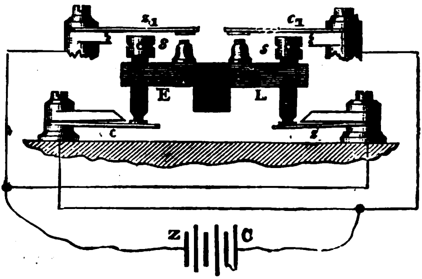

FIG. 133. ½ real size.

K_2 (fig. 132) is a simple key, known as the *increment key*, it is used simply to increase the strength of the current. Its construction is shown by fig. 134. L is a lever which in its normal position makes contact with the spring b, but which when depressed makes contact with *a*. The stud *s* is adjustable, and should be so arranged that it will just touch *a* at the moment that the lower contact leaves *b*.

The way in which the keys K_1 and K_2 combine their action is shown by fig. 135. E_1 and E_2 are the line batteries, the one having two and one-third ($2\frac{1}{3}$) the number of cells of the other, so that if E_1 be the electromotive force of the smaller, that of the whole combined battery will be 3·3 E_1. The negative pole of E_1 is connected to *z* and z_1 of K_1, and the positive pole of E_2 to *a* of K_2 through a resistance coil *s*.

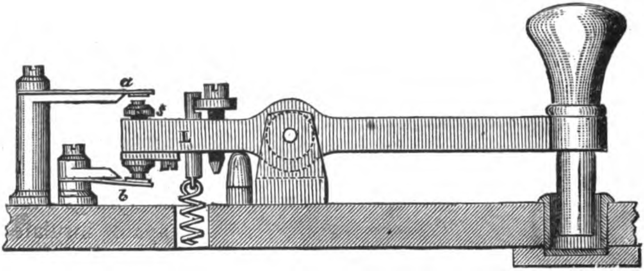

FIG. 134. ½ real size.

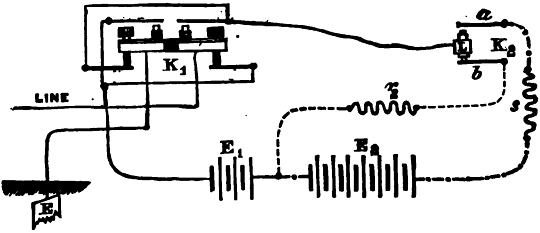

FIG. 135.

A wire, called the 'tap' wire, connects the positive pole of E_1 and the negative pole of E_2 to *b* of K_2. This wire has in it a resistance coil r_2. The springs *c* and c_1 of K_1 are connected to the lever L of K_2. Now, when both keys are at rest, the negative pole of E_2 is to line through *z*, and the positive pole of E_1 to earth through b of K_2 and c of K_1; the positive pole of E_2 being insulated at a of K_2. There is thus a weak negative current flowing to line. When K_1 alone is worked, the current of E_1 is reversed. When K_2 is worked alone, c of K_1 is transferred from b to a, and the *strength* of the negative current going to line is increased through the increase of the electromotive force from E_1 to 3·3 E_1, for the whole battery is brought into play. When K_1 and K_2 are depressed together, then the negative pole of E_1 goes to earth through z_1; and the positive pole of E_2 to line through a of K_2 and c_1 of K_1, and a *positive* current, due to the whole electromotive force 3·3 E_1, goes to line. Hence the effect of working K_1 is simply to reverse the current, whatever its strength, while that of K_2 is to strengthen it, whatever its direction.

The resistance coil s, figs. 132 and 135, of 100^{ω} resistance, is called a *spark coil*, because it prevents the high electromotive force of the whole battery from damaging the points of contact by sparking or forming an arc across when signals are sent; and the resistance r_2 is made approximately equal to the combined resistance of E_2 and the spark coil, so that the total resistance of the circuit may not be altered by the working of the apparatus.

A_1 and B_1 (fig. 132) are the relays which are used to respond to the changes in the currents sent by the keys K_1 and K_2 at the distant station.

A_1 is a simple polarised relay wound differentially, each wire having a resistance of 200^{ω}, and so connected up as to respond to the working of the reversing key K_1 of the distant station. It acts independently of the strength of the current, and is therefore not affected by the working of the increment key K_2. It is connected up so as to complete the local circuit of the sounder S_1 and the local battery l_1, and forms the receiving portion of the 'A' side.

B_1 is a non-polarised relay also wound differentially, each coil having a resistance of 200^{ω}. It responds only to an increase in the strength of the current, and therefore only to the working of the increment key K_2 of the distant station. A top view of the working parts of this relay is given in fig. 136, and the principle of its action is shown by fig. 137. The tongue normally makes contact with *c*, and the movement of the armatures under the action of a current brings the tongue against the insulated stop *s*. The armatures, one at either end of the electromagnets, are pivotted in the centre so that each end is attracted towards the near pole of the electromagnets when a current of sufficient strength passes through the coils; and the armatures are normally held off by the action of a spiral spring. In order to prevent the cores of the magnets and the two armatures from forming a closed magnetic circuit, each armature is made in two sections brazed together, like the needle of the Spagnoletti coil (p. 53). This is shown to the left in fig. 136. The spring is so adjusted that the armatures are not actuated by the weak current sent from E by the key K_1 (fig. 132).

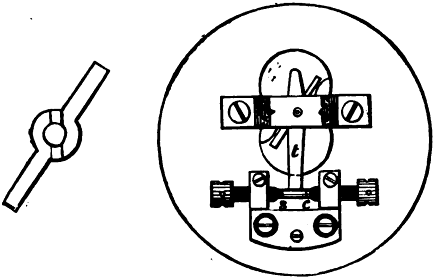

FIG. 136. ½ real size.

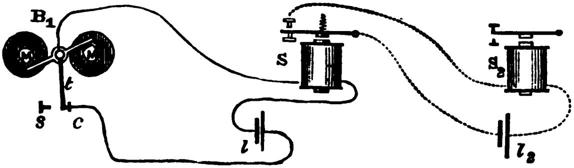

FIG. 137.

In its normal position this relay completes the circuit of the local battery through the sounder S. This sounder S, called the *uprighting sounder*, acts as a relay to a second sounder, S_2, called the reading sounder, which is worked by another local battery, l_2. Of course, normally the armature of S is held down and that of S_2 is up, but when the tongue t moves, as it does when the increment key K_2 is depressed so as to send the whole current to line, then the current from l is interrupted, and the circuit of l_2 is completed by the rising of the armature of S, causing the reading sounder S_2 to work. This is the 'B' side.

R (fig. 132) is a rheostat for balancing the resistance of the line, as described for duplex working (p. 135).

C is a condenser used for compensating the static charge of the line. It is provided with an adjustable retardation coil, R_1, to prolong the effect of the compensating current from the condenser.

G is a differential galvanometer, used for testing, and for facilitating adjustment and balancing.

Q is a switch for putting the line to earth, either for balancing, or for any other purpose. There is on the earth wire leading from Q a resistance coil, r_1, equalling approximately the resistance of the whole battery, 3·3 E_1, and the resistance s.

The connections shown in fig. 132, are for an 'up' office. At a 'down' office it is necessary to reverse the wires on the two lower terminals of the galvanometer and the two battery wires on the reversing key K_1.

The keys K_1 and K_2 are, for repeaters, replaced by 'transmitters.' A reversing transmitter (or pole-reverser, as it is called) is shown in fig. 138, and an increment (or single-current) transmitter in fig. 139. The principle of the joint working of the two transmitters is shown by fig. 140. Each transmitter is worked from a local battery, either by a key or relay.

The two levers shown in front in fig. 138 are normally held by the tension of the spiral springs against contact points on the armature-lever and the case. The armature-lever is marked E in fig. 140, the front levers *c* and *z*, and the contacts on the case, L. When the armature is attracted by M, the armature-lever makes contact with lever *z*, lifting it from L, and at the same time it leaves lever *c* free to make contact with L; the connections are thus reversed. The action of the increment transmitter is similar—when

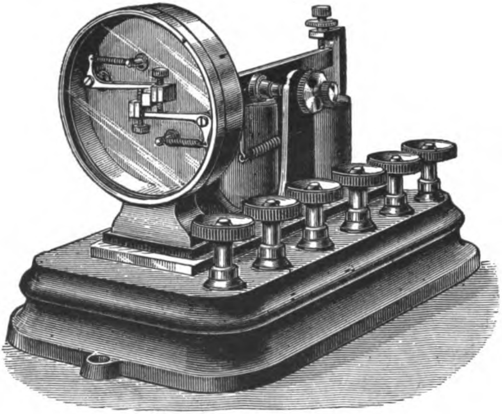

FIG. 138.

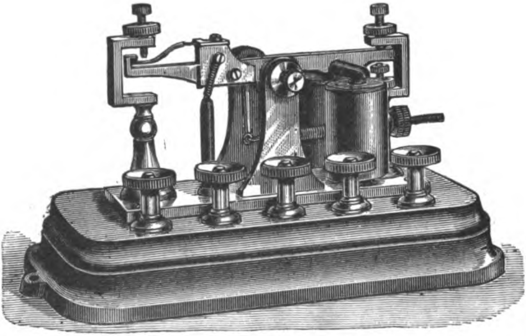

FIG. 139.

the armature is attracted, *a* makes contact with L, and *b* is disconnected.

These transmitters perform the same function as the keys

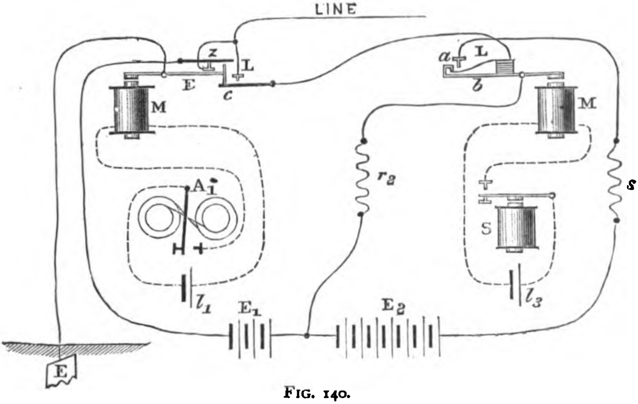

FIG. 140.

K$_1$ and K$_2$, and being lettered (fig. 140) correspondingly with those keys in fig. 135, their action can be readily traced without a detailed description.

It is now generally arranged to use pole-reversers in place of single-current transmitters, as, besides their being interchangeable, the contacts of the former are protected from dust, &c., whereas those of the latter are not.

The adjustment of this apparatus requires great care and great accuracy. Its good working depends essentially on technical skill that can only be acquired by patience and perseverance.

Faults in working generally arise from careless adjustments, dirty contacts, loose connections, battery failures, and the ordinary line interruptions, but there are no troubles that are beyond the reach of ordinary skill, and it can be safely said that, within moderate distances, wherever and whenever duplex working is practicable, then quadruplex working is so too.

There are many varieties of arrangement in use both in England and America. Fig. 141 illustrates one variation.

T and R are fitted with quadruplex apparatus, A′ and B′ with duplex; A′ works the A side, and B′ the B side of R. In this way an office (T) may work duplex on the A side to A′, and duplex on the B side to B′; the circuits to A′ and B′ being common between T and R.

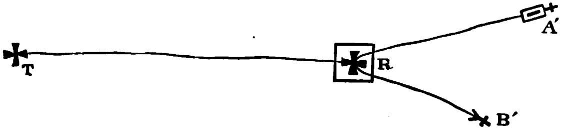

FIG. 141.

Again, the A side is sometimes worked by Wheatstone's automatic system. For example, between London and Grimsby the A side was worked automatic at 200 words per minute, while the B side was worked at the usual key speed.

CHAPTER X.

MULTIPLEX TELEGRAPHY.

IN 1873 Meyer conceived the idea of so arranging two corresponding sets of apparatus at distant places that, by causing them to move in exact synchronism,[1] the use of a telegraph line might be given successively to several operators for a very short period of time, so that one at each end would have it alone during the recurring periods. The

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[1] *Synchronism* implies exact relative position at any period of time. *Isochronism* implies exact similar movement. Thus, two clocks would be *isochronous* if their hands moved over the same space during any period, but they would not be *synchronous* unless they also indicated the same time.

synchronous movement of the two sets would insure that each operator at one end should always have communication with the corresponding operator at the other.

Now that the idea has developed into a practical system it is known as the MULTIPLEX system. Fig. 142 indicates the principle. If the arms *a*, *b*, which are electrically connected with the line-wire at A and B respectively, are made to rotate simultaneously around the circles 1, 2, 3, 4, making contact with the segments as they pass, then, when *a* is on A 1, *b* will be on B 1, when *a* is on A 2, *b* will be on B 2, and so on. Again, if 1, 2, 3, 4 at each station be connected to a set of telegraphic apparatus (say a single-current sounder set), then each of the four sets at A will be successively connected with the corresponding set at B as the arms *a*, *b* move over the segments 1, 2, 3, 4. Thus for each revolution of the arms the instruments connected to A 1 and B 1 will be in direct communication once, and so also with A 2, B 2 ; A 3, B 3 and A 4, B 4.

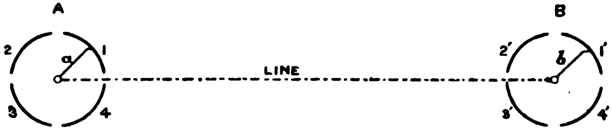

FIG. 142.

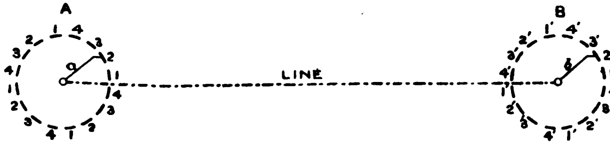

FIG. 143

Now suppose that each of the segments in fig. 142 be again divided into four and connected to each of the four sets of instruments instead of with only one of them (fig. 143). During one complete revolution of the arms each pair of instruments will be in communication four times ; and it is clear that if the arms in the two cases assumed are moving at the same rate, then, although the time during which each instrument is connected to line during one revolution of the arms will be the same, in the latter case it will be divided into four smaller periods, each separated by a period of disconnection of only one-quarter the length which occurs in the former case. This subdivision may of course be extended to a very considerable extent, and in practice it is so far extended that the intervals of disconnection are so short that with the apparatus used they may be neglected, so that each set of apparatus may be worked as if it and its corresponding set alone were connected to the line.

Meyer's system proving impracticable was improved upon by Baudot in 1881, whose apparatus was subsequently perfected and is used extensively in France. Paul La Cour of Copenhagen had in the meantime taken up the question of synchronism, and he invented a very ingenious plan which contained the germ of success. In 1882 Patrick B. Delany of New York perfected a plan for synchronism on La Cour's principle, and produced a complete and workable multiplex system in 1884.

It will be seen that the principle of multiplex working differs so materially from the principle of duplex or quadruplex, that all they really have in common is the capability of the simultaneous transmission of more than one message upon a wire. Hence the application of the same terms, duplex, quadruplex and sextuplex (working three messages each way on the quadruplex or similar principle), to the corresponding arrangements in multiplex working would tend to confusion, and therefore a special nomenclature, based upon the Greek word *hodos*, a way, is adopted. Thus two-way working, that is, a mode of working by which two messages may be sent over the same line on this system, is known as *diode*; three-way *triode*; four-way *tetrode*; five-way *penthode*, and six-way *hexode*.

It has been already stated that the great difficulty to be overcome was to secure the synchronous movement of the two arms rotating over the segments. The nearest approach to isochronism can be obtained with two tuning-forks pitched to absolutely the same note and set into vibration under exactly the same conditions ; but the least interference, even a variation of temperature, is sufficient to affect the rate of motion.

To drive the *distributor* (as the instrument with the rotating arms and the segments is called), La Cour arranged a 'phonic wheel' driven by an electro-magnet, through which intermittent currents are passed by means of a vibrating reed.

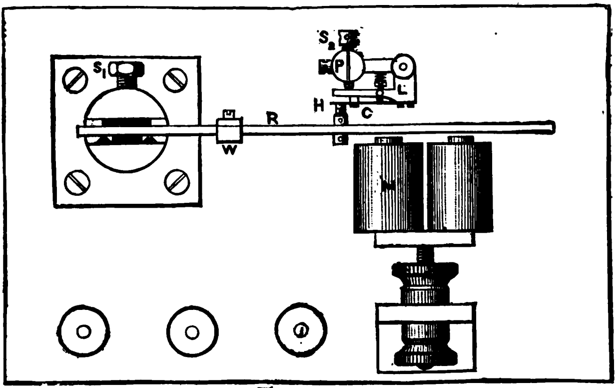

FIG. 144.

The *reed* R (fig. 144) is simply a flat bar of mild steel firmly clamped at one end by the screw S_1 between two V pieces and a steel plate. At one side of the free end is placed an electro-magnet M, the circuit of which includes the reed and the contact spring H. If a battery be joined in this circuit the reed will be attracted towards the electro-magnet; and the circuit being thus broken between R and H, attraction will cease and the reed will resume its original position. The circuit will thus be again complete and the same movement will be repeated, so that by this means the reed is maintained in vibration, and the rate of its vibration will depend upon its length, its mass, and the distribution of its mass. The normal rate of vibration may be regulated in many different ways : the most satisfactory is found to be by means of a rheostat of suitable resistances placed in the reed magnet circuit, and a sliding weight (w) fixed friction-tight upon the reed itself. The weight acts upon the principle of the bob on a pendulum, and so serves to adjust the rate approximately, bringing it within the range of the finer adjustment of the rheostat.

Moving the sliding weight towards the fixed end of the reed, or increasing the resistance in the rheostat, tends to increase the rate of vibration, and the opposite movement of course tends to decrease it. Advancing or withdrawing the driving magnet M also affects the rate, but this is not a satisfactory method for general use.

The contact spring H is so fitted as to be adjustable to any desired position, and its motion with the reed, that is, the extent to which it follows the vibration, is regulated by the check piece C, its pressure against which is a matter of great importance for satisfactory working.

The La Cour wheel, as shown at W in fig. 145, is an iron toothed wheel so placed as to be capable of rotation before the poles of an electro-magnet M. If regular intermittent currents pass through this electro-magnet, and the wheel be set in motion, it will continue to rotate, going forward one tooth for every impulse given by the intermittent magnetisation of M. These intermittent currents are sent by means of the reed R, and the movement of the wheel W is therefore effected and controlled by the vibrations of the reed. The position of M is adjustable, and the motion of the wheel is most vigorous when the poles of the electro-magnet are only just clear of the teeth of W. The circuit is so arranged that the battery B drives the wheel and effects as well as the vibration of the reed, the latter being done by the current due to the difference of potential at the terminals of the resistance coil r_1 in the phonic wheel circuit. A condenser of small correction to be received on the first receiving correction segment must be sent from the *second* sending correction segment; but, if there be considerable retardation, then the current, if sent from the first sending segment, may not be due to arrive until the trailer has got as far as the third, fourth, or even the fifth receiving correction segment, in which case the correcting relay would be connected to the previous segment.

Suppose that in fig. 147, with retardation equal to four receiving correction segments, the tendency of the reed at B is to drive slightly slower than that at A; when the two trailers are in perfect accord, the current sent by the trailer at A from a sending correction segment (.) as shown, will be received when the trailer at B is on a receiving correction segment (≣) which is connected direct to earth: but on the next revolution the current sent by the trailer at A from (.) will be received on (≡), because the trailer at B will have slightly lost; but this is connected to the correcting relay, hence the correcting current from A will pass through the relay R_1, which (by breaking the circuit of the battery B_1 through the relaying sounder S so that the armature lever is free to rise) will momentarily disconnect the reed driving circuit, so tending to accelerate the motion of the reed and consequently of the trailer at B. As A sends three correcting currents for every revolution of the trailer, only a very slight deviation is possible, and thus practical synchronism can be obtained. Should B tend to gain on A, then the correcting currents sent from B would similarly operate upon the motor at A through the relay R_1 at that station, so as to accelerate the motion of the trailer there.

The number of 'ways' which it is possible to work with this system is also determined by the static capacity of the line. It has been explained above how the retardation of the line affects the receipt of the correction currents, causing them to be received one or more segments behind the sending correction position, and this effect will of course occur also in connection with the ordinary segments. The result is that on a line of considerable static capacity the current sent from (say) No. 1 segment will be received not on No. 2, but on No. 3 or 4. This can only be met by making the receiving segments of greater breadth, or by so connecting the groups as to allot more than two consecutive groups to each arm; either course will reduce hexode working to tetrode or triode.

The rate of vibration of the reeds is so adjusted that the trailer makes about three revolutions per second, which makes the time of passing over one segment about $\frac{1}{500}$ (·002) of a second. If therefore the retardation of the line much exceeds that amount, a current sent on No. 1 will not be received until the trailer has passed No. 2 segment at the other end; that is, No. 1 arm must take groups 1, 2 and 3, and so with three other arms, and if the retarding effect exceeds ·004 second then each arm will require four groups of segments 1–4, 5–8, 9–12. For instance, a current from London to Birmingham takes about ·002 of a second in transit, therefore two groups of segments suffice for each arm and six ways (hexode) can be worked. Between London and Manchester the time of transit is about ·0035 of a second, which means that the current will be received partly on the second and mainly on the third segment after transmission, and therefore three groups must be allotted to each arm; consequently only four ways (tetrode) can be obtained from the twelve groups of segments.

The method of working each arm may now be described. Fig. 148 shows the general connections for each arm when worked on the single-current system. No. 1 arm is provided, in addition, with two galvanometers, one for the sending and the other for the receiving circuits. Station A is shown as sending from segment 1 and station B as receiving on segment 2, to which the trailer is supposed to have passed before the current is received. A large relay of standard form and wound to a resistance of 1,200 ohms is used in the receiving circuit; and, in order that the short impulses from the line (each lasting only $\frac{1}{500}$ of a second) may be converted into continuous signals, a condenser of large capacity (10 mf) is connected across the coils of the relay. One battery serves for all the arms, on the 'universal' principle (p. 121). This battery is also used for sending the correction currents.

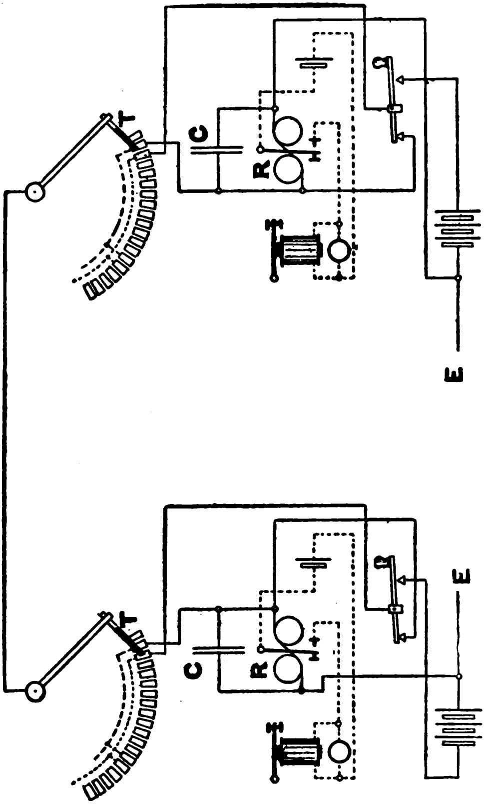

FIG. 148.

Double-current working is used on most multiplex circuits, in which case the keys used are of single-current form, made to work double current by means of a divided battery with earth near the centre—usually the sections of the battery for 'marking' and 'spacing' are in the proportion of about 7 to 4. Thus for circuits over 60 miles in length, 'marking' and 'spacing' batteries of voltages of about 280 and 160 respectively are generally used. For single-current working, about 160 volts would be used.

The full connections of an ordinary double-current multiplex set, working hexode, showing two arms, are given in fig. 149. The 8-bar switch provides means of joining the No. 1 arm as simplex when multiplex working is not required, the other arms in such case being left idle.

Referring again to fig. 146, assume that it is required to work only in one direction, say from A to B, and that the retardation of the line is such that the current is received two segments in advance of the sending segment. If now the apparatus be connected as for hexode, the currents from A will be received for each arm at B two segments later, that is, on segments 3, 5, 7, 9, and 11, the sixth being lost in the correction segments. Hence by such an arrangement it is possible on such a line (or even on one having a retardation equal to three segments) to work *penthode* in *one* direction. If a second line be available and be worked in the opposite direction, five messages in both directions can be transmitted simultaneously on the two wires. There is, however, the serious disadvantage that one faulty wire is liable to entirely stop communication in one direction.

It is necessary for multiplex working to make one station solely responsible for the adjustment of speed, &c. in order that the attempts of one station to secure good working shall not interfere with the arrangements made at the other end. The operator at the controlling office either adjusts his own apparatus or, if necessary, instructs the operator at the other office as to what adjustments should be made.

The maintenance of satisfactory working requires some skill and experience as well as a thorough grasp of the whole principle, as there are so many possible causes of failure, but

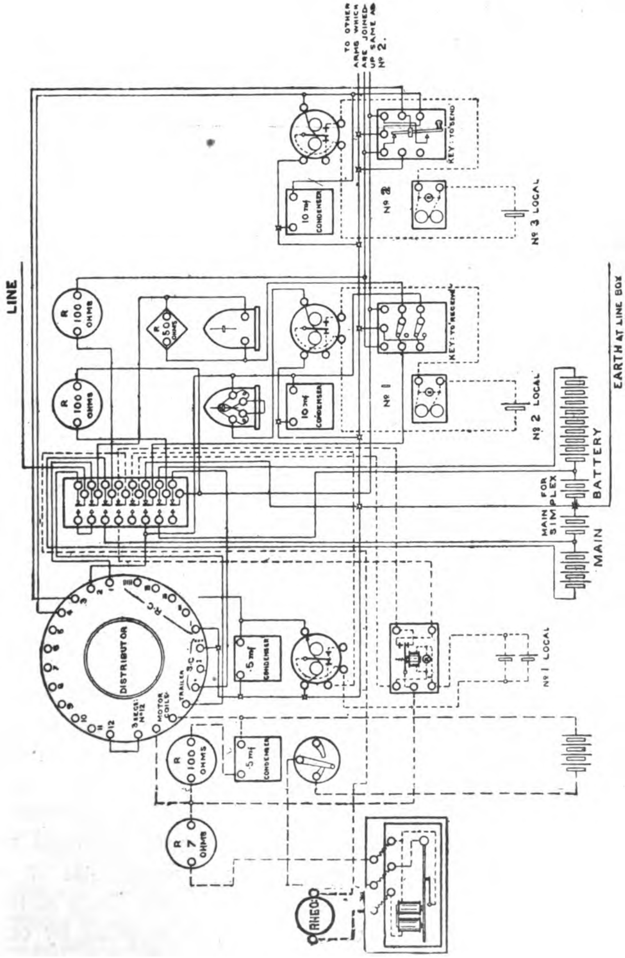

FIG. 149.

with experienced operators in charge at each end of the circuit, and with the present improved apparatus introduced by the Postal Telegraph Department, circuits worked on this system give comparatively little trouble. The tendency, however, is to rely on simpler apparatus and systems of greater reliability.

CHAPTER XI.

TELEGRAPH SWITCHING SYSTEM.

THE object of a telegraph switching system is to, temporarily, directly connect telegraph offices for the transmission of messages in order to save the retransmission otherwise necessary at the Central Office to which both circuits are connected.

The first system introduced was that known as the 'Umschalter,' or universal switch. This system consists of two series of insulated metal bars fitted at right angles to each other, each bar of one series crossing all the bars of the other. Connection between these bars is made by means of metal plugs inserted through and in contact with both bars at the crossing point.

The Telephone Exchange has modified our views of telegraphic switching. Not only do we use fewer instruments for the same number of local branch circuits in most central stations, but in London all metropolitan local circuits are brought to a large switchboard at the central office. This board is a 'multiple board,' arranged on what is known as the central battery system, that is to say, all the energy for working the circuits, both at the out-stations and in the central office, is supplied by one battery.

The board is divided into sections, each section consisting of two parts, one of which is again subdivided into three sections, called 'home sections'; and the other part is one panel called the 'multiple panel.'

The home sections and the multiple panels are made up of 'jacks,' mounted in strips. Under each jack on the home sections is fixed a small electric lamp, and under each jack on the multiple panel is fixed an indicator.

Each circuit controlled by the switchboard first goes to a test board, and from thence is taken to one particular jack on one of the home sections and also to one jack on each of the multiple panels. Each line is therefore connected to one home section and to all the multiple panels.

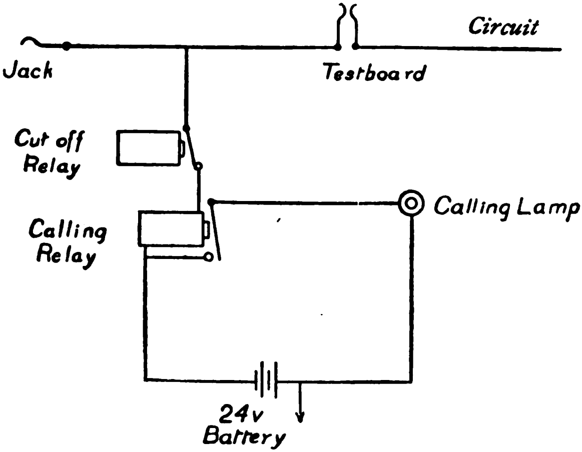

FIG. 149A

The line is also permanently joined to the armature of a 'cut-off' relay, which, when the relay is not excited, connects the line to one terminal of the magnet of a 'line' relay, the other terminal being joined to the negative pole of a 24-volt battery. The positive pole of this battery is to earth. The armature of the 'line' relay, when the latter is excited, completes a circuit which causes the lamp under the corresponding jack on the home section to glow.

Fig. 149A shows these connections. It will be seen that earthing the line at the out-station lights the lamp at the home section, unless the 'cut-off' relay is actuated. This lamp is termed the 'calling lamp.'

The 'jacks' consist of two springs of unequal length and a collar or socket. The lines in all cases are connected to the shorter springs, the longer springs are connected to the negative pole of the 24-volt battery, and the collars are connected to one terminal of the electro-magnet of the 'cut-off' relay controlling the same line, the other terminal being connected to the earthed positive pole of the 24-volt battery.

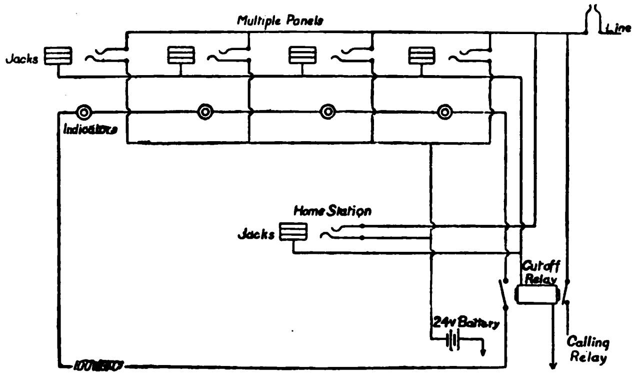

FIG. 149B.

This 'cut-off' relay when excited also completes by means of a second armature the circuit of the indicators on the multiple panels, under the jacks connected to the same line, which then show white discs. These connections are shown in fig. 149B.

The pegs (or plugs) which fit into these jacks consist of metal barrels with an insulated metal tip. The tip is connected to the insulated conductor in a cord attached to the peg. When a peg is in a jack this conductor is in metallic contact with the shorter spring of the jack, and therefore with the line. The barrel metallically connects the longer spring and the collar, thus completing the circuit from the battery through the 'cut-off' relay.

The pegs are coupled by the cords in pairs.

Each operator, of which there are three to a section, is provided with a certain number of the cords and pairs of pegs.

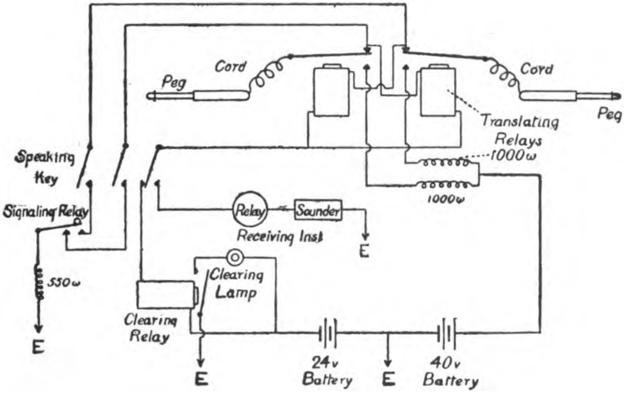

FIG. 194C.

In circuit with each cord is a 'speaking key,' a pair of translating relays, and a small electric lamp.

The speaking keys are for the purpose of bringing into circuit the operator's signalling key and receiving apparatus, in order that she may communicate with a calling office.

The translating relays are required for the intercommunication between stations.

The lamp is for the purpose of indicating when communication between stations is finished. It is called the 'clearing' lamp.

These connections are shown in fig. 149C.

Each out-station equipment consists of a sensitive polarised sounder and Morse signalling key and a special plunger, which when depressed is held down by an electro magnet, in which case the indicator attached to the plunger shows a white star. These connections are shown in fig. 149D.

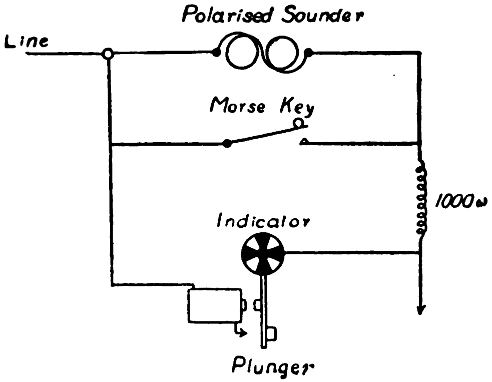

FIG. 149D.

The working of the system is as follows :—

When the operator at an out-station wishes to communicate with another station, he presses down his plunger. Under normal conditions a small current flows from the 24-volt battery through the line relay at the central office to the out-station polarised sounder, and a resistance of 1,000 ohms to earth (see fig. 149D). Both the relay and sounder are so 'biassed' as to be unaffected by this current. Immediately the plunger is depressed the resistance and sounder are short circuited, and the current increases sufficiently to actuate the line relay, and thereby causing the calling lamp to light.

The operator may, in place of depressing the plunger, work his key, which, by cutting out the polarised sounder, augments the current sufficiently to actuate the line relay. The working of the key thus makes the calling lamp flicker.

When the switchboard operator sees the lamp lighted she takes one of her pegs and places it in the jack immediately over the lighted lamp. As the peg is being inserted the tip touches the jack collar. This momentarily causes a current to flow through the 'cut-off' relay, which then opens the line circuit and releases the plunger at the out-station. This notifies the operator at the out-station that her call is being attended to and she then commences to call the station required with her Morse key.

The switchboard operator having pushed her peg home, the calling lamp is extinguished and the indicators of that line on all the multiple panels are actuated and show white discs; she then puts over her speaking key and brings her sounder into circuit. Upon hearing what station is wanted she takes the other peg on the cord to which the one in the jack is fixed, and pushes that peg into the jack on the multiple panel which connects to the line now required, unless the indicator under that jack shows a white disc. When this peg is inserted, the indicators on all the multiple panels connected to that line are energised and show white discs.

This operation puts the out-station in direct communication, and on the multiple panels both lines are indicated as 'engaged.'

When these connections are completed and neither station is working a permanent 'spacing' current flows out to both stations through the 'clearing' relay; and the pair of non-polarised translating relays, each of which is biassed against this small current. Each time the key at station A is pressed down, the current flowing through relay 2 is augmented, and this relay is sufficiently energised to attract its armature, thus sending a current from the 40-volt battery direct to the out-station B. When B is sending, relay 1 is actuated, and currents from the 40-volt battery are transmitted to A. The clearing relay is unaffected by these working currents.

When communication is finished both stations depress their plungers; this augments the spacing current sufficiently to actuate the clearing relay (see fig. 149C) and causes the 'clearing' lamp to glow; the operator then removes the pegs from the jacks, releasing the plungers at both stations as before by the peg tips touching the jack collars, thus notifying the out-stations that their lines are clear.

SPECIAL APPARATUS.

Every operator's section on the switchboard is provided with a special 'engaged' test-peg and lamp. These are only intended for use in the event of a failure of the indicators on the multiple panels from any cause.

The apparatus is simply a peg connected to one terminal of a glow lamp, the other terminal being earthed. If the peg tip is put against the collar of a line jack when the line is engaged the test lamp glows, the collars being connected to the negative pole of a battery, the positive pole of which is earthed; but if the line is disengaged the lamp is unaffected, for no peg being in any jack connected to that line the collars are not 'alive.'

In the common lead from the battery to the calling and clearing lamps is placed a 'pilot' relay, its function being to light a pilot lamp—of which there is one to each section of the board—or to ring a night bell in order to attract attention to a call during the slack time, when one operator is working several sections. A three-position switch is inserted, so that either the bell or the lamp may be in circuit, or neither of them.

Fuses are inserted in all circuits at convenient points, for the protection of apparatus in the event of short circuits occurring.

Continental cities are adopting similar commutators. At Brussels the board is provided with indicators for calling and for ringing-off as in a telephone switchboard. In addition, when two circuits are in connection, lamps are illumined to indicate to the operators at the board that the circuits are engaged. When a call is received for connection to another line, as there are two commutator or operators' positions, it is necessary to test whether the circuit is free. This is arranged to be done by aid of the head on one plug of a pair, and a relay which is caused to come into action and ring a bell if the line is available, the plug being inserted part way into the jack, and thrust home when such intimation is given. The introduction of the switching system has permitted the reduction of instruments in the Brussels Central to 53 for 121 lines and has secured the highest economy in the staff, as no idle moments need exist, the operators at the board switching on circuits which work Brussels, to any instrument that is available at the moment. The staff is thus reduced to the smallest number requisite for the traffic. There is also a saving of work in joining direct offices of small traffic, which formerly would have exchanged their messages through the medium of the Brussels Central. Further, supervision is rendered less costly, as the board affords knowledge of all that is going on, of vacant and of occupied lines and instruments, and of the time taken up in the exchange of telegrams.

CHAPTER XII.

THE TELEPHONE.

THE telephone is an instrument employed for the reproduction of speech at a distance. The history of the development of the electric telephone is full of absorbing interest, but the scope of this work does not allow of more than the briefest reference to a few of those who have taken part in the evolution of this important branch of practical electrical science. The production of sound by electrical means, which was shown by Page in 1837 to be possible by transmitting a rapid succession of currents round the coils of an electro-magnet, seems to have excited the conception of the electrical transmission of speech. Farrar in 1851 and Bourseul in 1854 pointed out that the transmission of sound would be possible if a piece of apparatus could be devised which would be affected by the impact of sound waves in such a way as to vary the strength of an electric current. Philip Reis of Fredericsdorf in 1861 was the first to put the idea into actual form. He fully grasped the conditions of the problem, studied the action of the ear, and devised an instrument that actually reproduced speech ; but it was reserved for Graham Bell to produce a really practical and commercial instrument (1876). Before describing this piece of apparatus it is desirable to consider what sound is, and how it is transmitted from one body to another. The word 'sound' is commonly used to denote the physiological sensations conveyed to the brain through the organs of hearing; it is, however, frequently employed to denote the actual cause of the effect upon the ear. When any body—a tuning fork or stretched string, for instance—is made to vibrate rapidly it emits sound; therefore, sound must consist of a series of vibrations, and when these vibrations reach the ear we experience the sensation of hearing. How these vibrations are transmitted to the ear will be best understood from the following analogy. Imagine a number of small balls to be placed in line upon a smooth table; then if the ball at one end be struck smartly, it will collide with the one next to it and its motion, thus transmitted to the second, will in turn pass to the third, and so on until the last ball is reached, and that being free will move clear of the rest of the balls, showing that the impulse has been propagated from one end of the row to the other by successive transmission from ball to ball. In the case of vibrations transmitted from a body emitting sound to the ear, the intervening particles of air or other medium react upon one another in a manner similar to that of the balls in the foregoing example; thus: suppose a tuning fork to be set in vibration and consider one limb of it; when this limb moves to the left the air particles in immediate contact with it on that side are struck by the fork and tend to move away from it; in so doing they strike against the next air particle, which in turn strikes the third and so on; the compression of the air particles travelling outward from the limb. Meanwhile the fork has changed its direction of motion, and is now moving to the right; this will cause the air particles to follow it by virtue of the pressure of the air on the side remote from the limb of the fork; there will consequently be a rarefaction of the air particles following each compression, and these alternate compressions and rarefactions will be kept up as long as the fork continues to vibrate. Such motions are known as *waves* of condensation and rarefaction. That sound is transmitted by the particles of air is conclusively proved by placing the vibrating body *in vacuo*, when no sound will be heard, the inference being that the absence of sound is due to the fact that there is no material in contact with the vibrating body to take up the vibrations.

When the vibrations of a body are regular the sensation produced upon the ear is pleasing, and we say that such a sound is *musical*; but if the vibrations be irregular the sensation is more or less disagreeable, and we call such a sound a *noise*. We are chiefly concerned in the former, since the sounds produced in the act of speaking consist principally of a rapid succession of various musical notes.

The character of a musical note depends upon three conditions, (*a*) pitch, (*b*) timbre or quality, (*c*) intensity. The *pitch* of a note varies as the rate of vibration of the body emitting the note; the higher the rate of vibration the higher the pitch of the note. The *quality* of the note depends upon the nature of the body which is vibrating; for instance, the same note may be obtained from a violin string as is obtained from a flute, but there is a marked difference in the quality of the sounds. The *intensity* or loudness of a musical sound depends upon the amplitude of vibration of the body emitting it. Any piece of apparatus used for telephone purposes must therefore be capable of reproducing these three acoustic properties.

Turning now to the electrical conditions, when a piece of iron placed near to the pole of a magnet has its position with respect to the magnet-pole changed ever so slightly, a redistribution of the magnetic field takes place: and if a coil of wire be wound around the magnet pole this redistribution of the lines of magnetic force will cause a current of electricity to be induced in the coil; the current being in one direction when the iron approaches, and in the reverse direction when it recedes from, the magnet pole. If the iron be made to vibrate in the direction of the axis of the magnet there will be first a current in one direction and then one in the other direction for every vibration of the iron. The frequency of the reversal of the current is the same as the frequency of the vibrations of the iron, and the strength of the induced current depends upon the number of magnetic lines of force cutting the coil in a given time; that is to say, the current induced varies as the amplitude of vibration of the iron. Conversely, if currents alternating in direction be sent through the coil they will alternately strengthen and weaken the pole of the permanent magnet and thus vary the attraction exerted upon the iron, which will therefore vibrate once for every alternation in the current flowing through the coils. If these facts be borne in mind no difficulty will be experienced in comprehending the action of Graham Bell's telephone.

This telephone in its first practical form is shown in plan by fig. 150. A is a compound permanent magnet of the horseshoe type, each pole being fitted with a soft iron extension part of which forms the core of an electro-magnet shown at C. The coils are joined in series in the usual way, and the free end brought out to terminals. Immediately in front of these polarised cores is a thin flexible soft iron disc D fixed about its periphery to a wooden support, which is recessed slightly to allow the disc to vibrate freely. Through the wooden support and opposite the centre of the disc a hole is cut into which is fitted the mouthpiece M; the whole arrangement being placed on a wooden base. The action is as follows: the sound waves entering the mouthpiece impinge upon the iron disc, which, being somewhat elastic, takes up the vibrations, thus causing the distance between the poles of the magnet (i.e. the soft iron cores) and the disc to vary. As already ex-

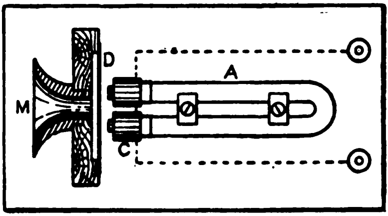

FIG. 150.

plained, this will cause undulatory currents in the coils which, as they correspond exactly with the varying motions of the disc, concide also with the condensations and rarefactions of the originating sound waves. It is obvious that if these undulatory currents be allowed to pass through the coils of a second instrument similar in every respect to that just described, the fluctuations produced in the magnetic field will cause the iron disc to vibrate in the same manner as the disc in the first instrument, and if the ear be placed opposite the mouthpiece the vibrations of the disc will be communicated to the ear. Since the sounds thus produced must be exact reproductions of the original sounds, the words spoken at one instrument will be distinctly heard at the other. With such an instrument Bell succeeded in speaking along a wire more than sixteen miles in length. The arrangement of two such telephones is shown in fig. 151. The instrument of the present day differs only in detail from the one already described, and is shown in partial section in fig. 152. The case is of ebonite, circular in cross-section, and the coil connections are made to the brass blocks shown at the lower end of the case; where also the screw which holds the permanent magnet in position is seen. This screw also clamps the brass loop, which forms a convenient fixing point for the flexible cord carrying the external connecting wires and thus prevents any strain being put upon the connection wires themselves should the instrument fall. The soft iron cores are arranged to approach very near to the iron disc. This

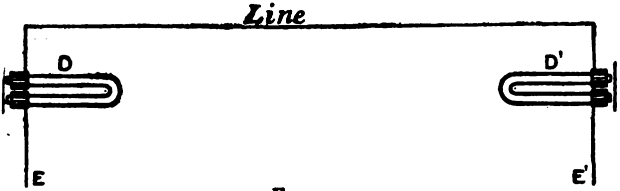

FIG. 151.

disc or diaphragm, as it is termed, is clamped by the mouthpiece of the instrument.

It will be noticed that in the arrangement shown in fig. 151 there is no battery; there is no accessory apparatus whatever. The two instruments are reversible; they may be transmitters and receivers in turn. When D is held before the mouth to transmit speech, D′ should be held against the ear to receive the spoken words. Simple and beautiful as this apparatus is, it has one serious defect: the electro-motive force induced by the movement of the disc D is of microscopic strength, while the resistance opposed to it is necessarily comparatively high, and the sounds reproduced are consequently a mere echo of those transmitted. It is evident also that the first disc, D, is able to take up only a portion of the sonorous vibrations of the speaker: and in this way also much of the actual energy of the voice is lost. Hence it is essential for practical purposes to devise some means of raising the electro-motive forces causing the currents to flow through the line.

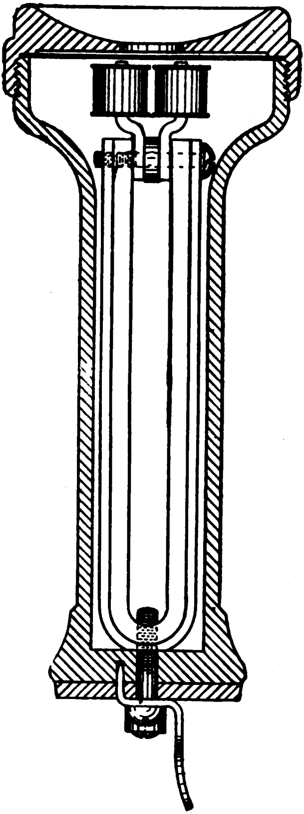

FIG. 152.

Edison did this in 1877 by the invention of the first form of carbon transmitter. This transmitter is constructed as follows: A disc of carbon is clamped between two platinum discs which act as electrodes. One electrode is fixed to a soft iron diaphragm by a cork pad, and the other banks against a screw passing through the framework of the instrument and by means of which the pressure on the carbon disc or button may be varied. Now when the diaphragm vibrates due to the impact of sound-waves upon it, a varying pressure upon the carbon will result, and the variation will correspond with the pitch, quality, and intensity of the sound producing the vibrations. As the pressure upon the surface of the carbon varies, so will its electrical resistance; and if a current be flowing through the carbon its strength will vary with the resistance, and therefore also with the sonorous vibrations impinging upon the diaphragm.

The function of the carbon transmitter is therefore restricted to the production of variations of electrical resistance in the circuit, which variations cause proportionate inverse variations of current; that is to say, an increase of resistance will produce a proportionate decrease of current, and a decrease of resistance a proportionate increase of current. Now, for a given movement of the vibrating disc the actual change in resistance will have a given value whatever the total resistance of the circuit may be, and in order that this change may produce its maximum effect it is necesary to make the total resistance as small as possible. For instance, assuming the change in the resistance of the carbon transmitter for a given movement to be one ohm, then, if the total resistance of the circuit be (say) 5 ohms, the variation in the strength of current will be $\frac{1}{5}$, but if the total resistance be 1,000 ohms the variation will be only $\frac{1}{1000}$, and in order that the same effect might be produced upon the receiver in each case the normal strength of current in the latter case would have to be two hundred times that in the former. Such an increase would be clearly impracticable. Acting upon a plan already used by Elisha Gray in 1874, Edison got over this difficulty by applying an induction coil to his transmitter.

The induction coil consists of a core made up of a bundle of soft iron wires surrounded by a few turns of thick 'primary' wire, and over this many turns of thin 'secondary' wire. If a steady current pass through the primary wire the core is magnetised and the two wires are in a magnetic field. So long as this field remains constant no effect is observed in the secondary wire; but if, by varying or stopping the primary current, this magnetic field is changed, then a momentary current will be induced in the secondary wire, assuming, of course, that that circuit is complete. Now, as each turn of wire in the coil is in the same magnetic field, the electro-motive force (E M F) induced in each turn will be equal, and the total E M F at the ends of the coil will be in proportion to the number of turns. Thus with a comparatively low electro-motive force in the primary circuit it is possible to get momentary secondary currents due to a very high E M F.

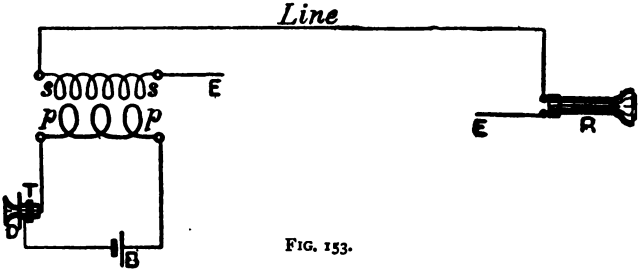

FIG. 153.

The application of the induction coil to telephonic transmission is shown in fig. 153. B is a Leclanché battery which is joined in circuit with the transmitter T, and the primary wire *p p* of an induction coil. The total resistance of this circuit is very low, being made up of the resistance of the battery, the primary wire (less than 1 ohm), and the telephone transmitter itself. These constitute the sole resistance of the transmitter circuit, quite irrespective of the length of the line. Hence variation in the resistance of the transmitter itself will have a very considerable effect on the strength of the current in the primary wire.

One end of the secondary wire (*s s*) of the induction coil is put to earth, and the other is connected to the line-wire, which at the distant end is connected through a Bell telephone, R, to earth. Now, when everything is quiet a steady current flows through the primary wire, and no current flows through the line-wire; but if there be any variation in the primary current, then for every increment in that current there will be a secondary current flowing through the line in one direction, and for every decrement there will be a secondary current in the reverse direction. Moreover, these secondary currents will vary exactly in number, form, and strength with the variations of the primary current, and as this varies in exact ratio with the sonorous vibrations impinging on the disc D, it follows that these currents will produce the same effects upon the Bell receiver R as the currents induced by the Bell transmitter.

But, as was just shown, these secondary currents are due to an electro-motive force which is very high compared with that which gives rise to the induced currents of the Bell instrument when used as a transmitter; and hence the total resistance in the secondary or line circuit is a matter of smaller importance. The Bell instrument is now used solely as a receiver.

Professor Hughes discovered another property due to the influence of sonorous vibrations which has still further improved telephonic operations. It is that if two conducting bodies lie against each other in loose contact, and a current of electricity flows through them, there will be resistance at the point of contact, and their vibrations will vary this resistance in exact ratio to the cause producing the vibrations. Metals and all conducting substances are subject to this effect, but carbon, probably because it is inoxidisable, is the best material, and although strenuous efforts have been made to produce a telephone transmitter without using carbon, no other material has been found to answer as well.

This effect is so sensitive that Professor Hughes was able with his *microphone* to render evident sounds that otherwise were absolutely inaudible.

One of the best known forms in which this principle is introduced is the Gower-Bell telephone, a modification of which has been extensively employed by the British Post Office. On a thin dry pinewood board are fixed two angular straps of thin copper plate, s s′ (fig. 154), and a carbon block, c. On each copper strap are fixed four carbon blocks, c_1, c_2, c_3, c_4. Holes are drilled in the sides of all these blocks, and eight carbon pencils, with their ends turned down, rest lightly in these holes in the positions shown, and there make loose and imperfect contact. This microphone replaces in fig. 153 the carbon transmitter of Edison (T). The actual resistance of the carbon contact varies from 8^{ω} to 10^{ω}. The effect of sonorous vibrations is the same. Secondary currents are formed and speech is reproduced.

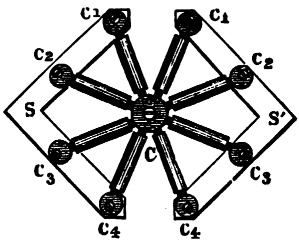

FIG. 154. ¼ real size.

Fig. 155 shows the later system of connections of the Gower-Bell telephone. c is the induction coil, the primary and secondary wires being for the sake of clearness shown distinct from each other. The primary wire has a resistance of $\cdot 5^{\omega}$, and the secondary, which is wound over it, has a resistance of 25^{ω}. L and L′ are two forked lever switches which are depressed by the weight of the two Bell receivers (not shown) when the latter are suspended upon them. These receivers are connected by flexible two-conductor cords between the two terminal screws marked 'receivers'; and are joined in 'multiple' circuit. R is a non-polarised relay which is employed for completing a local bell circuit only when the line wire is so long and has such a resistance that the bell cannot be worked direct. Where the latter course is practicable, the relay is not fitted and a wire is connected in place of the relay coils shown in the figure. The bell then takes the place of the wire shown between the first and third terminals. P is a press button, the function of which is to join the whole battery to line and permit a current to pass which is sufficiently strong to actuate the distant relay or bell as the case may be. The pine board upon which the microphone is fixed forms one face of the cover of the instrument, and the speaking is done immediately in front of the board; there is no actual mouthpiece. Normally both levers at each station are depressed by the weight of the suspended receivers and no current flows to line, but if station A wishes to speak to station B the button P is depressed, which permits a current to flow through the circuit and thus gain attention at B by causing the bell to ring. B answers the call by depressing the button at that end and causing A's bell to ring. Both correspondents then remove the receivers from the levers, which act completes the microphone circuit at each end through two cells of the battery and the primary wire of the induction coil, and also completes the line circuit

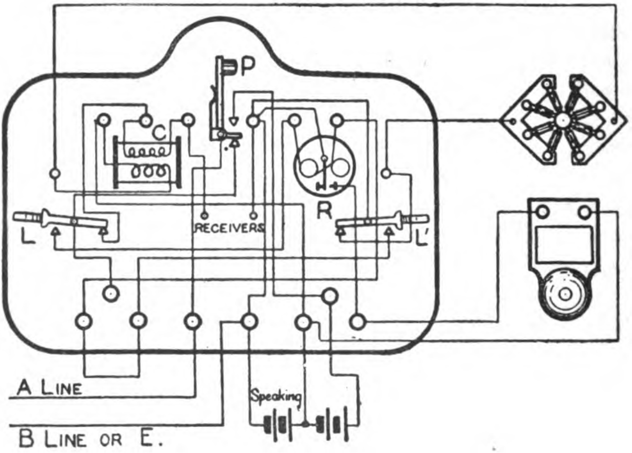

FIG. 155.

through the secondary wire of the induction coil and the receivers. Everything is then ready for the actual speaking. When the conversation is finished the receivers are replaced in the prongs of the lever, restoring the circuit to its normal condition; that is, with the call signalling apparatus only in the line circuit. The battery power required in excess of the two cells used for speaking purposes (which should be of low internal resistance) of course depends upon the length of the line.

An admirable form of transmitter and one formerly very much used is that of Blake. It differs from Edison's transmitter only in the fact that the carbon button has pressing against it a platinum point, the amount of pressure being regulated at will by means of a screw banking against one arm of a bent lever, the other arm of which bears a spring carrying the carbon button. Its action is due to the Hughes effect, that is, to the peculiar phenomenon of the loose contact between the platinum point and the carbon block.

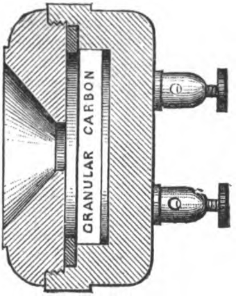

Fig. 156. ½ real size.

Representative of another distinct type of transmitter is Hunnings' transmitter. It is shown in fig. 156, and consists of a front diaphragm of platinum foil, behind which, and at a distance of from $\frac{1}{16}$ to $\frac{1}{8}$ inch, is a fixed plate of carbon. The intermediate space is filled with granulated carbon. Hence this form of transmitter is distinguished as 'granular.' The varying pressure between the carbon granules, caused by sonorous vibrations, varies the resistance which they offer to the current and effects a very clear and loud reproduction of speech. This instrument may be said to be the prototype of most of the best forms of transmitter yet devised.

A modification of the Hunnings' transmitter, invented by Deckert and known as the 'Hunnings Cone' or 'Deckert' transmitter, is the instrument now adopted by the British Post Office. A section through this instrument is shown in fig. 157. The case is made of ebonite, the back being shaped to admit of a plate of carbon C, the face of which is studded with small pyramids, as shown in plan by fig. 158. On the back of this plate is fitted a brass block drilled and tapped to admit the fixing screw S, which also forms the electrical connection to plate C. The diaphragm D is a thin carbon plate varnished on its outer surface to exclude moisture condensed by the act of speaking. The connection with this disc is secured through a metal ring upon which it rests. A woollen ring upon the diaphragm forms a pad for retaining the granules of graphited carbon between the front and back plates, and also 'damps' the vibrations. The centre pyramids are slightly truncated, and tufts of silk are gummed upon them also to act as 'dampers' to the diaphragm and so get rid of non-persistent vibrations. Connection is made with the front disc by a small brass rod B rivetted into the metal ring T, upon which the diaphragm

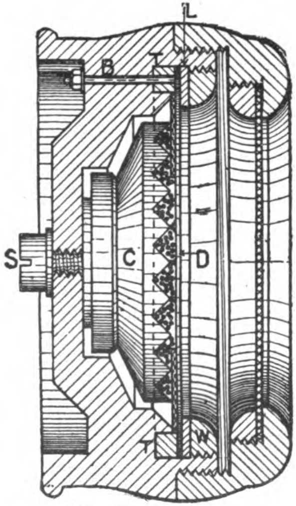

FIG 157. ½ real size.

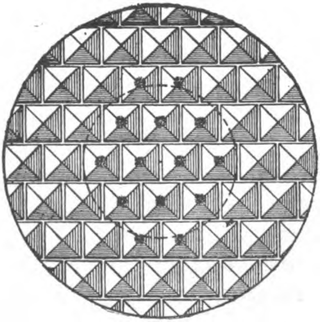

FIG. 158. ½ real size.

rests. L is a felt packing ring treated with paraffin wax to exclude moisture, and the whole is clamped together by the screwed ring W. There is no actual mouthpiece, but a piece of wire gauze fitted into the cover opposite the diaphragm protects the latter from injury. The presence of a bell-shaped mouthpiece in a telephone meant for general use is objectionable on sanitary grounds. For this reason also each operator at a telephone exchange where such transmitters are necessary should have a separate transmitter set apart for his or her special use. The efficiency of

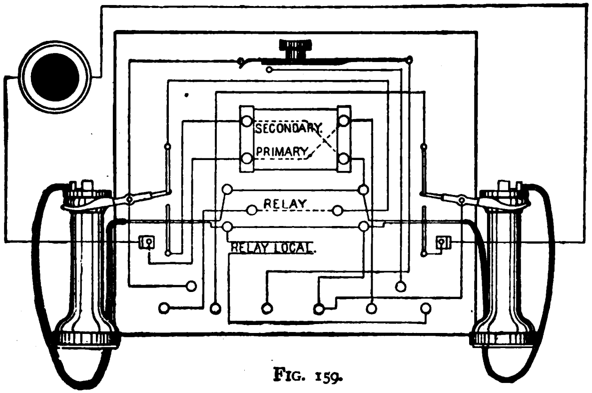

Fig. 159.

the Deckert transmitter in its most approved form bears favourable comparison with any form yet introduced.

The standard instrument of the Post Office, known as the Post Office telephone, is shown in diagrammatic form in fig. 159. The functions of the various parts are the same as in the Gower-Bell telephone; in fact, the one instrument is a modification of the other. The granular (Deckert) transmitter is electrically connected between the two points as shown, and is fixed upon the face of the cover in a vertical position. It is therefore directly opposite the speaker's mouth, whereas in the case of the Gower-Bell telephone the microphone is placed in an inclined position, which renders a slight stoop necessary on the part of the speaker in order to obtain the best effect. The electrical connections of the two instruments are so arranged that one may be made to replace the other upon any circuit. This will be clear if the internal connections of the two instruments be compared.

It has already been mentioned that an electric bell is provided on a telephone circuit to call attention between the two or more instruments on the circuit. Such a bell is shown in fig. 160. It consists of an electro-magnet E fitted upon a frame, which is mounted on a wooden base. Fixed by means of a spring S to the same frame is an armature capable of vibrating in front of the poles of the electro-magnet, and this is extended by a stout wire terminating in a small bell-hammer near to a bell-dome.

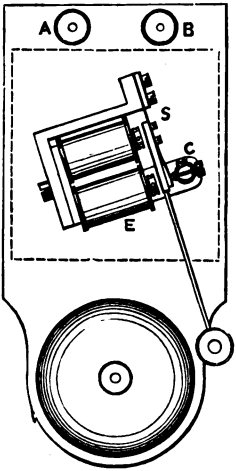

Fig. 160.

On the side of the armature opposite to that of the electro-magnet is fitted an insulated adjustable contact stop C, and the spring S is so formed that its flexible end normally rests against this stop. The electrical connections are from terminal A, through the coils to the frame, along the spring S to the contact stop C, and thence to the other terminal B. If now a current pass, the armature will be attracted and the bell-hammer will strike the dome, but this movement will break the circuit at C, and the tension of the spring will therefore bring back the armature; the circuit will be again complete, the armature attracted, and the bell struck; and thus the armature, being alternately attracted by the electro-magnet and replaced by the spring, will cause the bell to ring steadily so long as a current is kept on. There are many forms of these *trembler bells*, but the principle in all is alike, except that in some cases they are arranged to short-circuit the coils when the armature is attracted instead of breaking the circuit. The adjustment of the flat spring S which is sometimes necessary is at best an unsatisfactory and unmechanical device, and accordingly in the most recent bells made by the Post Office the armature is pivotted and fitted with an adjustable spiral spring.

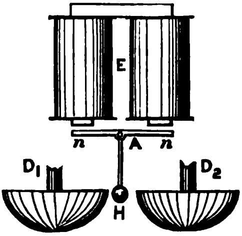

FIG. 161.

Magneto call bells are now very largely used in connection with the telephone. The principle is shown by fig. 161.

The armature A is polarised, and is so pivotted that it can be attracted and repelled alternately by the poles of the electro-magnet E. The hammer H attached to the armature moves between two domes, D_1, D_2, and so, when the armature is actuated by alternating currents, the domes are struck alternately. The alternating currents are obtained from a magneto machine.

The magneto instrument used is not of the form described in connection with the Wheatstone A B C system (p. 87), but is based upon a design of revolving armature invented by Siemens.

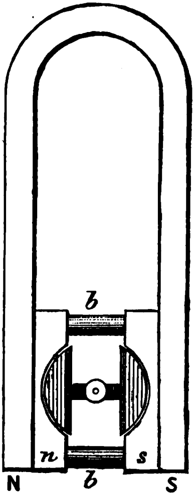

FIG. 162.

The general arrangement of magneto generators will be understood on reference to fig. 162. N S is one of three or more strongly magnetised magnets arranged in a series, but with a small space between. Fitted upon the poles are soft-iron polepieces *n*, *s*, kept apart by means of brass pillars *b* and curved on their inner faces to form segments of a circle.

Within this space and extending the whole length of the compound magnet is pivotted a Siemens H-armature. The core of this armature really consists of a solid soft-iron cylinder accurately turned and centred so as to nearly fill the circular space between the pole-pieces, and then so cut away longitudinally as to form a long bobbin with axial projections upon which it can turn. This core is wound longitudinally, the ends of the coil being connected to suitable points upon the shaft, one of which is insulated. From these two points the ends of the coil are connected to the lines.

When, by means of gearing, this armature is made to rotate, thus moving in and disturbing the magnetic field between the poles of the compound magnet, alternate currents are generated in the armature coil and flow thence to line, actuating the magneto bell as already explained. The armature coil is ordinarily short-circuited when not in use, but the short-circuit is automatically broken when the handle is turned. A good generator will ring a call-bell through as much as 60,000$^\omega$ in favourable conditions, and a good magneto bell will respond under these circumstances and yet will not fail when the external resistance is reduced to *nil*.

When a single telegraph or telephone wire runs parallel to one or more similar circuits for any distance, the currents set up in it by induction from the neighbouring conductors become very appreciable. These induced currents are, as a rule, not strong enough to affect telegraph apparatus, but the telephone, owing to its extreme sensitiveness and delicacy, is seriously affected by them and by similar disturbances due to leakage and to the use of the earth. The result is all kinds of confused sounds, mingled with the overhearing of conversation carried on upon other wires; and indeed the disturbances may be sufficient to preclude the possibility of telephonic communication through the wire. Up to the present no means have been devised of getting rid of this effect upon a single wire circuit, and in the present state of our knowledge it does not appear possible to do so. The difficulty can, however, be overcome by using a second wire as a return circuit instead of the ordinary 'earth' return Such an arrangement is called a *metallic circuit* (see p. 175).

Single wire telephone-circuits are now rarely constructed, except for unimportant systems and in isolated cases where a single wire can be erected remote from other lines. Apart altogether from inductive disturbance, also, no satisfactory single wire system of telephonic communication is possible owing to the presence of earth currents (p. 175), which would be a source of more or less permanent interference. Many plans for eliminating these disturbances have been suggested, but only one really effective plan has yet been found. This is shown in figs. 163 and 164. The use of the earth is discarded and return wires are employed, so that the circuit is entirely metallic; and the wires are, as it were, twisted round each other, making a complete revolution in every four spans. This insures that, while each of the two wires of a pair is maintained at the same mean average distance from all external disturbing wires as the other, the wires themselves shall be kept parallel with each other. Induction still takes place, but the effects of induction neutralise each other; while leakage and earth currents, the principal sources of trouble, are practically eliminated. Figure 163 shows the plan where a single telephone circuit is erected amongst ordinary working wires. The other figure shows two telephone circuits, each pair of wires diagonally situated being used for a circuit. The plan of using double wires for telephone circuits is now recognised as a necessity by all telephone administrations; but in lieu of the twist a plan of crossing-over the two wires at certain points is frequently adopted as being more simple. It is, however, also less efficient whenever, as in England, the sources of disturbance are numerous and irregular.

The presence of electro-magnets in a telephone circuit is very deleterious, their effect being to retard or choke the

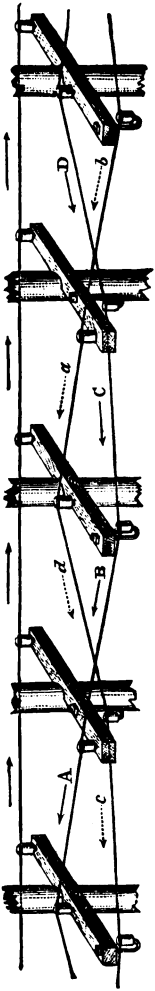

FIG. 163.

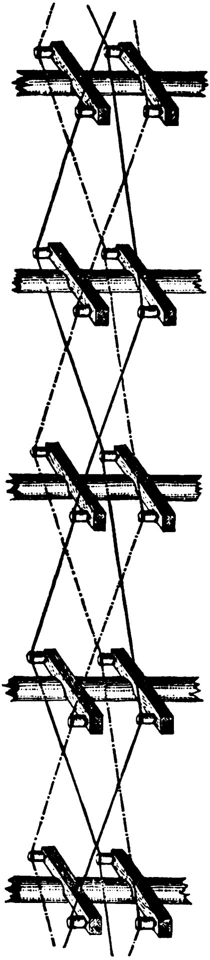

FIG. 164.

rapid undulatory currents and so render speech indistinct. This is obviated by the insertion of intermediate instruments in 'bridge' across the two wires or (in the case of single-wire circuits) in 'leak' direct to earth. The electro-magnet at the intermediate station is thus absolutely removed from the telephonic circuit, and the higher the 'self-induction' of the electro-magnet the more efficiently will it prevent the undulatory currents from passing by that circuit instead of going through the telephone at the distant end.

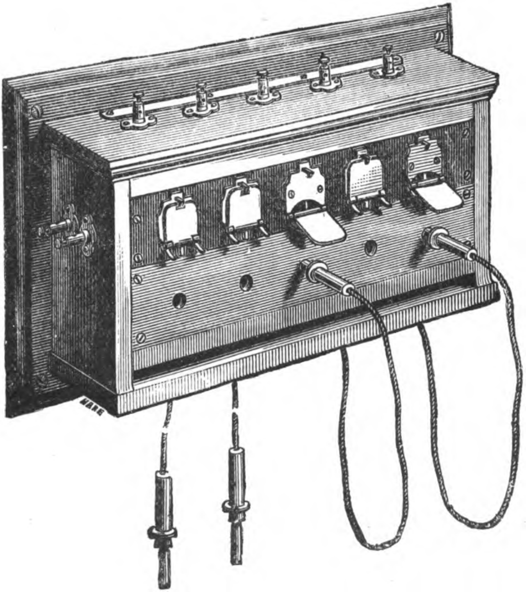

FIG. 165.

At an early stage of the growth of telegraphy the idea was evolved of concentrating one end of several lines at one office and there connecting them to each other as required. This system proved exceedingly useful when applied to private circuits connecting business houses, &c., and was extensively employed in England at the time that the telephone was invented. The adaptability of the new instrument for use by unskilled operators was at once evident, and its application to the purposes of an 'exchange' followed very soon. The principle may be illustrated thus: Assume that several wires from 1, 2, 3, 4, &c., all terminate at A. If it be required that any one place, say 2, shall be able to communicate with any other place, 5, it will need only a very simple contrivance at A to enable this to be done.

The forms of switch are very numerous, but for ordinary requirements they are very simple. A very good type of switchboard for a small system is shown by a general view in fig. 165. This is for five circuits, but a board on this simple plan may be considered suitable when the number of circuits does not exceed twenty-five.

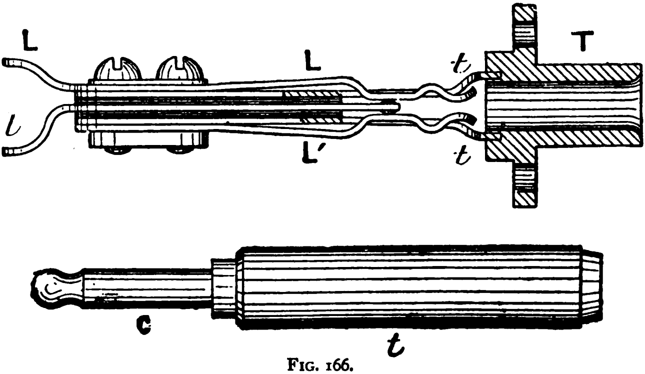

FIG. 166.

The construction of a single-wire circuit *springjack* or *switchspring* and its *peg* is shown by fig. 166. The cylindrical portion T (shown in section) is inserted from behind in the front board of the switch and fixed by screws passing through the flange. Two springs, *t*, *t*, gapped at their front end, are soldered into slots at the back of T; between them, and insulated by slips of ebonite, is a central spring *l*, and on either side are placed two other springs, L, L′, the whole being so clamped together that the forward ends of these two springs pass through the gaps in *t*, *t*, and normally rest on contact points on *l*.

The portion T is bored longitudinally to admit of the insertion of the end of a *plug* or *peg*, shown at the lower part of the figure. This peg, for a single-wire circuit consists merely of a brass cylindrical body formed to provide for an electrical connection, which is protected by a fibre tube, *t*, constituting a handle. This brass body is extended by a brass round-tipped pin, C, which when thrust into the socket T of the switchspring lifts L and L′ from contact with *l* and secures their electrical connection with itself. The body of the peg is connected with a conductor in a flexible cord, as shown in fig. 165. These flexible cords are constructed with the central conductor generally made of plaited tinsel covered with cotton, which is protected by an outer covering of braided mohair or (occasionally) silk.

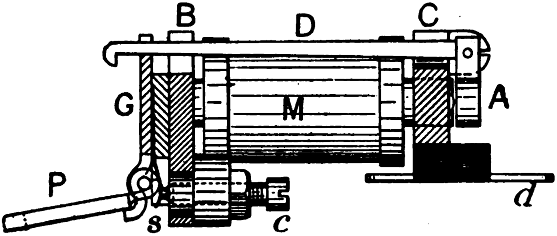

FIG. 167.

It is evidently necessary that means be provided for attracting the attention of the operator at the exchange. A type of *indicator* that is commonly employed is shown in side (sectional) elevation by fig. 167. M is an electro-magnet, one coil only of which is seen. B is a soft-iron strip which forms the common support and yoke of several such electromagnets placed side by side at distances of about 1½ inches centre to centre. C is a brass fitting which is clamped over the projecting cores of M, and provides pivot-bearings for the soft-iron armature A. This armature moves in a vertical plane, and is prevented from sticking to the cores by a brass pin projecting from them. At right angles to the armature is an arm D terminating in a catch; this arm lies centrally over the coils. The hinge-pin of the shutter P and a light local-contact spring *s* are clamped between the plate G and a smaller plate behind it. Normally, the shutter P is held in an almost vertical position by the catch on the detent-lever D, the weight of which keeps the armature away from the cores when no current is passing through the coils. When D is lifted by the attraction of the armature, P falls by virtue of its weight; and a small tail-piece on the shutter presses *s* against a contact-stud *c*, passing through an ebonite collet fixed in the iron base plate B. This is arranged to complete a local bell circuit, if necessary. To the brass block C a piece of ebonite is fitted which carries two thin connection strips *d*. The ends of the coils are soldered to the inner ends of the strips, and the external connections to the outer ends. One such indicator is placed at the exchange in the line circuit of each subscriber. The arrangement and electrical connections of the apparatus

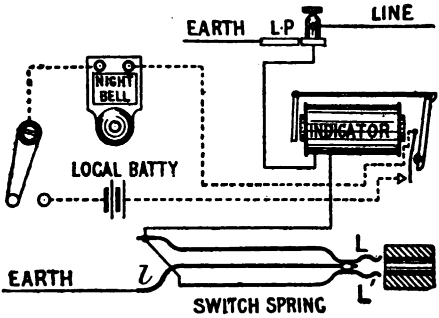

FIG. 168.

at the exchange end of a subscriber's line are shown by fig. 168. Normally, the line passes through the indicator and switchspring to earth; but the switchspring provides means whereby the earth circuit may be broken and through connection made to the operator's telephone or to a second subscriber's line. It will be seen that the insertion of the peg in the switchspring forces L and L′ outwards; thus breaking the earth circuit and connecting the line to the tip of the peg and to the flexible insulated conductor connected to it beneath the peg cover.

When a subscriber calls by joining a battery or magneto-generator to line, the shutter P of the indicator falls. The operator is provided with a telephone, earthed on one side, and terminating in a peg at the other. This peg is inserted in the switchspring of the calling subscriber, and when it has been ascertained to whom he wishes to speak the operator joins the two lines together by inserting one of a pair of pegs in each subscriber's switchspring, the pegs being connected by a single conductor cord. Both indicators are in circuit, and if the indicator shutters be replaced by the operator when connection is completed, a 'ring-off' signal given by either subscriber when the conversation is finished will cause the shutters to fall again, and indicate to the operator that the circuits may be restored to their normal condition.

L P is a lightning protector. The bell circuit shown is common to all indicators, and is only completed by the switch at night time.

If the lines were of any considerable length it would be necessary to have the indicators wound to a high resistance and connected in a 'leak circuit.'

This method of exchange working with pairs of pegs and continuous cords is not applicable to cases where the number of subscribers is greater than about twenty-five or fifty. When the number is large, a more elaborate switchboard is employed; but the connections at the exchange end of the line remain practically the same. The main differences between the small and the large switchboard consist in the arrangement of the operator's set, and the pegs and cords for through connecting purposes.

For each pair of pegs a special 'ring-off' indicator is provided, brought into circuit as a 'leak' only when through connection is made. This indicator is shown by fig. 169. The parts are lettered to correspond with those of the indicator shown in fig. 167. The electro-magnet has but one coil M, and is encased in an iron cylinder F. The armature A is provided with a screw, by means of which the 'play' of the arm D may be regulated. The ends of the coil are brought out in the form of two stiff wires passing through holes in the armature. When the shutter falls, the tail piece presses a spring contact (not shown in the figure), and completes a local bell circuit when necessary.

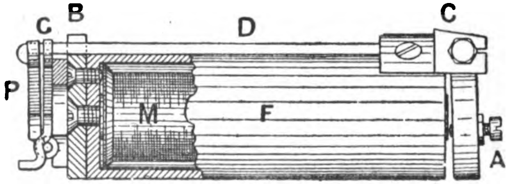

FIG. 169.

The complete connections of a peg and cord circuit, together with the switches used by the operator for 'ringing' and 'speaking,' are shown in fig. 170. The pegs A and A′ are shown in their normal positions, resting upon an earth-connected brass plate with which an extension of the brass barrel of the peg makes contact. Small pulley weights running on the peg-cords keep A and A′ in the normal position. The fixed ends of the cord are connected to the springs *t t′* of the table or speaking key which normally rest upon the inner contacts, both sides of the indicator being then to earth. R is a key the function of which is to connect the magneto-generator to the peg A when the table key is in the speaking position. Similarly R′ connects the generator to A′.

Suppose now that subscriber No. 52 calls; the shutter of the indicator in the line falls, and the operator at once inserts one of the pair of pegs, say A, into the subscriber's switchspring and pulls forward the lever of the table key, which forces the springs *t* and *t′* against the outer contacts, and joins the line through A, *t*, the upper contact of R, thence through the operator's set and the right-hand portion of the peg circuit, to earth at the brass plate upon which A′ rests. When the operator has ascertained that No. 52 wishes to speak, say, to subscriber 95, she inserts A′ into the switchspring of the latter, depresses the ringing key R′ (and at a small exchange works the generator), thus attracting the subscriber's attention by causing the bell in connection with his instrument to ring. When the attention of 95 has been gained, the operator restores the table key to its normal position (as shown in the figure), which completes the circuit from peg to peg and therefore from subscriber to subscriber. The 'ring-off' indicator is a permanent leak to earth on the circuit, but its impedance to telephone currents is so great that its presence does not sensibly lower the efficiency of the circuit. On the conclusion of conversation, the subscribers give a 'ring-off' signal by sending an alternating current

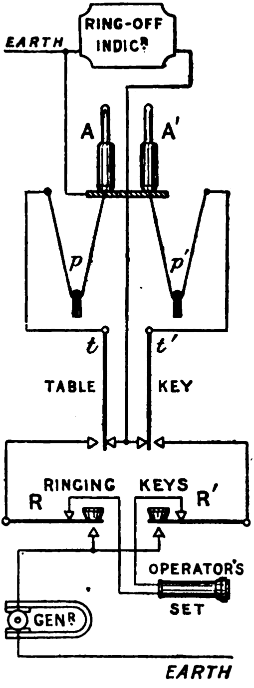

FIG. 170.

from their magneto-generators. The alternations of this current, which are much slower than those of the telephonic currents, actuate the indicator. The operator then withdraws the pegs, and everything is again normal.

It is obvious that there is a limit to the number of subscribers that can be dealt with by one operator, and for small exchanges an operator may be placed in charge of a switch section upon which 100, or even more, lines are terminated. This number is, of course, determined by the average number of calls per subscriber, which in turn depends upon the number of possible correspondents—i.e. upon the magnitude of the exchange system. The larger the system the smaller will be the number of subscribers which it is possible for one operator to satisfactorily deal with.

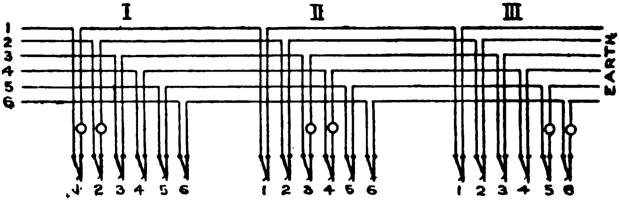

FIG. 171.

Where several switch sections are needed, means must be provided for connecting a subscriber on any one section to a subscriber on any other section. Communication between adjacent sections could, of course, be made by pegs and cords, but such a method is obviously impracticable in the case of switch sections far removed from each other. One method of overcoming the difficulty is to provide a number of circuits terminating in switch-springs, from each section to every other section, by means of which a subscriber's line may be extended or transferred from one to the other. Such circuits are known as 'through' or 'transfer' circuits.

In large exchanges, however, the delay introduced by the additional operation and the necessity for providing an abnormally large number of these transfer circuits between any one and each of the other sections render such a plan unworkable. What is really required is, that each operator, although only attending to the '*calls*' of his allotted subscribers, shall be able to make connection with all subscribers on the system without requiring the assistance of any other operator. This is effected by means of the 'multiple' switch.

The principle of the multiple switch will be readily understood from fig. 171. Each section, I, II, III, is arranged for a certain number of subscribers (usually 200), sufficient to require the attention of three operators. Each of these sections is fitted with switchsprings to accommodate the whole number of subscribers to the exchange, and the several lines are taken consecutively through each section; but at only one is there an indicator by which a subscriber can gain attention. Thus each operator is able, by means of the switchsprings at her own section and without moving from her place, to put a subscriber directly into communication with any other subscriber, although she still has to attend to the requirements of only a limited number. For instance, if subscriber 2 (fig. 171) wishes to speak to subscriber 5, the operator at section I simply connects 2 and 5 by means of a pair of switch pegs and a flexible conductor; while, if the reverse were the case, namely, No. 5 wishing to call No. 2, then the operator at section III would make a similar connection.

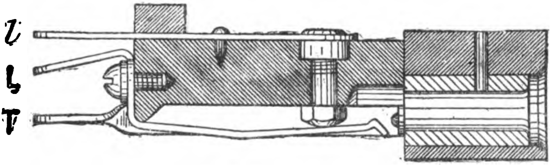

FIG. 172. Full size.

The construction of a multiple switchspring for single-wire working is shown in fig. 172. A complete series of twenty switchsprings is mounted on an ebonite slab built up of a thick front block, pierced with twenty holes, and a thinner broad plate with a ridge at the back, upon which the main parts of the switchsprings are planted. The holes in the front strip are bushed with a brass tube or socket which is electrically connected to strip T. L is a spring to which the incoming line-wire is connected, and *l* is an insulated stop on which L normally rests and to which the outgoing line-wire is joined. When the peg (similar to that shown at fig. 166) is inserted the incoming line-wire is disconnected from the stud *l* and joined through C to the brass socket T and to the conductor—the flexible cord.

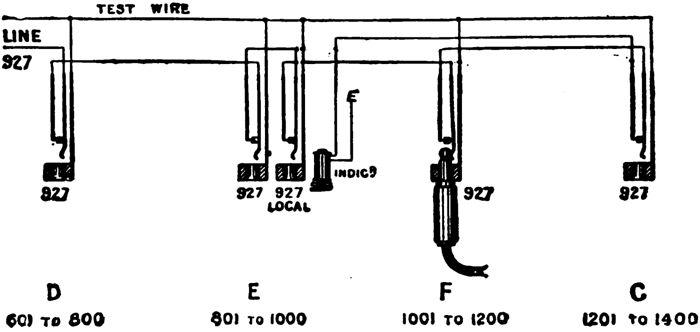

FIG. 173.

Fig. 173 shows the electrical arrangement of the switch for one line passing through four sections. From this it is seen that the line after passing through the switchsprings is connected through an indicator to earth, and that a test-wire connects all the sockets T of the corresponding number at each section.

When no outside connection is made the line-wire passes through the corresponding spring at each section from spring L through contact stud *l*, and thence goes through the electro-magnet of the indicator to earth. If now, a peg be inserted, say, at section F, stud *l* at that switch, and consequently everything beyond it, is disconnected, and the line is joined to T and to the flexible cord. By means of the flexible cord connection can of course be similarly made to any other subscriber. It will be noticed that by this arrangement the indicators are taken out of circuit, as it is usual to have 'ring-off' indicators, one of which is in circuit with each pair of pegs.

The multiple connections would, it is clear, lead to great confusion if the several operators had no means of ascertaining whether the subscriber required was engaged at any of the other switches. For instance, if, in the position shown in fig. 173, the operator at section D were to insert a peg, it would interrupt the conversation already arranged for at F; whereas a peg inserted at section G would be simply disconnected. This difficulty is ingeniously provided against by means of the brass socket connected to T. The insertion of a peg connects the incoming wire not only to the flexible conductor, but also to the test-wire at every switch. Now, in the circuit of the operator's speaking telephone, which is of course joined to earth on one side, is a battery; if therefore the other side of the telephone be put to earth, a current will flow and cause a click in the telephone. Before inserting a peg into the switchspring of the required subscriber, the operator simply touches the metallic socket with the tip of the peg, and if there is no peg inserted in that circuit at another section no sound will be heard at the telephone, but if a connection be already made, T will be to earth through the subscriber's line and the slight consequent click will show the operator that the line is engaged. Although the outline description of the system here given seems comparatively complex, even with absolutely no reference to many important details, the actual working of the complete system is wonderfully simple, and affords an exceedingly satisfactory solution of the difficulty in working large exchanges.

At a large exchange it is usual to provide ringing power for calling subscribers from a special generator driven concontinously by a small electric motor or by a hot-air engine. The operator then only needs to depress one of the two ringing keys which are inserted in the peg circuit system, in order to send a ringing current upon one or other of the lines to which the operator's set is for the time being connected.

For the sake of simplicity in description and brevity single-wire circuits have been dealt with; but, as already stated (p. 256), it is practically impossible to secure good working of a system of any extent except by the use of metallic circuits, and a brief indication of the general working conditions with metallic circuits will now be necessary.

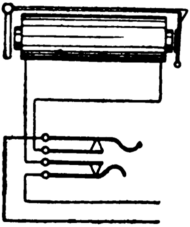

FIG. 174.

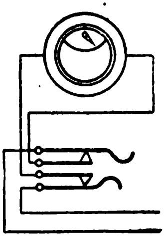

FIG. 175.

Fig. 174 shows the simplest arrangement of a metallic circuit where the indicator is to be replaced by a 'ring-off' indicator when one circuit is put through to another. The indicator would be of the form shown in fig. 167.

The corresponding system of the British Post Office is shown by fig. 175, in which a different type of indicator is given. From the first the Post Office adopted not only the metallic circuit system now universally admitted to be essential to good working, but also the principle of automatic signalling, the value of which is now well recognised.

The indicator employed for subscribers' circuits on this system is shown by fig. 176. M M is an electro-magnet having as an armature a ring of iron A A, hinged at *a* and so balanced that it tends to fall forward and attract attention. This ring carries a label bearing the subscriber's number. A small magnetic index *i* plays between the electro-magnet poles, and when a current passes is deflected to one side or the other according to the direction of the current. s s′ is an insulated stud by which a local bell circuit is completed for use as a night call or for similar circumstances. The electrical connections are as shown in fig. 175. A current from a battery fitted at the subscriber's end normally flows through the circuit, the relay in the subscriber's telephone being biassed against it. This current causes the indicator shutter A to remain up. The subscriber when he wishes to call the exchange lifts his

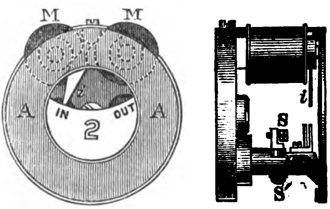

Fig. 176.

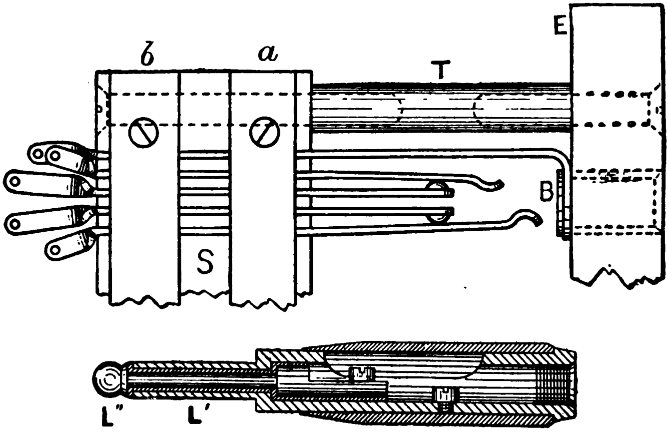

Fig. 177.

receiver, thus disconnecting the battery and thereby causing the indicator shutter to drop and attract attention. The operator replies by coming into circuit and speaking. In order to call a required subscriber from the exchange an augmenting current in the same direction as the 'permanent current' and strong enough to overcome the bias of the relay must be sent by means of the operator's ringing key.

A general indication of the construction of the switch-spring strips and of the double connection peg is given by fig. 177. The switchsprings, one only of which is shown, are mounted in rows of twenty upon an ebonite strip E. The bush B through which the peg passes has an internal diameter of a quarter of an inch, and is provided with an extension at the back terminating in a connection tag. The ebonite plate S is slotted at right angles to its length to receive the springs, which are fixed in position by an insulating cement and made secure by two thin ebonite strips *a b*, let into grooves on the surface of S, the strips being screwed down at each end. The strips E and S are fixed together at the proper distance apart by long screws passing through brass tubes, T. The inner springs are left sufficiently free to make a rubbing contact with the outer ones, which have a decided inward 'set.' The tip of the peg makes contact with the short outer spring, and the barrel of the peg with the long one. At the same time it breaks the contact of the outer with the inner springs, and thus disconnects the subscriber's indicator from the circuit.

The general principle of the multiple switch has already been indicated in connection with single-wire circuits. Fig. 178 shows its application to metallic circuits. The numbers I, II, III, and IV refer to different sections at which the corresponding switchsprings are fitted. These are similar in construction to the switchsprings shown in fig. 177, but are provided with an additional spring *c*, which normally rests against the bush *l*, through which the peg passes. When a peg is inserted the springs *a* and *b* are pressed outwards and break contact with the inner ones. The spring *a* is fitted with a small button of ebonite, which when *a* moves outwards presses *c* away from *l* and causes it to make contact with a brass strip *s*, continuous along the whole length of the strip in which the brass bushes are fitted. This brass strip is connected to one pole of a battery the other pole of which is to earth. A and B are the two wires of a subscriber's circuit, which it will be seen is taken through a switchspring at each section, but to an indicator S at section I only. The operator at that section only

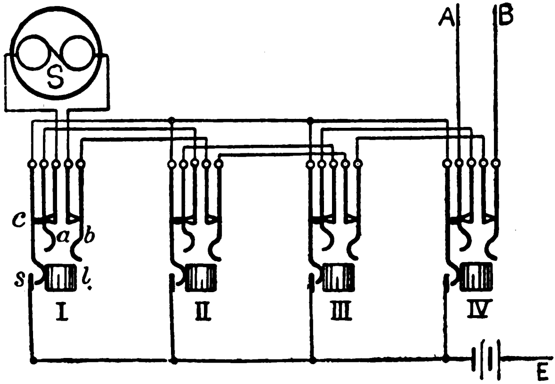

FIG. 178.

will therefore receive calls from that particular subscriber, while all the other operators will have access to the circuit.

Now assume a call to be received at S. The operator at section I inserts a peg, ascertains who is wanted, and then, if the required subscriber is not already engaged, immediately effects the connection by inserting the second peg into the switchspring of that subscriber's line. The method of determining whether any particular subscriber is engaged is very simple. On reference to fig. 179 it will be seen that the receiver of the operator's speaking set has the centre of its coils joined to earth, and when the key K is in the speaking (or listening) position the tip and barrel of each peg are joined to earth through one coil of the receiver. It will also be seen from fig. 178 that the extreme left spring of a switchspring is joined to the corresponding spring of all other switchsprings through which the given subscriber's line passes. Now, when a subscriber is engaged there must be a peg in one of the switchsprings allotted to that circuit, and *c* of the switchspring in which the peg is inserted will be connected to the earthed battery through *s*. As a consequence the bushes, *l*, of all the switchsprings corresponding to this subscriber throughout the exchange will be connected to earth through the test battery. To determine, then, whether or not a subscriber is engaged the operator (with the speaking key, K, in its speaking position) places the tip of either peg on the brass bush of the required subscriber's switchspring ; should he be engaged a current will flow to earth through one receiver coil and cause a 'click' to be heard on making and breaking the contact. This current, of course, flows from the earthed battery and does not affect the subscriber's telephone since it is confined to the local circuit common to all the left-hand springs, which is known as the 'test wire.'

The connections of the peg and cord circuit with the operator's telephone shown by fig. 179 are applicable for both multiple and non-multiple metallic circuit switchboards, except that for the former the receiver need not be earthed at the centre. L is a ring-off indicator (fig. 169). The key K, which is shown in the speaking position, consists of five springs, *a*, *b*, *c*, *d*, and *e*. Normally, *a* and *b* are in contact; so also are *c*, *d*, and *e*, in which position it will be seen that the pegs are connected together, with the ring-off indicator in 'bridge.' In the position shown in the diagram both pegs are joined to the operator's speaking set, P though ringing key R, and P′ through R′. These ringing keys are operated by a plunger, which when depressed forces the longer springs against the shorter ones and so connects the magneto generator to P or

P′, according as R or R′ is used. With the speaking key in the position shown, all the operator has to do in order to reply to a subscriber's call is to to insert a peg (say the left-hand one) in the corresponding switch-hole and receive the subscriber's instructions. Next the engaged test (as already described) is applied to the required subscriber's line with the right-hand peg P′, and if no click be heard in the operator's receiver the peg is inserted and the plunger R′ depressed. This causes a ringing current to flow from the generator along the required subscriber's line. Upon

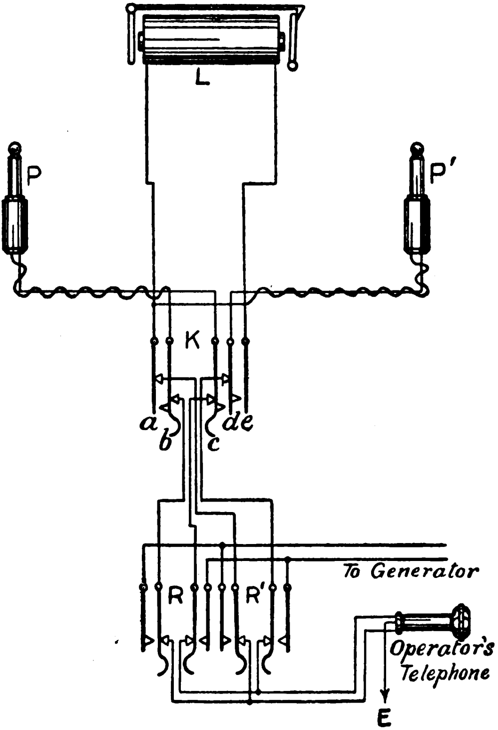

FIG. 179.

receiving a reply from the called subscriber the operator pushes back the cam-lever of the speaking key, which causes the springs to be forced outwards to the normal position, and by so doing cuts out of circuit everything except the through connection between one peg and the other with the indicator in 'bridge.' When conversation between the subscribers is completed they each give a turn or two of their magneto-generators, and thus cause an alternating current to flow through L strong enough to actuate the armature and cause the shutter to drop. The operator then pulls out the pegs and restores the indicator shutter by hand.

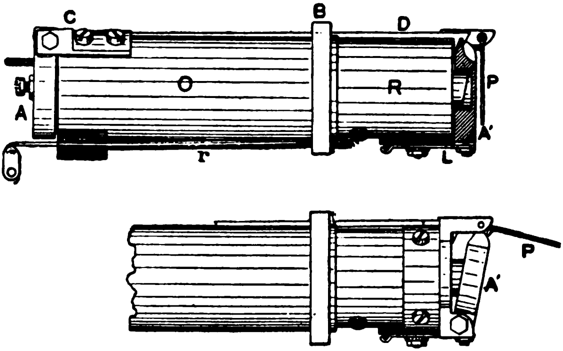

FIG. 180. ⅔ full size.

The replacement by hand of the shutter of the ring-off indicator is attended with considerable inconvenience at large or busy switches, and the practice of all modern telephony tends towards making every operation as far as possible automatic. Accordingly the so-called 'self-restoring' indicator is employed for ring-off purposes. It consists essentially of two coils, one operated by the subscribers and one (automatically) by the switch operator.

Fig. 180 is a side elevation, partly in section, of one form of this indicator. The back armature A is pivotted at C, and fitted with a light arm D terminating in a catch. This armature is actuated by line currents passing through the back and larger coil (1,000$^{\omega}$) of the iron-sheathed electro-magnet. The catch at the free end of D holds up a soft-iron armature A′, shown in section. The armature is pivotted at its lower edge, and in front of it is a light aluminium shutter P, freely pivotted at its upper edge and normally hanging vertical. When A′ is released by the catch on D it falls forward by virtue of its own weight and thrusts P outwards, as shown in the lower part of the figure. If, now, a current be sent through coil R, known as the restoring coil (450$^{\omega}$), the armature A′ will be attracted and the shutter will fall into the vertical position. When the current ceases the armature is detained by the catch.

The ends of the coil O are brought out through holes in the armature A; those of the coil R are brought out of the sheathing through ebonite collets, and connected to wires *r*, which terminate as connection tags.

Hitherto consideration has been given only to arrangements for urban telephone circuits, that is to circuits comprised within limited areas, in cities or towns with their suburbs. The necessities of commercial and social life, however, demand that all possible facilities be afforded for telephonic communication between distant places, and these facilities are provided by means of 'trunk circuits.' In England the system is now under the control of the British Post Office, and a network of trunk circuits is being steadily and systematically developed whereby it is becoming possible to secure direct telephonic communication between the most remote towns of the three kingdoms.

The electrical connections of the apparatus at one end of a trunk circuit are shown by fig. 181. The indicator P is really a very sensitive polarised relay wound in two sections to 1,000$^{\omega}$ and fitted with a sensitive polarised needle pivotted to move between the poles of the relay electro-magnet, and free to deflect to right or left according to the direction of the current through the relay coils. The A and B lines of the trunk circuit are connected together through the line springs and the inner contacts of the switchspring S, the coils of the relay in series and the '*main* permanent current' battery. The positive pole of the battery is invariably connected to the A line. In connection with one coil of the relay a circuit is formed through a resistance coil *r* (350$^\omega$), the middle and lower local circuit points of the switchspring S and a '*local* permanent current' battery. This local permanent current in the right-hand coil is in a direction to cause the indicator to be deflected to the right. It will be evident that the effect of the main permanent current is therefore to deflect the indicator to the left.

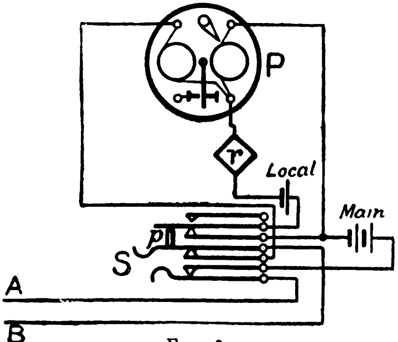

FIG. 181.

A consideration of fig. 182, which shows the theoretical connections of a trunk circuit complete under normal conditions, will enable the whole principle to be readily understood. As the main permanent current batteries at each end of the circuit are similarly connected they oppose each other, and no current passes to line from either. At each end, therefore, the local battery is fully effective through the right-hand coil, and the indicator is accordingly deflected to the right. This constitutes the *disengaged* signal.

In order, now, that an operator at one end of the circuit may attract the attention of the distant station, it is only necessary to insert a peg into the switchspring concerned. This disconnects both main and local batteries at the calling end and leaves the main battery at the distant end unopposed. The result is that a current from that battery passes through both coils of the relay P, which is strong enough to overcome and reverse the polarity due to the local current through one coil. The indicator is thereby deflected to the left, indicating a *call.*

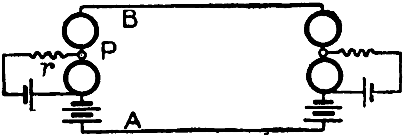

FIG. 182.

The distant operator promptly inserts a peg in the corresponding switchspring, thus disconnecting the permanent current batteries. Both indicators are consequently vertical, showing the circuit *engaged.* The two operators are, of course, immediately in communication.

Fig. 183 shows the connections of a peg and cord circuit at a trunk line switch section. Six such sets of apparatus are provided for five trunk circuits, except that the operator's speaking set is common to all. In series with the line coil of the self-restoring indicator is a 'telephone exchange galvanometer,' having a polarised needle and the coils wound to 1,000$^{\omega}$ resistance. The needle of this galvanometer is vertical when no current is passing.

S is a speaking key, shown in the speaking position; normally the four long springs are pressed outwards by the wedge-shaped ebonite block which is attached to a plunger actuated by a cam-lever. R and G are ringing keys; the former on being depressed joins the ringing battery to the black-covered peg P; the latter joins a generator to the red-covered peg P′. The key G is employed for calling such subscribers as are provided with magneto bells. R is used for calling the Post Office exchange when the insulation of the trunk line is so low as to render it necessary.

Under normal conditions the tip and barrel of one peg are joined respectively to the tip and barrel of the other, and in 'bridge' or 'derived circuit' across the cords is the ring-off combination of self-restoring indicator and telephone exchange galvanometer.

Special circuits have to be provided between the Telephone Company's exchange and that of the Post Office in order to secure through connection between trunk and subscribers' lines. One of these 'junction circuits' is provided for every trunk line so that no delay may arise for want of means of putting a trunk circuit through to the Company's system.

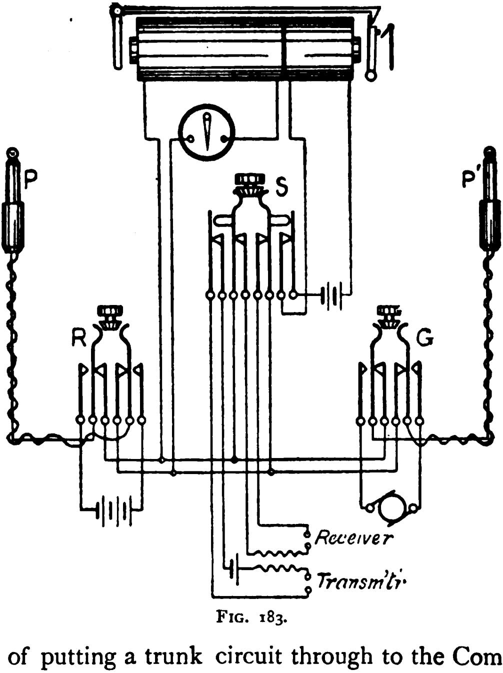

FIG. 183.

In order to trace the whole *rationale* of working, let it be assumed that a subscriber to the Telephone Company at A requires communication with another subscriber at B. He first calls the company's exchange in the usual way and gives particulars of his call, being switched through direct to the Post Office trunk exchange or having the call transmitted by the company's operator according to local conditions. Except at small exchanges the demands are made upon special 'record circuits.' In any case the record operator at the Post Office writes the particulars upon a ticket, which is timed and passed on to the trunk switch section to which the required circuit is connected. In its due turn according to time the operator inserts a black-covered peg in the line switchspring, thereby automatically calling the distant station. If it be a direct connection (that is, if a direct circuit exists between A and B), the operator at A is put through on a junction circuit to the required subscriber at B at once ; otherwise she gets forward step by step. After speaking to subscriber at B, and asking him to keep listening, the operator at A proceeds to get the calling subscriber in order to complete the transaction. Communication between the Post Office operator and the Company's exchange is conducted upon a 'call circuit' upon which an operator is constantly listening. The trunk operator has therefore only to depress a call circuit key to put herself into communication with the Company's operator and secure immediate connection to the required subscriber if he be disengaged or agrees to accept the trunk line call at once. On completion of the conversation the subscribers 'ring-off' by their generators, actuating the self-restoring indicator at each end of the trunk circuit. Or it may be that at the termination of the specified time the trunk operator proceeds to disconnect, in which case the restoration of the permanent current at A gives the ring-off signal to B on the telephone exchange galvanometer—the self-restoring indicator not being sensitive enough to respond to that current. The operator at B then withdraws the pegs and the conditions become normal.

Where through connection is required between trunk lines terminating on adjacent switch sections it may be secured by means of the ordinary cords, but such a course is not practicable except for adjacent sections. Where the number of sections is small direct transfer circuits are provided between the several sections, but this method is of no use at large centres, and in such cases the transfer circuits, instead of being taken direct from one section to another, pass from the trunk switch to a special 'transfer switch section,' at which it is possible to effect a connection between any two sections.

Trunk line communication is of such vital importance to many business firms that a direct connection to the trunk line exchange becomes necessary. By this means the initial operation of getting through the local exchange is entirely saved. Inasmuch as none of these calls become immediately effective, all that is needed in the first instance is for the recording operator to connect her telephone in the calling subscriber's circuit. This is effected by the special device shown diagrammatically in fig. 184. Beside the switchspring S allotted to each subscriber, is another switchspring, K, specially fitted as a 'plug speaking key,' the inner contacts of which are connected to the line springs of S, and the outer to the operator's speaking set, including the three ringing keys, D, R, and G. The polarised indicator relay P is connected in bridge across the two lines, which are taken thence to the switchspring, S, and speaking key, K. The normal position of the plug of K is as shown ; but when the plug is withdrawn to the limit of its movement (it cannot be entirely removed) the outer springs make contact with the inner ones and the lines are connected to the operator's set. By withdrawing the speaking plug, therefore, without the use of any pegs or cords, the subscriber's instructions can be received and recorded. The plug key is then restored.

When the call matures and the subscriber's attention is required, the plug key is again withdrawn and (by means of either D, R, or G) the subscriber is called. The through connection is effected by means of pairs of pegs and cords, and the indicator relay serves as a ring-off indicator. D, R, and G are used for calling by direct, reversed, or generator currents, according to the description of circuit concerned.

It is impossible within the limits of a short chapter to give other than a brief outline of working conditions of the telephone system, and many important details have necessarily to be omitted.

The superimposing of a telegraph circuit upon the two lines of a telephone circuit may be mentioned as one of the subjects to which only this passing reference can be made.

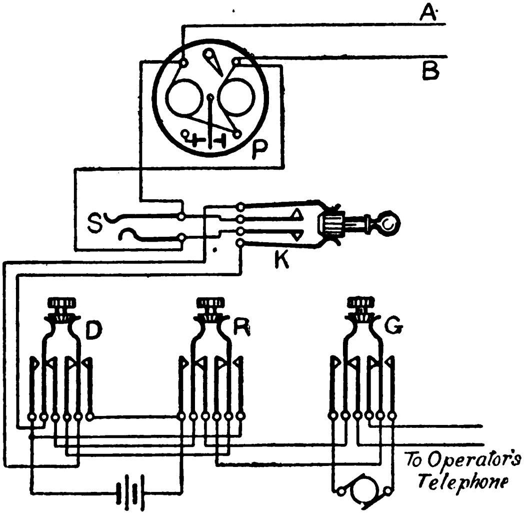

FIG. 184.

At p. 164 is described the retarding influence of the electrostatic capacity of the line wire upon the possible speed of transmission of electric currents. This influence is of course felt even more upon telephone than upon fast-speed circuits. The distance-limit of speaking by telephone depends upon the product of the resistance of the circuit (in ohms) R, and the capacity of the circuit (in microfarads) K—or K R. The following figures show approximately the K R which limits easy and practical speech, and indicate the telephonic value of the conductors :

Copper Wire (open) . . .	K R	10,000
Cables or Underground lines .	„	8,000
Iron Wire (open) . . .	„	5,000

The low value of iron is due to the presence of *electro-magnetic inertia* which is absent in copper. This shows clearly that all telephone circuits should be made of copper wire.

CHAPTER XIII.

CONSTRUCTION (MATERIALS).

TELEGRAPH lines are divided into two great classes. 1st. Those in which open, that is overground, wires are employed. 2nd. Those in which covered wires, whether subterranean or submarine, are employed.

When the choice lies between these there is no hesitation whatever in selecting the former ; for not only is their first cost less, but faults occurring upon them can be far more readily traced and rectified.

In England open or overground wires are for the most part erected either by the sides of the roads or along the banks of the railways. Occasionally they are put up by the edge of the canals, although as a general rule the road and the railway are to be preferred.

The advantages which road and rail respectively offer as routes for telegraph lines are so numerous that it is no easy matter to say which is to be preferred. Although the first cost of the erection of a telegraph line upon a road is greater than upon a railway, its subsequent maintenance, under certain conditions, is cheaper. The supervision of it is also likely to be more perfect, for the fact that the poles are erected along the side of a road induces better inspection. The inspecting officer can hardly help inspecting every wire and insulator, and little imperfections are thus easily detected and removed before they have time to become injurious. The lineman placed in charge of a length of road line must walk his length : even if he succeeds in obtaining a ride, he cannot be carried too fast for the examination of the wires. Upon the railway, on the other hand, walking is difficult, and is consequently too often neglected—the lineman contenting himself with travelling by train, from which close inspection is next to impossible.

The reparation of faults again is as a general rule more speedily carried out upon roads than upon railways. In the case of the former, the lineman can start immediately the fault is reported to him : with the latter, he has not only often to wait some time for the starting of the train, but frequently is carried past the fault, and has to return, perhaps many miles, on foot. Hence it is that not only is the number of faults less, but they are also of shorter duration upon roads than upon railways.

It has been generally assumed that a line by road is more liable to wilful damage than one upon the railway. With the earliest telegraph lines this was true, but experience of late years does not favour the assumption. Insulator breaking is the main evil which has been met with on roads ; but the examples made of offenders in this direction have acted as a wholesome lesson to others who may be similarly inclined.

The materials employed in the construction of an open line of telegraph may be classed under the three following heads :—1. Supports. 2. Wire. 3. Insulators.

1. *Supports.*

The choice for these lies between wood and iron. In England the former is all but universally employed. Iron is occasionally introduced, but only to meet the wishes of various persons who have an idea that an iron pole is not so unsightly as a wooden one. The main advantage which wood possesses over iron for the purpose of telegraph supports lies in its first cost. In England it is about one-third the price of iron ; and although the maintenance of wood, when left in all but its natural condition, far exceeds in cost that of iron, yet timber subjected to one or other of the preservative processes which have been invented in comparatively recent years has thus far shown so slight symptoms of decay that experience does not yet warrant our forming any definite opinion as to the relative cost of maintaining it and iron. If, again, the wire by any chance touches an iron pole, good 'earth' is at once obtained by the current, and the circuit is broken down ; a wire might, on the other hand, be in contact with a wooden pole, and only in very wet weather would it be found difficult to work through it.

On the earliest telegraph lines square poles cut from the best Baltic timber were employed, but for economical reasons these very soon gave place to native-grown larch, and now round red fir obtained from Norway and Sweden is almost exclusively used in this country. Terminal poles,[1] however, are exceptional, as it is generally convenient to have them square.

The dimensions of poles will, of course, vary with the number of wires which a line is intended to carry. Experience has suggested the convenience of classing three sizes of timber under the heads of (*a*) Light, (*b*) Medium, and (*c*) Stout ; the first being used for a maximum of five wires, the second for a maximum of ten wires, and the third for more than ten wires. The diameters will, of course, vary with the length of the pole in order to give approximately the same strength to all poles of the same

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[1] By a *terminal* pole is meant not only the last pole at each end of the line to which the wires are terminated, but also any pole at which the wires form any angle approaching to 90°.

class. The dimensions shown in the following table of the diameters at top of pole and at a distance of five feet from the butt will indicate the present practice in this matter.

Length of pole in feet	Diameters in inches					
	Light		Medium		Stout	
	At top	5 feet from butt	At top	5 feet from butt	At top	5 feet from butt
20	5	6	5½	7½	—	—
26	5	6¾	5¾	8¼	7½	10¼
40	5	8	6	9¾	7½	12

The trees are felled in the winter months when the sap ceases to rise, and those selected should be sound, hard grown, and free from incipient decay, large or dead knots, and other defects. The age of larch when fit for telegraph purposes ranges from twenty-five to fifty years, according to the soil on which it is grown. Its average life as a pole, if not specially prepared to resist rot, may be set down at about seven years. The poorer the soil on which the timber is grown, the harder and more durable it is, and the lighter and more porous the soil in which it is planted the shorter its life.

There are two kinds of decay to which a telegraph pole is liable, viz. dry-rot and wet-rot.

Dry-rot is very seldom met with in telegraph poles in England, and therefore no special steps have ever been taken to guard against it. It is due to a species of wood-fungus —the *Merulius lachrymans*—which destroys the tensile and cohesive power of the wood, and gradually reduces it to a fine powder. This fungus thrives best in a close moist atmosphere without draughts, such as is found in the close parts of the framing of ships ; in fact it seldom attacks open timber work except in parts where a free circulation of air is impeded, such as the butts of iron-shod poles and the like.

Wet-rot is the destructive agent at work more or less on all telegraph poles, and it is to stay its ravages that all the preservative processes have been invented. This wet-rot is of two kinds, *chemical* and *mechanical.* In the former a species of slow combustion or '*eremacausis*' takes place, as, through the influence of heat and moisture, the albuminous and nitrogenous materials of the sap ferment and decompose the cellulin and lignin—the two constituents of which every description of timber is formed—and by a gradual process of oxidation the pole slowly but surely rots away. The germs of animal and vegetable life gradually begin to make themselves evident, and exercise a destructive influence.

But it is to the second or *mechanical* kind of wet-rot that the decay of most of the telegraph poles in England is mainly due. The point at which it makes itself evident is unfortunately that of the ground line, or, as it is more frequently termed, the *wind and water line.* It is here that the varying conditions of moisture and temperature are most felt, and to this cause the decay is undoubtedly due. For if timber be kept in a uniform state as to temperature and moisture—whether it be perfectly dry or whether it be continually under water—a very long period will elapse before the symptoms of decay begin to appear, unless indeed dry-rot is present. But where there are rapid alternations of condition as regards heat and moisture, a process of disintegration is commenced which goes on steadily increasing until the entire structure crumbles away.

All the methods which have been adopted for the preservation of timber may be divided into two classes: those which have been applied *externally*, and those which have been applied *internally.*

The external applications are :—

(a) *Seasoning.*—The trees when felled are cleared of their branches, the bark is stripped off, and the knots shaved down ; they are then sheltered alike from the sun and the rain, and stacked in such a manner that the air is allowed to circulate freely amongst them. In this way the evaporation of the sap is promoted. To get rid of the sap and the inherent germs of decay, timber has been kept immersed for a time in salt water ; artificial drying in a hot-air chamber has also been resorted to, but the most perfect seasoning is effected by simple exposure to free currents of air.

(b) *Charring and Tarring.*—This process consists in gently roasting the butt end of the pole, after it has been well seasoned, for a length of about six feet, over a slow fire, and removing it immediately the surface becomes well blackened without being burnt. The object is to expel whatever sap remains, to kill whatever animal or vegetable life may be present, to prevent absorption of moisture when the pole is planted by destroying the external pores of the wood and substituting an impervious covering in their place, and finally to surround that portion most liable to decay with a powerful antiseptic in the shape of carbon. The bottom of the pole, as well as the portion which has been charred, should then be well coated with a mixture of three parts of Stockholm tar to fourteen parts of gas tar well boiled, and three parts of slaked lime added, care being taken, before the tar is put on, to scrape off any part of the wood which may have been burnt during the process of charring. The tar assists in more effectually accomplishing the object of the charring, and being applied to the bottom of the pole, prevents moisture from entering there and making its way upwards under the influence of capillary action.

In the early days of telegraphy various local applications were made at the wind and water line to prevent decay from setting in or to arrest it when once commenced, and although some of these proved moderately successful in attaining the end they had in view, yet all have been abandoned in favour of one or other of the preserving processes which have since been invented.

The decayed portions, if any, were at first scraped off and asphalte was applied for some distance above and below the wind and water line ; cast-iron and earthenware cylinders filled with asphalte were tried without success ; and finally wooden poles fitted with screw iron sockets, for excluding the moisture from the wood, were put up experimentally, and found to be unsatisfactory both as regards economy and efficiency.

The internal applications are of two kinds : (1) The introduction into the pores of the wood of certain metallic salts, which, by entering into chemical combination with the albuminous materials of the sap, produce chemical compounds unfavourable to decay. (2) The introduction of some oil which, in addition to acting as an antiseptic, renders the wood waterproof.

Of the former class the three best known processes are : (a) *Burnetising*, (b) *Kyanising*, and (c) *Boucherising*.

(a) *Burnetising* consists in impregnating the timber, when perfectly seasoned, with chloride of zinc. The poles are placed in an open tank filled with a solution of this salt, and allowed to remain for a length of time, varying according to their condition, until they are thoroughly well soaked.

(b) *Kyanising* consists in treating the poles in exactly the same fashion with a solution of corrosive sublimate (perchloride of mercury).

(c) *Boucherising* consists in injecting a solution of copper sulphate longitudinally through the entire length of the pole. The poles, instead of being well seasoned, must be in the green state in order to undergo this treatment ; if they are at all dry the process cannot be satisfactorily applied They are simply cleared of their branches, drawn into the boucherising yard, laid upon a rack, and the solution is then applied to the butt ends under the pressure which the liquid itself has acquired from a head of about fifty feet, at which height the tanks containing it are placed. This is kept on until the blue solution is observed to issue from the top of the pole. The time occupied by this operation varies according to the season of the year at which the work is carried on. It succeeds best in the spring and autumn, as at these seasons the pores of the wood are most open ; frost effectually stops it. As short a time as possible should be allowed to elapse between the felling of the timber and its being placed on the boucherising frame, for the more open the pores are the more easily is the process carried on. For the same reason Scotch fir can be far more easily boucherised than larch ; quickly grown timber more easily than that of hardy growth.

Of the second class of internal applications the only system which requires to be mentioned is that of *Creosoting*. Creosote is one of the numerous products of coal-tar, and is obtained from it by distillation. When applied to timber it not only acts as a powerful antiseptic, destroying the germs of vegetable life, but, by filling the pores of the wood with an oily substance, it checks the entrance of air and moisture and the consequent growth of germs. The process can be advantageously applied only to well-seasoned timber : upon green wood it is entirely thrown away, and is in fact worse than useless, for it encloses without reaching and neutralising the septic germs, and thereby fosters rather than prevents the progress of decay. The poles to be creosoted are placed in a cylinder which is rendered air-tight, and from which the air is very carefully exhausted. Creosote is then applied, and forced in at a pressure varying according to the contents of the cylinder ; the time during which it is applied will likewise depend upon the contents of the cylinder and the condition of the timber. When in proper condition timber ought to absorb from ten to twelve pounds of creosote per cubic foot.

Of all the processes which have as yet been devised for the preservation of timber, creosoting has been attended with the most beneficial results, and has given universal satisfaction. It would, in fact, be difficult to assign a limit to the life of a properly creosoted pole. Several which were erected between Fareham and Portsmouth, on the London and South-Western Railway, in 1848–49, when taken down owing to their small size in 1880, were found to all appearance to be in as good a state of preservation as on the day when they were first planted. Instances have occurred in which, after the lapse of only a few years, it has been found necessary to renew creosoted poles, but in such cases it is more than likely either that decay had commenced before they underwent the process, or that being improperly seasoned they were not in a fit state to be subjected to it. It should, however, be added, that the creosote which at the present day is sold for the preservation of timber is inferior in quality to that which was formerly employed, and that on this account no reliable conclusions can thus far be drawn from the experience of the past as to the value of creosoted timber in the future. The antiseptic properties of creosote are due mainly to the presence of carbolic and cresylic acids ; and these, which in former days were to be found in very large proportions in commercial creosote, have of late years become so extremely valuable as articles of commerce that they no longer exist to anything like the same extent as previously in what is now sold as creosote. How far this may affect the value of the process it is at present impossible to say. Creosoted timber after being planted for a few years has in some cases been served with a coating of tar, but the economical advantage of this is doubtful under ordinary conditions in view of the life of properly creosoted poles without it.

Creosoted poles cannot be painted satisfactorily. Where, for ornamental purposes, paint must be employed, the difficulty may be partly met by dipping the butt ends of the poles to a distance of about six or eight feet in boiling creosote and painting the remainder.

Next to creosoting the boucherising process has found most favour, and possesses some advantages over creosoting. It can be applied to the timber immediately it is felled, and the work of preparing the pole can then be completed, without much delay, in the forest where it is cut. Boucherised timber, again, can be employed where, from objections to either the appearance or the smell, creosoted cannot. Unlike the latter, too, it may be painted, although the blue marks of the copper sulphate gradually make their appearance through the paint, unless it be of a dark green colour, which for this reason is generally preferred. One great drawback to the employment of boucherised timber is the destructive effect which the copper sulphate has upon the ironwork made use of in fitting up the pole. This being generally of a very light character, is eaten away, and in the course of a few years is rendered useless. Viewed simply in the light of a preservative, boucherising ranks below creosoting, and it fails altogether in a certain proportion of cases in which it is applied. Thus, when a line has been built with boucherised timber one or two per cent. of the poles will be found to be worthless within five or six years ; but after these are renewed the line will last in good condition over twenty years.

Burnetising and kyanising are seldom adopted. The latter has been abandoned mainly on account of the poisonous nature of the salt ; and the former possesses the same inherent faults as boucherising, in addition to the further disadvantage that before it can be applied the timber must be well seasoned. Both the chloride of zinc and the copper sulphate are said to wash out, a result which is in all probability due to the compounds formed by them in the pole having lost their stability of character, owing to the

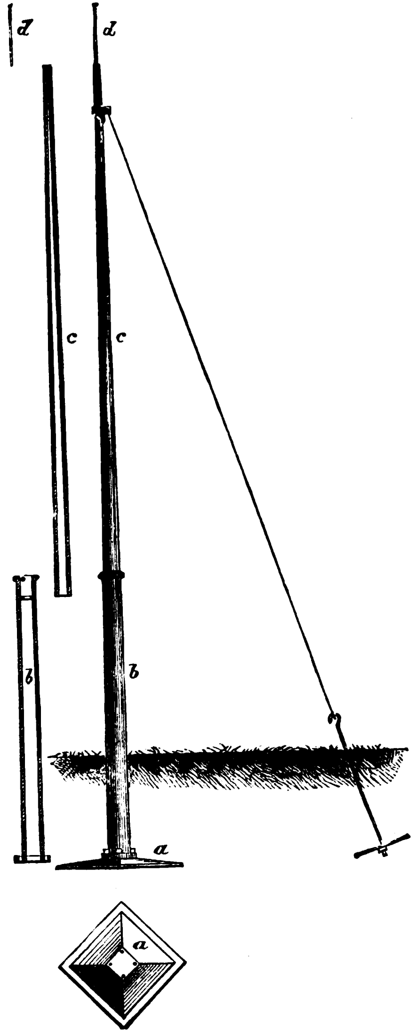

FIG. 185. $\frac{1}{48}$ real size.

entrance of either air or moisture through the pores of the wood.

Iron Poles.—As has been already remarked, iron is but little employed in England for telegraph supports; and when it becomes necessary to use it, the poles are usually of a light and ornamental description to suit the wishes of those who insist upon their use. But in countries where wood is extremely perishable, either from natural decay or from the attacks of the white ant; and preservative processes, on account of their expense, cannot be introduced; as well as where the means of transport are limited, iron poles are very extensively used. On account of their weighing less than wooden poles, and being manufactured in pieces of convenient weight and bulk, they can be more easily conveyed from place to place.

The pattern of iron pole which has found the most general acceptance, and which is now employed in almost every quarter of the globe, is the tubular post invented by Messrs. Siemens Brothers, section and elevation of one form of which are given in fig. 185. It consists of: the foot-plate (*a*), the lower tube of cast-iron (*b*), the upper tube of wrought-iron (*c*), and the lightning conductor (*d*). The foot-plate is a buckled plate of sheet-iron of the form shown; it combines great rigidity with a certain possibility of flexure which enables it to yield to sudden and excessive strains. The square elevation in its centre has four bolt-holes corresponding to the same number in the lugs at the bottom of the lower tube. This lower tube or socket is made of cast-iron, and is fastened to the foot-plate by means of the four bolts: near the top it has on its inner surface a projecting rim, upon which the bottom of the upper portion of the pole rests. The upper portion, which is secured to the lower tube by means of a cement composed of sulphur and oxide of iron, consists of a welded wrought-iron tube tapering towards the top, in which is welded an iron ring for the reception of the lightning conductor.

Messrs. Siemens Brothers also have a patent screw-ring joint between the wrought-iron upper tube and the cast-iron base, which has largely taken the place of the cement joint, and Messrs. Bullers Ltd. employ a taper ring shrunk on, near to the butt end of the upper, which closely fits into the bore of the base, while the extreme end of the tube rests upon a projection within the base. Both forms of joint have found wide use.

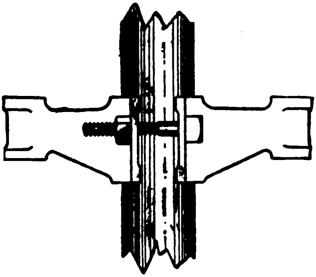

FIG. 185A.

Poles of the type referred to above are made in lengths of sixteen to thirty-two feet. Longer poles are usually built up of three or more sections. A pair of malleable iron brackets as commonly employed with these poles is shown in fig. 185A, and several such can be erected, according to requirements and locality, on one and the same pole. The brackets, and in some cases the bolts, are galvanised.

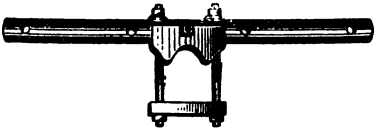

FIG. 185B.

When a large number of wires have to be accommodated, a cross arm made of iron tube galvanised is very useful.

Such an arrangement for four wires is exhibited in fig. 185B. By using a longer tube six or eight wires can be erected, but in ordinary practice it is more convenient to use two or more four-wire arms placed vertically one below the other, at a distance of one foot or fifteen inches.

The poles vary in size according to the work which is required of them, and as a general rule their cost may be set down at about three times that of wooden posts of the same strength. They are numbered according to their nominal breaking strain in *cwts*.

A form of iron pole, known as Hamilton's Standard, which was considerably modified and improved by Col. Mallock, has been largely employed in India. It consists of several wrought-iron tubes eight feet long made in a series to one taper, so that from two to five of them may be fitted together by simple hammering. The lower part of the bottom tube fits over a tapered cast-iron socket furnished at its lower end with a cast-iron disc of a diameter equal to four times that of the lower tube.

An excellent form of iron pole, known as Buller's Pole, is that shown by fig. 186. The upper part consists of a single wrought iron welded taper tube A B from 9 to 15 feet in length. About 4″ from the lower end a taper ring is shrunk on, and the end of the tube is made to the same taper. The cast-iron base or socket C is similarly tapered at the upper end, so that the tube need only be dropped into the socket and needs no further fixing. The webbed cast-iron base-plate G is held in position by a conical-headed screw D. Where the ground is of such a nature as to permit of the base being driven, the conical-headed screw is fixed into the lower end of the base C without the base-plate G. This forms a 'base-pile' type of pole, the lower tube being by this means rendered suitable for driving into the ground by means of a pole-driving apparatus. This consists of a tripod formed of three iron rods hinged on a common plate which is fitted with two pulley blocks. A rope passed over the pulleys supports a heavy weight terminated by an iron rod about five feet long. The driving apparatus being placed in position over the point which the pole is to occupy, an iron driving block is inserted into the socket of the base-pile to take the blow from the descending weight, and to serve also as a guide to the weight by allowing the iron rod attached thereto to pass into the base through a hole in its centre. By alternately raising and suddenly releasing the driving weight by means of the pulley tackle two men can readily drive the base

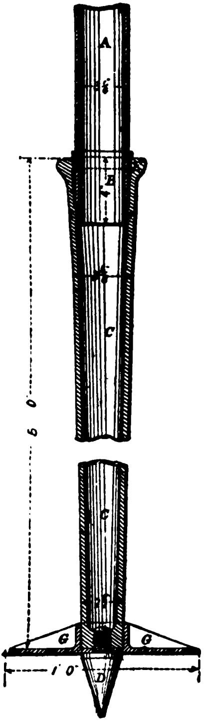

FIG. 186.

into any soil that is suitable for this method of construction.

The arms consist of iron brackets clamped to the pole either singly with back-straps or in pairs back to back, and the top of the pole is fitted with a lightning-rod. It is inexpedient, especially in tropical latitudes, to fit an insulator at the top of the pole, as it is so exposed to damage by lightning.

Base-plates that are not required as such serve excellently as stay-plates.

This pole possesses the great advantage of being suitable for use in rough countries where transport is difficult and skilled labour unobtainable. No portion weighs more than 60 lbs. It may be very quickly erected, and after erection may be adjusted and fitted throughout with great facility.

2. *Wire.*

In selecting wire for telegraphic purposes the points to be borne in mind are strength and durability, combined with low resistance to the passage of electricity. Copper is the material which most closely fulfils every condition, but iron wire has hitherto been all but universally employed for aërial lines. Until comparatively recently, copper has not only been too dear, but it has been of very impure quality and has lacked mechanical strength. Now, however, it is manufactured almost pure and as strong as steel, so that its cost is the only obstacle in the way of its general use.

Iron Wire.—There are various qualities of iron wire, known under the names of 'best best,' 'extra best best,' 'steel,' and 'charcoal' wire.[1] The last named is the most

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[1] These terms are employed simply to distinguish the various qualities of wire. 'Best best' means ordinary puddled wire, and is in fact indiscriminately applied to almost any kind of telegraph wire or iron bar. 'Extra best best' is a higher quality, and is obtained by the introduction of charcoal iron in connection with the last named. Charcoal wire has, however, a higher conductivity than any other kind of iron wire.

expensive, and in the earlier telegraph lines it was in general use on account of its being more easily welded than wire of a lower quality. Its high conductivity at present secures its retention for main-line purposes. It is Swedish iron; and owes its value not only to the comparative purity of the native ores, but to the fact that, as it is smelted entirely with charcoal, it is not contaminated with sulphur and other impurities which in English iron so materially reduce the conductivity. A high-class English iron is now largely used; it is of fair conductivity and of excellent mechanical qualities.

The mode of manufacture of all kinds of iron wire is very similar. We select the common wire for illustration. The 'pigs' of iron from which 'best best' wire is drawn are first of all 'puddled' in a furnace; the ball of puddled iron is then placed under a very heavy hammer, by which it is beaten out into a compact form. It is then passed between a series of rollers, from which it finally emerges in the shape of a bar, much increased in length and reduced in thickness.

The bar is then passed through what is technically known as the 'rolling mill.' This machine consists of a series of rollers, placed in pairs alternately horizontal and vertical. Each is grooved, but the size of the groove diminishes with each succeeding pair of rollers. Thus as the bar passes through these its diameter is reduced to whatever extent may be desired. The speed of each pair of rollers is controlled by separate driving gear arranged to make them revolve at a regularly increasing speed, for the length of the bar increases between every pair, so that what enters the mill very slowly, finally issues from it at a considerable speed, the increase varying of course according to the diameter to which the bar has been reduced to convert it into wire.

A wire is reduced to a gauge smaller than the minimum size to which it can be rolled by being forcibly drawn when cold through a series of dies whose diameters diminish regularly until the desired size is reached. The drawing operation hardens the wire, so that from time to time during the process it has to be annealed.

The largest iron wire employed for telegraph purposes in England weighs 800 lbs. per mile, and has a diameter of 242 mils. It is used, however, only under exceptional circumstances, or (because of its low resistance) upon very long circuits. The wire in general use for all through circuits weighs 400 lbs. per mile (diameter 171 mils). Two hundred lbs. wire (121 mils diameter) is used for circuits of minor importance. For binding purposes a smaller wire (diameter 66 mils) of the best selected charcoal iron, highly annealed, very tough, soft and pliable, is employed.

Iron wire if left unprotected in the open air speedily becomes oxidised, and to prevent this it is covered with a protective coating of zinc—commonly termed *galvanising*. On first exposure this zinc coating becomes superficially oxidised, and the oxide being insoluble in water ordinarily protects the remainder of the metal from further attack. Where, however, the air is more or less charged with acid vapours the zinc coating is quickly destroyed and the life of the wire correspondingly shortened. Of late years considerable improvement has been made in the method of galvanising; the most approved combines into one the three processes of annealing, cleaning, and galvanising the wire:—The hard iron wire is first tempered by being passed through a heated tube; it is then drawn for a few seconds through a bath of hydrochloric acid, which serves to remove all the surface impurities; it is next guided by means of rollers through a bath of molten zinc. After leaving this the wire passes through a mass of different material—including sand, &c.—which acts as a gentle scraper, and is finally wound on the coiling drums in a thoroughly galvanised state.

The wire should be manufactured in as long lengths as possible, consistent with convenience in handling it when being erected; but on no account should it be welded, for, in the great majority of cases where wires break from any other cause than that of being damaged during their erection or chafed after they are up, it will be found that the breakage occurs at a weld.

Flaws in a newly erected wire, due to impurities in the shape of cinders, &c. which have been allowed to find their way into the bars from which the wire is drawn during the process of manufacture, will make themselves evident on the occasion of the first frost by the wire breaking at the points where they exist. For this reason the bars should be carefully selected from the best material only, and the danger may be still further obviated by using, instead of one solid bar, a mass of metal composed of several different pieces laid together. Thus if eight pieces of iron be piled together—say four 1½-inch billets boxed up in 5-inch tops and bottoms with 3-inch sides—and if these be well wash-heated, and rolled out into bars of about 1½ inch diameter, they will when passed through the rolling-mill produce an entire length of about one-third of a mile of the 400 lbs. size. Iron wire manufactured in this way is found to combine the ductility of strand with the homogeneity of solid iron, and reduces to a minimum any danger of breakages occurring through flaws.

It is essential that the wire employed in telegraphy should be free from flaws, welds, and impurities—and that its power to resist breaking strain should be uniform throughout. Both these requirements are tested by one and the same process, which is as follows:—The galvanised iron wire is placed on a simple loose wheel, or 'swift,' as it is technically termed; from this it is drawn alternately over and under three or more small pulleys arranged in the manner shown in fig. 187. It then passes round a large V sheave, and is finally wound upon a drum which is turned with a velocity greater by about 2 per cent. than that of the V sheave. The strain, which it will be seen is thus put upon the wire, not only tests its strength, but makes evident any defects which it may contain. As a further precaution the coils of wire previously to being issued should be carefully examined by the eye.

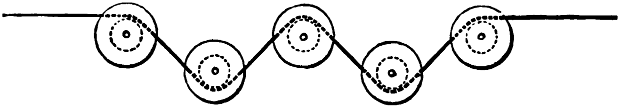

FIG. 187.

There are four mechanical tests to which iron wire may be subjected in order to prove its quality. 1st. It should be capable of being bent backwards and forwards at right angles to itself a certain number of times without breaking. 2nd. It should be capable of being wound around itself a certain number of times without showing signs of splitting. 3rd. It should be able to bear a certain number of twists in a given length without splitting—this is the torsion test usually applied. 4th. It ought to be able to carry a certain weight or resist a certain stress without breaking. This test is carried out either by means of a special machine or by a scale and weights. In the former method care must be taken that the additional strain in testing is not too rapidly applied, otherwise, the wire not having had time to yield to the previous strain, the machine will really show a higher breaking stress than the wire actually possesses ; with the latter the additional weights should not be put on until the wire has been allowed ample time to stretch under the influence of those previously in the scale. It is convenient to set the machine at the specified breaking stress in the first instance, so that the wire may certainly take that as a minimum. The breaking strain will of course vary according to the gauge of the wire ; that for 400 lbs. should not be lower than 1,240 lbs., and for 200 lbs. not less than 620 lbs. Galvanising, although it does not seem to have any appreciable effect upon the breaking strain of the wire, to some extent hardens the iron, and thus diminishes the coefficient of elongation.

The following is a copy of the latest specification issued by the British Postal Telegraph Department for the supply of galvanised iron wire to be employed on their system :—

NOTE.—In the following Specification the term 'piece' shall be understood to mean a single length of wire without weld, joint, or splice of any description, either before being drawn or in the finished wire; a 'coil' shall be held to mean a 'piece' of wire in the form of a coil; a 'bundle' two or more coils properly bound together; a 'parcel' any quantity of manufactured wire presented for examination and testing at any one time. A 'mil' is the one-thousandth part of an inch.

(1) The wire is **to be manufactured from charcoal puddled bars,**[1] to be uniformly annealed, soft, pliable, free from scale, inequalities, flaws, splits, and other defects, and must be perfectly cylindrical, and of one of the sizes shown in the annexed Table, and subject to the hereinafter specified tests.

(2) The wire is to be drawn in continuous pieces of the weights and diameters given in the Table. Every piece may be gauged for diameter in one or more places.

(3) The wire is to be well galvanised with zinc spelter, and this will be tested by an officer (hereinafter called the Inspecting Officer) appointed by the Postmaster-General for the purpose of inspecting and testing the wire taking samples from any piece or pieces and plunging them into a saturated solution of sulphate of copper at 60° Fahrenheit, and allowing them to remain in the solution for one minute, when they are to be withdrawn and wiped clean. The galvanising shall admit of this process being four times performed with each sample without there being any sign of a reddish deposit of metallic copper on the wire, which would be the case if the coating of zinc were too thin. Samples taken from pieces of the 800-lbs. wire shall also bear bending round a bar 2½ inches in diameter without any signs appearing of the zinc cracking or peeling off; the 600-lbs. wire shall similarly bear bending round a bar 2¼ inches in diameter; the 450-lbs. and 400-lbs. wire round a bar 2 inches in diameter; and the 200-lbs. wire round a bar 1½ inches in diameter.

(4) For the purpose of testing the wire as regards freedom from splits, it shall, after having been galvanised, be passed under and over

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[1] The words in thick type are inserted only for charcoal wire.

four or more rollers or pulleys, placed at such distances and in such positions (fig. 187) as the Inspecting Officer shall from time to time determine. It shall then be sufficiently stretched or straightened to remove all bends or sinuosities by passing round drums, either varying in diameter or differentially geared as to speed. This stretching or straightening process to be done to the satisfaction of the Inspecting Officer.

(5) If during the process of straightening more than 5 per cent. of the pieces break or show any defect, the whole of the broken pieces shall be rejected. If not more than 5 per cent. prove defective the whole of the broken coils will be accepted, provided always that the wire passes all subsequent tests, and that no piece be less than 80 lbs. (English avoirdupois) in weight for the 800 lbs., 60 lbs. for the 600 lbs., 40 lbs. for the 450 lbs. and 400 lbs., and 20 lbs. for the 200 lbs. wire. The persons tendering (herein called the Contractors) shall not weld, join, or otherwise splice any such broken pieces of wire as may be accepted, but the separate pieces are first to be bound in separate coils, and then bound together to form a bundle of the standard weight, so that the broken pieces may either be conveniently jointed on the work before being paid out, or be chosen for short lengths when required.

(6) Every piece may be tested for ductility and tensile strength, and 5 per cent. of the entire number of pieces may be cut and tested in any part. Pieces cut for this purpose, or for weighing samples, shall not be welded or jointed together again by the Contractors, but shall be treated in the same manner as the broken pieces referred to in paragraph 5.

(7) To prove its ductility the wire must be capable of bearing the number of twists set down in the said Table without breaking or showing any sign of splitting or other defect. The twist test will be made as follows:—The piece of wire will be gripped by two vices and twisted by one of the vices being made to revolve at a speed not exceeding one revolution per second. The twists to be reckoned by means of a straight ink-mark, which forms a spiral on the wire during torsion. The full number of twists must be distinctly visible between the vices, no fractions being reckoned.

(8) Tests for tensile strength may be made by a lever or other machine which has the approval of the Inspecting Officer, who shall be afforded all requisite facilities for proving the correctness of the machine. The wire shall at first lift a weight equal to at least nine-tenths ($\frac{9}{10}$ths)

of the minimum tensile strength entered in the said Table for the size under trial, and the remaining tenth is to be added gradually, by convenient ordinary weights of not less than one-tenth ($\frac{1}{10}$th) of the remainder, i.e. one hundredth ($\frac{1}{100}$th) of the minimum tensile strength.

(9) The electrical resistance of each test piece shall be reduced according to its diameter and shall be calculated for a temperature of 60° Fahr. ; the length of such test piece shall not be less than one-thirtieth ($\frac{1}{30}$th) part of an English statute mile. In the event of any dispute as to the diameter of any test piece, the Inspecting Officer may have the length in question weighed, and if the weight per mile of any such test piece is either more or less than the standard weight, the resistance shall not be so high as that when multiplied into its weight per mile it would exceed the constant number shown in the said Table, and in all cases where the product is greater than this constant the wire will be rejected.

(10) It must be understood that the tests referred to in paragraphs 3, 7, 8, and 9 are to be applied to the wire after it has been straightened as specified in paragraph 4.

(11) If after the examination of any particular parcel of wire 10 per cent. of such wire does not meet all or any of the requirements of this Specification and of the Table, the whole of such parcel shall be rejected, and no such parcel or any part thereof shall on any account be again presented for examination and testing, and this stipulation shall be deemed to be, and treated as, an essential condition of the Contract.

(12) Each piece when approved by the Inspecting Officer shall be smoothly and uniformly coiled so that the eye of the coil shall not be less than 26 inches or more than 30 inches in diameter, and each coil shall be separately bound with black varnished binders and in no case shall two or more pieces be linked or otherwise joined together.

(13) The coils shall be made up in bundles, properly bound, within the limits of weight shown in the Table. Each bundle of approved wire shall be weighed separately, and its weight (in English avoirdupois) stamped on a hexagonal metallic label which shall be provided by the Contractors, the label being firmly affixed to the inner part of the bundle. The Contractors shall also provide the assistance necessary for properly affixing to each coil or bundle of approved wire, under the direction of the Inspecting Officer, a metallic seal which will be provided by the Postmaster-General.

TABLE REFERRED TO IN THE FOREGOING SPECIFICATION.

Weight per Mile		Diameter		Strength and Ductility						Maximum Resistance per mile of the Standard Size at 60° Fahr.	Limits of Weight of each piece or coil of Wire
Standard	Range allowed	Standard	Range allowed	Minimum Breaking Weight	Required Number of Twists in 6 inches	For Breaking Weight not less than	Required Number of Twists in 6 inches	For Breaking Weight not less than	Minimum Number of Twists in 6 inches		
lbs.	lbs.	mils	mils	lbs.		lbs.		lbs.		Stand. ohms	lbs.
800	767 833	**242**	247 237	**2,480**	15	2,550	14	2,620	**13**	**6·66**	90 120
600	571 629	**209**	214 204	**1,860**	17	1,910	16	1,960	**15**	**8·88**	90 120
450	424 477	**181**	186 176	**1,390**	19	1,425	18	1,460	**17**	**11·84**	90 120
400	377 424	**171**	176 166	**1,240**	21	1,270	20	1,300	**19**	**13·32**	90 120
400	***377*** ***424***	***171***	***176*** ***166***	***1,075***	***20***	—	—	—	—	***11·84***	***90*** ***120***
200	190 213	**121**	125 118	620	30	638	28	655	26	**26 64**	40 65

NOTE.—The lower line of 400 lbs. gives the particulars for charcoal wire.

The actual weight per mile multiplied by the actual resistance per mile must give a constant result. For charcoal wire the constant is 4,736, and for the best quality ordinary wire as specified above the constant is 5,328. For example, with 400-lbs. charcoal wire 400 × 11·84 = 4,736; or with 600-lbs. ordinary wire 600 × 8·88 = 5,328. If the actual weight in either case be higher than the standard, the actual resistance must be proportionately less.

Except when cut for testing or removal of defects, coils must not be bound together in the case of any but the 200-lbs. wire where two coils are to be tied together to form a 'bundle.'

Copper Wire.—At p. 299 the great superiority of copper over iron wire as regards conductivity is pointed out.

In order to attain high conductivity in copper wire great care has to be exercised in its manufacture; thus, Matthiessen found that contact with air when the metal was in a molten state reduced its conductivity 24 per cent., and a mere trace of arsenic reduced it as much as 40 per cent.

For overhead lines, although the question of conductivity is of very great importance, tensile strength and durability are of even greater. When telegraphy first came into practical use copper wire was tried, but proved itself deficient in these requirements. Its ductility and its want of tensile strength and elasticity rendered its use impracticable. The improvement which has taken place of late years in the manufacture of copper wire is due to the attention directed to its production necessitated by the exacting demands made by the users. The result is that 'hard drawn' copper wire can now be produced which has a breaking strain of 28 tons on the square inch; that required of iron wire according to the foregoing specification being about 22½ tons. Copper wire is also less affected by impurities of the air, which is a very important quality, for, in some localities—such as the neighbourhood of chemical works—where iron wire is destroyed in a few months, copper wire has stood eight years' exposure without deterioration. The principal advantage, however, which the use of copper wire presents is its superior electrical qualities. Gauge for gauge its conductivity is more than six and a-half times that of iron; its electro-magnetic inertia (p. 284) is negligible and its capacity (which varies directly as the diameter of the wire) is materially reduced. Hence the employment of copper wire leads to an actual and important increase in the possible speed of signalling on fast-speed circuits, as well as in distinctness of speech and in the actual possible speaking distance upon telephone circuits (see p. 283). For long telegraph lines, therefore, and for telephone circuits, copper is being very generally introduced, and it is probable that its use will be much extended.

The following is the specification for hard copper line wire now issued by the Postal Telegraph authorities:

NOTE.—In this Specification the term 'piece' shall be understood to mean a single length of wire without joint or splice of any description either before being drawn or in the finished wire; a 'coil' shall be held to mean a piece of wire in the form of a coil; and a 'parcel' shall be any quantity of manufactured wire presented for examination and testing at any one time. A 'mil' is the one-thousandth part of an inch.

(1) The wire shall be drawn in continuous pieces of the respective weights and measures given in the Table hereunto annexed, and every piece may be gauged for diameter in one or more places.

(2) The wire shall be perfectly cylindrical, uniform in quality, pliable, free from scale, inequalities, flaws, splits, and other defects, and shall be subject to the tests hereinafter provided for.

(3) Every piece may be tested for ductility and tensile strength, and five per cent. of the entire number of pieces may be cut and tested in any part. Pieces cut for this purpose shall not be brazed or otherwise jointed together, but each length shall be bound up into a separate coil.

(4) The wire shall be capable of being wrapped in six turns round wire of its own diameter, unwrapped, and again wrapped in six turns round wire of its own diameter in the same direction as the first wrapping without breaking; and shall be also capable of bearing the number of twists set down in the Table without breaking. The twist-test will be made as follows: The wire will be gripped by two vices, one of which will be made to revolve at a speed not exceeding one revolution per second. The twists thus given to the wire will be reckoned by means of an ink mark which forms a spiral on the wire during torsion, the full number of twists to be visible between the vices.

(5) Tests for tensile strength may be made with a lever or other machine which has the approval of the officer appointed on behalf of the Postmaster-General to inspect the wire, and hereinafter called the Inspecting Officer, who shall be afforded all requisite facilities for proving the correctness of the machine.

(6) The electrical resistance of each test piece shall be reduced according to its diameter, and shall be calculated for a temperature of 60° Fahr. Such test piece shall measure not less than one-thirtieth ($\frac{1}{30}$) part of an English statute mile.

(7) If after the examination of any parcel of wire five per cent. of such parcel fail to meet all or any of the requirements of this Specification and of the Table, the whole of such parcel shall be rejected, and on no account shall such parcel or any part thereof be again presented for examination and testing; and this stipulation shall be deemed to be, and shall be treated as, an essential condition of the Contract.

(8) Each piece when approved by the Inspecting Officer shall be made into a coil and be separately bound; and in no case shall two or more pieces be linked or otherwise jointed together. The eye of the coil shall be not less than 18 inches nor more than 20 inches in diameter.

(9) Each coil of approved wire shall be weighed separately in the presence of the Inspecting Officer, and its exact weight stamped on a soft copper label which shall be firmly affixed to the inner part of the coil. Each coil as aforesaid shall also have a printed label affixed to it on which shall be written the contract-number, the consecutive number of each coil, and the exact weight as stamped on the copper label; all these particulars shall be entered upon the label by the Inspecting Officer, who will add his initials as a certificate of the correctness of the weight. The Contractors shall also affix to each coil of approved wire under the direction of the Inspecting Officer, a metallic seal, the weight of this seal being deducted from the invoiced

weight of the wire when each delivery is made, or on completion of the order, as may be arranged.

The copper labels shall be provided by the Contractors, the printed labels and the seals by the Postmaster-General; but the Contractors shall provide the assistance necessary for properly affixing such labels and seals.

The wire shall be charged for and invoiced according to the weights specified on the labels.

(10) The approved wire shall be wrapped in canvas, and be delivered as required, securely packed in casks or cases.

A piece of string shall be threaded loosely through all the coils in a cask or case, and the ends of the string shall be sealed by the Contractors in such a way as to effectually prevent the removal of any coil or coils without the string or seal being broken; a label shall be securely affixed showing the number of coils enclosed in the sealed string.

TABLE REFERRED TO IN THE FOREGOING SPECIFICATION.

Weight per Statute Mile		Approximate equivalent Diameter		Minimum Breaking Weight	Minimum No. of Twists in 3 inches	Maximum Resistance per mile of Wire when hard, at 60° F.	Minimum Weight of each piece (or coil) of Wire[1]
Standard	Range allowed	Standard	Range allowed				
lbs.	lbs.	mils.	mils.	lbs.		Standard ohms.	lbs.
100	97½ 102½	79	78 80	330	30	8·782	75
150	146¼ 153¾	97	95½ 98	490	25	5·855	75
200	195 205	112	110½ 113¼	650	20	4·391	75
400	390 410	158	155½ 160¼	1,250	12	2·195	100

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[1] Except in the case of pieces cut for testing, as provided for in paragraph 3 of the Specification.

Bronze Wire.—In special circumstances where a stronger material than copper is required, bronze is used, but it is of a lower conductivity than copper. A silicium bronze wire weighing one hundred pounds per mile is often employed which has a breaking strain 50 per cent. higher than that of copper wire of the same weight, but its conductivity is only half that of the copper. Bronze wire is, however, preferred in some localities where violent storms are prevalent, and where branches of trees are liable to be thrown upon the line, the extra strength obtained being a consideration.

Standard Wire Gauge.—Before quitting the subject of wire it is desirable to draw attention to the gauge according to which it is specified. Until recently this has invariably been what is known as the Birmingham Wire Gauge. This, however, varied with every manufacturer, and there was not only no standard in existence from which it could be corrected, but, from the fact that the basis on which it was originally formed is hid in obscurity, it was impossible to have one reproduced in a reliable shape. The Board of Trade therefore dealt with the matter and issued a standard gauge (see Appendix H) which has at least the merit of being fixed, authorised, and legal.

For ordinary purposes, probably the usual plan of referring a gauge of wire to the dimensions of its diameter is the most practicable; but where, as in the case of telegraph wire, the range is limited to a few easily recognisable sizes, it is quite open to question whether the gauge may not with advantage be referred to some other function of the wire. And when it is remembered that wire is purchased, transported, and distributed along the line by weight, that its breaking strain is in proportion to its weight, that its electrical resistance—varying inversely as its sectional area—is a function of its weight; and, finally, that weight is invariable in all temperatures and latitudes, it will be admitted that multiples of a unit of weight are the natural telegraph-wire gauge. A size of wire dependent upon a number of pounds per mile will be constant as long as pounds and miles exist, and if these units be adopted as a basis there is a ready means of correcting the gauge at all times. At the suggestion of Col. Mallock, then Director-General, the Government Telegraph Department of India adopted an iron-wire gauge of this nature. It is based upon the weight per mile of the wire, and the unit is a wire weighing twenty-five pounds per statute mile; all other sizes of wire are known by their multiples of this unit, and in terms of this unit size the resistance, breaking strain, and comparative strain of the wire upon the insulators or posts can all be readily calculated. This plan has been, at least partially, followed in this country; the specifications just quoted show that the Postal Telegraph authorities in all cases describe line wires by the actual standard weight per mile.

3. *Insulators for Aerial Lines.*

In the manufacture of insulators two points have to be kept in view—1st, the material; 2nd, the form.

1. *The Material.*—The main object, of course, in the selection of this is to find a substance which will offer the greatest possible resistance to the passage of electricity. Nothing has yet been found which will perfectly insulate; nor can a theoretically perfect body in this respect ever be looked for. Porous substances are inadmissible on account of their absorbing moisture too readily, and being thus transformed into conductors. A glaze or surface can, it is true, be imparted to such substances, but no dependence should ever be placed upon a surface glaze for insulating purposes, as it soon becomes cracked, so that a porous insulator then becomes useless. The smooth surface is indispensable, however, for other reasons; with it the conductor is not so liable to be worn through by friction, and dirt and dust, which in damp weather would form a conducting film, will not so readily adhere to a smooth as to a rough surface.

Glass possesses both of the qualifications named above, viz. high resistance to the passage of electricity and a smooth hard surface; but along with these it has one inherent disadvantage which is fatal to its employment as an insulator. It is a very hygroscopic body—that is to say, it condenses the moisture from the air very readily, and, in a climate such as that of England, it is for this reason altogether unsuitable. The surface of a glass insulator will be almost always covered more or less with a thin conducting film of moisture. Glass, moreover, is very brittle, and has been consequently abandoned in favour of one or other of its rivals. Some years ago Mr. Brooks introduced in America a form of insulator manufactured from blown glass, which is stated to have given very good results. These he considered to be mainly due to the 'air surface' of the insulator, nothing but dry air being allowed to come into contact with it whilst it was being manufactured. It is probable, however, that the real explanation of its success was the comparative dryness of the atmosphere in America as compared with that in this country.

Ebonite[1] was at first looked upon as a most promising material for insulators. It offers a very high resistance ; it is strong, and when first used possesses a good smooth surface ; it has an unassuming appearance, and so escapes from wilful damage where glass, porcelain, &c., owing to their inviting look, would run the risk of being broken. The defect, however, which practically precludes its employment as an insulator is that when exposed to the weather its surface rapidly deteriorates. Instead of remaining smooth and hard as when the insulator was first put up, it gradually becomes porous and spongy ; dirt and moisture readily adhere to it, and the insulator is thus deprived of one of the first qualities which it ought to possess.

Porcelain is the material from which are made most of the insulators employed at the present day in England. Its insulating power is high ; it possesses a good smooth surface ; and, provided it has been perfectly vitrified throughout so as to be homogeneous, impervious to moisture, and free from flaws, it is eminently adapted for the formation of an insulator. Porcelain, however, varies very much in its quality ; and unless the manufacture has been carried out with the greatest care, no reliance can be placed upon it. To all kinds of porcelain a glaze can be communicated ;

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[1] Ebonite is a mixture of two or three parts of sulphur and five parts of caoutchouc baked for several hours at 170° F. under a pressure of four or five atmospheres.

and so long as this remains good, so long will the insulator continue to give good results; but, unless carefully manufactured of vitrified material, when the glaze cracks moisture enters, and the value of the insulator is greatly diminished. In order to ascertain the capability of manufacturers to make thoroughly vitrified insulators it is usual to test unglazed ware submitted for that purpose; and when the finished insulators are delivered, a portion of the glaze is ground off some of them to admit of the material being proved.

Brown Earthenware has been very largely used, and is still used to a limited extent in the manufacture of insulators. It does not insulate so highly as good porcelain, nor can it be so perfectly glazed. It, however, possesses the advantage of cheapness over the other materials which have been named.

2. *The Form.*—Equally important as the material of which an insulator should be composed is the form which should be given to it. In considering this, the main object to be kept in view is the same as in the selection of the material, viz. the highest possible resistance to leakage of the current; at the same time the strength of the insulator as a support must not be altogether lost sight of. Seeing, however, that the insulators have little more than the weight of the wire to withstand, except at the terminal poles, no trouble is experienced in suiting the form of insulator to this. The main difficulty which has to be surmounted is the leakage which takes place more or less at every support; every insulator is to a certain extent a fault, and the magnitude of the fault depends upon the form which the insulator possesses. The resistance to the passage of the current depends not so much upon the mass of the insulator as it does upon the configuration of the surface; the most perfect form of insulator will be that in which the surface exposed is a minimum, and the wire is as far as it can be from the insulator's support, due allowance being of course made for the insulator itself being sufficiently strong.

Numerous forms have from time to time been tried. Fig. 188 shows one frequently employed for earthenware insulators. It consists of two separate cups, C and *c*, the inner one being fixed in the outer by means of cement; the iron bolt is also cemented into the inner cup. The principle of the two cups, or *double-shed* as it is called, is now generally adopted in all insulators. The object gained by this form is improved insulation, as the current, to escape from the wire (which is bound into the groove shown), must make its way over the entire surface of the two cups before it reaches the bolt and so gets to 'earth.' It will be seen that while the outer surface is exposed to the cleansing action of the rain to remove any dust or dirt which may have adhered to it, the inner cup is kept dry during wet weather, and consequently continues to offer considerable resistance to the escape of the current.

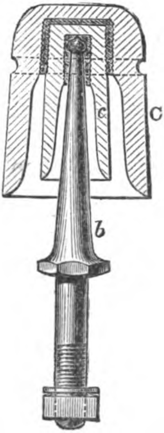

FIG. 188. ¼ real size.

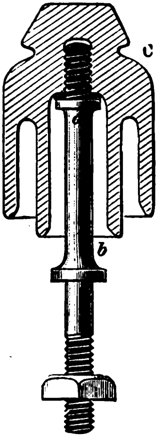

FIG. 189. ¼ real size.

A radical defect of this insulator, however, was the method of fixing. When an insulator was broken, not the cup but the bolt had to be removed, which, owing to rust, was frequently a difficult matter; and the insulator was liable to breakage, not only from accident and stone-throwing, but also from the unequal expansion of the bolt, the cement and the earthenware under changes of temperature. This difficulty has been entirely removed by the introduction of Cordeaux's screw insulator, shown in fig. 189. The principle can, of course, be applied to any form of insulator, but fig. 189 shows the double-shed porcelain insulator most generally used. Improved methods of manufacture enable this to be made all in one piece.

The principle of the screw insulator is as follows: a coarse thread is formed on the head of the bolt, and a corresponding hollow thread is made in the porcelain cup. The bolt is also provided with a shoulder *a*, upon which an elastic ring is placed, and the cup is screwed down upon this shoulder. By this means not only can the cup alone be easily removed at any time to allow of renewal or cleaning, which is a very great advantage, but the india-rubber ring admits of the unequal expansion of the bolt and cup without fracture of the latter, and when from any cause fracture occurs, it is more readily detected and the insulator removed.

When the insulators have to be protected from either accidental or wilful damage, such as that occasioned by stone-throwing and the like, it is customary to cover them with an iron cap, and bind the wire into a small lug upon the surface of the cap. Inconvenience attending the use of iron caps is occasioned by the accumulation of dust, insects, &c., beneath them, which, being protected by the caps from the cleansing influence of the rain, leads in time to a deterioration of the insulation. An effort has been made to get over this by cutting slits in the iron cap, and although this remedies the evil to some extent, yet only where actually rendered necessary by excessive liability to breakage should iron-capped insulators be had recourse to.

Great difficulty is invariably experienced in maintaining good insulation upon lines which skirt the sea-coast, no matter what material is employed or what form of insulator is adopted. The insulator becomes coated with salt, which, being more or less moist, conducts in all except the driest possible weather. The difficulty is greatly increased when the prevailing wind is from the sea. Upon no account should iron-capped insulators be made use of upon such lines as these ; advantage should be taken of the rain to the utmost for washing the salt from off the outside surface at least of the outer cup ; on such lines rain materially improves the insulation. Wire covered with prepared tape is occasionally employed in extreme cases of this nature ; but by chafing against the insulator the tape gradually gets rubbed off, and leaves the wire exposed just at the point where protection of this nature is most required. Open wires skirting the sea-coast should therefore be resorted to only when no other route by which they might be carried is available.

CHAPTER XIV.

CONSTRUCTION—(OPEN WIRES).

A. OVERGROUND TELEGRAPHS.

Surveying.—The route for a line of telegraph, whether by road or by rail, having been decided upon, the next point is to make a careful survey of it. For this purpose the surveying officer should be provided with a book prepared upon the following plan, in which are inserted the requisite particulars to enable him to estimate the total quantity of stores which will be required, and to provide for their being laid out, as well as to make arrangements for obtaining permission to erect the poles where such permission is required.

State here the Locality, Town, Village, Bridge, or Landmark by which the spot to which the first entry relates can generally be identified.

1 No.	2 Distance in Yards	3 Position of Pole	4 Length of Pole	5 Double or Single Stays	6 Length of Strut	7 Reference to Schedule of Consents needed	8 Remarks

Each page contains the particulars required with regard to 13 poles or supports.

Column 1 should show the number of each pole consecutively from terminal station to terminal station.

Column 2. The spans, or the distances between the poles.

Column 3. Their distances from some fixed object, such as the rails on a railway; water on canals; hedges, walls, or ditches on roads. This is done to guide the hole-diggers in case the marks are lost.

Column 4. The length of the pole required; A-poles and double poles being so marked.

Column 5. The position and number of stays.

Column 6. Details of struts.

Column 7. Reference to the schedule of private consents needed.

Column 8. The general remarks should contain any special instructions to the foremen, such as points where terminal insulators, guards, leading-in cups, &c., are necessary, where the line crosses a road, diverges through private property, &c.

The surveying officer should have at least two assistants. They should carry with them a supply of wooden stakes and a can of white paint to mark the position of the poles, and they should likewise be provided with three or more surveying rods, six or eight feet long, shod with a conical spike so that they may be stuck into soft ground. They should be painted in black and white sections each one foot long. These are indispensable if an accurate survey is to be made, especially for a line carrying several wires, for only by their means can an estimate be formed of the amount of the curve, and the consequent strain to which each pole will be subjected ; and without this information the requisite provision for suitable timber and proper staying or strutting cannot be made. The positions of the poles may be marked in various ways : the plan which has been found to answer best is the insertion of wooden stakes in the ground, aided by a distinctive mark of white paint on neighbouring walls, fences, &c., to provide against the stakes being removed.

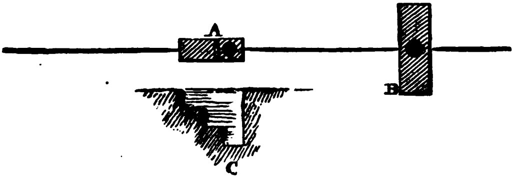

FIG. 190.

Hole-digging.—The operation of digging a hole for a telegraph pole, although to all appearance simple enough, yet requires more experience than at first sight would be imagined. The holes should invariably be dug in the line of the wires, as at A, and never at right angles to it, as at B (fig. 190), the object being to get the solid natural earth as much as possible in the line of the lateral stress of the wires.

The rectangular opening which is thus made averages about four feet in length by one in width : this size is continued to a depth of about two and a half feet below the surface, whence, by a step-like arrangement, the length of the opening is gradually curtailed, until at the bottom it does not exceed one foot, as shown in c.

As little of the ground as possible should be disturbed, for no matter how well the punning and ramming may be done after the pole is planted, yet a considerable time will always elapse before the earth settles back to its former condition, and the more the ground has been disturbed the less is the pole able to withstand any strain that may be put upon it during this time.

For this reason various tools have been devised whose object is to remove only just sufficient earth to admit of the pole being planted ; and which, in addition to effecting this, combine several other incidental advantages of considerable value. When it is borne in mind that in order to dig a hole four feet six inches deep for an ordinary telegraph pole, by the pick and shovel in the usual method, no less than twenty-three cubic feet of soil, representing a weight varying from 2,600 to 3,000 pounds, according to the nature of the ground, have to be removed, whereas not more than three and a-half cubic feet, or about 376 pounds, need actually be disturbed, it will readily be understood that many attempts at improvement in this branch of telegraph construction have been made.

One of the earliest efforts made in this direction was in Spain, where a tool, since known as the *Spanish Spoon*, was devised. Various modifications have from time to time been introduced, but they are all constructed on the same principle, which is that shown in fig. 191.

It consists of a segment of a metallic disc *a*, the chord of which serves as a cutting edge. The periphery is fitted with a ledge *c* two inches in height, which serves to retain the accumulation of the soil upon it. The whole is fitted to a wooden handle *b*. The adjunct to the spoon is a long bar, by means of which the soil is first loosened : the spoon is then inserted, and a rotating motion is conveyed to it so that the earth is heaped up on the blade; the whole is then removed, and the bar again employed. For light lines, on which the poles need not be inserted to a greater depth than four feet, the *Spanish Spoon* answers the purpose for which it is intended very fairly; but for heavy lines, where holes varying from six to seven feet in depth are required, it cannot be pronounced a success. The difficulty of loosening and collecting the soil increases to a very great extent with the depth, and the advantage which at the outset it possesses over the pick and shovel in point of speed is almost, if not entirely, lost before a six or seven foot hole is completed.

Earth Borers represent more elaborate attempts to provide for the excavation of holes. Various kinds have been tried, but those most generally known are the inventions of Spiller, Bohlken, and Marshall.

Spiller's is but a modification of the ordinary ship's auger on a large scale, which is forced into the ground, and in clay or sand has been found to work well.

Marshall's borer, although resembling Bohlken's, has several distinctive features about it. The general arrangement of the apparatus is shown in fig. 192. The cutting blade consists of a metal disc cut from the centre to the circumference, and having the two edges bent into the V-shape shown. The lower forms the cutting edge, and as the apparatus is rotated, the earth passes through the radial V opening on to the upper surface of the blade, from which it is

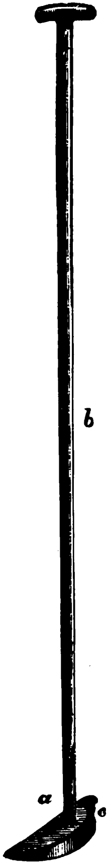

FIG. 191.
$\frac{1}{18}$ real size.

removed from time to time by lifting the apparatus out of the ground. The stock to which the blade is attached is squared at the end, and has screwed on to it a tapering metal point, which, in addition to serving as a nut, plays the

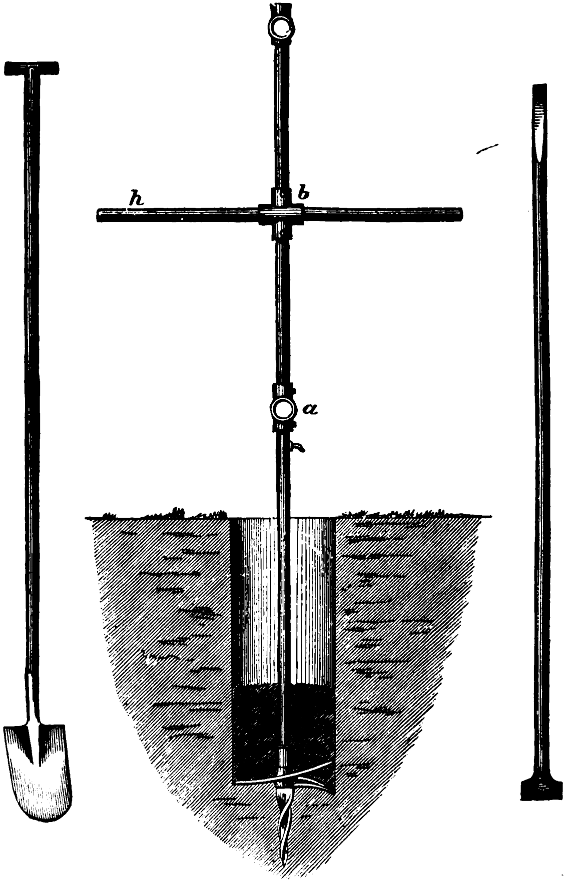

FIG. 192. $\frac{1}{24}$ real size.

part of a drill in front of the cutting-plate, and so to some extent facilitates its work. The stock is attached to two or more sections of tube, according to the depth of the hole: these are provided with cross sockets, as shown at *a* and *b* in fig. 192, to admit of the insertion of the handle *h*, which is employed for rotating and lifting the apparatus.

The 'punner bar' forms an essential feature of Marshall's borer. It is shown to the right in fig. 192. One end of this is tapered down to the form of a chisel, with the point tempered to deal with stones, and is used for loosening the soil as well as breaking and removing as far as possible whatever obstacles are met with in the hole: the other end, which is shaped like a punner, is employed for ramming and consolidating the soil around the pole when once planted. The borer is rotated by two men walking steadily round and pushing the handle before them: at intervals it is lifted, and the earth removed: the chisel end of the punner bar is inserted, if need be, to loosen stones or other obstacles, and the process repeated. A shovel attached to a long handle, shown to the left in fig. 192, should likewise accompany the apparatus. In sandy or gravelly soils it is employed to remove the loose earth which does not adhere to the blade of the borer.

In the latest form of borer brought out by Marshall, the tapering metal point is entirely dispensed with, and the cutting-plate itself is in the form of a screw, and thus acts both as a drill and cutting-plate. This apparatus is cheaper than the earlier issue, and for light work can be worked by one man. Beyond this it possesses no other feature calling for special remark.

An evident drawback to the general employment, even in suitable soils, of a borer of this form, is the impossibility of working it by the sides of fences, where, in road telegraphy, poles have generally to be placed. Another drawback is the enormous strain thrown upon the men when lifting a load out of the hole, especially when some considerable depth has been attained: for in a clay soil, or if the ground is close, not only is there the weight of what has accumulated on the plate to be lifted, but that of a superincumbent column of air as well. The difficulty was got over by inserting a small valve which can be opened at will by the workmen, and greatly facilitates the raising; perhaps the best cure, however, is to lift the borer more frequently, and not to accumulate such heavy loads upon it. The difficulty in raising heavy poles so as to let them slip into the holes which have been prepared for them is a decided disadvantage inherent to the employment of all earth borers: light poles can be handled easily enough, but the same cannot be said when poles from thirty to forty feet in length, or even more, have to be dealt with. The only possible way of lifting them is by means of shears, which have to be carried about with the gang of workmen employed; and although the work can then be performed with comparative ease, the multiplication of tools is always a disadvantage more or less, and, in countries where roads do not exist along the routes of the telegraph lines, should be avoided to the utmost.

Thus the disadvantages incidental to the employment of special appliances of the above type are found in practice to outweigh their advantages. They cannot be employed in rocky soils, they are of no service for stay holes, nor can they be used for strutted or A-poles where blocks or ties have to be bolted on below the ground. Sets of ordinary tools must therefore be carried, and on modern heavy lines the use of special borers is thus so very restricted that it is scarcely worth while to burden the gang with their extra weight. Only for comparatively light lines in other than rocky soils can such tools be used with advantage.

Pole-setting.—Poles are, as a general rule, planted in the ground to a depth of one-fifth of their length when under thirty feet long. They should never, however, be buried less than four feet, and need not as a rule be more than six in good solid earth, but for very long poles or in soft ground a greater depth should be allowed. In embankments, and all made or loose ground, they are planted about a foot deeper; whereas in rock, where blasting has to be had recourse to for the purpose of excavating the hole, they may be set a foot less than in the general case. As a check upon this portion of the work being honestly performed, the poles, before being issued, are branded at a distance of ten feet from the bottom with a distinguishing mark, and beneath this is given the year in which they were felled. Poles planted upon a curve should invariably be set a trifle 'against their work;' that is to say, they should bear slightly against the lateral strain of the wires. If this is done it will generally be found that by the time the ground has set perfectly hard the tension of the wires will have pulled them into the perpendicular position; whereas, if this precaution be neglected, and the pole be planted perfectly upright at first, the stress of the wires is almost certain to remove it from the perpendicular, and, apart from any other consideration, make anything but a sightly object of it.

Too much stress cannot be laid upon good sound punning. The earth, as it is thrown in, should be thoroughly well punned at every stage: the hole should not be hastily filled up, but ample time be given to the punners to do their share of the work. Stones, if available, may be employed with advantage to assist in ramming the pole against the side of the hole where the earth has not been disturbed. Upon the punning and ramming of the holes being carried out as they ought to be depend to a large extent the stability and good working of the line when once erected.

The number of poles per mile and their length will vary according to the route and the number of wires which they are intended eventually to carry. No hard-and-fast line can be drawn. For minor road-lines, or the branch lines upon railways, twenty or twenty-two to the mile may be adopted; but on trunk lines the number should be between twenty-six and thirty to the mile. The length of the poles will depend not merely on the ultimate number of wires to be supported, but also on the obstacles which have to be surmounted. On roads 22 feet is the minimum length except on one-wire extensions, where 20 feet may be employed. On railways 20 feet is the usual length, although on branch lines 18 feet, and even 16 feet, have been occasionally used. One foot is then allowed in addition to these lengths for every two wires that have to be erected. The lowest wire should never be less than 12 feet from the ground; and at all crossings, whether on roads, railways, or anywhere else, the minimum is raised to 20 feet. When it becomes necessary to vary the length of the poles, the variation should take place gradually: the appearance of the line is thereby not interfered with, and the increased vertical stress which would otherwise be thrown upon the insulators is avoided. For instance, if in a line of 22-feet poles the necessity arises for employing a 26-feet, the pole on each side of it should be a 24-feet.

Upon roads and railways poles should be planted upon that side where the prevailing winds would tend to blow them off the roadway or rails. Similarly, if the route is tortuous, the inside of the curve should be selected, so that the wires may be kept as clear as possible of the traffic. Due regard should at the same time be had to the facilities for staying or strutting; and for this reason, as well as to prevent the possibility of vehicles coming in contact with them, they should be planted as close as possible to the fences on roads, and as far as possible from the metals on railways, retaining them, however, within sight of passing trains to allow for the observation of breakdowns. On embankments and cuttings they should be placed just so far down as will admit of their being stayed both ways, and in such a position that in the event of their falling they may fall on the embankment and clear of the traffic; they are then protected also from the violence of the winds. In the case of steep cuttings the top is to be preferred to the slope, and the poles when so placed should be stayed on both sides, as shown in fig. 193. This applies to poles in any exposed position, no matter in what direction the lateral strain of the wires may be; for the influence of the wind upon the area exposed to it, and more especially when the wires are coated with snow, must be carefully guarded against in every direction.

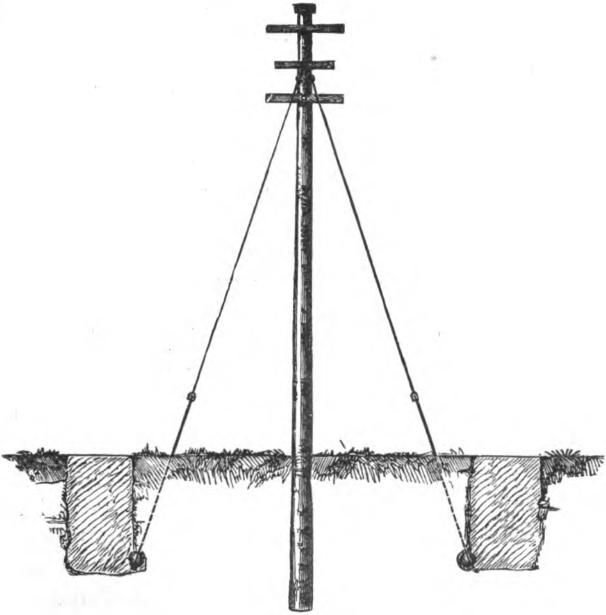

FIG. 193.

Although it is very desirable to preserve the poles as nearly as possible in a straight line, yet it is highly objectionable to do so when to attain this object they will have to swing either across or over the roads. Every crossing of a road by the wires introduces an element of danger, and should be had recourse to only when absolutely essential:

more than one accident has arisen from their breaking or running back at these points in gales, frosts, or snow-storms. Occasions may of course arise when by crossing the road a decided advantage is gained, as, for instance, when by so doing the inside of a curve is secured for some distance; and less danger results from taking this step than by leaving the wires to follow the outside of the curve.

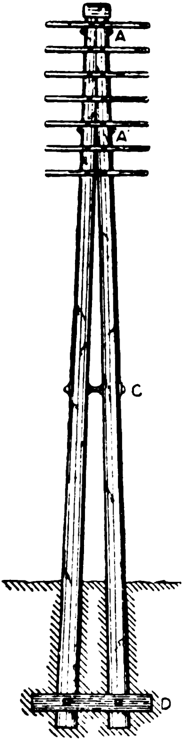

FIG. 194.

At points where no facilities for staying or strutting exist, or where, on account of the number of wires, sound timber of sufficient strength cannot be obtained, *A-poles* are made use of. One of these is shown in fig. 194. It consists of two ordinary poles scarfed at the top so as to fit into each other closely, and united together by means of two bolts, shown at A, A′. The distance between them at the base varies according to circumstances, but should never be less than 18 inches. Rather more than half-way down, at C, a tie-rod is inserted to aid in holding them together, whilst at a distance of about 18 inches from the butts a piece of timber, D, is mortised and bolted on to both. Without this there is a tendency for one pole to cant the other out of the ground, which the superincumbent earth over D prevents.

Where several lines converge or where the number of wires is very large, H-poles are employed. Such a combination is shown by fig. 195. For ordinary telegraph lines the poles are placed 3 feet apart and for telephone lines 18 inches apart in the clear; the general construction is, however, the same. At the upper extremities the poles are united by arms of suitable length, and a timber brace is notched in and bolted to the butt ends. In order to secure lateral rigidity a system of trussing is resorted to, converting what would otherwise be two independent supports into the equivalent of a lattice girder. The truss rods (in the case of poles 18 inches apart) are 3 feet long by ⅝ inch in diameter and they are attached to the poles by ¾ inch tie-bolts, over each of which is placed a wrought iron tube of one inch internal diameter of sufficient length to keep the ends of the truss rods well against the poles. The other end of each rod is screwed and passes through a ring; two locking nuts are provided so that the requisite tension may be placed on the rod. The ring and nuts also afford a means of tightening the rods should they subsequently become elongated. The lowest tie-bolt is placed six inches above the ground line, and three sets of truss rods are employed.

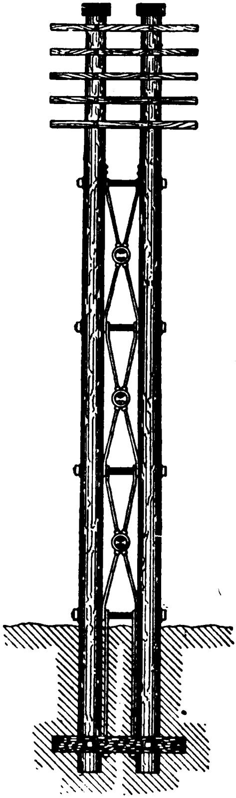
FIG. 195.

Tarring.—Poles erected in their natural condition, without having been subjected to any preservative process, should be allowed to remain until well seasoned, when the ground should be opened out around them to the depth of a foot. They should then be tarred to a height of three feet above the ground line, and upon roads where by any possibility they could be run against they ought to be painted white for three feet or more above that, so as to render them clearly visible at night. Above this they may be painted or tarred, according to circumstances. Tarring is to be preferred, unless there are local objections to its being done. The recipe for tar has been already given (p. 289); the following is the mixture for paint usually adopted in England :—

For 100 lbs. of paint—

White lead	70 lbs.
Driers	8 lbs.
Ochre	¾ lb.
Umber	½ lb.
Raw linseed oil	7 quarts
Boiled oil	3½ quarts
Turpentine	3 pints

Numbering.—Upon every telegraph line exceeding a mile in length the poles should be numbered after the line has been erected. The work of maintenance will be thereby greatly facilitated, for no difficulty then exists for the inspecting officer to indicate the position upon the line of whatever requires attention.

Staying and Strutting.—It has been already remarked (p. 325) that the stability and efficient working of a line depend in a great measure upon the manner in which the punning is done, but however well this is done it does not, of course, prevent the pole from bending or taking a set above the ground line; and occasions frequently arise when poles cannot be made sufficiently strong or stable to resist unaided the forces which are brought to bear against them. Artificial means must then be had recourse to in order to supply the additional strength required; and for this purpose *stays* and *struts* are employed. By a *stay* is meant whatever takes the pull or tension of the forces acting upon the pole; by a *strut* is understood whatever takes the thrust or pressure of such forces. The former consists of an iron wire, rope, or rod; the latter, in England, is usually timber of the same class, and subjected to the same treatment, as the pole which it is intended to strengthen.

Stays.—The wire rope forming these stays is as a rule supplied specially manufactured for the purpose, but it is frequently found necessary to make them of wire upon the spot, in which case No. 7½ (400 lbs.) iron wire is employed. Several lengths—their number depending upon the work which the stay is required to perform—are twisted together by hand in long lays. Close twisting should never be had recourse to, nor should the wires be simply placed together without a twist; for under either of these conditions each single wire is not certain to take its proper strain, so that the total strength of the stay may be thereby reduced. No definite rules can be laid down as to the number of wires which should be used in the formation of the stay, seeing that so much depends upon the angle which it will make with the pole when fixed; yet upon roads stays of less than three wires laid together should never be employed, and this number should be increased according to the number of wires on the pole, the curve on which the pole is placed, and the angle which the stay makes with it. On straight roads it may generally be said that for a line of six wires a strand of three No. 7½'s will be sufficient, and for any number from that to thirteen wires seven No. 7½'s.

The main object to be kept in view in the formation and fixing of the stay is to obtain the maximum of efficiency out of the materials which are employed in it. For this purpose it should be fixed at, or as nearly as possible at, that point where the whole force which it is intended to counteract may be supposed to be collected—known in mechanics as the *resultant point*—and it should be placed in such a position as to form with the pole as great an angle as possible up to 90°. The resultant point may be assumed to be about midway between the top and bottom wires. The best possible direction in which the stay can act is at right angles to the pole; as it falls from this and gradually approaches the line of the pole itself, its effective power to resist the horizontal stress of the wires becomes less ; and to make up for this loss of efficiency increased strength of material is necessary.

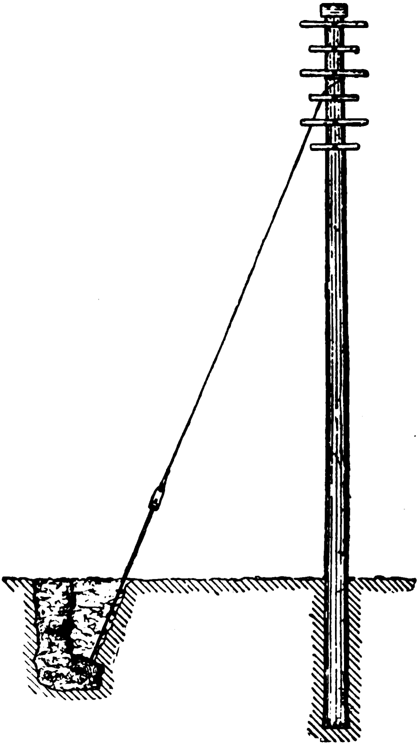

FIG. 196.

The lower end of the stay is fixed to the eye of a galvanised iron rod (fig. 196) from six to eight feet in length. This stay rod is passed through a block of creosoted timber three feet to four feet six inches in length ; the square head of the rod banks upon a suitable iron washer under the block, which is then buried to a depth of from three feet six inches to five or six feet in the ground. The hole for the stay-block should be under-cut in the manner shown in fig. 196, so that the stay-block may have firm solid earth to press against, and thus be prevented from drawing.

The attachment of the stay-wire to the pole and the stay-rod is a matter of considerable importance. Where the stay passes through the eye of the stay-rod an iron thimble should be employed. The stay-wire is first bent around this and made to lie closely in the groove of the thimble at a distance (according to the number of wires in the stay) of from thirteen to twenty-two inches from the end. This end is then unstranded and the splicing effected by means of the tool shown in fig. 197. Pick out one strand and lay the others longitudinally around the main stay, the tool being placed

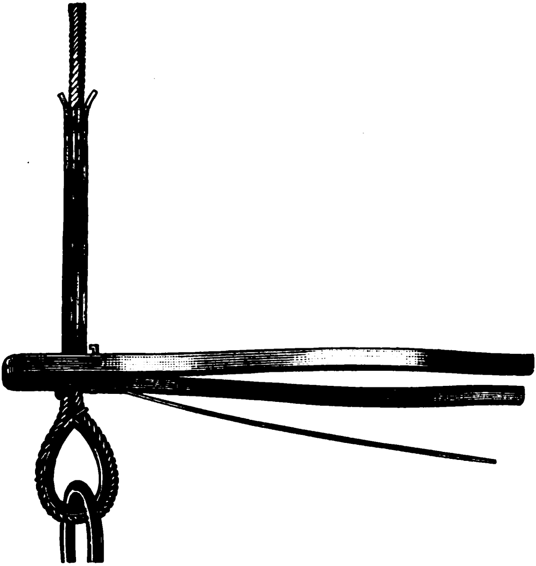

FIG. 197.

over all with the single strand beneath the hook on the thimble side. By gripping the tool and revolving it, the single strand will bind closely around the stay and the remaining wires. It should make eight laps. There will of course still be a considerable length of the remaining strands not bound in, and one of these should be similarly selected and bound round the remainder, and so with the other loose ends until all have been bound round the main stay. The attachment of the stay to the pole is effected by first taking a double turn with the stay round the resultant point on the pole, fastening with suitable staples, and splicing the loose end and the main stay with the tool as just described.

Should any difficulty exist in the way of fixing the stay at the resultant point, a forked stay similar to that shown in fig. 198 should be employed, whose wires, coming from E and D and uniting at B, are continued on and fixed to the stay-rod. In such cases the two forks should be so placed that the main stay A B, if continued in a straight line, would strike the resultant point.

After having been erected for some time stays are liable to become slack, especially if the strain upon them is not constant. A *stay-tightener* therefore becomes necessary, and is fixed at the upper extremity of the stay-rod. A very useful form consists in a galvanised iron loop rivetted hot into a malleable cast-iron cross-head. Through this cross-head passes the end of the rod, upon which a screw-thread is cut, and the screwing down of a nut upon the rod serves to tighten the stay.

Where a single stay does not suffice, or where it is inconvenient to remove the loop and alter the position of an existing stay, a second stay may be employed. If this be done, both stays may meet at the same point, a rod and block of suitable size being employed; and each branch of course having a tightener. A better plan where the original stay is not fixed in the resultant position, or where that position has been shifted by the addition of more arms to the pole, is to provide a second stay parallel to the first, and to fix it as much below the resultant point as the other is above it.

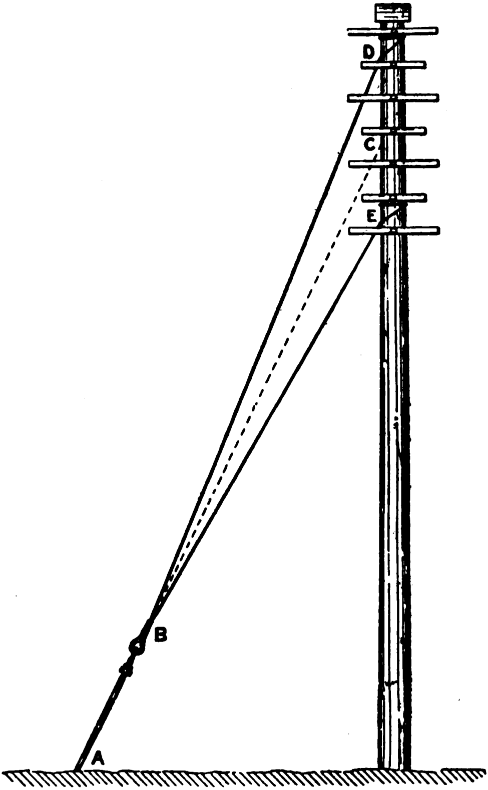

Fig. 198.

As there is always a danger that faults may arise from the wires expanding and touching the stays, by means of which the current finds 'earth,' the stay-wires should be at least three inches distant from the line wire nearest to them, and where this cannot be effected by applying the ordinary means of affixing the stay to the pole, an iron arm or bracket to take the stay clear of the arms should be employed.

Upon a line carrying a very large number of wires it is very advisable to stay the poles on both sides *in the line of the wires* at a distance of about every quarter of a mile. The object of this is to prevent the poles from being drawn from the upright in the event of an accident occurring to the line. The breakage of the wires, either through a pole being knocked over or (in the case of overhouse work) from fire, imparts a sudden strain, which, unless it be resisted, makes itself felt for a long way upon the poles on both sides of the accident.

The greatest care must be taken in staying all terminal poles, for they form as it were the keystones of the line, and upon their being properly seen to its appearance to a great extend depends. To guard as far as possible against their yielding, iron rods may be employed, although wire stays can be made quite effective. The strength of the stay should obviously be equal to the sum of the breaking stresses of all the wires terminated on the pole, allowance being made for the fact that the actual stress on the stay will vary inversely as the distance between the point where it is anchored and the base of the pole; this distance should, as a rule, never be less than the height above ground of the terminal pole. Under these conditions, the maximum stress on the stay will be roughly equal to one and a half times the sum of the breaking stresses of the wires terminated. Thus, with twelve wires, each having a breaking stress of 1,200 lbs., the maximum stress along the stay will approximately equal 1,700 lbs. for each wire; and a one-inch iron rod with a breaking stress of twenty tons per square inch will satisfactorily resist this stress.

If a stranded stay of No. 8 steel wire with a breaking strain of 1,400 lbs. for each wire be employed, the number of wires in the stay should be one-fourth more than the number of line wires to be terminated under the same conditions as above. If the stay base should necessarily be shortened, then the strength of the stay (whether it be a solid rod or a stranded wire rope) must be proportionately increased. The stay-blocks employed for terminal poles should be much larger than those for ordinary stays; they should be buried in the ground to a depth of from six to eight feet, and the ramming and punning carried out with even more than usual care. Where it is possible to attach the rod to a good sound permanent building instead of using a stay-block at all, it is advisable to do so. Upon terminal poles where the wires form an angle anything nearly approaching a right angle it is preferable to place two stays, one in the line of each component strain, rather than a single stay in the direction of the resultant of these; for by doing so provision is made against accident—in the same way as staying a crowded line in the line of the wires (p. 336)—from any sudden stress being thrown from either quarter upon the pole.

Struts.—It is more difficult to erect struts to satisfactorily withstand heavy stresses than is the case with stays, so, as a rule, where the latter can be safely employed they are to be preferred. In fixing a strut the same object must be kept in view as in fixing a stay, but it is preferable to fix the strut at that point of the pole which, allowing for future requirements of the line, will ultimately be the resultant point (fig. 199). The guiding principle in the erection of struts is so to fix them that they will act both as struts and stays, and thus be able to withstand both pressure and pull.

But the more convenient method of fixing a strut is shown by fig. 200. It is placed in the ground to a depth of not less than four feet, and attached to a creosoted block B (similar to the stay-block) which is slightly mortised into the strut and fastened by a bolt; and a similar block A should be attached to the bottom of the pole. The strut, like the stay, should form as great an angle as possible with the pole, for the same principle regulates the direction of both. The pole should not be weakened by being cut in any way where the strut is attached, but the top of the strut should be neatly scarfed, so as to fit the pole as closely as possible. At the points of contact both should be carefully tarred or painted for the purpose of making the joint watertight. The pole and strut are firmly secured together by means of one ½- or ⅝-inch bolt. In the case of poles fitted with two-wire arms (fig. 199) such as are used for ordinary telegraph lines, the strut is fitted to the pole at the resultant point, or, if the line is not fully fitted, the strut is fixed at the position which will become the resultant point when the pole is carrying the full complement of wires. Where four-wire arms are employed it becomes necessary to fit the strut below the arms, and extra stiff poles must then be used (fig. 200).

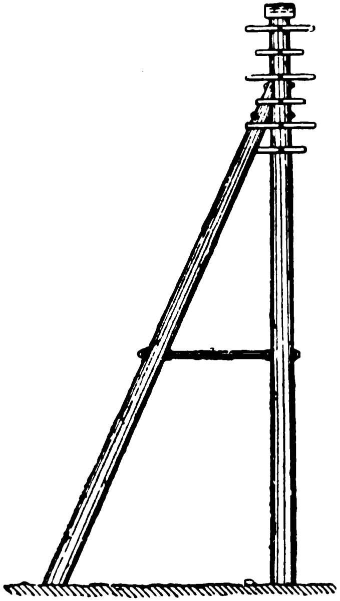

Fig. 199.

Fitting-up the Pole.—With the exception of placing the spindles and insulators, this is always done before the pole is planted in the ground. The first point in fitting-up the pole is to protect the top from the effects of the weather. For this purpose galvanised iron roofs of the shape shown on the pole in fig. 201, and of a uniform size, are invariably employed in England. The pole is cut to fit them, and they are then nailed on with two 2-inch clout nails. Before the roof is nailed on, the top of the pole should be either painted or tarred. If a wire is to be run along the top of the pole a support for the insulator, of the form shown in fig. 201, known as a *saddle bracket*, or simply a *saddle*, is placed over the roof. A small aperture about an inch square is cut in the middle of the roof, and a hole about an inch deep in the top of the pole. The insulator spindle is passed through the saddle and the roof, and tightly screwed up by a nut on the under side. The whole is then fixed to the top of the pole by 3-inch galvanised iron nails.

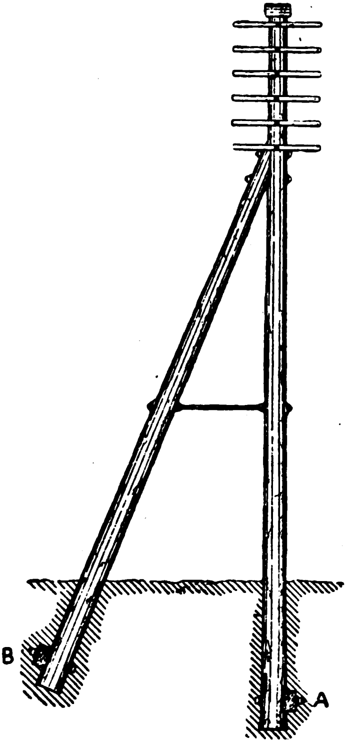

FIG. 200.

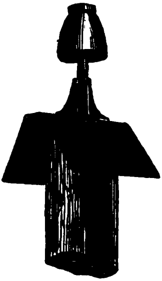

FIG. 201.

The supports for the insulators are either *arms* or iron tubes and *brackets*, the latter being used only under exceptional circumstances. The arms in England are of oak, thoroughly seasoned previous to being issued. When only two wires are erected on each arm, two lengths of arm are employed, 24 inches and 33 inches, the scantling of both being the same, viz. 2½ inches square. The unequal lengths are adopted for the purpose of allowing one wire to fall clear of that beneath it in the event of the insulator supporting it being broken or the binding giving way. They are therefore fixed alternately, the longer arm generally being uppermost. When four wires are erected upon each arm, the usual length is 48 inches; but longer arms are employed for double poles and in exceptional cases.

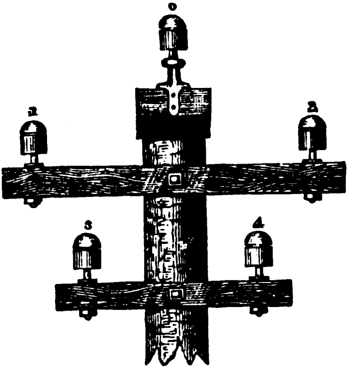

FIG. 202. Up Side of Pole.

The first arm is placed 9 inches from the top of the pole, and the others should be 12 inches apart, measured from centre to centre; they should all be on the same side of the pole; in England the 'up' side, that is, the side in the direction of the 'up station,' is adopted, and the groove into which they are fitted should never exceed 1½ inch in depth. The arm is held in the groove by means of a galvanised iron bolt, which passes right through both the pole and the arm, and varies in length from 7½ inches upwards, according to the scantling of the

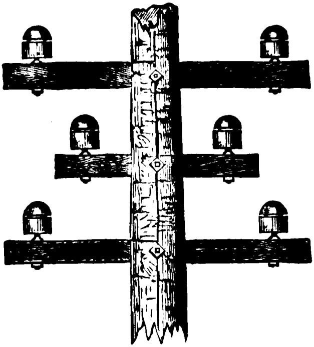

FIG. 203. Down Side of Pole.

timber. The head of the bolt on the 'down' side of a pole (fig. 203) beds upon a washer, whilst on the 'up' side in front of the arm, as shown in fig. 202, a nut with a washer clamps the arm in position.

Pole-brackets, except the saddle brackets already alluded to, are of a tubular form (fig. 204), and made of malleable iron. They are secured to the pole by means of three coach screws. They are used when a second wire has to be run along a line already carrying one wire, and where there is but little likelihood of another being required for a long time to come; they may also be used on poles where, brackets having been already employed, it is desirable to preserve a uniform appearance. In such a case they should be placed alternately on opposite sides of the pole as shown in fig. 204 and spaced six inches apart, the uppermost one being eight inches from the top. They ought never to be fixed in the same horizontal plane, for if this be done the risk of contact in the event of the insulators getting broken or proving faulty is incurred. The screws would often touch each other in the head of the pole, and on the breakage of the insulator form a short-circuit across from one wire to the other. Brackets of special construction, and known under the general name of single or double *bridge brackets*, are made use of when brickwork or masonry has to be employed as the support; these require no special description. The single and double bridge brackets are both shown in fig. 205. Iron tubular arms, similar to those described on page 339, are now being extensively employed with wooden posts.

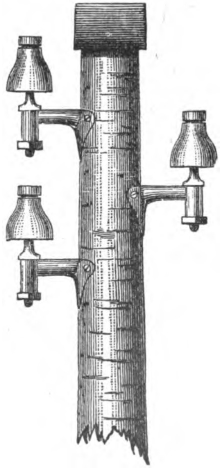

FIG. 204.

One most important part of the fitting of a pole has yet to be described. If an insulator becomes faulty a portion of the current passing along the wire attached to it escapes; and, provided there be no other wire upon the line, makes its way entirely to earth by means of the pole. The only evil resulting from this is a weakening of the signals, which, until the defect is made good, can be remedied by increased battery power. But if there be two or more wires upon the line, the leakage from any one will then, instead of going to earth, partly pass to the other wires—not entirely, but to an extent depending upon the electrical resistance which the pole offers in comparison with the materials intervening between all the wires. The working of wires is thereby more or less interfered with—the wires appear to be in 'contact.' An increase of battery power, instead of doing any good, is now positively injurious, for it serves merely to increase interference arising from the leakage. The only way to get rid of the inconvenience which is caused is to afford the leakage a path to earth the resistance of which is inappreciably small compared with that which exists between the wires. This path is afforded by the *earth-wire*, a 400-lbs. galvanised iron wire which is carefully stapled to the pole, passing from above the roof to the butt, with a sufficient length to admit of a spiral or two being formed below the pole so as to ensure good contact with the ground. The earth-wire should be placed beneath the washers of the bolts that fix the arms, being stapled close round the arms if fitted on the up side

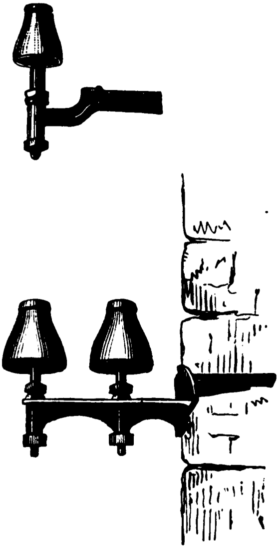
FIG. 205.

of the pole. In fig. 203 it is shown on the down side of the pole, but it should always be fixed on that side of the pole where there is least likelihood of its being tampered with. The wire is carried, clear of the roof, a few inches above the pole, so as to serve as a lightning conductor, protecting the pole and wires from damage by lightning.

It is of the utmost importance that the earth-wire should make good earth ; if this cannot be secured it is better not to fix one at all, for it would merely tend to promote contact amongst the wires rather than to prevent it. In dry sandy soil, or in rock, earth-wiring is therefore to be avoided ; but if any considerable extent of line is so situated it may often be found advisable to carry a special wire along the poles for the earth-wires to some spot where a good earth can be found. Of course insulators are not required for such a wire.

Upon long lines earth-wires render most important service, whether an insulator is actually faulty or not ; for, seeing that up to the present time no really perfect insulator capable of withstanding the effects of weather has been devised, the slight leakage which inevitably takes place at each would otherwise pass into the neighbouring wires, and the sum-total of these would on a line of considerable length tell upon the working of the circuits, more especially if delicate fast-speed instruments are employed. It has been urged as an argument against the use of the earth-wires that the inductive capacity of the line-wires is increased where they are adopted. There can be no doubt that this is the case, but no practical inconvenience has ever been found to result ; and even if it did, the evil could be but slight compared with that which the employment of earth-wires successfully prevents.

On iron poles earth-wires are, of course, unnecessary.

Fixing Insulators.—When the pole is raised, the next step is to fix the insulators in the supports, whether arms or brackets, by placing the spindles into the holes prepared for them, and securing them from beneath by a nut and washer; it is essential that this should be made as tight as possible. The insulators, before being actually fixed, should be thoroughly well cleared of all dust and dirt adhering to them, for this, if left, would tend seriously to impair their efficiency.

Terminals.—Where the wire either actually terminates or goes off at a sharp angle, the stress thrown upon the insulator is very great, and there is considerable risk of accident to the public through the wire flying into the road, especially when the outside of a curve is selected. An ordinary insulator is not constructed to bear the heavy leverage thrown upon it when a wire is thus situated; the bolt may bend, and the porcelain or earthenware break. For these reasons a special form of insulator, known as a *terminal insulator* and constructed to withstand considerable stress, is employed. At one time *shackles* of the form shown in fig. 206 were invariably used in such cases; but, although mechanically they are well adapted to resist heavy stresses, electrically they are very bad insulators, and are only fit for use on lines so short that even a considerable amount of leakage is of little importance. The present practice in the case of sharp angles is to use insulators fitted on steel spindles of extra strength, and made with a broad flange to give a considerable bearing upon the arm. For actual termina-

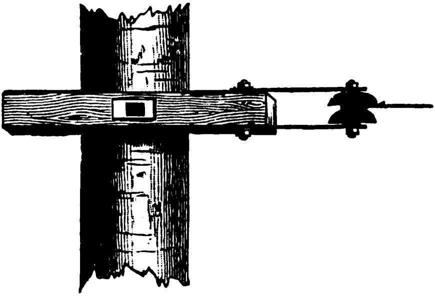

FIG. 206.

tions, special large terminal insulators on extra strong steel spindles are employed. The arrangement is shown by fig. 207. The pole P is of rectangular section, and the arm A is bolted to one side in line with the wires.

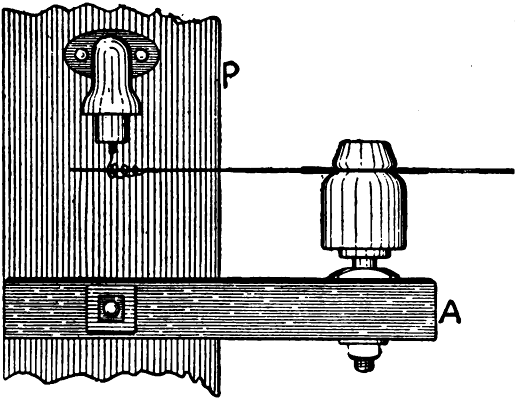

Fig. 207.

The extra stress on the saddle at the top of a pole at a sharp angle is provided for by what is known as a *saddle stay*. This is shown in fig. 208. The pole roof and saddle (which are fitted to the pole in the usual way) have a galvanised iron band, A, placed over them as shown; the flange of the steel insulator spindle then clamps it in position. In fitting-up, a wedge of hard wood, B, is fixed to the front and to the back of the pole, so as to fill up the space between the pole and the edge of the roof in each case, and the stay beds down upon these wedges and is fixed by means of two 3½-inch coach screws.

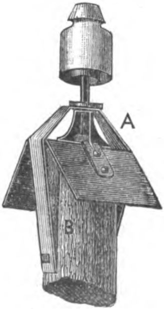

Fig. 208.

Guards.—Upon every curve, or even upon the straight, where, in the event of the insulator being broken, there is a possibility of the wire coming into harm's way, guards should be employed. They are of two kinds, hoop and hook. The hoop guard is now practically never used in England, for, in winter, snow adhering to the hoop in time brings wire and arm into contact with each other, and, when it begins to melt, leads to a deterioration in the insulation of the line. The hook form is shown in fig. 209. It serves the purpose for which it is intended very well. These guards are fixed in the position shown; and it is needless to observe that every care must be exercised in making them as tight as possible, so as to prevent their coming by any possibility into actual contact with the wire. This danger is now provided against by a small lug at the lower end of the guard, which rests against a flattened part of the flange of the insulator bolt.

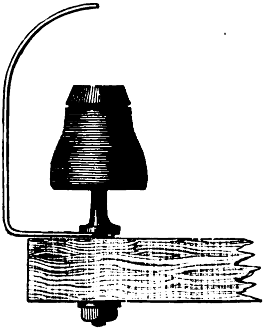
FIG. 209.

Wiring.—The poles having been properly fitted-up, stayed or strutted as the case may be, raised and fitted with insulators, the running of the wire is then proceeded with. The coils as supplied from the manufacturers are mounted upon drums which, for convenience of transport on roads, can be fitted on hand-barrows. One end of the wire is then taken by two men and drawn out, the drum being steadily revolved so as to avoid kinking the wire. As each pole is reached the wire is lifted into position, and this is continued until the whole coil is drawn out.

The wire is then stretched; and too much importance cannot possibly be attached to this portion of the construction of a telegraph line. The stretching is at first accomplished as far as possible by hand; light blocks and tackle are then applied to the wire, a species of vice, technically known as the *draw-tongs* (fig. 210), being used to grip it. By means of this the wire is drawn as tight as may be required, and the actual stress to be put upon the wire is then regulated as follows. One end of a cord is attached to some fixed point and the other to the drum of a *tension ratchet* of the form shown in fig. 211. This drum is fixed across the end of an iron frame, and is provided with a ratchet-wheel acted upon by a suitable pawl. On this frame is arranged a graduated spring balance with a hook. The wire which is to be pulled-up is gripped at a convenient point by the draw-tongs, which is hooked to the tension ratchet by the loop. On revolving the drum by means of the key, and so winding-up the cord, the tension on the wire is increased until the indicator shows that the proper stress is being applied. If the wire were pulled up too tightly it would break; if it were left too slack, it would be liable to get into contact with the others in its neighbourhood: both extremes must be carefully guarded against. When simply placed on to the arm the wire dips or hangs in a curve. This curve diminishes

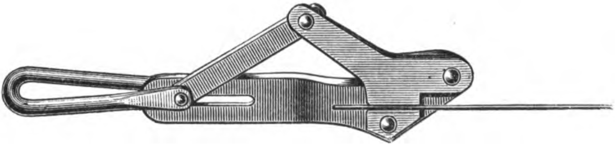

FIG. 210.

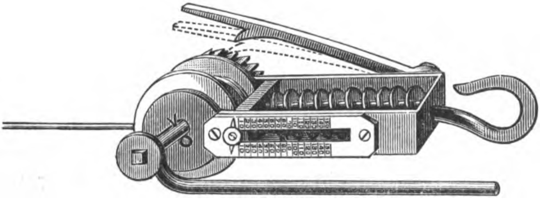

FIG. 211.

and approximates more closely to a straight line the tighter the wire is drawn; in other words, the dip or *sag* depends upon the tension of the wire. The maximum tension to which wires should be drawn is one-fourth of their breaking stress; for instance, 600 and 200 lbs. wire, whose breaking stresses are respectively 1,860 and 620 lbs., should never be drawn up with a tension greater than 465 lbs. for the former and 155 lbs. for the latter.

Wires are usually erected in the summer, since conditions for outdoor work are then more favourable. Now since metals expand with a rise of temperature, it follows that the wire will be longer at summer heat than at ordinary winter temperature, and if the wire when erected were subjected to a tension equal to one-fourth its breaking stress, the contraction which would result from the fall to winter temperature might cause the tension in the wire to become equal to the breaking stress. Indeed, until proper precautions were adopted, it was quite common for a line erected in summer to break at several points when the first frost of the succeeding winter set in.

In order to facilitate the erection of wires, and to avoid the above difficulty, the sags and stresses for various usual spans at varying temperatures have been calculated and issued in tabular form by the British Post Office. These tables are based upon the following formulæ, allowing for a factor of safety of 4 at low winter temperature.

Let

l = length of span in feet;
d = sag (or dip) in feet at minimum temperature;
d_1 = ,, ,, ,, higher ,,
s = stress in lbs. at minimum temperature;
s_1 = ,, ,, higher ,,
w = weight in lbs. of one foot of the wire;
L = true length of wire in feet;
T = difference of temperature Fahr.;
k = coefficient of expansion per degree Fahr.;

Then
$$d = \frac{l^2 w}{8s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$d_1 = \sqrt{d^2 + l^2(\mathrm{T} \times \tfrac{3}{8}k)} \ldots\ldots\ldots\ldots (2)$$

$$s_1 = s\frac{d}{d_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\mathrm{L} = l + \frac{8d^2}{3l} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Also

w for 400 lbs. iron = ·075758 lb. per foot.
,, 150 ,, copper = ·028409 ,, ,,
,, 100 ,, ,, = ·018939 ,, ,,

And

k for iron = ·00000683.
,, copper = ·00000956.

The Tables are given as Appendix Sections M, N, and O.

If one wire upon a line of poles is once properly regulated, the regulation of all the succeeding wires that are run may be taken from it and becomes a very simple matter: for, assuming that they are all of the same metal, they will all (although, it may be, of different gauges) take exactly the same dip with the same proportional strain.

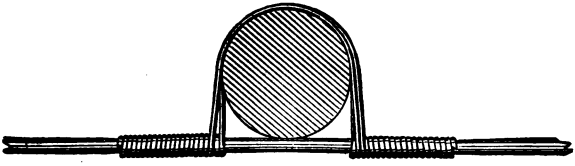

FIG. 212.

Binding.—The wire, when duly strained, is placed in the groove of the insulator, and, if iron, is very tightly bound to it in the manner shown in fig. 212. No. 16 galvanised soft wire is always used for binding iron wire. It is applied as follows:—Two laps are taken over the line wire at A.

The inner end is then taken round the neck of the insulator to the under side of the line wire at B, and, after one complete lap, is taken back round the insulator to A and lapped on the line wire for about a dozen turns to C. The other end of the binding wire is taken from the under side of the line wire at A round the neck of the insulator to the upper side at B, and similarly lapped over the line wire to D.

For copper wire the following method is adopted (fig. 213):—The line wire is first served from A to D with a sheath of copper tape 47 mils thick. The binder (which consists of wire more or less corresponding with the line wire, with its ends rolled flat) is then placed round the neck of the insulator and the ends (brought *over* the conductor at B and *under* it at C) closely wrapped around the served portion of the conductor as shown. The wrapping is done by hand, and it is then tightened by means of two pairs of gas-nipple tongs supplied for the purpose.

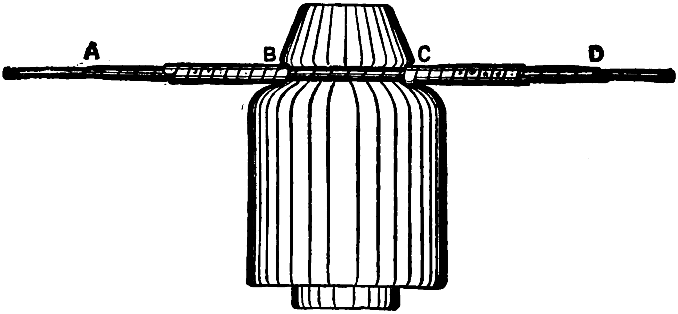

FIG. 213.

If the position of a pole has to be altered, care should be taken that every trace of the old binders is removed, unless, indeed—as at road-crossings—they have been soldered to the wires. Portions allowed to remain are apt to wear the line wires so that they break at the first touch of frost.

Numbering of Wires.—The wires when erected should each have a distinguishing number, and should, if possible, occupy the same position upon each pole on the line along which they are carried. The following system, applicable to both road and railway, and independent of the side on which the poles are planted, is now generally adopted: Where a wire is run on a saddle, that is invariably known as No. 0; then, standing with back towards the up station —that is to say, looking at the up side of the pole—the wire on the left-hand side of the top arm is No. 1; that on the right-hand side, No. 2; the wire on the left-hand side of the second arm, No. 3; that on the right-hand side, No. 4; and so on. The numbering of the wires where there are two upon each arm is shown in fig. 202. Similarly, when there are four upon an arm they should be numbered as shown in fig. 214, so that at points where the wires are transferred to short arms, 3 and 4, 7 and 8 naturally fall into their proper places.

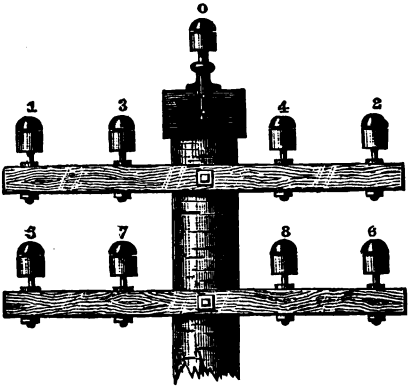

FIG. 214.

Joints.—Bad joints in telegraph wires have given rise to more trouble than any other defect, for the faults caused by them being intermittent, the time spent in localising them is greater than is the case with faults of any other description; and as each joint in open wires is generally at some little distance from the support the search for the defect is a tedious and difficult matter.

The form which is now universally adopted was introduced by Mr. Edwin Clark, and is known as the 'Britannia' joint. It is shown in fig. 215, and is made as follows: The ends of the wires are carefully scraped clean and laid side by side for a distance of about two inches; they are then bound firmly together with the ordinary No. 16 binding-wire; over this is smeared a prepared flux known as 'Baker's fluid.' Chloride of zinc, known as 'spirits of salts,' should not be used. The solder, without which no electrical joint can be considered perfect, being then applied welds the whole together in one solid metallic mass, and renders the electrical continuity complete. The waste ends of the two wires should be cut off as close as possible to the joint, so as to prevent their hooking into the neighbouring wires and causing contacts when swayed by the wind. Originally the ends of the wire were bent at right angles after the joint had been whipped, but, as in a well-made joint the hooked ends serve no useful purpose, the practice has been discontinued.

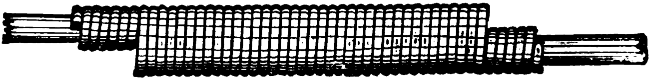

FIG. 215.

Terminating.—The wire is sometimes terminated on a shackle. This shackle is fixed and the wire is attached to the shackle as shown in fig. 206. The wire is simply bent round the porcelain and bound in exactly the same manner as an ordinary joint with the exception that it need not be soldered.

As has already been pointed out (p. 344), shackles are electrically very imperfect: therefore the terminal insulator, shown in fig. 207, is now more generally used, and acts much more efficiently as an insulator.

When the wire has to be terminated at intermediate points with shackles, or 'shackled off,' as it is termed, the following is the mode of procedure which should be adopted: A double shackle is fixed, and each side is first 'tailed'—that is to say, a wire is passed round the porcelain and bound in the ordinary way, leaving one end projecting to a distance of from eighteen inches to two feet. To this end the line wire is firmly bound and soldered, and is then bent round at a distance of not less than six inches from the pole, and similarly dealt with on the opposite side. Thus, the line wire itself is continuous.

The leading-in wire from the terminal pole (fig. 207) consists of a copper conductor insulated with gutta-percha, and well-protected by a coating of tarred tape served around it. This wire is bared for a distance of several inches, then wound round the iron wire and soldered only at the end, so as to admit of its being disconnected for testing purposes if required; and, as gutta-percha when exposed to the effect of wind and weather rapidly deteriorates, the wire is carefully protected in a casing down the pole until it is led inside the office. The small portion that is unavoidably left unprotected is passed through a 'leading-in cup,' which prevents leakage where the wire enters the troughing. On square terminal poles a hollow facing is fixed, through which the leading-in wires are led; this is preferable to cutting grooves, which tend more or less to reduce the strength of the pole.

An important point to notice is that in no case should gutta-percha be brought into contact with creosoted timber, as the oil of the creosote exercises a destructive influence upon it. Care should also be taken that the leading-in wires, when carried underneath the flooring, should be protected from the possible attacks of rats, which in more than one instance have been known to gnaw through the gutta-percha, and, having laid bare the conductors brought them into contact with each other. The leading-in wire should likewise be kept clear of *leaden* gas-pipes ; a distance of not less than six inches should intervene between them, for during a thunderstorm great risk is incurred if there is a possible line of discharge between the leading-in wire and a leaden gas-pipe. Several instances of damage have occurred owing to the lead having been fused and the gas ignited by lightning. The same danger does not, of course, exist with an *iron* pipe.

Earth.—This, although the last point to be seen to in the construction of a telegraph line, is one of the most important, for without a good earth-connection satisfactory working upon any circuit becomes an impossibility. The first object to secure is a good damp soil, and, next to that, as large a conducting surface as possible ; for this reason a metal pump or, better still, the iron water-pipes of a town are taken advantage of, and in most instances good earth is obtained by soldering the earth-wire securely on to them. But if there are no water-pipes, and an *iron* gas-pipe is at hand, it will be found to answer the purpose ; when both gas and water-pipes exist the earth-wire should be well soldered to each. Upon no account whatever is a leaden gas-pipe to be employed for the purpose of affording earth ; the danger incurred by their being even near to the wires has been indicated ; that danger is increased considerably when the wire is attached to them.

When neither iron water-pipes, a pump, nor iron gas-pipes can be procured, a plate of metal from two to three feet square, usually of galvanised iron, is buried in the ground at a depth sufficient to ensure its being always damp, and the earth-wire is attached to that. Care must be taken that, on short circuits, or circuits where delicate instruments are employed, earth at each end is obtained by a plate of the same metal. Unless this is seen to a permanent current is set up ; for the two dissimilar metals being united by a conductor the necessary conditions for a current are present. For instance, iron water-pipes at one end and a copper plate at the other would give rise to this, and the combination of different metals must therefore be avoided.

B. OVERHOUSE TELEGRAPHS.

In large towns, where it becomes impossible to plant poles for the support of the wires on the ground level, overhouse telegraphs are had recourse to. They should be adopted, however, only when the number of wires is comparatively small ; if many wires have to be run, or are likely to be required, underground work is to be preferred.

In the construction of overhouse lines nothing but the very best materials should be employed. The supports are iron standards, whose length will vary according to the conditions of the work. They are fixed into sockets planted upon the ridges of the houses or placed in 'chairs.' These chairs are generally made of iron, although occasionally wood is employed. A hole is cast or bored in them, as the case may be, and into it the pole is firmly fixed. Poles employed in overhouse work should be stayed in every possible direction.

The conductor employed is, if of iron, a strand of three No. 16 wires ; but more generally copper or silicium bronze wire is preferred. Where exposed to the action of smoke or the gases which are given off in the neighbourhood of most of the centres of industry, the iron wire is covered with tanned tape saturated in a composition of ozokerit and Stockholm tar ; but copper needs no such protection.

Every effort must be made to reduce to a minimum the risk arising from the breakage of the wires. Thoroughfares should be crossed as far as possible at right angles, and not longitudinally ; the shorter the length of wire hanging over them, the less liability is there of danger to the public.

In soldering the joints at each point of support the utmost caution should be observed in the use of the fire-pot. Instances have occurred where, from carelessness and negligence with it on the roofs of houses, the leads have been melted and the buildings set on fire. In leading-in from iron standards as well as from all iron supports, extra precaution must be observed to avoid leakage in consequence of deterioration of the gutta-percha covering of the wires.

When the standards cannot be fixed, and chimneys have necessarily to be taken advantage of instead, great care should be exercised in their selection; none but those which upon examination are proved to be perfectly sound should be used, and brackets should never be inserted even in these, but an iron band encircling the entire chimney should be employed.

A very frequent objection urged by the owners of buildings against the attachment of the wires is the noise which they cause. If the binding be imperfectly performed, or the wire be strained too tightly, the vibration conducted down the solid walls proves to be an almost intolerable nuisance; in frosty weather, as might be expected, it becomes worse and worse as the wire contracts. Various efforts have been made to surmount this: the bolt of the shackle has been padded with chamois leather, india-rubber, and the like, the wire itself as it passes round the insulator being encased in the same material. This has been found to answer fairly; but the plan which effectually puts a stop to the noise is the insertion of a small section of chain in the line-wire upon each side of the shackle. To the extremity of the chain, which, of course, does not form part of the circuit, the wire is doubly bound and soldered. Perhaps the most satisfactory plan is to use only light copper or bronze wire, not too tightly strained.

Too much care cannot be exercised by the workmen in the erection of overhouse wires. The damage done to the buildings where the supports are fixed, as well as to those intervening over which the wire has to be drawn, should in every instance be rectified the moment it is observed; the dislodgement of slates and tiles, unless speedily seen to, becomes in time the source of great expense, and forms one of the main barriers in the way of overhouse telegraphs.

CHAPTER XV.

CONSTRUCTION—(COVERED TELEGRAPH LINES).

UPON open lines short lengths of covered wire should be avoided as far as possible, but occasionally they are rendered necessary by local causes; whilst through tunnels and in towns they are decidedly to be preferred, not more for economical reasons than on the ground of safety in working. From the first, copper has been invariably employed as the conductor for underground lines, but the insulating material has varied considerably, and even to the present day there is a difference of opinion as to whether gutta-percha or indiarubber—the two rival substances—is to be preferred for this purpose.

Gutta Percha Covered Wires.—Covered wires through railway tunnels are laid in wooden boxing, the top of which should be tied by iron wire and not nailed on. Where exposed to the likelihood of being interfered with by the public, screws may be used, but not nails. In driving nails more or less danger is incurred of piercing the gutta-percha and thereby causing faults. The boxing is supported upon hooks driven into the brickwork of the tunnel. The timber employed for the purpose should be tarred, but never on any account creosoted, because, as already stated, creasote in contact with gutta-percha exerts a marked influence upon it, and speedily leads to its deterioration; under no circumstances should these two materials be brought together.

The earliest underground wires placed upon the roads in England were laid in grooved boarding formed from creosoted Baltic timber. This plan was after a short time discontinued, and is now entirely abandoned. In place of boarding, cast-iron pipes are now generally employed for telegraph lines. These pipes are dipped while hot in a composition consisting mainly of tar and oil, which leaves a hard 'glaze' upon the metal. Glazed earthenware, set in cement, is now also used for lead-sheathed paper-insulated multiple cables.

The gauge of the pipes will vary according to the number of wires that are to be, or are likely to be, drawn into them before their renewal becomes necessary. In no case is it advisable to lay a pipe of smaller gauge than two inches in internal diameter, and generally 3-inch pipes would be preferable. The labour charge in connection with the laying of the pipes is such an important factor that the increase in the cost as between a 2-inch and a 3-inch pipe may often be justified in view of possible extensions.

As an indication of the accommodation afforded by the different sizes of pipes it may be assumed that 2-inch, 3-inch, and 4-inch pipes should not be expected to take respectively more than 40, 80, and 120 No. 7½ prepared G.P. covered wires (p. 361).

The interior of the pipes should be carefully scraped and cleaned before they are laid, for the purpose of removing any inequalities on the surface due to imperfect manufacture. If these are allowed to remain, the risk of injury to the gutta-percha is incurred when the wires come to be pulled in. Steel dies or cylinders, rather smaller than the interior of the pipe, may be used for this purpose ; or, if there is any difficulty in procuring these, a heavy iron chain drawn to and fro in the pipes will be found to answer the purpose very well.

Cast-iron pipes are generally laid at a depth of two feet; in no case should the depth of the trench be less than one foot, and where the traffic is exceptionally heavy the limit should be increased to at least two feet six inches. In towns the pipes should as far as possible be laid under the pavement, where the traffic, being mainly confined to foot-passengers, is comparatively light. The joints in the pipes should be made as follows: First a layer of tarred yarn is inserted into the socket and hammered in tightly with a special tool. Then the remainder of the socket space is filled in with molten lead, which, finally, is caulked or hammered tightly into the joint. In filling up the trench every care should be exercised to remove all stones of any size until a layer of six inches of good mould has been punned down over the pipes.

As each pipe is laid in its place, an iron wire of No. 7½ gauge is threaded through it; to the end of this the cable to be pulled-in is attached. The iron wire is carried through the pipes at the time they are being laid; it is next to impossible to thread it through for any length after they are laid; the difficulty in doing so is almost incredible until it has once been experienced. Bamboo sticks capped and fitted with screws joined together like chimney-sweeps' rods are sometimes used. At distances of 100 yards apart where the line is straight, and less if the route is at all tortuous, 'flush' boxes are laid to facilitate the operation of pulling in. The name flush box was originally given to these from the fact of their being laid level with the surface of the ground, which is still the practice in London and some other paved towns where the pipes are laid beneath the pavement. As the cable to be pulled in should be manufactured in lengths of 400 yards, every fourth box of this class becomes a joint box, in which the junction with the succeeding section of cable is made. These boxes are of cast iron, measuring about two feet six inches in length by eleven inches in width and one foot in depth; they have an opening at each end sufficiently large to admit the end of a pipe at any angle. Figs. 216, 217, and 218 show the construction of one of these boxes; being respectively a plan of the lid, a longitudinal section of the box, and a transverse section. The pipes are led into the boxes so as just to project inside them, and the space around each pipe is stopped, in order to prevent the ingress of dirt. The figures show the kind of box that is fitted flush with the pavement, the lid consisting of an iron frame filled in with stone; but for buried boxes closely fitting iron covers are used. In order that the position of these buried boxes may be readily ascertained a distinguishing mark should be placed on the ground. The Postal Telegraph Department use a recognised cast-iron 'marker,' but, failing that, a wooden stake or a paving-stone will suffice to indicate the place.

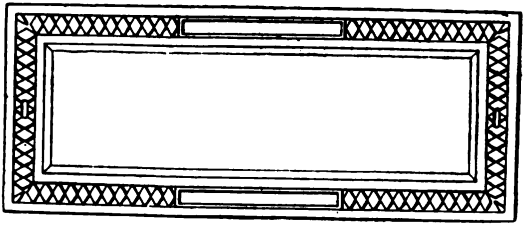

FIG. 216. $\frac{1}{12}$ full size.

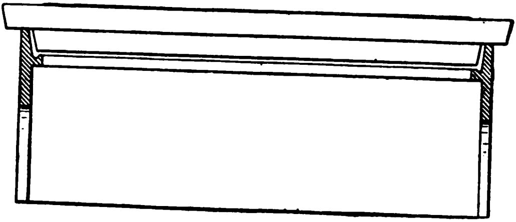

FIG. 217. $\frac{1}{15}$ full size.

The wire hitherto largely employed for tunnel and underground work in England is that known as No. 7½ prepared gutta-percha. The copper conductor is No. 18 gauge, and is insulated with gutta-percha up to the gauge of No. 7½; it is then served with a covering of tanned tape which has been drawn through a composition of Stockholm tar and melted ozokerit. When several wires have to be drawn in at the same time, they are first of all laid side by side and tied together at short intervals, forming what is technically called a 'cable.' As they are pulled into the pipes the binders are cut and removed. Occasionally the plain gutta-percha wires are laid parallel to each other, and the whole are then served over with a covering of prepared tape. A true cable, however, is now more generally used, formed of a strand of four plain gutta-percha wires laid (that is, twisted) together and protected with a coating of tape prepared as above, or braided with hemp so as to form a neat rope or cable.

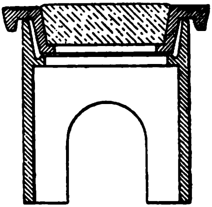

FIG. 218. $\frac{1}{15}$ full size.

The 'cable' is coiled on a clean tarpaulin laid at a convenient distance from the flush-box where the work is commenced, so as to prevent its chafing as it is drawn into the pipes. To guard against damage to the cable, in drawing-in a wooden roller is placed at the mouth of the pipe; and a mat is spread at the bottom of the box, which has been previously well cleaned out, so as to prevent the cable from dragging any dust or dirt along with it. The ends of the copper wires of the cable are stripped for two or three inches of their covering, and are twisted on to a loop formed in the end of the iron wire which, as already remarked, has been threaded through each length of pipe as it was laid; and the ends are then lapped over with tape and yarn to prevent abrasion of the gutta-percha as the wires are drawn through. The work of hauling-in commences, in a straight length of

400 yards from the central box (fig. 219): one end of the cable is drawn from A to B, and the other from A to C. Where there are two or more intermediate boxes, the operations in pulling-in are increased with each additional box; thus, in fig. 220, one-half of the cable would first of all be drawn from A to *b*, where it would be carefully coiled, and subsequently drawn in from *b* to B; while on the other side an exactly similar course would be adopted by drawing-in the second half first to *c* and then to C. The coil being placed so as to give a straight lead to the cable into the pipe at the first hauling-in box, the work of pulling-in is commenced. One man sees to the proper uncoiling of the cable, another attends to the lead, and the rest pull the iron wire through at the further box until the end of the cable makes its appearance there. In the case of intermediate boxes, such as at *b* and *c*, the cable drawn out of the pipes between A and those points is coiled there as in the first instance at A, care being taken to protect it from friction by means of a small roller as it emerges from the pipe. Before being pulled into the sections *b* to B and *c* to C the cable is 'turned over' by being re-coiled on the opposite side of the boxes at *b* and *c*, in order to give it a fair lead to the mouth of the pipe in the proper direction.

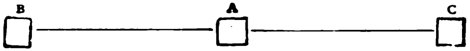

FIG. 219.

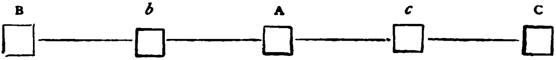

FIG. 220.

When the section of cable is got into the pipes the numbering of the wires is proceeded with. From a small portable battery a current is sent along each wire and noted at the further end upon a galvanometer; corresponding numbers are then affixed to the ends of each wire in succession until all have been gone through. These numbers consist of small leaden pellets with the numerals imprinted upon them.

Should it at any time be necessary to increase the number of wires in an existing line of pipes, the method to be adopted is as follows: Let B A C (fig. 219) be a section of line with joint-boxes at B, A, and C, and containing seven wires; it is desired to increase the number to eleven. A cable of eleven wires, equal in length to the distance between B and A, is first of all formed and joined on to the end B of the existing cable. The same precautions are adopted to protect the wires from friction as in the case of a new line; the new cable is then pulled in at B, the old one being drawn out at each intermediate flush-box between B and A in succession until the section B A is completed. To the old seven-wire cable, after it has been carefully examined and tested, and any damage which the covering may have sustained has been repaired, four new wires are added, and the eleven-wire cable thus formed is drawn in from A to C. This operation is repeated throughout the entire line until the work is completed. In this way only one set of eleven joints—viz. that at the second box—becomes necessary; at each joint-box the four new wires have of course to be jointed.

Under no circumstances should any attempt be made to draw new wires into pipes which already contain existing wires without removing the latter. The friction which inevitably takes place between the old and the new wires leads to the abrasion of the protective covering in both, and lays the foundation of innumerable faults, which may only begin to make their appearance and interfere with the working of the circuits some time after the laying of the additional wires has been completed.

Dry-Core Cables.—Of late years paper insulated and lead covered cables have come into use, both for underground telegraph and telephone lines, as well as for overhead construction. Each wire is enclosed in strong specially prepared paper, free from metallic particles, applied spirally or longitudinally, in such a way as to completely cover the wire, and perfectly insulate it from its neighbour. For telephone purposes the wires thus insulated are twisted in pairs, and the copper conductors vary, according to the use for which they are destined, from 20 to 200 pounds per mile in weight. For the smaller sizes, 300 pairs or more can be made up into one cable, and such cables for underground work in large cities, while occupying small space, are highly convenient. The lead sheath varies from ·108 to ·183 inch in thickness according to the number and size of conductors which it contains. The sheath, as specified by the British Post Office, is of the finest English lead, applied at a temperature not exceeding 600° Fahr., the quality and durability of the tube being of the highest importance. The electrostatic capacity of dry-core cables is only one-fourth that of gutta-percha or india-rubber. They are therefore well adapted for telephone purposes. With the lead sheath and all other wires connected to earth the electrostatic capacity per mile of each 20- or 40-pound conductor of twisted pairs, as ordinarily put up, is not more than ·08 microfarad in cables containing 300 wires, at a temperature of 50° Fahr. The mean electrostatic capacity from wire to wire of each pair in any length of cable (all the wires in the cable and the testing battery and apparatus being insulated) does not exceed 70 per cent. of the mean wire-to-earth capacity, tested as above described.

Where a cable contains numerous wires the cost per conductor is only one-fourth to one-third that of the other forms of insulated wire. The lead covered cables, iron pipes, and earthenware conduits are almost imperishable under the conditions in which they are applied, and if properly laid the durability should be very great. The cables are, however, not without disadvantages. For their success it is essential that the paper insulation should be kept dry. Therefore any defect in the lead sheathing or at a joint will probably cause faults on all the circuits in the cable. Further, this type of cable involves increased risk of damage from lightning.

In the course of manufacture, as the cable is laid up it is wound on an iron drum which is subsequently placed in an oven and subjected to heat until all moisture is driven off. The temperature of the oven is not allowed to exceed 225° Fahr. After passing through the lead press, the ends are sealed to exclude moisture.

The length of cable that can safely be drawn into a line of pipes varies with the number of wires, the weight of the cable, the alignment of the pipes, and other conditions.

Heavy cables should, as a rule, be ordered in such lengths as may be conveniently drawn into a pipe from box to box. Lighter cables may generally with advantage be ordered in the maximum lengths which a drum will hold.

In drawing into a section of pipe which contains a bend the cable should be fed in from the end further from the bend ; so that the shortest possible length of cable may have to pass the difficult point.

Where two or more cables have to be drawn into one pipe in succession (a practice that should be resorted to as rarely as possible) joint boxes or slide pipes should be provided at every seventy-five yards as a maximum, as the friction in such cases is very greatly increased.

In all cases the cable should be two yards longer than the distance from centre to centre of the joint boxes, to allow for waste in pulling-in, jointing, testing etc., and in the case of manholes the length may have to be still further increased to meet local conditions.

It is most economical to manufacture multiple dry-core cables in long lengths. Where the standard lengths cannot be employed and the use of short lengths is unavoidable, they should be aggregated into longer lengths within the limits laid down as the practical maxima in the tables. These maxima are determined in some cases by the capacity of the drum and in other cases by the weight and limit of flexibility of the cable.

When ready to commence the drawing-in the drums of cable are carted to the work, preferably in a low waggon, technically known as a 'float,' and care should be taken not to roll the drum about more than is absolutely necessary. The drum is fixed immediately over the end of the pipe through which the cable enters, and in such a position that the cable will pay out from above in a curve of large radius. A steel spindle, square in the central portion and round at the ends, is passed through the centre of the drum to form an axle; under each end of the spindle is placed a lifting jack, and by this means the drum is raised to a sufficient height above the ground to admit of its revolving freely on its axis.

The ground over the drawing-in slide pipes should be opened to a convenient sized hole, and a rope, three or four inches in circumference, drawn through the pipes. This is done by means of the drawing-in wire when one is provided, or by threading through the empty pipes a length of sweeps' rods. The former is the more expeditious and less costly method where the pipe is to be used at once, but it should not be resorted to when the wire is likely to be left in the pipe for any considerable time.

At one end of the rope is fitted a split link, and the other end is attached to a crab-winch, which should be securely anchored down either to bars driven in the ground or to the line of pipes itself. When the latter course is adopted, a small hole in the ground should be opened at a distance of at least four yards from the drawing-in pipe, and the winch placed over it.

A clip is used for attaching the rope to the cable. These clips are made in various sizes, and it is important that a size be selected exactly fitting the cable to be drawn in.

When about to be used the clip is fixed over the end of the cable without removing the seal from the latter or exposing the wires to moisture, and the positions of the four holes in the side of the clip are carefully marked on the lead sheathing with a pointed tool. The clip is then removed, and two holes are bored with a small gimlet right through the sheathing, care being taken that they emerge on the far side in the position marked. A drift pin having been driven through in order to clear a passage for the screws, the clip is replaced and screwed up tightly. The end of the cable is, finally, dipped into a narrow pot of thoroughly melted paraffin wax, in which it is left immersed to a depth of three inches beyond the clip. When the wax has thoroughly sealed the interstices between the screws and the screw holes it is withdrawn and allowed to set.

The end of the cable is attached to the rope by means of a split link, which when sprung into place should be lapped with tape or yarn to prevent its becoming loose in passing through the pipe. All is then ready for pulling-in.

Petroleum-jelly and black-lead are the best lubricants for drawing in cables. When a single cable is drawn into a pipe, the former is preferred, but where, exceptionally, two or more cables must be accommodated in one pipe black-lead should be used. The lubricant should be applied to the cable as it enters the pipe.

The cable is steadily hauled in by two, or not more than four, men at the winch, and the pull on the rope should be in the line of pipes, snatch blocks being introduced if necessary.

The remainder of the men are engaged in the meantime in revolving the drum and feeding the cable into the pipe from over the drum in a curve of such radius as will cause it to enter horizontally, without strain, bends, reverse twists or other injury. The hole through which the drawing-in operations take place should be sufficiently long to ensure a straight lead for the cable.

When it is necessary to pull more than one cable into a pipe, each cable should be dealt with independently, as a simultaneous drawing-in of two cables has been found impracticable.

When the cable has been pulled in, the end to which the clip is attached should be cut off with a hack-saw, and the interior examined to ascertain if moisture has entered. If free from wet, the conductors should be driven back within the lead by means of a dry punch to a depth of about a quarter of an inch; a disc of lead of the exact size should be fitted in the recess thus formed and securely soldered to the pipe, thus providing an absolutely watertight seal which will remain intact until the time for jointing arrives.

The exposed length should be laid in the trench and (when the jointing cannot be proceeded with at once) carefully protected by pieces of timber, three inches by nine inches, one on each side and one on the top, over which the loose soil can be filled in and punned. The timber is needed to protect the cable from damage in filling in or in subsequently opening the ground for jointing. The space between the cable and the end of the pipe should be filled with cotton waste to prevent the entry of soil. Where the size of the cables will admit of both ends entering the slide pipe, the latter should be used as a protection instead of the wood slips, the interstices between the slide and the pipes being filled with waste.

Ample room must be allowed for jointing purposes. For a heavy cable a hole about six feet long, three feet broad, and three or four feet deep, should be opened over the proposed joint, to admit of two workmen engaging in the operation, the trench being also opened to a sufficient length to admit of the slide-pipe being slipped along the end of one pipe. For a small cable a reduction in the size of the hole may be permitted.

The sides and the bottom of the hole are protected by sheets of ungalvanised iron of No. 22 gauge, three feet by two feet, which are placed immediately around the place where the joint is to be made. The object is to protect the exposed cable from moisture, which rises freely, especially when charcoal braziers, subsequently referred to, are introduced. Galvanised iron is unsuitable, as solder droppings which have been in contact with galvanised iron cannot again be used.

Two planks, ten feet long, nine inches wide, and three inches thick, are then placed along the sides of the hole, and two ordinary jointers' tents, fitted end to end, are mounted on them.

Where water abounds the earth is banked up along the supporting timbers to prevent its entry, and in rainy weather a tarpaulin is placed over the top of the tents to make them absolutely waterproof. The windward end of the tent must always be kept closed to prevent currents of air, which are always more or less damp, from passing over the joint.

If the sub-soil be saturated a sump hole should be sunk in a suitable position outside the tent, to admit of the use of a pump for removing the water as it accumulates. The water should on no account be baled out because of the liability to splash the joint.

In the case of mixed soil or gravel, it is necessary to shore-up the whole with timber to prevent the sides falling in during operations. For this purpose the hole should be lined with vertical planks known as 'poling boards' three feet six inches by nine inches by one inch, supported by two horizontal planks, 'whalers,' six feet by nine inches by two inches, which are kept in position by 'putlogs.'

In the case of cables of any considerable size, it is generally desirable, where a joint is to be made, to open the hole over night in order that an entire working day may be available for the process of jointing. When once commenced, the work must be continued until the joint is finished.

Before jointing is commenced the whole of the interior of the excavation must be covered with canvas sheets, so as to ensure absolute cleanliness in all subsequent operations.

When the preliminary arrangements are complete the jointing is commenced thus:

(*a*) The surplus length of each cable is cut off, leaving an overlap.

(*b*) Next, the required length of lead sheathing is removed from each cable, care being taken not to damage the paper insulation. When the lead sleeve has been passed over the end of one cable the conductors are tied in half layers and are turned up at right angles. For cables one and half inch in diameter and over, a slit about one inch in length is previously cut in the centre of the sleeve and dummied outwards, for a purpose to be explained later.

(*c*) The other end is then similarly tied in half layers and turned up at right angles, and the first copper joints (those of the central pair of the bottom half of the outer layer) are made. The method of jointing the copper wires is explained on page 372.

(*d*) Paper insulating sleeves are next drawn over the conductor joints and tied together with thread in order to prevent them from being moved out of position during the subsequent operations.

(*e*) A strip of insulated paper is now wrapped spirally round the pair so jointed, and is tied at the end with thread to keep it in position. This spiral wrapping of paper is necessary to complete the insulation of the wires in consequence of a portion of each conductor being left bare in the process of jointing.

(*f*) The jointing of the remaining pairs of the bottom half layer and the six pairs forming the bottom half of the second layer in the cable are dealt with in a precisely similar manner.

(*g*) The next half-layer towards the centre of the cable and the central pair having been dealt with, the jointing of the cable is continued in reverse order towards the outside half-layer, and the joint is thus completed so far as the insulation of the pairs is concerned.

The paper insulating sleeves are carefully dried in a tin vessel in which they remain until required for use. This vessel is placed in a clean thoroughly dried galvanised iron bucket kept hot by a spirit lamp in the jointer's tent.

The wrapping of paper, which in the cable itself is placed between successive layers, is not interposed in the joint, as it would delay the final drying described later. An external wrapping of paper is, however, wound round the completed cable.

When dealing with main trunk wires great care must be taken not to introduce any crosses between neighbouring pairs during the process of jointing, as it is of the utmost importance that the conductors shall occupy the same relative positions throughout the entire length of the cable Checking the accuracy of the jointing should be made a part of the test instituted after the completion of each joint, and should any crosses be discovered they must be removed before the work is proceeded with. Such crosses as may be needed to avoid mutual induction must be made subsequently and in a systematic manner.

In town telephone systems the cables may be divided into two classes : (*a*) Those used for long junction circuits, which must be treated in all respects in the same manner as trunk line cables. (*b*) Those containing smaller gauge of conductors to be used for local circuits. This may apply to 40-lbs. conductors. The relative positions of the pairs of conductors in these cables need not be maintained, but the utmost care must be taken to ensure that pairs shall be through to pairs.

The actual method of jointing the copper wires varies slightly with the gauge of the conductors. With 100-lbs., 150-lbs., and 200-lbs. wires, the two are cut so as to abut when drawn out straight; the paper insulation is removed for a distance of about three inches on one side and one inch on the other and tied with lined thread. The ends of the wires are cleaned and tinned, a copper jointing sleeve of the right gauge and a paper insulating sleeve are slipped over the wire from which the three inches of insulation has been removed, the copper sleeve is drawn forward so as to enclose both conductors equally. It is then soldered and the paper insulating sleeve drawn over the joint. No flux but resin must, under any circumstances, be used.

The companion wire of the pair is then similarly dealt with, the only difference being that if the greater length of insulating paper has been in one case removed from the right-hand wire, then, in the companion wire, it should be removed from the left-hand one. It will thus be seen that, although this necessarily leaves each conductor bare for a length exceeding that of the paper sleeve, as the two jointed conductors are bared on opposite sides of the joint, the bare portion is insulated from its neighbouring conductor by the original insulation of the latter.

The pair of conductors so jointed is then wrapped spirally for a length of eight inches with strips of insulating paper of the same character as that employed in the manufacture of the cable.

With smaller gauge conductors the use of copper jointing sleeves would be troublesome, therefore the following practice has been generally adopted. The two wires are cut off so as to overlap to the extent of one and a half inches, the paper sleeve is passed over one of the wires, each wire is bent three-quarters of an inch from the end at right angles to itself, and the two ends are then grasped with the pliers and carefully twisted together with just sufficient tension to straighten the main conductor. The end of the twist is snipped off, the twist is tipped with solder, and bent back to lay parallel and close to the conductor, and finally the paper sleeve is drawn forward. Three stages are shown in fig. 221.

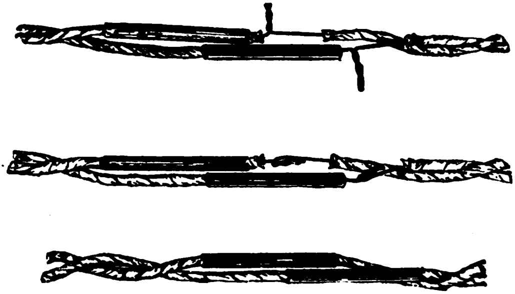

FIG. 221.

It is necessary to slightly modify this process in the case of pairs of 40-lbs. conductors with **S**-type insulation. In this case, the pair of wires being enclosed together, large sleeves are necessary and each sleeve is passed over the pair of wires. Two sleeves are required for each pair, the joints in the conductors being alternated as usual and the sleeves correspondingly spaced out, as indicated in fig. 222.

After the conductors are jointed, and before they receive the final wrapping of insulating paper, the joint should be thoroughly dried by means of charcoal braziers, which are supplied on requisition. Two men should be engaged in this operation, each commencing at opposite ends of the joint at the point where the lead sheathing emerges from the iron pipe. When the sheathing has been thoroughly warmed on both sides, the braziers are gradually moved forwards towards the centre of the joint until it is judged that every particle of absorbed moisture has been expelled. Great care should be taken not to carbonise the paper, and in order to avoid this the braziers should be moved slowly backwards and forwards, parallel with the line of the cable.

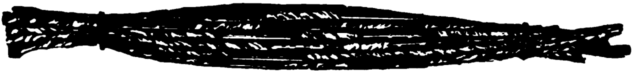

FIG. 222.

With large cables, even under favourable conditions as to weather, this operation should last an hour, and it should be continued until a mirror, which has been kept cool, shows no trace of moisture when applied to the joint. The joint is next wrapped spirally with insulating paper, a hole being cut opposite the point at which the hole in the sleeve will come.

FIG. 223.

The lead sleeve is next drawn over the joint, and secured in place by a thoroughly well made plumber's wiped joint at each extremity, as shown in fig. 223. The heat necessary for this purpose tends to expel any moisture absorbed in jointing, and it is to admit of its escape that the slit is cut in the lead sleeve. As a further precaution, however, the braziers are again applied to the completed joint and moved to and fro until the mirror referred to above shows no evidence of condensation when applied to the vent-hole. The edges of the slit which were dummied out to form the vent are now dubbed down as closely as possible, sealed with a hot iron and completed with a carefully made plumber's 'patch-pipe.'

The vent is not needed for small cables—those less than one and a half inch external diameter.

The careful and judicious use of the braziers is imperative in order to obtain a high degree of insulation, and a plumber of the highest skill only should be employed in making the wiped joints, as joints which appear well made, and which would suffice for a water pipe, have failed some months after they have been made, owing to minute imperfections.

Finally (fig. 224) the iron slide pipe is drawn into place, caulked and leaded at the ends, the soil filled in, and the joint-box marker fixed.

FIG. 224.

Where a cable stretches across a long gap in the pipes, care must be taken that it shall be properly supported in suitable positions.

A method of testing the perfection of a wiped joint is known as the dry air test. For this purpose an air-pump and a desiccator are employed. The latter contains calcium chloride and a cotton-wool filter, through which the air is driven, in order that it may be thoroughly dried before it enters the cable. When the pressure has been applied to the cable for a sufficient time for it to reach the joint under test, a defect in the plumber's work will, in most cases, be evidenced by a whistling sound, or the escaping air may be detected by passing the hand round the joint. To make yet more certain, however, the flame of a lamp or taper should be passed round the wiped portion of the joint. By this device the most minute leak may be readily discovered.

Where cables are being laid from a post office the pressure should, when possible, be supplied from the pneumatic service of the office. This will admit of the testing of cable joints within a radius of about half a mile.

When this distance is exceeded a portable apparatus is necessary, and it should be connected by means of a flexible pressure tube to the far end of the jointed cable, the lead cap being temporarily removed for the purpose or an air nozzle fitted. Air nozzles must not be permanently attached to cables in manholes or underground boxes.

A pressure gauge connected to the pump, if carefully studied, gives valuable information to the officer in charge. When a cable is full of dry air the indicator remains steady ; when the cable has not been fully charged with air, and there is no defect in the sheathing, there is a gradual and uniform fall ; when there is a defect in the lead sheathing or the wiped joint, the fall of pressure indicated is irregular.

Where there is, at an intermediate point, a cable connection or other form of test box, the pressure applied to the cable for a joint test, or for drying out a fault in a cable must be less than where there are no such testing points ; for, whereas 20 to 25 lbs. air-pressure per square inch may be safely applied to a dry-core cable pure and simple, the same pressure on a cable having a cable head intermediate on it would be likely to result in much damage.

The air driven into the cable must be absolutely dry, otherwise actual lowering of the insulation will result. The calcium chloride must therefore be renewed periodically, but a fixed time for this renewal cannot be given, as much depends on the humidity of the atmosphere, as well as the extent to which the calcium chloride may have been used. If there is a choice of position, the pump should be placed where the air to be drawn in is coolest and driest.

A useful indication that the calcium chloride needs renewal is afforded by the depth to which it has sunk in the containing trays. Under no circumstances should it be allowed to fall to less than half its original height. The amount of water drawn off from a cylinder is another indication of when the supply of calcium chloride requires attention. If the air driven through the desiccator be very moist, fresh supplies of calcium chloride should be added frequently.

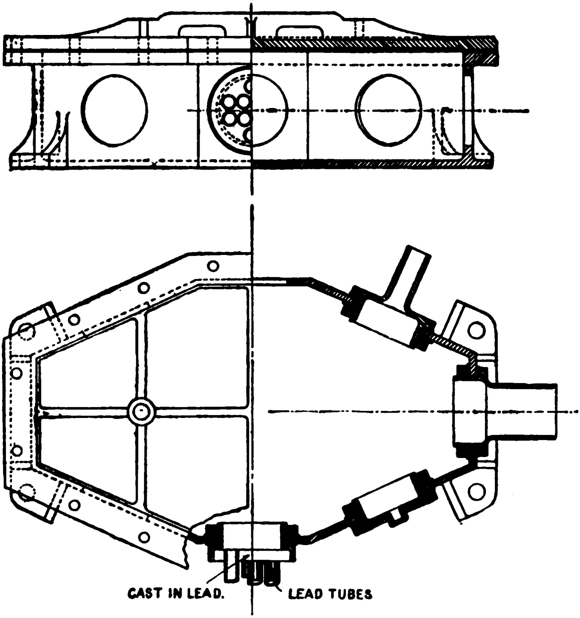

FIG. 225.

The function fulfilled by the desiccator is so very important that its condition demands the most careful attention on the part of those responsible for its use.

The stock of calcium chloride should be kept in airtight canisters or jars.

A few particulars of the cables and street work in London will not be out of place. The entire cable system for telephones of the Post Office is underground, and the main cables leading from the exchange to the distributing points are 217-pair paper-insulated and lead-covered cables with conductors weighing 20 lbs. per mile (No. 20 S.W.G.). At the distributing points these cables are led into boxes from which, as a rule, seven-pair cables of the same type are branched. One of these boxes is shown in fig. 225. It is seen that it contains eight holes for the insertion of gunmetal sleeves, through which the cable is led, the sheath of the cable being jointed on to the gunmetal by a 'wiped' joint. Different sized sleeves are employed according to the size of the cable to be led out, and until a hole is wanted it is plugged up with a screw plug. In the figure, a sleeve for the 217-pair cable is shown at the right hand end, and a plug and sleeves of different size

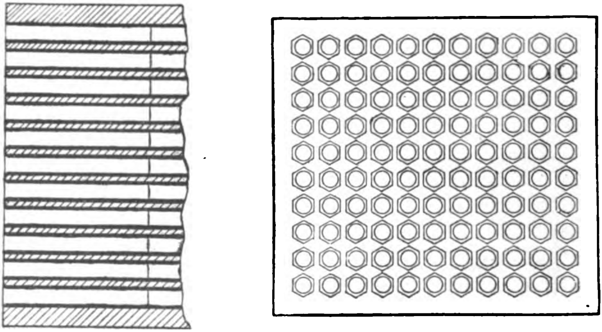

FIG. 226.

are also shown. In the case of the smallest cable it is seen that it is brought through lead pipes which are cast with lead into the gunmetal sleeve or lining. The seven-pair cables end in a pothead for distribution, and from this No. 22 single-pair silk and cotton insulated wire is led to the individual subscribers. These potheads are filled with compound, but the distributing boxes are left dry. A number of earthenware cable ducts, as built up in cement at the exchange basement, are shown in fig. 226.

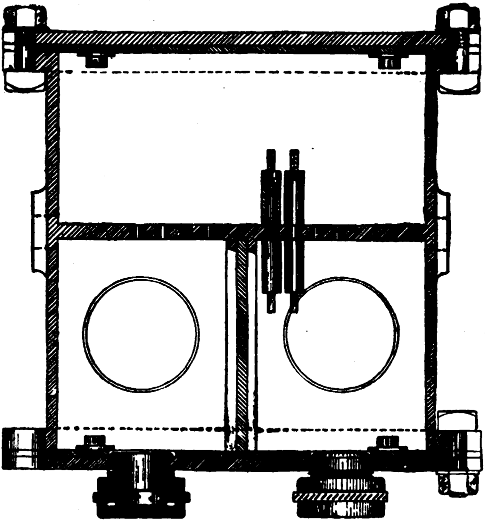

FIG. 227.

At points where access to the several wires is necessary for purposes of tests, re-arrangement of distribution etc., various types of 'leading-in box,' 'cable head,' etc. have been employed. The cable-connection box shown in fig. 227 is of iron, and its front and back are removable and can be closed hermetically by means of gunmetal bolts and nuts. The box is divided into front and back chambers by means of an intermediate panel pierced with holes, through which are inserted the requisite number of insulated pins of the form shown in the figure. In order to make the panel air-tight each hole is first dressed with rubber solution, the pin is inserted from the back of the panel, the ebonite sleeve is slipped over the front end, and the pin is then tightly screwed up by means of the brass nut and washer. The back compartment serves practically as a cable head, while the front one is used for cross-connecting, testing, etc. The back cover is fitted with an air-tight nozzle with a screw-cap, which, when removed, permits of the attachment of the air-drying apparatus for removal of faults. Every lining with nut and washer must be screwed up air and water tight, a leather washer dressed with red lead being interposed between its flange and the surface of the box.

The end of the box at which the linings are fitted should be recognised as the 'cable end.' As a preliminary to jointing the lead sheathing of the cable is stripped back to a suitable distance and the wires led through the lining until the sheathing either abuts against or enters the brass tube. A plumber's wiped joint is then made which unites the sheathing and the lining. When the wires inside the chamber have been soldered to the insulated pins, the back compartment is thoroughly dried and the back tightly screwed up. Access to the wires for testing, cross-connecting, and other purposes, is obtained from the front chamber, which is the only one to be opened for all ordinary maintenance purposes. Great care must be taken to exclude moisture from the dry-core cables in connecting up the wires with the test box apparatus or with open wires. In the front chamber such precaution is not required, but it should, when opened, be dried out by means of charcoal braziers before closing.

If these cable connection boxes are used for terminating cables inside offices, they may be attached to a framework or suspended by their lugs from a rigid support.

Dry-core cables are also successfully used overhead and are a great convenience in large towns where the liability to contact and interruption with bare wires is considerable. The cables may be either lead sheathed as above described where there is no objection on the part of the local authorites to heavy cables overhead, or they may be sheathed in vulcanised rubber, taped, braided and compounded. If the latter plan is adopted the copper wires must be tinned to prevent injury during the vulcanising process. The rubber sheath is 80 mils. in thickness and is tested for soundness, with the cable immersed in water, by air pressure of 35 lbs. per square inch. Care must be taken to keep the ends of the cable sealed except when required to be open for testing, as the dry paper readily takes up moisture from the air, and this will travel a considerable distance within the core of the cable during short exposures. The capacity of a wire in such a cable is rather higher than that experienced with a lead sheath, but it should not exceed 0·1 microfarad per mile when measured with all other wires

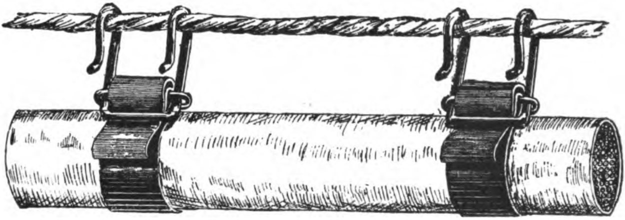

FIG. 228.

connected to earth. The insulation required on manufacture is not less than 500 megohms per mile, with wires connected as above. When such rubber covered cables are jointed, paper sleeves are used as before described, a metal connector or sleeve is slipped over the whole of the conductors thus united, and the rubber covering on each side of the joint is drawn down over the end of the metal sleeve and bound tightly to it. Lead or rubber covered dry-core cables, whether carried over house tops or on a line of poles, should be suspended by hangers from steel stranded galvanised wires as shown in fig. 228, as they are not sufficiently strong in themselves to support their own weights in the spans usually met with.

CHAPTER XVI.

FAULTS.

THE faults to which every circuit is more or less liable may be divided into three classes, viz :—

1. *Disconnections.*
2. *Earths.*
3. *Contacts.*

Total disconnection is such as that produced by a broken wire with its end insulated, a wire off its terminal, an open switch in an office, &c.

Intermittent disconnection is caused by a bad joint, which, moved either by the wind, by passing objects, or by heat, makes and breaks contact irregularly; dirt or dust accumulating on contact points will frequently produce the same effect.

Earths may be *total*, *partial*, or *intermittent*, and are indicated by an increase in the strength of the current at the sending end, and by a decrease in the strength, or its entire cessation, at the other end.

Full or *total earth* (sometimes termed *dead* earth) is due to the wire resting on the damp ground, or touching a stay or some good conductor in connection with the earth. In the case of a cable it would be caused by the conductor being in contact with the water.

Partial earth is the result of the insulators being cracked or defective; or it may be produced by the wires resting upon walls, posts, trees, or other imperfect conductors in connection with the earth.

Intermittent earth is produced by the wire touching at intervals conducting bodies in connection with the earth, either by being blown against them by the wind or by expanding and dropping upon them under the influence of heat.

Contacts are indicated by the signals from one wire passing into another wire.

Full contact (sometimes termed *metallic* contact) is that which is produced by the wires being hooked or twisted together; or by being joined across by means of another piece of wire making firm electrical connection with each.

Partial contact is that which is produced by imperfect conductors being thrown across the wires, by bad earths or by defective insulation on lines not earth-wired.

Intermittent contact is produced by the wires touching each other at intervals, and is due to a variety of causes which will be alluded to hereafter.

A.—FAULTS IN THE BATTERY.

Disconnections, or apparent disconnections, in the circuit are the only faults which occur in the battery Total disconnection would be evidenced by no current being obtained from it. This may be due to the battery wires being knocked off the terminals, or it may be caused by the two battery wires being in metallic contact with each other. In the latter case a 'short circuit' is formed, and no current whatever proceeds to the line. One of the cells may be empty, and this would produce the same effect. In the trough form of battery this may be caused by leakage chiefly owing to the marine glue having been either imperfectly applied or not being of the required consistency. In the Leclanché it may result from a fractured glass cell. If any of the cells in a battery be faulty, either from leakage or from any other cause, it should be bridged over and so cut out of circuit. This can be done by joining the plates on each side of it by means of a wire, as shown in fig. 230. A battery wire, again, may be broken either mechanically or by the chemical action of the cell; as already mentioned (p. 27), the free ammonia in Leclanché's battery not infrequently eats through the wire.

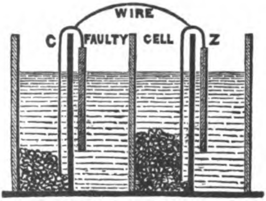

FIG. 230.

Intermittent disconnection in the battery—that is, when the current occasionally fails—is usually to be attributed to the wires being loosely fixed instead of being firmly connected by the terminals.

Apparent disconnections are often due to the battery having been allowed to work too long without being attended to. Or the solutions may have mingled too much by diffusion, or have become either too strong or too weak, as the case may be. Dirty plates, cracked porous cells, corroded and dirty terminals, all tend to diminish the strength of the current. A similar result is also produced if the battery be standing in a damp place, since the damp exterior partially short-circuits the battery.

B.—FAULTS IN THE INSTRUMENTS.

The Needle.—Faults in the needle instrument, and in fact, in the instruments generally, may be due to either mechanical or electrical causes. The indicator on the dial of the needle instrument often sticks against one of the ivory pins, the result either of damp or of the pin being partially worn away. In the former case the fault is removed by wiping the pins with a cloth, and thus making them perfectly dry ; in the latter case they ought of course to be replaced by others.

Disconnection, or apparent disconnection in the needle instrument, evidenced by the needle failing to respond to the currents, may possibly result simply from a broken pivot. Weak currents sent to line may be due to the axles of the tappers being oxidised, but loss of magnetism in the permanent magnets employed for polarising the needle will also cause an apparent high resistance fault. The carrying power of these magnets should never be less than ¼ oz. ; in the event of its falling below this, the magnets should be remagnetised. Lightning is a source of trouble not only in this but in every form of instrument. Apart from the occasional demagnetisation or the reversal of the magnetism of the permanent magnets, the coils of the instrument are liable to be fused by the intense currents induced, and special measures have to be taken, which will be described further on (p. 398), in order to guard against them.

Considerable difficulty is sometimes experienced, usually in the autumn, in working the single-needle instrument on account of the earth currents, which then prevail with more than their usual strength. Their effect is to deflect the needle permanently ; and in order to get rid, at least to some extent, of the inconvenience which is thereby caused, the dial is so constructed as to be capable of rotation. When the earth currents make their appearance the dial should be turned round upon its centre, until it stands at a suitable angle for the needle to work independently of the earth currents.

To prove that the single-needle instrument is in working order, it is only necessary to short-circuit the instrument, by joining together terminals A and B (fig. 28) with a piece of wire, and depress the keys. Should the needle not respond, the fault will be either a failure in the batteries, a loose connection of the wires with the terminals, a bad contact between the tappers and contact springs, a broken wire in some part of the apparatus, a fused coil, or a broken needle-axle pivot. Should the needle respond properly, it will show that the instrument under test is in order.

The Sounder.—The Sounder, on account of the extreme simplicity of its mechanism, is less liable to faults than any of the other forms of instrument which are employed. Those which are to be met with are usually due to bad adjustment, and are the result of ignorance or inexperience on the part of those employed to work it. The antagonistic spring will, in the course of time, get weak and refuse to do what is required of it, but its replacement is a simple and inexpensive matter.

In the key the only faults likely to arise are disconnection caused by dust or waste getting on to the contact points ; a constant current, owing to the battery and line terminals being connected with each other, either by a weight pressing on the key, and the antagonistic spring being too weak to pull it on to the back stop, or from a conductor, such as a metallic pen, or the like, connecting the two parts together. If the axle of the key be loose or dirty, a high resistance is introduced and weak currents will flow to line.

The Ink-writer.—The same faults as are to be met with in the Sounder must also be looked for in the Ink-writer, but in addition to these there are several others from which the Sounder is free.

The clockwork in the Ink-writer is more or less liable to become deranged ; broken stop work, caused chiefly by its being over-wound, is the accident which most frequently happens. Grit again, or dust, or the 'fluff' from the paper slip making its way into the driving gear, will prevent the paper from running, and the friction among the various parts renders it necessary to overhaul them from time to time.

Another source of trouble inherent to the Ink-writer is to be met with in the inking arrangement ; the passage between the well and the reservoir may get choked, and the disc being unsupplied with ink no marks whatever are recorded ; or, the ink becoming too thick from the accumulation of dust in the well, will render the marks altogether illegible.

As the electrical arrangement and the method of working are precisely similar to the Sounder, in case of failure or defect in either the clockwork or the ink, the clerk should revert to reading by sound.

The Relay.—The only specific fault to which the relay is subject is due to the spark which passes between the points of contact every time the local circuit is completed or broken. It is the effect of the extra currents due to the self-induction of the coils of the receiving instrument in the local circuit, and is strongest at the moment the circuit is broken. It is more marked in wet than in dry weather, owing to the fact that the motion of the tongue of the relay is then more sluggish ; the more rapid the movements of the tongue, the less is the inconvenience felt from the spark. As far as possible to prevent the contact points from being burnt away they are made of platinum, and a small piece of roughened watch spring should from time to time be gently passed between them for the purpose of removing any metallic dirt that may have gathered there. Paper should on no account be used for this purpose, as the roughened platinum damages the surface of the paper, fibrous matter adheres to the tongue or the contact stud and prevents the one from making electrical contact with the other.

Several methods have been suggested to prevent the spark itself from forming. The coils of the receiving apparatus (the sounder or inker) may have their ends connected with a condenser whose capacity is regulated by the length of wire in the coils and the strength of the local battery. A plan which answers equally well is to connect either the contact points of the relay or the ends of the receiving coils through a high resistance acting as a derived circuit and forming what is technically called a *shunt*. This resistance, which ought to be varied according to the strength of the local battery, should never be less than five times, and need not be more than forty times that of the receiving apparatus. The induced current will then traverse this resistance rather than pass through the air in the form of a spark. This latter plan is now generally adopted by the British Post Office, sounder coils which are wound to 20 being shunted by a resistance of 500$^{\omega}$.

The A B C.—The delicate mechanism of the various portions of the A B C apparatus renders it more liable to faults of a mechanical nature than any of the instruments already alluded to. In dealing with the question of the adjustment of the A B C, reference has been made to the difficulty sometimes experienced from the endless chain in the communicator, and the method of adjustment adopted in order to overcome this. Other faults of a mechanical nature to be met with in the communicators are :

(*a*) Damaged teeth in the driving-wheels. This results either from a lack of oil or from the driving gear having been taken to pieces and so put together again that the teeth do not properly come into gear with each other.

(*b*) The jewel against which the armature axle is fitted may be broken, or the adjustment screw may work loose, which will permit the armature to be drawn against the poles of the large compound horseshoe magnet, so that the handle cannot be turned.

(*c*) The socket in which the axle of the armature works is sometimes insecurely fastened, or it gradually gets loosened, and then it produces the same fault as the broken jewel.

(*d*) Bad oil, becoming hard and clotted, will lead to indifferent working; only good watch-oil should be employed in the treatment of the apparatus.

The chief complaint which is made as to the working of the A B C is that of either 'gaining letters' or 'losing letters.' This, as has been already remarked (p. 92), is generally a question of defective adjustment, but it may be due more or less to one of the causes named above. Disconnections, either partial or total, are by no means rare. The former are mainly due to oxidation of the terminals or contact points; the latter are chiefly caused by the contact-maker K (fig. 66) in the communicator taking up a position midway between the line and earth contact-points without touching either. This is mainly to be attributed to the spiral spring L being too weak. The fault was at one time an extremely troublesome one, as it was apt to come on at any time and disappear before it could be localised, but in instruments of later pattern the contact-maker normally short-circuits the communicator coils, so that its being out of adjustment cannot disconnect the line but only bring in the coils.

Duplex Apparatus.—The causes of the irregularities in duplex telegraphy have been already dwelt upon (p. 133 *et seq.*) when treating of the subject generally. The smallest fault will speedily make itself felt on a duplex circuit, and in the event of earth currents, thunderstorms, or any other electrical disturbance appearing on the line, the system, being in a state of balance, is specially subject to interference. It is for this reason that duplex circuits must always be worked by skilled telegraphists who thoroughly understand adjusting. A line worked upon the duplex principle is, so to speak, subjected to a constant test, and faults which with ordinary working would probably escape observation, at once show themselves in duplex working.

Automatic Apparatus.—Only upon well-insulated lines can the full advantages of automatic telegraphy be gained. A loss of insulation is felt sooner with this than with the ordinary apparatus; it compels a reduction of speed with the automatic instruments before it is felt in general working. Still, the lowest speed of the former is always above that which can be done by hand-sending in the same circumstances.

The mechanical faults to which the different portions of the automatic apparatus are subject are as follows:

(*a*) *The Perforator.*—Defective spacing is one of the main faults; it may be due to defective adjustment of the mechanism, or to the rubber pads beneath the punching keys being too thin. Blunt punches and loose screws are to be guarded against. Care should also be taken that the paper is properly moved forward, and does not stick in any way.

(*b*) *The Receiver.*—The paper at times runs irregularly, owing to the friction discs becoming greasy, to dust or grit interfering with their action, or to friction in the rollers &c., by which the paper is fed forward from the coil.

(*c*) *The Transmitter.*—Apart from dirty contacts, which should be carefully guarded against in every form of telegraphic apparatus, but in none more carefully than this, the chief faults which are met with in the Transmitter are broken spiral springs, or loose adjusting screws. The same difficulty of irregularity in the running arising from smooth or greasy discs, is experienced with the Transmitter, as has already been referred to in connection with the Receiver.

Quadruplex.—Faults generally arise from careless adjustments, dirty contacts, loose connections, battery failures, and the usual line interruptions.

It is essential to keep the platinum points of the uprighting sounder and the relays in good condition. Bad working is sometimes caused through the batteries for the A and B sides being of disproportionate strength (see p. 212), and it becomes desirable to test the condition and comparative strength of the batteries at the instrument. In order to do this, request the distant office to 'put to earth,' which will cause the needle of your galvanometer to stand at zero. Then increase the resistance in the rheostat by 4,000$^{\omega}$ (this may be done on most circuits by simply withdrawing the 4,000$^{\omega}$ plug). Note the deflection, which should be not less than 12° of the differential galvanometer. Then depress the B side key and again note the deflection, which should be not less than twice that of the first deflection. Now depress the reversing key; if it reverses properly the needle of the galvanometer will be moved over to the opposite side.

Restore the original line resistance balance and instruct the distant office to 'cut in.'

The *battery resistances* are liable to become heated if the resistance of the batteries is allowed to fall very low. When this happens the solution in the zinc cells should be partially removed and replaced with water. It is also desirable to remove such porous pots as are found to be of too low resistance and to replace them by others of greater resistance. The resistance should range from 2 to 3 ohms per cell.

The duplex and quadruplex systems apply a constant test to a line, and line faults of all descriptions should therefore be easily detected and remedied without loss of time, as it is impossible to maintain a balance for many seconds with an intermittent earth or contact.

Multiplex. Variation of the speed.—This fault may be caused by oxidised and rough contacts of the reed, loose connections, loose magnets or other parts on the base of the reed, imperfect connections from lacquer, and loose clamping screws in connection with the reed. It may also be due to the battery which actuates the reed and distributor, to check which the battery should be changed for one which is known to be good.

The contact points of the main correcting relay and the intermediate corrector should be carefully cleaned on both the unused side and on that in use, in case either may be dirty. If these contacts fail intermittently, or if the unused point is dirty, the tongue of the relay will be held over too long and will cause the apparatus to run out of synchronism, although the normal speed may appear to be correct when the corrections are on the reading sounders.

The distributor itself may be the cause of an apparent variation of the speed, if the adjustment is such that the galvanometer needle is seen to oscillate very perceptibly. The oscillation is generally caused by the motor magnets of the distributor at one end being adjusted too far from or too close to the wheel ; or a slightly inaccurate wheel may just touch the magnets in one position and consequently revolve with a jerky motion. The fault will show itself on the sounders during the normal speed adjustment by an occasional oscillation in the reverse direction to that of the actual tendency when the speed is adjusted practically correct.

The electro-magnet under the distributor being loose, or the pressure of the trailing brush at either end being too great or too light, will also produce variation.

A deposit of metal dust between the segments will cause contact between the arms, or between an arm and the correcting segments ; or, as some segments are connected to earth, the others may also be put to earth by being in contact with them. To remove this fault carefully clean between all the segments by means of a brush reserved for this purpose.

When it has been necessary to remove the centre plate it should be very carefully handled and replaced in its proper position, which is marked by one or more pits in its under side, with corresponding marks in the ebonite base on which it rests. A bent tooth in this plate will cause much difficulty and may pass unnoticed for a long time.

If after having been carefully adjusted the apparatus frequently runs out of synchronism, the correctors should be carefully observed, as an occasional spark at the intermediate corrector, or a momentary failure of the line correcting relay to complete the local circuit of the intermediate correcting sounder after a correction has passed, may be the cause by making the correction to act too long. The distributor also is likely to be stopped by this fault.

It is necessary that the local battery which actuates the intermediate corrector be kept in the best condition.

If the battery which keeps the reed and distributor in motion gradually loses its power, the amplitude of vibration of the reed will diminish.

Contact between the arms, or excessive sparking on the segments of the distributor will occur if the wires of the trailer are of unequal length, or if the angle to which the end of the trailer is cut be materially different from the angle of the edges of the segments.

Faults on any individual arm can be proved by crossing with a good arm at the terminals at the back of the distributor ; and after proving at which end the fault exists its removal is not difficult as the apparatus is of the simple telegraphic form.

C.—Faults on Open Lines.

Total disconnection upon the line is the result of a broken wire. The breakage may be due to a variety of causes, but among the principal of them may be mentioned the following :

(*a*) A concealed weld or other flaw in the manufacture of the wire.

(*b*) The wire having been carelessly nipped by pliers when first erected by the workmen.

(*c*) Friction of the wire against the insulator (the result of imperfect binding in), or against a chimney or other object in its neighbourhood.

(*d*) Friction of an old binder which has been allowed to remain on the wire.

(*e*) The wire having rusted away.

(*f*) The wind, fallen trees or boughs, travelling cranes and high loads, snowstorms, &c.

Intermittent disconnections and high resistance faults are invariably the result of bad joints; attention has been already drawn (p. 352) to the importance which attaches to the joints being carefully seen to.

Metallic contact is the result of the wires being twisted or hooked together, or connected either by means of a short piece of wire thrown across them, or by dropping on to a metallic roof, chimney, iron post, or other conductor. When the line is being erected great care should be taken to remove all pieces of short wire that may have been cut off; if any of these are left lying about, they are very likely sooner or later to be thrown across the line wires by passers-by. Apart from the ordinary causes which bring the wires together, such as the wind, high loads, workmen engaged in building operations near them, &c., a frequent source of trouble in this respect is bad regulation. This is especially the case when wires of different metals are vertically over each other. The sun's influence upon such wires causes them to expand unequally, and so drop one upon the other; if the line runs through a cutting and is thus exposed for only a short time to the sun's rays, or if the sun becomes obscured by clouds, the wires soon return to their normal position, and the fault often disappears before the lineman can reach its locality.

Partial contact between two or more wires is caused by bodies which offer considerable resistance to the passage of electricity, such as kite-strings or cotton waste, hanging across them, or by their resting simultaneously against an imperfect conductor, such as a brick chimney or a scaffold-pole.

Partial contact not infrequently results from *bad earth*, which is often a source of trouble, especially in rocky, chalky, or sandy ground. Thus, in fig. 231, let station B communicate with stations A and C by means of a separate circuit to each ; if the earth at B is bad while that at A and at C is good, then a part of A's current, on reaching B, instead of going to earth there, will take the course of the wire to C, working C's apparatus, and go to earth at C. The effect is the same as though the wires A B and B C were actually in contact with each other, and the strength of the contact will depend upon the resistance which the earth at B offers as compared with the circuit B C. If the steps named at p. 354 are not sufficient to secure a suitable earth at B, the only way of overcoming the difficulty is to run a wire from there to the nearest point where good earth can be found.

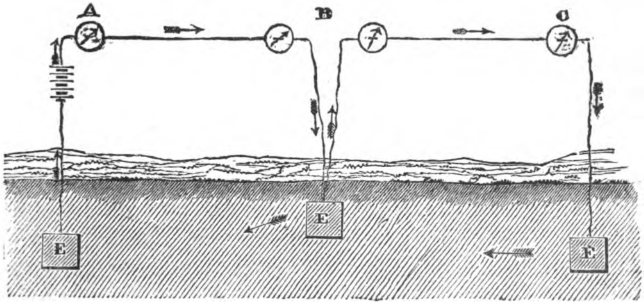

FIG. 231.

Weather contact is a form of partial contact to be met with chiefly in foggy or rainy weather, and mainly upon poles which have not been earth-wired. The leakage which takes place at the insulators there, instead of going to earth by means of the earth-wire, finds its way into the neighbouring wires and the working of all is more or less impaired. The effect of weather contact upon the working of a circuit is very similar to that of indifferent earth ; the latter, however, makes itself felt more or less in all weathers, while the former makes its appearance only during fogs, rain, or snow.

Intermittent contacts are almost entirely due to bad regulation. The wires are swayed to and fro by the wind and brought from time to time against each other, more especially if those upon the same arm differ in gauge, and are therefore not equally influenced by the wind. Pieces of wire thrown across the line wires and loosely adhering to them will also give rise to intermittent contacts.

Full earth may be due to one end of a broken wire lying in water or resting upon damp ground ; it may likewise be caused by the line-wire being in metallic connection with some conductor affording good earth, such for instance as an iron post, an iron stay, or the earth-wire.

Partial earth is most frequently due to broken or otherwise defective insulators ; it may be also produced by the wire resting upon imperfect conductors in connection with the earth, such as walls, the guards or arms on wooden posts, trees, &c. Trees form a great barrier to the erection of a line of telegraph, and their interference is one of the main points to be guarded against in the selection of the route. When however it is impossible to avoid them permission must be obtained to lop the branches where necessary.

Intermittent earth is due to the wires being blown by the wind or otherwise brought from time to time into contact with some conducting body in connection with the earth.

D.—FAULTS IN UNDERGROUND WIRES.

Underground wires are free from most of the dangers to which overground wires are subject. Most of the faults which make themselves evident in underground wires, apart from those which arise from the deterioration in the materials due to age, are the result of either imperfect manufacture or carelessness on the part of the workmen engaged in laying down the line. Among these may be mentioned flaws in the copper wire employed as the conductor; imperfections in the insulating covering; bad joints and abrasion of the insulating covering whilst the wires were being drawn into the pipes. If reliance could be placed upon the manufacture of covered wires, if due care were exercised upon the work of laying them, and in working them after they are laid, it is difficult to see what faults could arise until they were decayed to an extent calling for complete renewal.

Rats sometimes find their way into the pipes by getting in at the bottom of the flush-boxes; they then eat through the gutta-percha and either bring the wires into contact or put them to earth. Their ingress may, however, be provided against by setting the flush-boxes in cement mixed with pieces of broken glass.

In localising a fault upon one of a number of wires lying in the same pipe, considerable difficulty is experienced in selecting from the bundle that in which the fault exists. At each joint-box the wires are numbered, and no difficulty is found there in getting hold of the proper wire; it is at intermediate points, where the wires are not numbered, that the inconvenience is felt. The old practice of 'pricking' the wires should never be had recourse to. The holes which were made were either imperfectly closed up or not closed up at all, and in time developed into faults causing far more trouble than the original fault in search of which they had been made. An instrument known as the *wire-finder* well answers the purpose in picking out any wire that may be required without doing any injury whatever to it. The wire-finder consists of a magnetic compass, beneath which the several lines are brought in succession, until a permanent deflection of the needle indicates that upon which a constant current is passing. This constant current is put on the wire which it is required to trace. A yet more satisfactory way of tracing such faults is by passing intermittent currents, giving either certain definite 'beats' or a musical note, along the wire to be traced. The lineman then carries a coil with a hollow core, so formed that a wire can be placed within it, and, the ends of this coil being connected to a Bell Telephone Receiver, the beats or note can be distinctly heard. The advantage of having distinct beats is that, as the signals can be heard faintly on all the wires, the lineman may be somewhat doubtful as to which is the wire he wants ; but in such case on cutting the selected wire and joining it to his galvanometer (detector), the beats should be reproduced, so that he may be quite certain as to whether he has the right wire or not.

If an underground wire becomes earthy, owing to the insulating covering being partly destroyed, and a positive current flow to line, an oxide of the metal forming the conductor is deposited at the point of leakage, and as this is a non-conductor, the insulation of the wire appears to be improved. This, however, is only temporary, for the metal is gradually transformed into its oxide, and the wire is thus disconnected. The action of the negative current is the reverse of this; its effect being to keep the wire clean, and thus to maintain the leakage. For this reason negative currents should invariably be used in testing covered wires, for leakages will be brought to light by them which, with positive currents, would in all likelihood escape notice.

E.—FAULTS DUE TO LIGHTNING.

Lightning is the most fruitful source of faults upon telegraph circuits in countries where thunderstorms are rife, and atmospheric electricity is undoubtedly the greatest enemy which those employed in their maintenance have to encounter. The damage done by it to the telegraph plant may be subdivided under two heads, viz. :

a. That affecting the poles, wires, and insulators.

b. That affecting the apparatus.

It is only in the case of very severe thunderstorms, when powerful lightning discharges take place, that the former is to be met with. The poles are then shattered, or have grooves cut out from the top to the ground line : the insulators are sometimes smashed, and the line-wires occasionally fused. Underground wires are free from these injurious effects of lightning, provided they are not connected to an open section of line. If, however, the latter is the case, they are liable to be affected, and numerous faults arise. Some form of lightning protector is therefore usually employed at those points where the open and covered sections are connected with each other. If the lightning finds its way into a covered wire, it will, in all likelihood, ruin the insulation at one or more points by bursting through the dielectric in its passage to the earth. The earth-wires alluded to at p. 342 play the part of efficient lightning conductors to those poles which are fitted with them. Instances of earth-wired poles being affected by lightning have occurred, but the damage has never gone farther than the point at which the earth-wire commences : for this reason earth-wires should always be carried above the roof of the pole. Upon single-wire lines or loops where earth-wires are not required for the prevention of contacts, it is always advisable, as a protection against the effects of lightning, to earth-wire at least the last five supports on each side of every office.

The dangers of damage to instruments which arise from the powerful currents which are induced by lightning discharges have been practically surmounted by the use of various forms of *lightning protectors*, all of which are based upon the different behaviour of electricity of high and low potential.

It was observed that when two silk-covered wires were knotted or tied together, electricity of high potential was discharged across this knot in preference to going through the loop. When a discharge takes place through a dielectric, such as dry air, at the moment of discharge the resistance along the line of discharge is broken down so as to allow the passage of the greater part, if not the whole of the

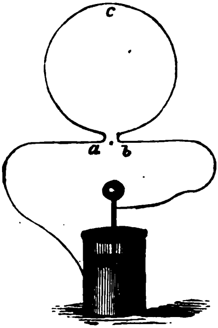

FIG. 232.

current; so that, in point of fact, at the moment when the discharge occurs through a layer of air or other elastic medium, a conductor of very low resistance is formed. Hence, as a current divides itself in inverse ratio to the resistances opposed to it, the greater portion, if not all, flies across the knot or shunt. This is only an example of Faraday's well-known experiment, in which a long wire in air is so bent that two parts, *a b* (fig. 232), near its extremities, approach within a short distance, say a quarter of an inch. If the discharge of a Leyden jar be sent through such a wire, by far the largest portion, if not the whole, of the electricity will pass as a spark across the air at the interval separating *a* and *b*, and not by the wire *c*. If, on the other hand, the source of electricity be a galvanic battery instead of a Leyden jar, the entire current will take the path of the wire *a c b*. Acting upon this principle, Mr. C. F. Varley, in the old form of single-needle coils, simply twisted together the two ends of the coil-wire before they were attached to their proper terminals, and it was found that this acted as a protector, the lightning discharging through the silk covering in the twist in preference to going through the coil. In order to make this idea more practically workable two wires covered with silk of different colours were twisted together and wound on a small boxwood reel, one wire being then connected to each end of the coil. As it was found that damp affected these wires and so caused contacts, the wires were still further protected by being drawn through melted paraffin. This 'reel' protector is interesting as having been the first practical form of lightning protector introduced in this country, but it has long been superseded by improved arrangements. Although it protects the apparatus fairly well there is a very serious objection underlying its principle, inasmuch as whenever a discharge occurs through the protector at least a part of the circuit is broken down until the faulty protector is removed.

Probably the most efficient form of protector yet introduced is the 'plate' protector, originally devised by Siemens. This is now made in several patterns, but the principle is, of course, the same in each. It consists essentially of two conducting plates superposed, and separated from each other by a thin air-space. The line is connected to one plate, while the earth connection is made to the other. The lightning discharge takes place across the air-space. As originally devised the protector consists of two iron plates finely corrugated on their opposing surfaces, the corrugations of the upper plate running at right angles with those of the lower. The plates are prevented from making contact one with the other by the insertion between them of thin ebonite washers. Great care has to be exercised in order to keep the surfaces clean and prevent the accumulation of dust between them—a fault to which they are very liable. This description of plate protector is still used very extensively in India and many of the colonies, but in England it is not employed, the British Post Office pattern being very much superior and more reliable. In its original form it consisted of two brass plates, the opposing surfaces of which are perfectly plane and carefully tinned to prevent oxidation. The faces of the plates are kept separate by a sheet of thin mica (talc), considerable perforations in which provide the necessary air-space, while the mica itself serves to exclude dust.

A discharge between the opposing plates is occasionally sufficient to fuse the two plates together, thus introducing an 'earth fault' upon the circuit which can only be got rid of by removing the faulty protector. This difficulty has now been surmounted by the substitution of carbon plates for the original brass ones. When a spark passes between the carbon surfaces, deflagration occurs, but fusion is impossible. A typical form of this protector is shown in fig. 233. B and B′ are brass blocks, one of them being connected to 'line' and the other to 'earth.' A flat brass spring S is clamped at one end to B by a milled-headed screw, while the free end exerts sufficient pressure upon the top carbon plate to keep it in position. The lower carbon plate is fitted into a brass dish, from the centre of which on the under side projects a screw, forming a means of fixing the lower plate to the block B′. A thin disc of perforated mica is placed between the plates.

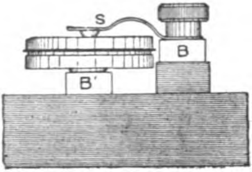

FIG. 233.

Every possible precaution has to be adopted to protect submarine cables from the effects of lightning discharges; as not only is the cost of removing a fault in such a case considerable, but the delay caused is of serious consideration. For these reasons the plates of the cable lightning protector used by the British Post Office are of larger size than those shown in fig. 233, and the design also embodies a special form of inductance coil or 'reel' protector; besides which in the circuit is placed an easily fused wire. Very great care is taken in the periodical examination of these protectors.

Underground lines, where they join open work, are frequently protected by means of 'vacuum' protectors, they being found to answer the purpose fairly well, occupying little space where space is a consideration, and being little liable to be affected by moisture. In this instrument the line-wire and the earth-wire are connected respectively to two wires fused into a glass tube in which a partial vacuum has been made. The two wires terminate in points, which are placed very near to each other. Each tube should be tested from time to time by means of an induction coil. Tubes which show a bright violet glow are in good condition.

CHAPTER XVII.

INSTRUMENTS FOR TESTING.

ALL materials and instruments employed in the construction and fitting-up of telegraph circuits that have to do with their resistance or insulation should be subjected to electrical tests before being brought into use; in practical working also, it is most desirable to test the electrical condition of lines and instruments from time to time. Hence the necessity arises for various forms of testing instruments, some of which will now be described.

The galvanometers used in practical telegraphy indicate the presence rather than the strength of working currents, so that no very special attempts need be made to secure extreme sensitiveness and freedom from friction upon the pivots. These conditions, however, are essential to a galvanometer which is to be used for testing purposes. One form of such an instrument, called the *Astatic* galvanometer, is shown in general arrangement by fig. 234. It consists essentially of a divided coil of wire, with a vertical central axle fitted with two magnetic needles so pivotted that the needles move in the horizontal plane, one, *n s*, within, and the other, *s′ n′*, immediately above the coil, the opposite poles being in the same direction. By a consideration of the theory explained at p. 45, it will be seen that a current passing through the coil will tend to have the same effect upon both needles, and, therefore, the addition of the outer needle is advantageous from that point of view; but, further, it must be borne in mind that a magnetic needle properly balanced and pivotted to lie horizontally, points in a certain direction (north and south), in virtue of the directive force of the earth's magnetism, and, other conditions being constant,

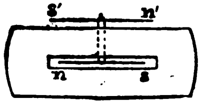

FIG. 234.

tends to remain in that position with a force dependent upon the magnetic strength of the needle. But in the astatic needle the *n′* pole of the upper magnet is placed over the *s* pole of the lower, and *vice versâ*, so that if the two magnets were absolutely alike the needle would not be at all affected by the earth's directive force, but would stand in any position and would yet be quite free to be acted upon by the directive force of a current traversing the coil. In practice the two magnets are made slightly dissimilar in strength and the directive tendency resulting from this difference is under control. Sometimes the compound needle instead of being pivotted is suspended from a long silk fibre—an arrangement which eliminates the friction at the pivots and so increases its delicacy. The astatic galvanometer is a very useful form, but its sluggishness in coming back to zero is its weak point.

A more generally useful galvanometer is that known as the *Horizontal.* In this case a small magnet, cup-pivotted like a compass needle, and fitted at right angles with an extremely light ebonite pointer, is made to slide into a simple flat coil, and the pointer projects over a scale, just below which is a small reflector, to prevent parallax error.[1]

This instrument when properly constructed is as sensitive[2] as the astatic, and has not the defect of being sluggish. It is very largely used for ordinary circuit testing in connection with the Wheatstone Bridge.

Perhaps the most useful galvanometer for general testing purposes is the *Tangent.* It consists of a circular coil of wire with a very short magnet pivotted in its centre. Theo-

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[1] As the pointer is necessarily elevated slightly above the scale, if the observer reads the deflection from a point not perpendicularly over the pointer, the reading is more or less inaccurate, but by the use of the mirror beneath, if the pointer and its reflection coincide when the reading is taken, no such error can arise, as the point of observation is then correct.

[2] The *sensitiveness* of a galvanometer is judged not necessarily by the extent to which the needle will deflect with a certain current, but rather by the amount of variation in current strength that must be made in order to affect the deflection.

retically this magnet should be of such dimensions that the influence of the magnetic field of the coil upon it should not vary with its position, but this is impossible, and practically it is found that with a simple ring coil, as shown in fig. 235, a needle whose length is from one-eighth to one-tenth the diameter of the coil gives sufficiently accurate results. The tangent galvanometer is so called because with the needle and ring arranged to fulfil the conditions just described, the ***strength of the currents*** which, in passing through the coil, will produce the various deflections are directly proportional to the *tangents of the angles of deflection* of the needle. Thus, if two different currents produce deflections of 30° and 45° respectively, the relative strengths of the two currents are as tan 30° to tan 45°, and these are respectively $\frac{1}{\sqrt{3}}$ and 1, so that a current which gives a deflection of 45° is $\sqrt{3}$ times the strength of one which gives a deflection of 30°.

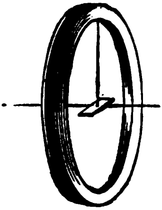

FIG. 235.

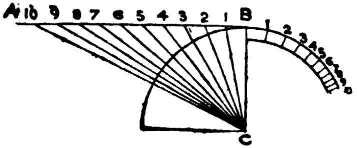

FIG. 236.

If a line A B (fig. 236) be drawn at right angles to the radius C B of a circle, then the proportion $\frac{\text{B 1}}{\text{B C}}$ is said to be the tangent of the angle BC1; and $\frac{\text{B2}}{\text{B C}}$ is similarly the tangent of the angle BC2, and so on. The tangents then are proportional to the lengths B1, B2, &c. Thus, if the pointer of a tangent galvanometer were long enough to reach the tangential line A B, deflections of the needle over the equal divisions 1, 2, 3, 4, &c. would represent proportional current strengths; but as it would be inconvenient to read from this straight line, the tangent scale is formed where lines drawn from the centre C to the various tangential divisions cut the circle described from the centre. This is clearly shown to the right in the figure.

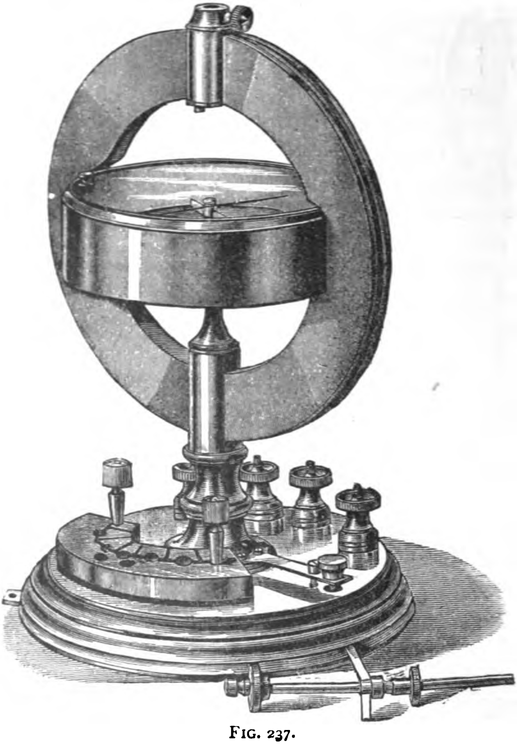

FIG. 237.

The latest pattern of the Post Office form of the instrument is shown by fig. 237. This provides a series of shunt coils beneath the base which can be brought into use by means of the switch on the base, so that this instrument can be used for measuring a very considerable range of currents (Appendix, Section D).

At the front of the figure is shown the directing magnet, the stem of which is fitted vertically above the ring, so that the magnet—more properly *controlling* than *directing*—may be placed so as to assist or oppose the directive force of the earth's magnetism. It should always be placed magnetically north and south, but if required to reduce the sensitiveness of the galvanometer (for measuring heavy currents), its N pole should point south, whereas if it is desired to increase the sensitiveness, the N pole should point north. In these positions either effect is increased by lowering the magnet on its stem.

Another form of tangent, the *Gaugain* Galvanometer, which, however, is never used for telegraphic purposes, consists of two large rings placed parallel at some distance apart, with the magnetic needle midway between.

The *Thomson* Galvanometer is among the most sensitive and beautiful instruments known to practical science. The principle of its construction is that of employing a very light, delicately suspended magnet, so arranged as to indicate its movements by a long beam of reflected light. This can be best explained by reference to fig. 238.

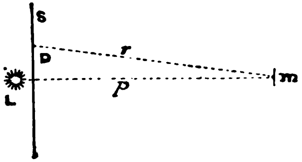

FIG. 238.

Let S be a screen upon which is fitted a scale of equal divisions; L, a lamp behind the screen, from which a beam of light is projected through a lens to fall upon a small mirror *m*, placed about three feet distant from S. This beam will be reflected on to the scale fixed at S. So long as the plane of the mirror is at right angles to the beam of light, the reflected beam will be in the same line (except that, as the reflected beam is required to be upon the scale above the lamp, the projected beam is directed slightly upward towards the mirror); but if the mirror be turned through a small angle as shown, the beam will be reflected upon the scale at D, and this distance will represent *double* the actual angular deflection of *m*. For it is clear that when the projected and reflected beams coincide, they each are at right angles with the plane of the mirror, and, if the mirror turns to the extent of angle *a*, the projected beam *p* will fall upon it at that angle from the perpendicular, but it is a fundamental law of reflection that the reflected beam makes the same angle with the mirror as the incident beam, and in the opposite direction; hence *r* will make the same angle with the perpendicular as *p* makes, and therefore the angle between *p* and *r* will be equal to twice the angular movement of the mirror. In this way the beam of light becomes equivalent to a fixed pointer about six feet long, and absolutely without weight. In applying this to the Thomson Galvanometer, upon the back of the small mirror (which is about three-eighths of an inch in diameter) several small magnets formed of highly magnetised watch-spring are fixed; and the mirror is suspended upon a single fibre of silk without torsion, in the centre of a large divided coil of wire, which so completely surrounds it that the influence of the coil is the same in any position of the needle. Very frequently this arrangement is doubled, a second coil being placed beneath, and the second series of magnets is connected to the first by a piece of aluminium wire, so as to form an astatic pair of needles. The arrangement of the parts furnishes all the conditions required for a tangent galvanometer, but as the range of deflection is always very small, it is permissible to assume that the strengths of current are practically proportional to the deflections of the spot of light on the scale. Only for tests where extreme accuracy is required is it necessary to reduce to tangents. The reading is taken from a black line across the reflected spot of light, which is caused by a wire placed across the lens through which the projected beam passes.

The sensitiveness of the instrument can be regulated by a directing magnet, as described in connection with the tangent galvanometer (p. 407). A high resistance galvanometer of this form is so sensitive as to be capable of giving a fair deflection with a current from one Daniell cell through 100 megohms,[1] and it is therefore necessary for many tests to be able to reduce the amount of current actually flowing through the coils of the galvanometer. This is done by means of *shunts*,[2] whereby only a certain definite proportion of the total current—$\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1000}$—is allowed to pass through the coils of the galvanometer. This shunt is connected across the terminals of the galvanometer.

All tests for resistance depend upon a comparison between the resistance to be tested and some standard resistance, hence various arrangements of *resistance coils* for testing purposes are made. Usually a series of resistances is so arranged that the resistance actually in circuit can be varied at will by the insertion or withdrawal of a brass plug between two brass blocks. The coils themselves consist of silk-covered platinoid, manganin, or eureka, wire wound upon bobbins, and in order to avoid the effects of extra currents from self-induction, the wire is double-wound upon the bobbins, the inner ends being connected together, and

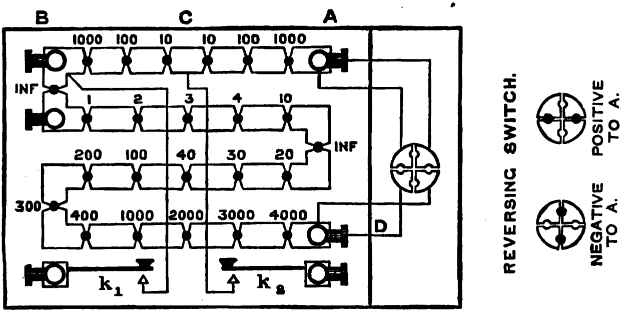

FIG. 239.

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[1] A *megohm* is one million ohms.

[2] See Appendix, Section D.

the outer ends treated as the two ends of the coil : by this means the induced current from one half is neutralised by that from the other, because they are in contrary directions.

One of the most useful forms of resistance coils is shown in fig. 239. It represents a very generally used form of *Wheatstone Bridge.* The numbers indicate the resistance in ohms of the various coils, which are short-circuited by the insertion of the plugs between the blocks, and brought into circuit when the plugs are withdrawn.

The principle of the Wheatstone Bridge can be best understood from an examination of the following diagram (fig. 240). Assume a, b, d, and x to be resistances, some of which are adjustable. If the battery circuit be completed by depressing the key k_2, the point D will be raised to a higher potential than the point C, but the difference, or fall, of potential between these two points along the path $(x+a)$ will be the same as that along the path $(d+b)$.

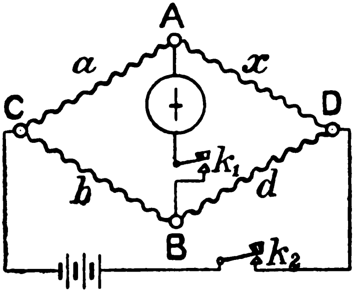

FIG. 240.

Consider the potential at the point A ; it lies between that at D and that at C, and since the fall of potential along each path is the same, it follows that there must be a point in $d+b$ at the same potential as A. Assume B to be this point. Then, clearly, the fall of potential along D A is equal to that along D B; and that along A C to that along B C. Now since the fall of potential in any part of a circuit is proportional to the resistance of that part, the difference of potential between D and A is to that between D and C as the resistance x is to the resistance $x+a$. If the potential difference between D and C be V volts, then that between D and A will be $V\frac{x}{x+a}$ volts; similarly, the potential difference between D and B will be $V\frac{d}{d+b}$, and since these potential differences are equal, we have :—

$$V\frac{x}{x+a}=V\frac{d}{d+b} \quad \text{....................(1)}$$

For similar reasons

$$V\frac{a}{x+a}=V\frac{b}{d+b} \quad \text{....................(2)}$$

Dividing equation (1) throughout by V we get :—

$$\frac{x}{x+a}=\frac{d}{d+b}$$

that is, $$xd+xb=xd+ad$$

and $$xb=ad,$$

or $$x=\frac{ad}{b}.$$

This, then, is the relation which exists between the resistance a, b, d, and x, when A and B are at the same potential. In practice these two points are fixed and a sensitive galvanometer G may be connected between them by depressing the key k_1. The unknown resistance occupies the position denoted by x, and convenient known resistances are placed in the arms a and b. The arm d is then adjusted until B arrives at the potential of A. This equality of potentials is indicated by the absence of any deflection when the galvanometer circuit is completed; for if there be the slightest difference of potential between the two points a current will flow through the galvanometer coil and produce a deflection of the needle.

Now, by referring to fig. 239, where the lettering corresponds with that of fig. 240, the resistances a and b will be seen to be adjustable coils, each arm consisting of 10^{ω}, 100^{ω}, and $1{,}000^{\omega}$. Between B and D is a series of coils, giving a range of adjustment from 1 up to 11,110. The two former series a and b are known as the *ratios*, while the larger series (represented by D in the above equation) is generally called the *rheostat.*

The equation $x = \frac{ad}{b}$ may be written $x = \frac{a}{b}d$, and then it is evident that if the ratios a and b are equal, x, the unknown resistance, is equal to d, but if a is made $1{,}000^{\omega}$, while while b is only 100^{ω} or 10^{ω} (so that $\frac{a}{b}$ is 10 or 100), then x is 10 or 100 times the resistance of d; if, on the other hand, b is 10 or 100 times a, then x must be $\frac{1}{10}d$ or $\frac{1}{100}d$. This latter arrangement is the most accurate where practicable, as by this means it is possible to determine the value of x within $\frac{1}{10}$ and $\frac{1}{100}{}^{\omega}$ respectively. For measuring small resistances, therefore, it is advisable to have b larger than a.

It is necessary to observe that in order to make a test with the Bridge, the insertion of resistance in each ratio is essential—otherwise, as will be seen by a consideration of the formula, if in the equation $x = \frac{a}{b}d$ either a or b have no numerical value (that is if one ratio be either zero or infinite) the value of x cannot be determined.

If the ratios are equal, they can be either 10 and 10, 100 and 100, or 1,000 and 1,000, and the best value to employ may be determined by experiment. The condition required is that the relative values of a, b, d, and x shall be such that the galvanometer G is in its best position (that is, where the deflection will be greatest if the balance is nearly, but not quite, perfect). For instance, with the ratios 10^{ω} and 10^{ω}, and an approximate balance, note the deflection ; change the ratios to 100^{ω} and 100^{ω}, or $1{,}000^{\omega}$ and $1{,}000^{\omega}$, and that ratio which gives the greatest deflection is the best to employ. In the same way when unequal ratios are used, 10^{ω} and 100^{ω} may in some cases be better than 100^{ω} and $1{,}000^{\omega}$, and *vice versâ.* As a general rule, the higher the resistance to be measured (x), the higher should be the values of a and b.

A and D are the two points between which the ends of the unknown resistance are joined, and in practice there is a reversing switch connected between these points (fig. 239). A is really a double terminal, the lower part of which is connected to the ratio a and to one of the lower segments of the switch, while the upper part is connected to one of the upper segments of the switch. Similarly, with the terminal marked D, the lower part of which is connected to one end of the coils d and to the upper left-hand segment of the switch, while the upper part is connected to the lower left-hand segment. By this means the ends of the resistance under test, which are joined to the upper part of A and D respectively, may through the switch be electrically connected either to A and D (if the switch connections are as shown by the figure at the side marked 'negative to A'), or to D and A (if the switch connections are reversed, as shown by 'positive to A'). The direction of the battery current through the resistance can thus be readily reversed, a requirement that often presents itself.

One galvanometer terminal, instead of being actually connected to B, is joined to k_1, and the negative pole of the battery is joined to C through k_2. This provides means of breaking or closing the galvanometer and battery circuits independently and at will. In all tests the battery (right-hand) key should be first closed, and not released until after the galvanometer key, as otherwise the inductive effect of the wire under test may act upon the needle. The galvanometer key should at first be momentarily depressed, since if the resistance in *d* is not right, a lengthened depression of k_1, by giving a full deflection, will lead to much loss of time in making a test. When, however, the adjustment appears nearly perfect, that is, when only a very slight deflection is given, then the key may be held down, and the final adjustment made. It should be noted that too much resistance in B D will cause a deflection of the galvanometer needle in one direction, and too little resistance a deflection in the reverse direction.

The two plug-holes marked INF (Infinity) serve to disconnect the series at those points if required.

For the accurate measurement of small resistances, the ratios of the Wheatstone Bridge are sometimes formed of a straight German silver wire one metre long (the instrument hence being called the 'Metre Bridge') stretched upon an oblong board parallel to a metre scale divided throughout in millimetres. The junction C (fig. 231) of the two ratios depends simply upon the position of the slider along the slide wire; the positions of the battery and galvanometer are also reversed. This instrument, however, is not used for ordinary telegraphic testing.

CHAPTER XVIII.

TESTING.

Testing Insulators.—The testing of insulators should be always carried out before the bolts are inserted into them. The method of testing usually adopted is as follows (fig. 241). A trough T, lined with lead, is filled with water. Into this trough is fitted a rack so constructed as to hold the insulators which are to be tested, and the outer and inner cups of each are filled with water, and are allowed to stand for several hours to give the water time to percolate. Just before testing a hot iron is taken slowly over the whole batch very near to the rim of each cup, so as to insure that there shall be no moisture there.

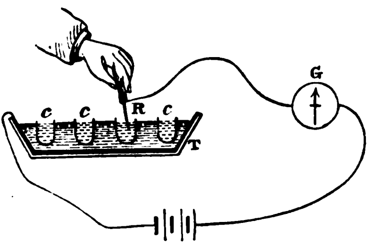

FIG. 241.

A powerful testing-battery, consisting of from 200 to 300 cells, or their equivalent in electro-motive force, is employed. One pole of this battery is connected to one terminal of a very delicate galvanometer G—usually a Thomson reflecting galvanometer—and the other pole of the battery is connected to the lead lining of the trough. The wire from the other terminal of the galvanometer is connected to a metallic rod R, which is fitted with an insulating handle to be held in the hand. This metallic rod is then dipped into the outer and inner cups of each insulator in succession, and, so long as they are perfect, little or no movement of the galvanometer mirror takes place. But immediately the rod is inserted into a faulty cup the leakage which occurs through the mass of the insulator—owing either to the cup being cracked or to the material of which it is composed being porous—causes the needle to be deflected, showing the existence of a fault and so necessitating the rejection of the insulator.

Testing Covered Wire.—The method adopted for testing gutta-percha or india-rubber covered wires is as follows. The coil of covered wire is immersed in a tank of water for twenty-four hours to insure the water finding its way through any defects that may exist in the insulating covering. The water is maintained at a temperature of 75° F. to secure a known uniform temperature. The negative pole of a battery of about 300 volts is then connected to one end of the coil, the other end being kept dry and clear of the water; the positive pole is connected through the galvanometer to the tank, and by the deflection of the mirror the amount of leakage which takes place through the insulating material can be ascertained. If a coil is found to be faulty it is wound upon a reel, and the wire is then drawn slowly off and passed through the water, the connections of the battery and galvanometer remaining the same. Immediately the fault reaches the water the mirror is deflected, and the exact locality can thus be readily found.

The *insulation resistance* per mile of a description of gutta-percha-covered wire which is very often used is never less than 200 megohms, and may reach 1,000 megohms. The conductor also is tested for resistance, the minimum *conductivity* allowed being carefully calculated. It is usual to require 99 per cent. of the conductivity of pure copper according to the authorised standard. The *electrostatic-capacity* is also an important point, the test for which is carried out as follows:—A 'constant' is taken by observing the deflection given by the charge or discharge of a standard condenser of suitable capacity ($\frac{1}{3}$ mf. or 1 mf.), and by comparing this with the deflection given by charging or discharging the wire under test with the same electro-motive force. The capacities are in direct proportion to the deflections.

Testing Circuits.—The subject of testing ordinary telegraph circuits may be conveniently considered in two parts, viz.:

a. Testing to ascertain the condition of the circuits for the purpose of preserving a record, and to anticipate as far as possible the occurrence of faults.

b. Testing to determine the locality of a fault when its existence is known.

Daily Tests.—The former of these is carried on daily in England, and the tests which are taken are of two kinds, according as they are applied to sub-office or head-office circuits. Every sub-office on a circuit is called by the head office at the hour of commencing work, and reports the state of the signals, whether 'good' or 'weak.' The head-office can likewise judge of the state of the signals received from each of the sub-offices. If the attention of any or all of them cannot be gained it is assumed that there is a fault upon the circuit, and the responsible officer is informed accordingly.

All important circuits are tested every morning between 7.30 and 7.45, in order that the condition of the wires may be ascertained before the day's work commences.

A remarkably ingenious and satisfactory method of carrying out the 'Morning Test' devised by Mr. A. Eden has been introduced in connection with all the principal circuits.

In the first place, as far as possible the wires are tested in pairs by 'looping' at one end, thus reducing the actual number of tests required by half. In the second place, the observations are made with one instrument only at one end of the looped wires, thus eliminating the errors due to differing 'constants' which are apt to follow when the results depend upon testing instruments at both ends.

The theoretical connections of the system are shown by fig. 242, from which it will be seen that the lines to be tested, which are looped at the distant end, are connected at the Testing Office with a double-wound tangent galvanometer (fig. 237), two 10,000$^{\omega}$ resistance coils, and a testing battery, E. Under these circumstances, if the lines, both as regards insulation and continuity, were perfect, the whole of the current sent from the battery through coil 2-4 of the galvanometer would be received in the reverse direction through coil 3-1, and the galvanometer needle would be unaffected. The less perfect the insulation of the line the greater will be the current sent out and the less will be the current received, and the resulting deflection of the galvanometer needle will become a measure of the actual loss at the insulators. Now, as the actual resistance of any sections of line ordinarily tested is small compared with the resistance coils of $10{,}000^{\omega}$ inserted at the end of each line, no material error will arise if the total amount of leakage that takes place upon the whole loop be treated as a single fault in the middle of the circuit having a definite resistance.

This, then, is the plan adopted. The leakage, which is really due to faults of high resistance distributed (chiefly at every insulator) along the entire length of line, is, under the conditions described, properly represented by an assumed resultant fault in the middle of the loop of such resistance that, with the same electro-motive force, it will take off a current equal to the total leakage at all the insulators, etc. This resultant fault (shown as R_1 in fig. 242) represents the *total insulation resistance* of the line under test.

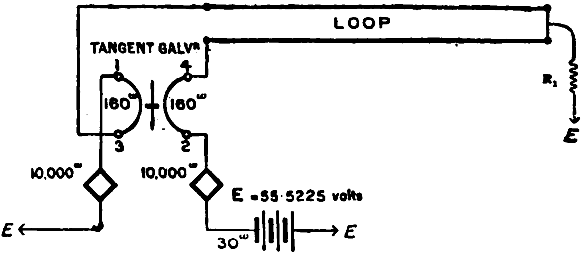

FIG. 242.

The relative values of the insulation resistance of various lines, however, must evidently largely depend upon their length; and, for purposes of comparison, it is therefore customary to reduce the *total* insulation resistance to the *insulation resistance per mile.* This is done by *multiplying* the total insulation resistance by the length of the circuit in miles. That this multiplication is correct will be clear when it is considered that, if the leakage along the line be supposed to be uniform, and that there is no specific fault, the leakage along *n* miles will be *n* times greater, and the insulation resistance consequently *n* times less than for *one* mile of the same circuit. Now, the insulation resistance per mile which is found in England to be capable of being maintained upon open lines under the worst ordinary wet weather conditions is $200{,}000^{\omega}$; and this is accordingly adopted as the minimum maintenance standard for engineering purposes.

Turning now to the actual conditions of the insulation test:

First, the tangent galvanometer is adjusted to give a 'constant' deflection of 80 divisions on the outer tangent scale[1] with one milliampère of current, so that any given deflection of D divisions represents a definite strength of current C. That is,

$$C = \frac{D}{80} \text{ milliampères};$$

or conversely, the current in milliampères may be represented in divisions on the tangent scale, thus:—

$$D = C \times 80 \ldots\ldots\ldots\ldots (1)$$

when the current passes through both coils of the galvanometer.

This 'constant' of the galvanometer having been obtained, the connections of the looped section that is to be tested are made as shown theoretically by fig. 242. Now, with these conditions, and with a leakage fault (representing the total insulation resistance of the loop) of resistance, R_1, in the centre of the total resistance (R), the current passing from the battery (E) through coil 2–4 of the galvanometer to line, divides at the fault, part going back through the second coil 3–1 of the galvanometer, and the other part going to earth at the 'fault.'

It is, therefore, required to determine (1) the strength

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[1] The outer tangent scale has a double range, the zero being at the left hand end of the scale instead of, as on the inner scale, in the centre.

of the current 'sent,' (2) the strength of the current 'received,' and (3) the strength of the current which passes to earth through the leakage. As regards (1) and (2), it has already been stated that the 'received' current passes through the second coil of the galvanometer in a direction which tends to neutralise (or at least reduce) the effect of the 'sent' current; hence the deflection observed will indicate the difference in effect between the two when acting through one coil of the galvanometer.

Now, taking R to represent the total resistance of the circuit, including 10,000• coils, battery, galvanometer, and loop, the total resistance (including the leakage fault) from the battery (of electro-motive force E), is made up of $\frac{R}{2}$ and the combined resistance of $\frac{R}{2}$ and R_1—which is (*see* Appendix, Section C, 2),

$$\frac{\frac{R}{2} \times R_1}{\frac{R}{2} + R_1} \quad \text{or} \quad \frac{R \times R_1}{R + 2R_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

therefore, the total, including leakage resistance, is

$$\frac{R}{2} + \frac{R \times R_1}{R + 2R_1} = \frac{R(R + 4R_1)}{2(R + 2R_1)}.$$

The total current sent to line C_S (in milliampères, if E be taken in millivolts [2]) is therefore,

$$C_S = \frac{E}{\frac{R(R + 4R_1)}{2(R + 2R_1)}} = \frac{2E(R + 2R_1)}{R(R + 4R_1)} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

This represents the 'sent' current.

Again, the proportions in which this 'sent' current divides into the 'received' current C_R, and the 'leakage'

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[2] A millivolt is $\frac{1}{1000}$ of a volt.

current C_L, is determined by the law of shunted circuits,[3] to be respectively for C_R,

$$\frac{R_1}{\frac{R}{2}+R_1} \quad \text{or} \quad \frac{2R_1}{R+2R_1} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and for C_L,

$$\frac{\frac{R}{2}}{\frac{R}{2}+R_1} \quad \text{or} \quad \frac{R}{R+2R_1} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The 'received' current will therefore be found by multiplying equations (3) and (4) together, thus :

$$C_R = \frac{2E(R+2R_1)}{R(R+4R_1)} \times \frac{2R_1}{R+2R_1} = \frac{4E \times R_1}{R(R+4R_1)} \ldots\ldots (6)$$

and the current $(C_S - C_R)$ actually measured will be the difference between equations (3) and (6), or

$$C_S - C_R = \frac{2ER + 4ER_1 - 4ER_1}{R(R+4R_1)} = \frac{2E}{R+4R_1} \ldots\ldots\ldots (7)$$

Further, the 'leakage' current will be (equations 3 and 5 multiplied together) :

$$C_L = \frac{2E(R+2R_1)}{R(R+4R_1)} \times \frac{R}{R+2R_1} = \frac{2E}{R+4R_1} \ldots\ldots\ldots (7a)$$

But equations (7) and (7*a*) are identical, which shows that the current actually observed on the galvanometer represents the 'leakage' current.

It must be noted that the deflective effect of the received current is practically equivalent to that of a current $(C_S - C_R)$ passing through *one coil* only (2-4) of the galvanometer. As already explained, the tangent galvanometer is adjusted to give a deflection of eighty divisions on

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[3] *See* Appendix, Section D, where it is shown that the proportion of current which will pass in the sections of a shunted circuit is in *inverse* proportion to the resistance of the sections.

the outer scale with one milliampère of current passing through *both* coils, which is equivalent to forty divisions if the current pass through only *one* coil. If, therefore, the right-hand side of equation (7) be multiplied by forty, it will represent in divisions, D, the actual equivalent of the 'leakage' current. Thus :

$$D = \frac{80\,E}{R + 4\,R_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In the above equation (8) all the factors are known or can be derived from calculation ; and the object of the foregoing explanation has really been the determination of this equation. All the essentials of the looping-test system are dependent upon it.

The insulation resistance, R_1, is the only factor in the equation that is not actually known, and that is determined as follows :—

(1) Assuming the *total* insulation resistance of a circuit which is L_1 miles long to be R'_1, the insulation resistance *per mile* will be $L_1 \times R'_1$, and the total insulation resistance, R_1, of the length (in miles) under test L will be

$$R_1 = \frac{L_1 \times R'_1}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Now, by a series of careful experiments it has been shown that for any circuit that is wanted to meet the most exacting of telegraphic requirements (namely, automatic working) the total insulation resistance must not fall below the actual conductor resistance of the same circuit. This, therefore, gives a standard for insulation resistance which will meet the highest working conditions. This may be called the 'working standard.' In equation (9), taking R'_C, the total conductor resistance of the circuit, to be the total insulation resistance for this standard, the insulation resistance of the section evidently will be

$$R_1 = \frac{L_1 \times R'_C}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

(2) Further, at p. 419 it was explained that the average climatic conditions in England are such that it is not ordinarily possible in unfavourable weather to maintain a mileage insulation much above 200,000$^{\omega}$; and this accordingly determines another standard of insulation, which may be designated the 'maintenance standard.' Under this standard the total insulation resistance, R_1, of any section L miles long will evidently be

$$R_1 = \frac{200,000}{L} \qquad \text{......................} \quad (11)$$

Equations (10) and (11) therefore give two values for R_1 which may be inserted in equation (8).

The further development of the explanation can be most conveniently proceeded with by help of a specimen weekly report of 'Morning Tests' (p. 424).

The particulars given in columns 1 to 10 are in the nature of fixed records; and for offices where a considerable number of tests have to be made, the forms are printed with those columns filled in.

Columns 1 to 3 need no comment.

Columns 4 to 8 are obtained from engineering records, checked by actual tests made when opportunities occur.

Columns 9 and 10 are obtained by calculation in the manner which will now be explained.

First, as to column 9—'Working Standard Deflection.' This is simply a calculated deflection obtained by giving to R_1 in equation (8) the value deduced from equation (10).

(1) Thus, for example, in order that the LV.EH 1[1] circuit may have its maximum efficiency, the total insulation resistance, R_1, of the (double) section between EH and the office at which the wires are looped (CE[2]) must not be less than

$$R_1 = \frac{217{\cdot}75 \text{ (column 7)} \times 3160 \text{ (column 8)}}{198{\cdot}31 \text{ (column 5)}} = 3469{\cdot}78^{\omega};$$

3160$^{\omega}$, in accordance with the rule just explained, representing the 'working standard' of insulation resistance for the whole

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[1] Liverpool-Edinburgh. [2] Carlisle.

POST OFFICE TELEGRAPHS.

MORNING TESTS.

Edinburgh Office.

Engineer's Department, East. Scot. Dist.
Week ending Saturday ———

1	2	3	Looped section			Circuit		Standard deflections		11 Leakage in tangent divisions						12	
Circuit	Office at which the wires are looped or earthed	Route	4 Con-ductor resis-tance	Mileage 5 Open	6 Cov-ered	7 Mile-age (open)	8 Total con-ductor resis-tance	9 Work-ing	10 Main-ten-ance	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Insulation resis-tance per mile if below maintenance standard	Remarks
LV.EH 1 CE.EH	CE ,,	Rail ,,	3110	101· 97·31	1·06 ·51	217·75 97·31	3160 1560	119 167	162	105	66	108	70	100	83	—	—
LV.EH 2 MR.EH 2	,, ,,	,, ,,	2410	,, ,,	,, ,,	228· 220·	2040 2800	138 125	165	100	10	110	55	62	22	—	—
100 136	,, ,,	,, ,,	2330	,, ,,	,, ,,	180·5 192·	2470 2360	139 139	165	101	12	28	42	55	25	—	—
MR.EH 3	,,	,,	1150	,,	,,	210·5	2600	101	150	72	6	28	4	34	28	—	—
ANGLO 102	DE ,,	Road & rail ,,	1130	60·06 ,,	5·28 ,,	104·38 251·	1460 2900	167 97	158	15	INF.	40	10	27	35	—	—
									State of weather	W Fine	Calm Dry	W Fine	SE Fine	SE Fine	S Dull	— —	— —

circuit. This calculation explains the need for columns 5, 7, and 8 upon the Test Sheet. If the total insulation resistance fall below the total conductor resistance, loss of speed in automatic working will immediately result.

The value of R_1 in equation (8) for this example is thus found to be $3469{\cdot}78^{\omega}$.

(2) The value of R in the same example is $20{,}000^{\omega} + 30^{\omega} + 320^{\omega} + 3110$ (column 4).

$$R = 20{,}000^{\omega} + 30^{\omega} + 320^{\omega} + 3110^{\omega}\text{ (column 4)}$$
$$= 20350^{\omega} + 3110^{\omega} = 23460^{\omega}.$$

(3) Further, as regards E. When the galvanometer has been adjusted to give a deflection of 80 divisions with one milliampère, the 'constant' of the testing battery is taken. This is made as nearly as possible 110 divisions, or $2\frac{1}{2}$ milliampères. With the resistance which is in circuit when this constant is taken, the electro-motive force, E, that would give exactly 110 divisions would be 55·5225 volts or 55522·5 millivolts; and E for all purposes of calculation is therefore assumed to be of that value.

To continue, then, the example of the LV.EH 1 circuit: E is 55522·5, R is 23460, and R_1 is 3469·78; therefore (equation 8)

$$D = \frac{55522{\cdot}5 \times 80}{23460 + 4\,(3469{\cdot}78)} = \frac{4441800}{37339{\cdot}12} = 118{\cdot}95,$$

or practically 119, which is accordingly entered in column 9 as the working standard deflection. If the observed deflection does not exceed this, the section, so far as insulation is concerned, is good enough for the maximum high speed which can be maintained upon the whole circuit.

A similar calculation for circuit CE.EH [1] shows the Working Standard Deflection in that case to be 167.

Column 10. By the insertion in equation (8) of the value of R_1 obtained for the Maintenance Insulation Standard of $200{,}000^{\omega}$ per mile from equation (11), namely,

$$R_1 = \frac{200{,}000^{\omega}}{198{\cdot}31} = 1008{\cdot}52^{\omega},$$

[1] Carlisle-Edinburgh.

the value which represents the 'Maintenance Standard Deflection' is found. Thus :

$$D = \frac{4441800}{23460 + 4034} = 161{\cdot}55,$$

which is entered on the Test Sheet as 162 divisions.

Similar calculations for the next two pairs of wires in the Test Sheet give the results indicated.

The *observed* deflections are entered in column 11 for each day of the week which is embraced by the Report.

The foregoing test as described is, however, applicable only in cases where two wires can be paired in a section; but it is sometimes impracticable to obtain two such wires. When this is so, the sections which cannot be paired are put to earth at the distant end through a resistance of 10,160$^{\omega}$. The conditions are then as represented by fig. 243. By comparison of this with fig. 242, it will be seen that the general conditions in the two cases are precisely similar, except that the 'received' current does not pass through the second coil of the galvanometer.

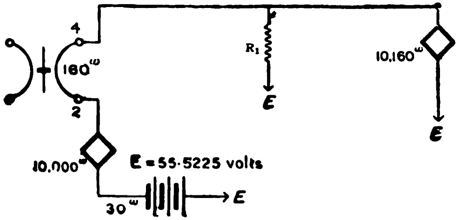

FIG. 243.

For purposes of comparison the Standard Deflections for single-wire tests are therefore calculated in precisely the same way as for looped wires—that is, by means of equation (8). In this way the Standard Deflections for the MR.EH[1] 3 circuit are found to be 101 and 150.

The actual deflection observed in the application of the test, however, is determined by very different conditions.

[1] Manchester-Liverpool.

The deflection is really a measure of the 'sent' current, which is represented by equation (3).

But if the insulation of the line were perfect the current sent, C'_S, would of course be

$$C'_S = \frac{E}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

In each of these cases the current circulates in only one coil of the tangent galvanometer, so that its deflective power is 40 divisions per milliampère. Converting the currents represented by these two equations, (3) and (12), to their equivalents in tangent divisions, they become respectively

$$D_S = \frac{40\,E}{R}\left(\frac{2R + 4R_1}{R + 4R_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

and

$$D'_S = \frac{40\,E}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

and if (14) be deducted from (13), then

$$D_S - D'_S = \frac{40\,E(2R + 4R_1 - R - 4R_1)}{R\,(R + 4R_1)} = \frac{40\,E}{R + 4R_1} \quad \ldots(15)$$

Comparing this with equation (8), it will be seen that the difference between the sent current reading upon the galvanometer and the theoretical sent current for a perfect line (equation 15) is exactly half the deflection which is the equivalent of the actual leakage current. Therefore, in order that the entries in the 'Daily Test' spaces of the Test Sheet (column 11) may be comparable with the standard deflections, for single wires the actual galvanometer reading is reduced by the theoretical 'perfect insulation' reading, and the result multiplied by 2.

For example, the MR.EH 3 circuit on the Test Sheet (p. 424) is tested as a single wire. Equation (14) shows that the deflection with perfect insulation would be

$$D'_S = \frac{40 \times 55522{\cdot}5}{20350 + 1150} = \frac{2220900}{21500} = 103{\cdot}3,$$

or practically 103 divisions; but the deflection actually observed on Monday was 139 divisions; the entry made was, therefore,

$$(139-103)\times 2=72 \text{ divisions.}$$

It should be observed that if on a looped circuit there be no deflection, or if on a single-wire circuit the deflection be equal to the perfect insulation deflection, then it is a sign that the insulation is 'perfect'—that is, good beyond the measuring power of the galvanometer.

Again, if on a single-wire circuit the deflection be *less* than the 'perfect insulation' standard, it evidently indicates that the proper current does not pass to earth at the earthing office—that is, that the line is either fully or partially disconnected. If, on the other hand, the deflection be about *double* the 'perfect insulation' standard, it is evident that the resistance has been reduced by half—that is, that the circuit is direct to earth, so cutting out the $10{,}160^{\omega}$ coil at the distant end. The range of deflection, therefore, for single-wire tests is between that for 'perfect insulation,' which is entered as 'Inf.' (infinite), and double that deflection. This range is noted against the circuit as a fraction, thus: $\frac{103}{206}$, in the Test Record Book (p. 430.)

Hitherto, in the examples taken the underground section of the wires, both as regards the section under test and the two circuits of which that section forms parts, has been so inconsiderable as compared with the whole length involved that it could be ignored without materially affecting the accuracy of the test. This, however, is not the case if for either condition (the section or the whole circuit) the underground portion reaches (say) five per cent. of the whole. It must then be properly allowed for. Now, the proper minimum standard of insulation for covered work is one megohm per mile, and the total insulation resistance, $\text{R}_1{}^{\text{u}}$, of any length in miles, L, is therefore

$$\text{R}_1{}^{\text{u}} = \frac{1{,}000{,}000}{\text{L}} \text{ ohms.}$$

It will be at once understood that this R_1^u, which is virtually a covered work leakage fault, is practically a shunt upon the open leakage fault, R_1^o; and that consequently the total insulation resistance, R'_1, of the whole circuit will be (Appendix, Section C, 2) :—

$$R'_1 = \frac{R_1^u \times R_1^o}{R_1^u + R_1^o}.$$

From this the insulation resistance, R_1^o, of the open work is seen to be :—

$$R_1^o = \frac{R_1^u \times R'_1}{R_1^u - R'_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

which value must be used instead of the total insulation resistance of the circuit which is obtained by reference to column 8 in the Test Sheet.

If a considerable length of covered work exist also in the section under test a similar modification of the value of R_1 obtained from equation (9) must be used for insertion in equation (8).

Taking, for example, the entry of the 'Anglo' wire on the Test Sheet (p. 424), other records show that the total length of underground work on this circuit is 16·48 miles. The insulation resistance of the covered length is therefore taken as 1,000,000/16·48 = $60{,}679^{\omega}$; and (equation 16) the insulation resistance, R_1^o, of the open work of the circuit, instead of being taken as $1{,}460^{\omega}$, must be

$$R_1^o = \frac{60{,}679 \times 1{,}460}{60{,}679 - 1{,}460} = 1{,}495{\cdot}9^{\omega}.$$

From this the total insulation resistance of the section under test (equation 9) would therefore be

$$\frac{104{\cdot}38 \text{ (column 7)} \times 1{,}495{\cdot}9}{120{\cdot}12 \text{ (column 5)}} = 1{,}299{\cdot}8$$

if there were no considerable amount of covered work in the section; but there being 10·56 miles (with an insulation resistance of $\frac{1,000,000}{10{\cdot}56} = 94,696^{\omega}$), the actual total insulation resistance, R_1, must be

$$R_1 = \frac{94,696 \times 1,299{\cdot}8}{94,696 + 1,299{\cdot}8} = 1,282^{\omega};$$

which value, being inserted in equation (8), gives the standard working deflection as 166·9 divisions, and this is entered in column 9 as 167.

It will be observed that the insulation standard for the whole circuit is fixed upon the basis of the open work (equation 16), but that for the section under test the total insulation, including the covered work in the section, is recorded.

It may be as well also to follow this example by the corresponding calculation for the maintenance standard (column 10).

If in this case there were no considerable amount of covered work in the section, the insulation resistance would be taken as

$$\frac{200,000}{120{\cdot}12} = 1,665^{\omega};$$

but as it was just found that the insulation resistance of the 10·56 miles of covered work is $94,696^{\omega}$, the maintenance insulation standard, R_1, of the section must be

$$R_1 = \frac{94,696 \times 1,665}{94,696 + 1,665} = 1,636^{\omega};$$

and by the insertion of this value in equation (8) the maintenance standard deflection (column 10) is found to be practically 158 divisions.

Similar calculations might be made for circuit 102, on which the total length of covered work is 23·86 miles.

In the first instance, the results of the tests are entered in the Test Record Book and copied on to the Test Sheets weekly. This book differs in some details from the Test Sheet: for instance, besides the entry of the range of deflection for single wires (p. 428), correction of the actual to the leakage deflection is not made at the time of testing, because the testing officer often has a great many observations to make in a very limited time, and must therefore not be troubled with unnecessary details.

The testing officer, however, is expected while entering the observed deflection in the Record Book to note, by comparison with the Standard Deflections (or with the range for single wires), whether the condition of the section is such as to necessitate the localisation of a fault. Thus, the reading on Wednesday for the second loop on the sheet (p. 424) is noticed to be 110, although on the two previous days the deflections were less than those for the third (and practically similar) loop. Immediately, by turning the lever of his testing switch, he alters the connections to those shown by fig. 244, so that the current from the testing battery divides in opposite directions through the galvanometer coils, and so to earth through the fault. According as the resistance between 1 and the fault and 4 and the fault is the less, the deflection will be to the left or right. If the records (as in this case) show that the two wires of the loop have approximately the same resistance, the direction of the deflection will indicate whether the fault is on A or on B. If the wires

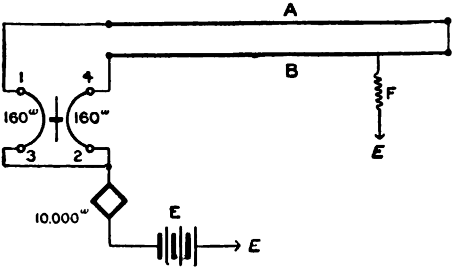

Fig. 244.

are unequal in conductor resistance, the rule is that the wire of higher resistance shall in all cases be connected to 1, and then that wire may be assumed to be the faulty wire if there be either no deflection or if the deflection be to the left. If the deflection be to the right, then the test does not show for certain on which wire the fault exists. This rough trial affords a basis for subsequent localisation.

If time permits, when all the other tests are completed, the distance of the fault may be localised thus: Connecting the two wires so that a deflection to the right is obtained with the connections as in fig. 244, this deflection, d, is noted. Turning the lever of the testing switch, the officer secures the connections shown in fig. 245, and again notes the deflection, D.

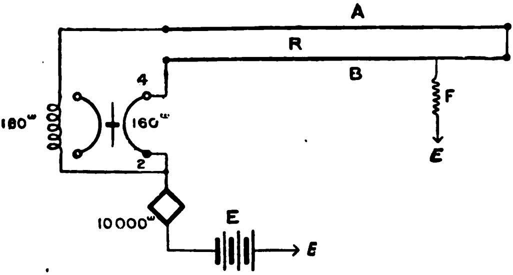

FIG. 245.

In both instances currents of same strength pass to the A and B lines; but d represents in divisions the difference between the two currents, while D represents the (greater) current passing through B. The two currents are, therefore, in the proportion of D (through B) and D — d (through A); and accordingly the resistance R_B between 4 and the fault is

$$R_B = \frac{D - d}{2D - d} \times R - 160^{\omega} \ldots\ldots\ldots\ldots\ldots (17)$$

where R represents the total resistance of the loop (column 4) + the resistance of the galvanometer coils (320^ω).

For example, in the case just referred to, *d* was found to be (say) 36 divisions, while D was (say) 149 divisions. Then the resistance from 4 to the fault was

$$R_B = \frac{149 - 36}{298 - 36} \times (2{,}410 + 320) - 160 = 1{,}017^\omega.$$

This information, namely, that the MR.EH 2 circuit is faulty at a distance of $1{,}017^\omega$ from EH, is accordingly supplied to the sectional engineer; and on reference to his records it appears that the actual conductor resistance of this wire is $1{,}150^\omega$ (LV.EH 2 being $1{,}260^\omega$); so that (as the line is of same gauge throughout) the distance of the fault from CE is evidently about

$$97{\cdot}31 \times \frac{1{,}150 - 1{,}017}{1{,}150} = 11{\cdot}16 \text{ miles.}$$

In taking the readings the testing officer should be careful not to read D too high, or *d* too low. The error in the estimation of the distance in ohms need not exceed 2 per cent. if the observations be accurately taken and the loop resistance correctly stated, even allowing for the unavoidable range of variation permitted in the electro-motive force of the testing battery.

It will be observed that a 'fault' is localised in the instance just cited, although the deflection given by the test is below even the standard working deflection. In fact, the testing officer should know by experience when the observed deflection is higher than it would be if there were no specific fault, and should 'localise' accordingly.

Still considering the specimen Test Sheet (p. 424), it will be noticed that the first loop, although its 'maintenance standard' is lower than that of either of the next two loops, gives generally a higher leakage deflection. As the three loops are very similar, and for the most part go by the same route, the testing officer should proceed to test the first, with a view to ascertaining whether there is any particular sub-section whose insulation is below the average for the whole section.

To make this comparison it is necessary that he shall be able to determine what actual total insulation the whole section has; that is, what the observed 'leakage deflection' represents as regards insulation resistance. This could, of course, be calculated from equation (8); but, in order to save such calculation, the officer is provided with a series of tables giving the required information as accurately as is necessary for the purpose.

A portion of such a table is shown on p. 435.

Assuming a fixed series of conductor resistances for loops by stages of 500^{ω}, the insulation resistances that would give the various deflections from 1 to 198 divisions on the tangent scale are calculated on the basis of equation (8). For this purpose the equation needs to be re-stated thus:

$$\mathrm{D}\,(\mathrm{R} + 4\,\mathrm{R}_1) = 80\,\mathrm{E},$$

that is

$$\mathrm{R}_1 = \frac{80\,\mathrm{E} - \mathrm{D}\,\mathrm{R}}{4\,\mathrm{D}};$$

and the most convenient form for the purposes of the calculation is

$$\mathrm{R}_1 = \frac{80\,\mathrm{E}}{4\,\mathrm{D}} - \frac{\mathrm{R}}{4} = \frac{1{,}110{,}450}{\mathrm{D}} - \frac{\mathrm{R}}{4} \qquad \ldots\ldots\ldots\ldots(18)$$

R in this formula is, of course, the sum of the conductor resistance of the loop, R_{L}, the two $10{,}000^{\omega}$ coils, the galvanometer coils (320^{ω}) and the nominal resistance of the battery (30^{ω}), or $\mathrm{R}_{\mathrm{L}} + 20{,}350^{\omega}$. The calculation then becomes very simple. Taking 100 divisions deflection, for a 500^{ω} loop

$$\mathrm{R}_1 = \frac{1{,}110{,}450}{100} - \frac{20{,}350 + 500}{4} = 11{,}104{\cdot}5 - 5{,}212{\cdot}5 = 5{,}892,$$

TABLE OF INSULATION RESISTANCES.

Leakage in tangent divisions	Insulation Resistance of Loops											Leakage in tangent divisions
	500ω Loop	1000ω Loop	1500ω Loop	2000ω Loop	2500ω Loop	3000ω Loop	3500ω Loop	4000ω Loop	4500ω Loop	5000ω Loop	5500ω Loop	
100	5892	5767	5642	5517	5392	5267	5142	5017	4892	4767	4642	100
101	5782	5657	5532	5407	5282	5157	5032	4907	4782	4657	4532	101
102	5675	5550	5425	5300	5175	5050	4925	4800	4675	4550	4425	102
103	5569	5444	5319	5194	5069	4944	4819	4694	4569	4444	4319	103
104	5465	5340	5215	5090	4965	4840	4715	4590	4465	4340	4215	104
105	5364	5239	5114	4989	4864	4739	4614	4489	4364	4239	4114	105
106	5264	5139	5014	4889	4764	4639	4514	4389	4264	4139	4014	106
107	5166	5041	4916	4791	4666	4541	4416	4291	4166	4041	3916	107
108	5070	4945	4820	4695	4570	4445	4320	4195	4070	3945	3820	108
109	4976	4851	4726	4601	4476	4351	4226	4101	3976	3851	3726	109
110	4884	4759	4634	4509	4384	4259	4134	4009	3884	3759	3634	110

which is entered opposite 100 divisions in the 500^{ω} loop column. But the calculation for the second column differs from the first only in that R_L is $1{,}000^{\omega}$ instead of 500^{ω}. This only necessitates that $\frac{500}{4}$ be substracted from the previous figure. This is entered in the second column and so on, deducting 125 from each column to determine the value of the next following.

By means of these tables the total insulation resistance of any loop can be approximately determined without calculation. For instance, the insulation resistance of the second loop in the report on p. 424 for Wednesday, when the deflection was 110 divisions, is found to be $4{,}384^{\omega}$ from the $2{,}500^{\omega}$ loop column. Actual calculation for the loop of $2{,}410^{\omega}$ would have given a result of $4{,}400^{\omega}$.

Reverting again to the disparity between the deflections from the first loop in the report and those from the other similar loops, let it be supposed that on Friday, when the deflection was 100 divisions, the testing officer determined to see whether the high deflection was due to a specific fault or not. By reference to the tables he finds that for a $3{,}000^{\omega}$ loop (that in question being $3{,}110^{\omega}$) a deflection of 100 divisions represents a total insulation resistance of $5{,}267^{\omega}$, or $1{,}044{,}499^{\omega}$ (that is, $5{,}267^{\omega} \times 198{\cdot}31$) per mile. He then proceeds to test the lines to localise the fault by deflection *d* and D or by Wheatstone Bridge before the wires are unlooped at the distant office; or, if necessary, after 'Morning Test' by testing the faulty wires singly to avoid stopping two wires at once, or it may be done by getting the wires looped at various points between EH and CE. If it be found that the presence of any particular section tends to reduce the insulation below the average of $1{,}044{,}500^{\omega}$ per mile for the whole loop, that section is reported as requiring attention.

The tables are calculated only for loops ranging up to $5{,}500^{\omega}$, but occasionally this resistance is exceeded. When this is so the insulation can still be read from the tables, thus: Take the insulation resistance for the observed reading from the column which is nearly 4,000$^{\omega}$ less than the actual loop resistance, and reduce that by 1,000$^{\omega}$, which will represent the insulation resistance for the higher loop. The accuracy of this procedure will be easily seen from an inspection of equation (18). It is evident that by whatever amount R is decreased, if the equation is to be true R_1 must be increased by one-quarter the same amount. Hence, when R is taken as 4,000$^{\omega}$ below its actual value, the insulation must clearly be shown as 1,000$^{\omega}$ above, and the reading must accordingly be reduced to that extent. The tables themselves indicate this; for instance, the values in the 5,500$^{\omega}$ loop column are in all cases exactly 1,000$^{\omega}$ less than those in the 1,500$^{\omega}$ loop column.

Special Tests.—The above test is quite sufficiently accurate for ordinary purposes, but every important wire should be accurately tested at least once a month, both for insulation and conductivity (that is, the actual conductor resistance), and the results should be carefully recorded. By comparing these with previous tests incipient faults can be readily detected, so that they may be removed before they become serious enough to interfere with the ordinary working. This testing is done by means of the Wheatstone Bridge.

Insulation Tests.—The necessary connections required when testing are indicated by fig. 246, and little further need be added respecting them. For the insulation test the line is attached to terminal A, and an earth-wire is connected to terminal D, to which the positive pole of the battery is also brought. The negative pole of the battery is joined to the k_2 terminal. The negative current is invariably employed for insulation testing, so the reversing switch should be arranged as shown in fig. 239 'negative to A.' If the test be within the total of the resistance coils, viz. 11,110$^{\omega}$, the whole of the resistance in each arm, viz. 1,110$^{\omega}$, should be unplugged. As a general rule the resistance in each arm while a wire is being tested should approximate as closely as possible to the expected result of the test. If the test be over

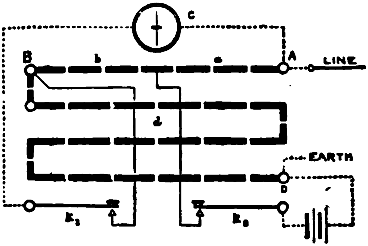

FIG. 246.

11,110$^{\omega}$ and under 111,100$^{\omega}$, then the resistance in *b* should be made to bear to that in *a* the ratio of 1 to 10, by inserting only 100$^{\omega}$ in the former, while the 1,000$^{\omega}$ coil is inserted in the latter. Again, if the test be over 111,100$^{\omega}$ and under 1,111,000$^{\omega}$, the resistance in *b* should bear to that in *a* the ratio of 1 to 100, and this can be effected by inserting 10$^{\omega}$ in the former and 1,000$^{\omega}$ in the latter. The highest resistance which can be measured by this form of bridge is 1,111,000$^{\omega}$ or 11,110$^{\omega}$ $\times \frac{1{,}000}{10}$, the latter factor being the highest ratio which can be obtained from the resistances in *a* and *b*. The total insulation resistance being thus found, the insulation per mile is obtained by *multiplying* this result by the number of miles of wire tested.

Conductivity Test.—In taking the conductivity or wire-resistance test the connections are the same as in the previous case; the only difference in the arrangement is that the distant station now puts the wire to earth, instead of leaving it disconnected. The same remarks as have been made about the resistance which should be inserted in the arms of the bridge when taking the insulation test apply equally to this test. But as the wire-resistance never exceeds 11,110$^{\omega}$, the test obtained when 1,110$^{\omega}$ is inserted in each of the branches can be verified by varying the ratio of a to b, making it either 1 to 10 or 1 to 100, and altering the resistance coils accordingly.

In making this test it has been assumed that the distant end of the line has been put to earth, and that earth has been joined to terminal D. Considering the difficulty, however, which frequently exists in the way of obtaining good earth (p. 354), and the danger which is thus incurred of additional resistance being thereby inserted in the circuit, it is advisable if a second wire is available to dispense altogether with the earth and to use the second wire as a return, so as to obtain a metallic circuit. The end of this wire should then be joined on to terminal D in place of the earth-wire, and the distant station should be instructed to loop the two together. If the wires are of the same gauge and traverse the same route, the resistance of each will be half of the total resistance. But supposing that they are not of the same gauge or go by different routes, and that a *third* wire is available, the resistance of each wire can then be found as follows :—

Let Resistance of No. 1 wire $= x$
" " 2 " $= y$
" " 3 " $= z$

Take three tests of these, having two of the wires looped for each test, so that the resistance of

$$x + y = a$$
$$x + z = b$$
$$y + z = c$$

Then

$$x = \frac{a + b - c}{2}$$

$$y = \frac{a + c - b}{2}$$

$$z = \frac{b + c - a}{2}$$

The resistance test should invariably be taken with both the negative and positive current; for, although the result obtained would be the same with each supposing the wire to be quite clear throughout, in actual practice it is seldom, if ever, the case. Earth currents are always more or less present, and defective joints in the wires, as well as hidden flaws that may exist in them, introduce a disturbing element on account of the different effects produced by the negative and positive currents at these points. The mean of both tests should then be calculated, *i.e.* calling x_1 the test obtained by the negative current, and x_2 that obtained by the positive current, the real conductivity resistance of the line may be taken as $= \frac{x_1 + x_2}{2}$.

The conductivity resistance *per mile* is this total resistance *divided* by the number of miles of line tested.

Localising faults.—When a test shows the existence of a fault, the first step to be taken is to ascertain as nearly as possible its locality. Practically, on over-ground wires, a fault is localised by simply disconnecting or putting the wire to earth at successive stations until it is localised between two stations. At certain stations along the line the wires are led into test-boxes for the purpose of affording facilities for crossing, disconnecting, and putting to earth. Previously to communicating with any of these offices, however, it ought to be ascertained whether or not the fault may not be in the apparatus at the station itself. This is done by short-circuiting the apparatus or, if there be a line-box in the office, puting the wire to earth, to see if that removes the fault.

Taking first of all the case of a *disconnection.* Let A D (fig. 247) be a circuit between A and D led into line-boxes at B and C, and suppose that a disconnection has appeared upon it. Then, if A is the testing station, the wire is first of all put to earth at the test-box there, and a galvanometer inserted between it and the instrument. As soon as it is ascertained that the fault is outside the office by the galvanometer being deflected when the instrument key is depressed, A advises B to put the wire to earth for one or two minutes. If, when this is done, the indication of the current is still obtained on the galvanometer, the fault is beyond B, and C is next advised to treat the wire in the same way, B having of course restored it at the expiration of the time named. If the line be through to C, D is advised, and if the galvanometer be now unaffected (or affected but very slightly, that is, simply through the normal leakage between A and the locality of the disconnection) the fault is between C and D, and the lineman is at once advised of its nature and locality.

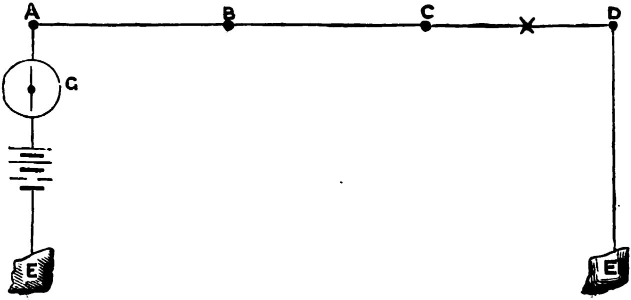

FIG. 247.

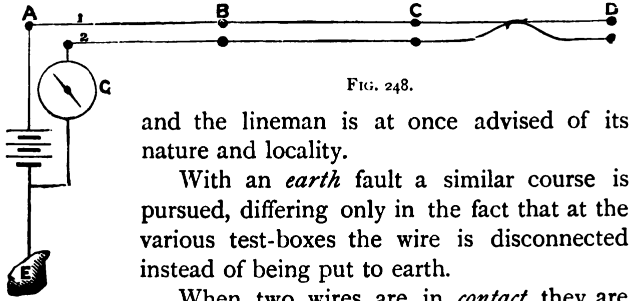

FIG. 248.

With an *earth* fault a similar course is pursued, differing only in the fact that at the various test-boxes the wire is disconnected instead of being put to earth.

When two wires are in *contact* they are both put to earth at the testing station, and disconnected at the others. Thus (fig. 248) the indication at A of the two wires Nos. 1 and 2 being in contact would be that the current sent along one would be received on the other. To No. 1, therefore, the current is applied, and in circuit with No. 2, which is put to earth direct at the test-box, a galvanometer is inserted; B is then asked to disconnect both wires, and if when this is done no indication is observed on the galvanometer the contact is beyond B. The same is done at C. If there is then no deflection, although when C restores the wires the current sent along No. 1 is received on No. 2, the fault must be between C and D. Upon no account whatever should B, C, or D put either wire to earth; no reliable test for a contact could be made if this were done, for if earth be put on near the contact the greater portion of the current would go to earth and not along No. 2 wire to A.

Crossing Wires.—The speedy restoration of communication upon busy circuits is a matter of such importance that immediately a fault upon such a circuit is localised every effort should be made to cut it out of the circuit, and so restore communication at once. This can be done only by crossing the wire with any other of less importance which may happen to exist between the two stations where the fault has been localised. Suppose that A E (fig. 249), an important through circuit between A and E, becomes faulty between C and D, and that there is between the same points a less important circuit picking up the stations B, C, and D. At C and D the faulty section of the through wire is thrown out until the fault is removed. In its place is substituted the section C D of the 'pick-up' circuit, the instruments of which at C and D are joined to earth. Communication is thus preserved between A and E, the former of which can transmit the work of B and C, and the latter that of D. In this way the inconvenience felt from faults is, in a well-organised

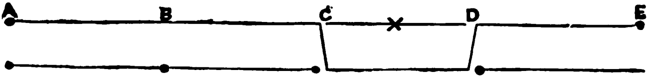

FIG. 249.

system, reduced to a minimum, and frequently four or five wires between two important centres may have faults upon them, and yet only one of them be really broken down, provided the faults are not in the same sections. Upon trunk lines of telegraph which are traversed by important wires it becomes a question for grave consideration whether it would not be advisable to erect a spare wire for the sole purpose of restoring the normal communication as far as possible when a fault occurs upon one or more of the working circuits.

Every important office should have one or more alternative routes by means of which, in the event of its main line of communication being broken down, an outlet may be found for the traffic. Thus (fig. 250), supposing all the direct wires between Brighton and London to be broken down, Brighton has cross country circuits to Portsmouth, Southampton, Eastbourne, Hastings, and various other towns which are themselves in direct communication with London, so that any one of them can, by simply removing the earth and crossing the wires in their line-box, restore communication between London and Brighton.

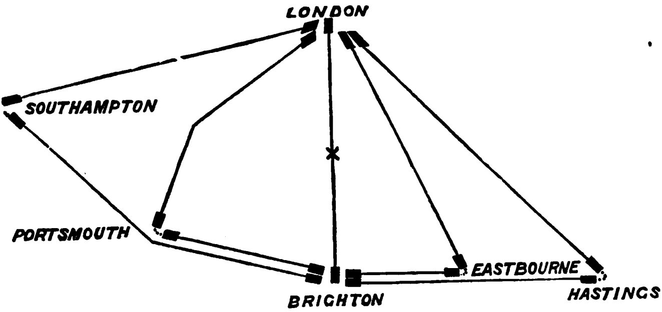

FIG. 250.

Intermittent faults are by far the most difficult to deal with; and it is often impossible, on account of their short duration at one time, to localise them at once by crossing in the usual way. Where a wire subjected to an intermittent fault can be crossed with another, the fault can be traced thus :

Suppose that on the wire A E (fig. 249) an intermittent fault makes its appearance, the wire should be crossed with the section A B of the other wire, and kept so until the fault reappears ; and then in succession the other sections B C, C D, &c., are crossed until the fault is found to be upon the wire A B C D E. Only in this way can it be ascertained in what section the fault exists.

The testing at an intermediate station is exactly the same as that described for a terminal station. By putting earth on either side, and thus ascertaining on which side the fault exists, the station does really become terminal for the time for all practical purposes.

The method generally adopted for ascertaining the locality of faults upon the over-ground lines in England is that which has been described above. The testing stations are comparatively close to each other, and a fault being known to exist between two of them, can generally be removed an hour or two after the lineman has started in search of it. But upon covered wires this cannot be done, for, although the fault can be localised in the same way, the same facilities for examination do not exist as in the case of an over-ground line. If no other steps are taken for ascertaining the locality of a fault upon a covered wire beyond the disconnecting or putting it to earth at the testing stations, then the wire has to be cut and tested at each successive flush-box until the defective section is found. The inconvenience and delay attending this may be overcome in many instances by employing what is known as the *loop test*, provided there is available another wire in good condition between the testing points. (But see p. 397, *Wire-Finder.*)

The Loop Test.—If the insulation of a line were perfect, a condition which is never practically attained, the localisation of earth faults would become a very simple matter. Thus, for instance, let the wire A D (fig. 247) find earth at a point between C and D, and suppose that the fault is a perfect earth, that is to say, offers no resistance. If A is the testing station, and the wire when tested in this condition gives a resistance of 140^{ω}, then, allowing 14^{ω} as the resistance per mile, the distance of the fault from A is $\frac{140}{14} = 10$ miles. But the majority of faults of this kind do offer a greater or less resistance, and the insulation of the line is always more or less defective, so that theoretical calculations of this nature cannot be carried out in practice.

The advantage of the loop test consists in its being independent, within certain limits, of the resistance of the fault.

First Method.—A reference to fig. 251 will show the connections which have to be made in one method of taking

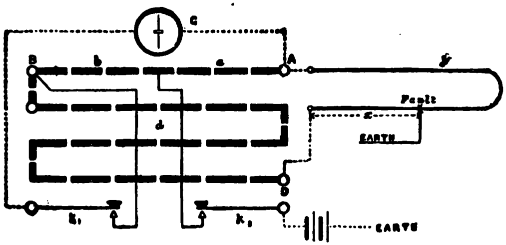

FIG. 251.

this test with the Wheatstone Bridge. The negative pole of the battery is brought to the key k_2, the positive being put to earth. The galvanometer is inserted in the usual way, the good and bad wires are joined together at the line-box of the distant station, and the end of the former is connected to terminal A and of the latter to terminal D. The resistances in the Bridge should then be adjusted until equilibrium is obtained. Calling x the resistance between the fault and terminal D, and y the resistance from terminal A, according to the principle of the bridge :

$$a : y :: b : d + x$$

$$\text{or} \quad a(d + x) = b \times y.$$

But L, the total wire resistance of the whole loop (which can be ascertained on reference to the record of periodical tests), is $x + y$. Therefore $y = L - x$, and, substituting this value of y in the former equation—

$$a(d + x) = b(L - x)$$

$$\therefore x = \frac{b \times L - a \times d}{a + b} \quad \text{........................} (1)$$

And the values of a, b, d, and L being known, the resistance of x is obtained : this divided by the resistance per mile of the wires gives the distance in miles of the fault from the testing station.

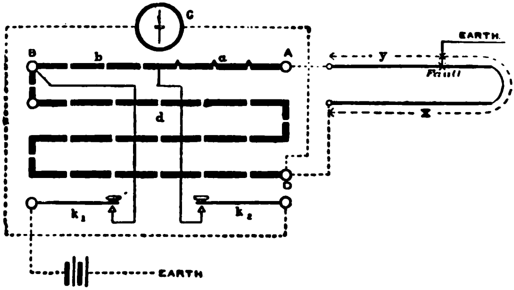

FIG. 252.

If the two arms of the bridge a and b be made equal to each other the above equation becomes—

$$x = \frac{L - d}{2} \quad \text{..............................} (2)$$

Second Method.—A second method of taking the loop test is shown by fig. 252. In this the resistance in the arm a should be plugged up, and b, d then become the two arms of the Bridge. The connections being made as shown in the figure, and b, d adjusted until equilibrium is obtained (x and y being the resistances between the fault and terminals D and A respectively) it follows that—

$$b \times x = d \times y$$

but $$x = \mathrm{L} - y$$

$$\therefore b(\mathrm{L} - y) = d \times y$$

that is $$y = \mathrm{L}\frac{b}{b + d}$$

and this, divided by the wire-resistance per mile, gives the distance in miles of the fault from the testing station.

If the two wires employed have not the same resistance per mile, then the value of y must, of course, be divided by the resistance per mile of the faulty wire.

And if the total resistance of the two wires be not known, it must be found by making the connections as shown in fig. 251, except that the earth connection should be removed and the positive pole of the battery taken to terminal D.

If two wires are in contact the distance of contact from the testing station can be readily found, provided that the fault itself offers no resistance. The two wires form a loop whose resistance can be measured by means of the Bridge, and half of this divided by the resistance per mile of the wires, will give the distance from the testing station.

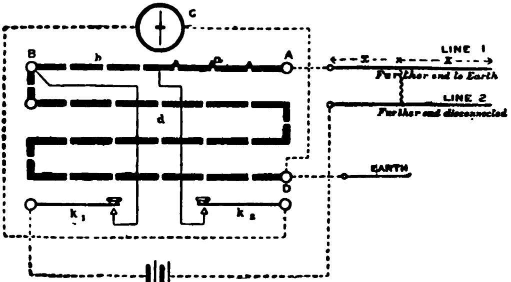

FIG. 253.

If, however, the contact does offer a certain resistance, the locality can be ascertained by connecting the Bridge in much the same way as was done in the second method of taking the loop test described above. The connections required for this are shown in fig. 253. The resistance in *a* is plugged up as before, and b, d become the arms of the Bridge. One of the two wires is disconnected at the distant station, while the other is put to earth there. The former is connected to the positive pole, and being thus made practically only a battery wire, does not enter into the calculation. The resistances in b and d being now adjusted until equilibrium is obtained, it follows that :

$$b \times \mathrm{X} = d \times x$$

but $\mathrm{X} + x$ is known, let it be L,

then $$\mathrm{X} = \mathrm{L} - x$$

therefore $$b\,(\mathrm{L} - x) = d \times x$$

that is $$x = \mathrm{L}\frac{b}{b + d}$$

the distance of the fault from the testing station can thus be ascertained.

Unless the circumstances are very exceptional, the resistance of an 'earth' should not be permitted to exceed 10^{ω}. Ordinarily it is by no means a simple matter to make a reliable test of the resistance of an 'earth,' but, where facilities exist, the following method of testing, devised by Mr. F. H. Pomeroy, is satisfactory and simple. The Wheatstone Bridge is connected up as shown in fig. 254, where LINE I is any line-wire put to earth at the further end, and A is the 'earth' which is to be tested. Balance is obtained on the Bridge in the usual way. Let the resistance required to balance be R.

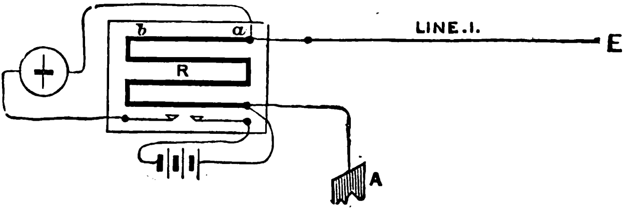

FIG. 254.

The battery is now reversed and the other connections are altered as shown in fig. 255. The negative pole of the battery, instead of going direct to earth at A, is connected with a second circuit (LINE 2), which runs in a different direction to LINE 1 (preferably at about right angles to it), and which is put to earth at the further end. A second balance is then obtained on the Bridge. Let the resistance required to obtain this be r. Then the resistance of the earth at A is

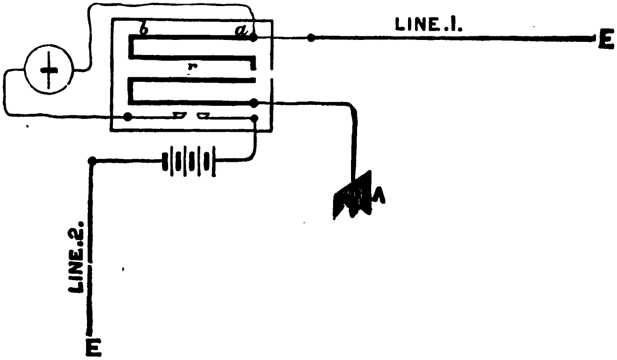

FIG. 255.

$$\frac{a(\text{R} - r)}{a + b} \qquad \text{(General Case).}$$

Or, if the two arms a and b of the Bridge are equal, then the resistance of the earth is

$$\frac{\text{R} - r}{2} \qquad \text{(Special Case)}$$

that is, *half the difference between the two resistances.*

As it is desirable in making the two tests that the current passing at the earth-plate in both cases should be approximately equal, the battery power for taking the second test should be rather greater than that used in taking the first.

If a galvanometer be kept in circuit with the battery, and the battery be so adjusted that the deflections of the galvanometer are about the same in both tests, then the current passing at the earth A will also be about the same in both cases.

The object of reversing the battery for the second test is to arrange that the current flowing out at the earth-plate under test (A) may be in the same direction as it is in the first test.[1]

Test-Boxes.—If an office contains but a few instruments, and is not a testing station, each wire is led direct to the instrument which it is intended to work. But if the number of instruments be considerable, each wire is first led to a *test-box* and brought thence to its instrument. Test-boxes are likewise fixed at offices situated on a trunk line, and into them are led all the wires which pass, for the purpose of giving facilities for testing. The plan usually adopted in fitting up line-boxes is shown in fig. 256, but this is frequently departed from to meet local requirements.

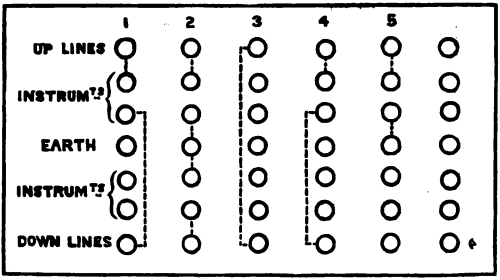

FIG. 256.

On a wooden frame, generally formed of mahogany, and varying in size according to the number of wires which are to be led up to it, seven rows of brass terminals are symmetrically fixed. The upper and lower rows of terminals are

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[1] For the Theory of this Test, see Appendix, Section G.

used for the 'Up' and 'Down' line wires respectively: the two rows below and above them are 'Instrument' terminals, and the centre row are 'Earth' terminals. The number of earth terminals varies according to the number of line-wires, but, as a general rule, for every two of the latter there should be one earth terminal. The line terminals are numbered consecutively from left to right. Various systems have been adopted in assigning the numbers to the wires in a test-box; that which has been found to answer best is to assimilate the test-box in this respect to the terminal pole outside the office, where such exists, and so arrange the numbers upon both as to coincide with each other.

In addition to marking the numbers, it is advisable to attach bone labels to the terminals, and indicate upon these the names of the various circuits. The labels can be changed according to any alteration rendered necessary by a rearrangement of the wires. In fig. 256 the wires going to terminals 1 and 4 have intermediate instruments joined up on them; at 2, two circuits, one 'Up' and one 'Down,' are connected, and at 5 only the 'Up' side is in use, while at 3 the wire is brought in simply for testing purposes. It is always advisable to leave a few spare terminals, in order to provide for the normal increase of wires.

The wires are connected to the terminals at the back of the box; these connections should invariably be soldered. The earth-wires running along the back of the box should be carefully soldered to each of the terminals marked earth. The terminals themselves should be kept bright and clean, and ought always to be well screwed down, so as to prevent disconnections. To guard still further against this, the wire employed in the connections for a test-box should be of a stouter description than the No. 20 gutta-percha covered wire which is frequently used.

At large offices where there are a great many circuits it is found convenient to have a battery-box fitted up upon the same principle as the line-box, and in close proximity to it.

In these boxes the terminals are arranged in sets of four, forming the corners of a square, the left and right-hand top corners being used respectively for connecting the negative and positive poles of the battery, and the two lower terminals being for the instrument. The battery can by this means be easily disconnected from the instrument for testing, changing, or increasing power. All the batteries in the battery-room are connected to the battery-box.

Battery Testing.—There are two requirements with regard to which batteries need to be tested—*resistance* and *electro-motive force*, and the different methods by which each of these may be determined are very numerous. It is proposed to describe only the simplest of these.

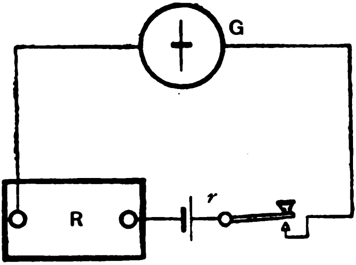

FIG. 257.

Resistance Test. Half Deflection Method.—First, to find the internal resistance (r) of a battery, having given a galvanometer of a known resistance G, and of which the relative values of the different deflections are known (for example, a tangent galvanometer), and a set of resistance coils. Join the galvanometer and the coils in circuit with the battery as shown in fig. 257 and adjust the resistance so as to get a convenient deflection, D. Suppose the resistance to be R_1. After noting the deflection, increase R_1 to R_2 until the value of the deflection is reduced to $\frac{1}{2}$ D.

In the first case we have in circuit $r + G + R_1$ and in the second case $r + G + R_2$, but the current in the second case is only half that in the first, which shows that by increasing R_1 to R_2 the *total* resistance was doubled ; therefore the difference between R_1 and R_2 is equal to the total resistance in the first test, that is

$$R_2 - R_1 = r + G + R_1$$

or $$r = R_2 - (G + 2 R_1) \ldots\ldots\ldots\ldots (1)$$

As all the quantities on the right of the equation are known, the resistance (r) of the battery can easily be deduced.

Very frequently this test is made with a galvanometer of practically no resistance, and then the first reading is taken with no resistance in circuit except that of the battery itself. In that case

$$r = R_2 \ldots\ldots\ldots\ldots (2)$$

or the resistance of the battery is *equal to the added resistance.*

Electro-motive Force Test.—The value of the electro-motive force of a battery requires to be compared with the unit (the *volt*) ; but as there is no actual practical standard it is usual to compare the electro-motive force with that of a recognised standard cell (see p. 41), or with a special form of Daniell cell, the electro-motive force of which is fairly constant and is assumed to be equal to 1.079 volts.

Equal Resistance Method.—If now, it be required to find the electro-motive force of a battery, join up the standard cell whose force (E_1) is known to be 1.079 volts in circuit with a tangent galvanometer and a set of resistance coils, as shown in fig. 257, and insert a sufficient resistance to obtain a convenient deflection on, say, the tangent scale ; let this deflection be d_1 divisions. Note the total resistance in circuit (R). Now remove the standard cell and insert the battery whose electro-motive force (E_2) is to be ascertained, and, if this has a different resistance (which must be ascertained by previous test) readjust the resistance in B D so that the total resistance may be the same as in the former test. Again note the deflection, d_2.

Now, by Ohm's law, the current C_1 producing the deflection d_1 is

$$C_1 = \frac{E_1}{R},$$

and the current C_2, producing the deflection d_2, is

$$C_2 = \frac{E_2}{R}.$$

And, dividing the latter by the former we obtain

$$\frac{C_2}{C_1} = \frac{E_2}{E_1},$$

but, as the relative values of the deflections are directly proportional to the current strength, they may be substituted; thus—

$$\frac{d_2}{d_1} = \frac{E_2}{E_1} \text{ or } \frac{d_2}{d_1} = \frac{E_2}{1.079} \text{volts.}$$

Since 1.079 is the assumed electro-motive force of the standard cell, and as d_1 and d_2 are known, the actual electro-motive force of the battery can be easily calculated.

With the tangent galvanometer shown in fig. 237, if the deflection given by the battery under test be inconveniently great as compared with that given by the standard cell, one of the 'shunts' may be inserted, in which case E_2 must be multiplied by the reciprocal of the shunt; for instance, if the shunt be $\frac{1}{10}$, multiply by ten, and so on.

Equal Deflection Method.—This is another simple way of testing for electro-motive force. Join up as in fig. 257, and having inserted a convenient resistance note the deflection D and the total resistance (R_1) in the circuit when E_1 is in circuit. Remove E_1 and insert E_2, adjusting the resistance until the previous deflection is reproduced. Now again note the total resistance R_2 in the circuit.

In this case, by Ohm's law the current in each case being equal (since the deflections are so)

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

that is to say, the electro-motive forces of the batteries are directly proportional to the total resistances in circuit, and

$$E_2 = E_1 \frac{R_2}{R_1}$$

E_1 (1.079 volts), R_1 and R_2 being known.

CHAPTER XIX

WIRELESS TELEGRAPHY

WIRELESS TELEGRAPHY is a mode of signalling through space without line wires. It is not a complete and accurate term, for the system cannot act without the presence of wires. A better term is 'Ætheric Telegraphy,' because it depends chiefly upon electric disturbances transmitted by the æther in the form of definite electric waves.

We owe the conception of the propagation of electricity in waves to Faraday, who detected currents in this form through long underground copper wires insulated with gutta percha; and Cromwell Varley made an artificial cable, representing a long line from England to Australia, through which several waves were simultaneously seen following after each other. It was Maxwell, however, who developed the general principle of undulatory propagation and placed it on a solid mathematical basis. Hertz practically and experimentally confirmed the accuracy of Maxwell's laws. Maxwell also established the doctrine of circuitation, which implies that every electric disturbance works through a closed circuit and is some form or other of energy. If electricity passes through conductors it takes the form of currents, which may be continuous, intermittent, or alternating, according to the form of the exciting voltage; they follow Ohm's law. Work is done, heat is generated according to Joule's law, $H = C^2Rt$, and the voltage drops.

If it pass through dielectrics when the voltage is alternating, it assumes the form of waves analogous to those of light. These are called displacement currents; they do not follow Ohm's law. Heat is not generated, and there is no drop of voltage—at any rate in the æther.

The Source of Energy.—In all the earlier experiments batteries were used as the prime source of energy, but it is now found much better to use steam, gas, or oil engines, for with long distances the energy required rises rapidly.

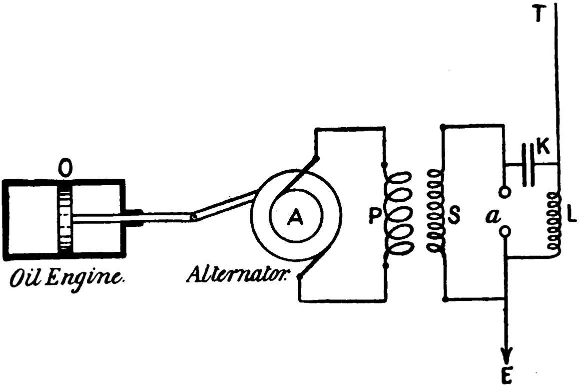

FIG. 258.

These engines are used to rotate alternators, which in their turn generate alternating currents of various voltages and frequencies.

A (fig. 258) is an alternator excited by a small oil engine, O, sending alternating currents through the primary circuit P. The secondary circuit, S, is a fine wire of many times more convolutions than P, and so constructed that the voltage of P can be multiplied many times. If we use 300 volts in the primary and the ratio of transformation $\frac{P}{S} = \frac{1}{100}$, the voltage at *a* will be 30,000 volts. This will cause a spark to break down the air space at *a* if the distance of the balls apart is about 1 cm. The tendency of experience is to use greater capacity, and several smaller sparking gaps to make the sparks *fatter* or of greater quantity. This is done by reducing the resistance of *s* and increasing the time constant of the coil. When the voltage reaches its maximum the sparks fly across *a*, and in doing so set up oscillations in the circuit containing K, L, and *a*, thus exciting the antenna or aerial A, E, to set up electric waves in the æther. In all our previous applications we have dealt with circuits formed entirely of conductors through which electric currents flow. We have now to consider circuits a large part of which is composed of a dielectric—the æther. Maxwell showed us that his *displacement currents* passed through dielectrics when the exciting E.M.F was alternating, while no such current at all passed when the exciting force was direct. We have seen in the description of the working of long submarine cables (p. 176) that the circuit at each end of the cable contains a condenser, thus having parts of it dielectrics. The question now is, how does the energy pass through the dielectric whether it be the mica or paraffin of a condenser or the æther of space?

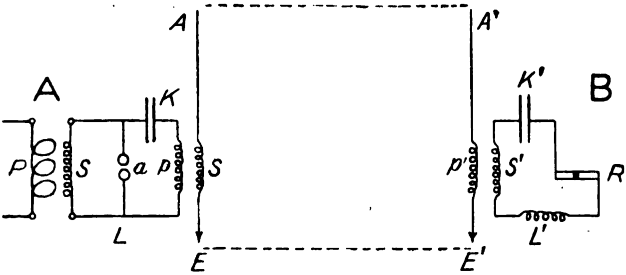

Fig. 259.

A (fig. 259) is the transmitting station, B the receiving station; P is the primary coil of a transformer excited by the alternator. A is the aerial or *antenna* in contact with the atmosphere. E is the earth connection, which may be either a plate of metal buried in the moist ground or in the sea, or a surface of wire netting resting on the ground. At B, A′ is the antenna in connection with which the primary wire (P′) of a transformer is placed, ending in an earth connection E′ as at A. The secondary of this transformer S′ is part of a circuit containing a receiver R, a condenser K′, and inductance L′, which render the currents that pass evident to the senses so as to convey readable electric signals. The circuit is therefore complete through air and earth, and when a throb of energy passes around the complete circuit to make an electrical signal at B, we have to consider what occurs, (1) in the transmitting portion AE, (2) in the æther AA′, (3) in the receiving portion A′E′, and (4) in the return portion (earth) E′E.

1. *The Transmitter.*—Each revolution of the crank of the prime moving engine, O, fig. 258, can make one or many complete alternations of current. A complete alternation means that in one period of time the current passes through every stage of voltage or difference of potential from zero through a maximum of positive, down to zero again, then through a maximum of negative to zero once more.

In fig. 260 the abscissa (OO′) indicates *time*, not motion, and the ordinates indicate the potential at any spot at each instant. This complete succession of changes forms a wave, and each state in which it is considered at any moment is a *phase* of that wave. Thus 1 is the start, 2 is a quarter-phase, 3 is a half-phase, 4 is a three-quarter phase, 5 is the end or commencement of the next wave.[1] This complete cycle is called a period and the number of these periods which occur in one second is called the *frequency* of the waves—the standard frequency for alternators is now fifty. This is the frequency of the exciting currents in the secondary circuit, S, fig. 258.

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[1] 1, 3, and 5 are called *nodes* + and − *loops*.

But this frequency is very much modified in the circuit AA′ E′E by *sparks*. A spark is the sudden development of energy when the strength of the dielectric—air, oil, glass, gutta percha, etc.—is broken down by an excess of voltage. The dielectric strength of air is 30,000—that is, it requires 30,000 volts to rupture a centimetre length of air with that sudden vehemence which produces an explosion, a sharp snap, and a brilliant flash. Lightning is a spark of gigantic dimensions.

A mere spark alone does not produce great frequency. It requires the presence of electromagnetic inertia (or *inductance*) L, and of *capacity* K to do this. In fact, the frequency F is given by the equation

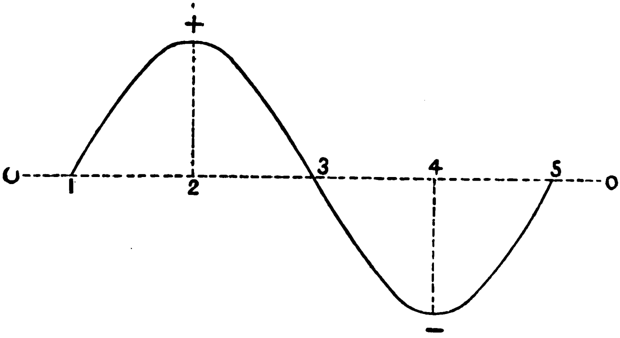

FIG. 260.

$$F = \frac{1}{2\pi\sqrt{KL}}$$

when K and L are expressed in absolute units. Experience shows that this is true with marvellous accuracy, and it is the foundation on which *tuning* is based.

A spark is followed by a train of waves, but these are rapidly damped down by resistance and radiation into space.

The actual operating pulsation may be, and probably is, in untuned systems only the first wave, but tuning requires persistence. The wave length used for wireless telegraphy varies. It is measurable in metres, in feet, or yards. Roughly, it is four times the height of the antenna when the antenna is a single wire, but this is much modified by the intrusion of additional capacity (K) when a network of wires is employed. Any addition to the antenna increases the length of the wave, and the addition of capacity enables the height of the antenna to be reduced.

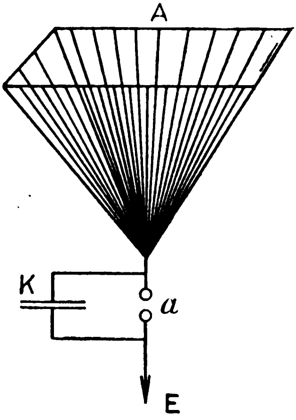

FIG. 261.

Devices have been introduced to increase the capacity of the antenna.

The single vertical wire which formed Marconi's original antenna has, by his eight years' experience, passed through several phases, and is now an inverted pyramid, as shown in fig. 261. Its capacity is very small, and it has to be supplemented for tuning purposes when used for receiving by an adjusting condenser K.

Another device is Lodge's network. This is shown by fig. 262 and is designed for military purposes over land.

A_1 A_2 and B_1 B_2 are wooden yards of about thirty feet in length, and strong enough to support a network of copper wires, No. 14 S.W.G., seventy-five feet long, strung together in the manner shown in the figure. All the wires of the network meet at the loop C_1 and are continued in a strand to C_2. The network of wires is supported at H_1, H_2 by well-hooded ebonite insulators and fastened to the two poles at E_1 and F_1. The yards A_1, A_2 and B_1, B_2 are guyed at the ends by light ropes attached to four hooded ebonite insulators, I_1, I_2, I_3, and I_4.

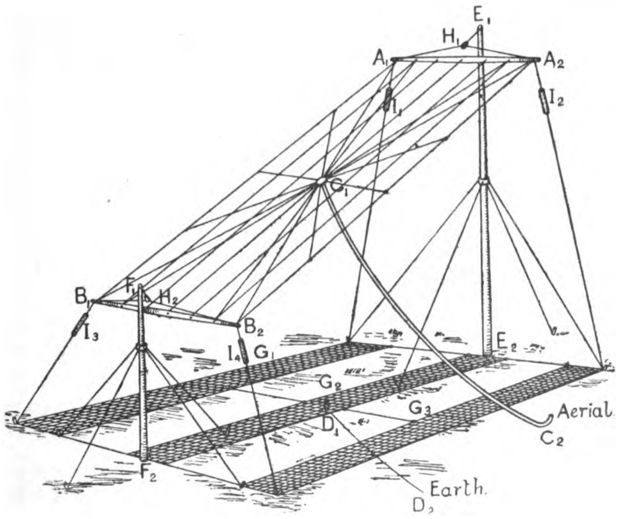

FIG. 262.

For the second or earth capacity area three lengths of copper netting, G_1, G_2, G_3, about five feet wide, are laid out on the ground immediately underneath the aerial A_1, A_2, B_1, B_2 and connected together by a stout stranded copper lead D_1 D_2.

The chief object in long-distance signalling is to throw all the energy we can into the spark determining the radiating waves. Tuning must be carefully nursed. Tuning depends on resonance, and this means the sympathetic vibration of two circuits, the one being the exciter and the other the responder. Sympathetic vibration cannot be set up except when the circuits are in tune, that is, the raising of a similar frequency in the responder to that produced by impulses in the transmitter. This is effected by adjusting the capacity and the inductance. Excessive damping is injurious to tuning. There must, therefore, be a certain persistence in vibration so that the tuning may be carefully regulated.

Thus the transmission of signals to a distance from the sending station depends on several well-considered conditions—energy, capacity, inductance, height of antenna, radiating power, frequency, damping and tuning, not the least important of which is the last. The improvement in the strength of signals due to tuning and the accuracy with which it can be effected by small steps in varying K and L, is remarkable. It is here that the skilled expert shines. Two circuits are in tune when $L_1 K_1 = L_2 K_2$. Fig. 263 illustrates Sir Oliver Lodge's mode of making up the transmitting end. A is the antenna where the vibrations must be excited, S and *p* the transformer which regulates the voltage in the antenna, K_1 K_2 K_3 the capacities, *a* the spark gap which oscillates the energy, S the secondary and *p* the primary of the transformer, E the earth, and D the source of energy. The antenna A radiates forth into space electric waves of given intensity and frequency some of which are picked up by the receiving station, the circuit being ultimately completed through the earth.

2. *The Dielectric.*—The antenna at A (fig. 259) radiates forth these electric waves in all directions, but it is only one tuned station which ought to receive and use them as signals. Any other station and even buildings and trees may receive these waves. It is not difficult to tap and disturb the

operations between A and B. This is the grave defect of Ætheric Telegraphy. Secrecy at present is impossible.

The antenna is thus thrown into a state of electrical oscillation which excites waves in the æther which surrounds it. Every point of the antenna sets up complete periods of variable voltage (fig. 260). Waves are excited in the æther which have three components, having the velocity of light 3×10^{10} cm. per second: one of propagation, in a forward direction; the second, in a lateral direction, having electrostatic properties; and the third, also lateral, having electromagnetic properties—the two latter act at right angles to each other and to the line of propagation. The electrostatic waves are like rays of polarised light vibrating in a vertical plane; the electromagnet waves similarly vibrate in a horizontal plane. The system of wireless telegraphy which Sir William Preece introduced in 1886 uses the latter. Mr. Marconi used the former in 1896. Fig. 264 illustrates these waves. The abscissæ in this case indicate distance.

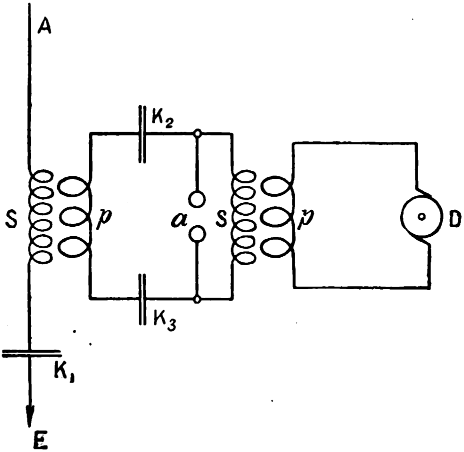

FIG. 263.

The electrostatic waves are meridian lines and are lines of electric force, the electromagnetic waves are lines of latitude and are lines of magnetic force moving onwards and outwards. The direction of the flow of energy is the line of propagation onward. The intensity of action of these lateral waves—that is, their amplitude—varies in clear space inversely as the square of the distance from the antenna. The intensity is not the same in all directions. It is a maximum at the equator for electric waves and at the poles for magnetic waves. Hence for utilising the former, we use vertical antenna, and for the latter, horizontal wires on poles. If we take in the latter case, a wire along which a current is flowing, every point gives lines of electric and magnetic force as shown by fig. 265. The direction of the current is the wave front and the line of the flow of energy. The lines of magnetic force are closed curves and they expand outwards. The lines of electric force are radial and are projected outwardly. All three components move with the velocity of light either in the æther or the wire.

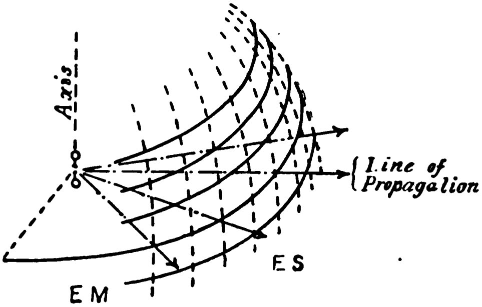

FIG. 264.[1]

The mean waves used have a frequency of the order of a million, and the length of those sent out from the Marconi station at Poldhu are about 1,000 yards from loop to loop.

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[1] Due to Poincarré.

3. *The Receiver.*—The antenna at the receiving station should be the same in dimensions as that at the sending station, but this cannot always be secured, especially on board ship. Anyway, the product of the inductance (L) and of the capacity (K) should be the same to secure the best signals.

A (fig. 266) is the antenna, *p* the primary wire of the transformer, K_1 K_2 K_3 are adjustable capacities, C Lodge's coherer, R the receiver, *b* the local battery.

The aerial is the recipient of an alternating electromotive force due to the impact of successive electric waves received from space, which are cumulative in their action upon the receiving system and generate in time a potential difference between the ends, measurable in volts. They are not continuous, but they come in trains of thirty or forty waves gradually damped down to nothing. Each wave is a minute store of energy, and every aerial is so constructed of capacity, inductance, and resistance that this energy is accumulated and formed into those conditions required by Ohm's law to give us current and therefore drop of voltage, which is its transformed state in the receiving system.

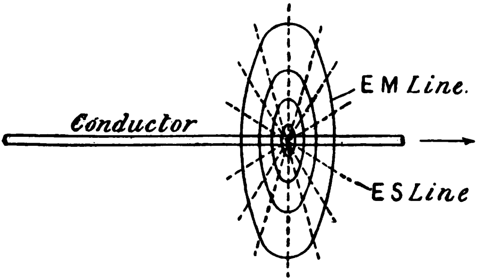

FIG. 265.

The first relay used by Marconi was called a 'Coherer,' and the term remains, though the Branly form of coherer itself is obsolete. The term *Coherer* was introduced by Sir

Oliver Lodge, who found that when two imperfectly conducting surfaces were in light touch and a current was passed across the contacts they stuck together or 'cohered.' But this adhesion was easily ruptured by sound waves or by mechanical vibration. Lodge found that the coherer responded to electric waves absorbed by the apparatus without any previous current having passed. The waves did not produce absolute adhesion, but they lowered the resistance of the surface by improving the imperfect contact.

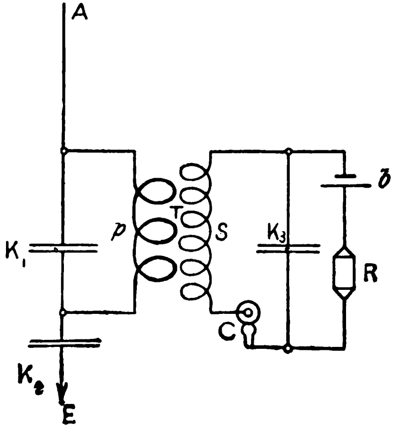

FIG. 266. (Lodge's System.)

Tubes of glass were filled with metallic filings. Thus the number of imperfect contacts was greatly increased and the sensitiveness improved; in fact, the resistance varied from infinity to a few ohms.

Marconi's orginal coherer, a modification of the inventor, Branly, was a glass tube, shown in fig. 267, in which two silver pole pieces *dd'* were fixed, separated from each other by, but in contact with, some fine silver and nickel filings. The tube was exhausted of air and the ends sealed, and wings w w_1 fixed. It was made part of a circuit containing a local battery and a sensitive telegraph relay whose contact points 1 2 completed the circuit. But it required decohering. This was done by the blows of a light hammer fixed in the same local circuit actuated by electro-magnetism and tapping the glass tube after the signal was received.

Castelli of the Italian Royal Navy showed how to dispense with the tapper. He proposed iron or carbon poles, C I C′, separated by a globule of mercury. The latest form is shown by fig. 268. The mercury and carbon cohere only when currents are flowing. But it is not reliable. It sometimes ceases to act and often fails to decohere.

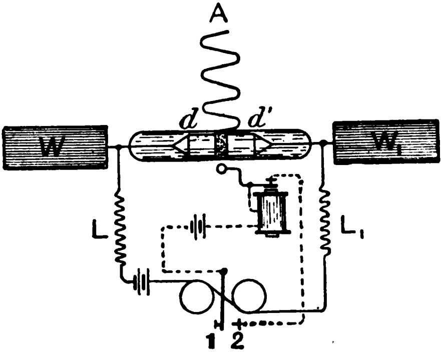

FIG. 267.

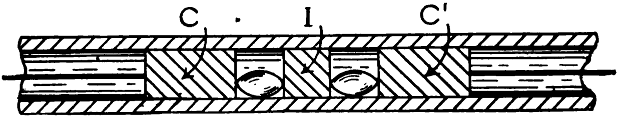

FIG. 268.

Lodge's coherer (fig. 269) is a distinct improvement on this. He keeps his contact surfaces in constant motion. One electrode is a thin steel disc *d* constantly rotating in oil, to which a fine film adheres, and in mercury *b*. The film is easily pierced by the voltage in the receiving circuit, but it is at once restored on the cessation of the current. The contact surfaces, steel and mercury, are clean and fresh and are always in working order.

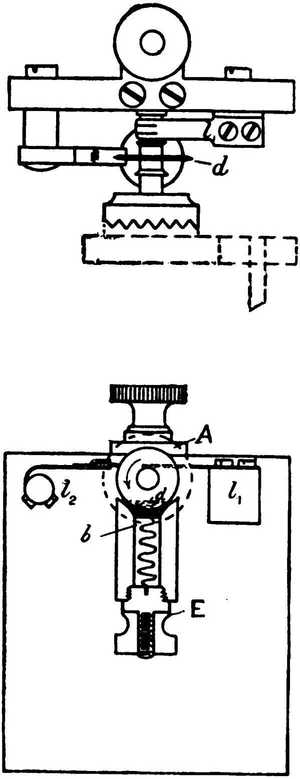

FIG. 269. (Lodge's Coherer.)

An excellent relay is Dr. Lee de Forest's electrolytic 'responder,' as he calls it.

The two electrodes are separated by an electrolyte through which a local current passes, and the polarisation and depolarisation of the faces of the electrodes by the impact of the received currents make or break the circuit.

The messages are read by telephone, and the speed of signalling acquired is simply marvellous—forty words by hand sending and sound reading have been attained. Its sensitiveness is said to be remarkably delicate and far surpassing that of Marconi's original coherer.

Marconi has more recently introduced a magnetic detector that is apparently giving considerable satisfaction.

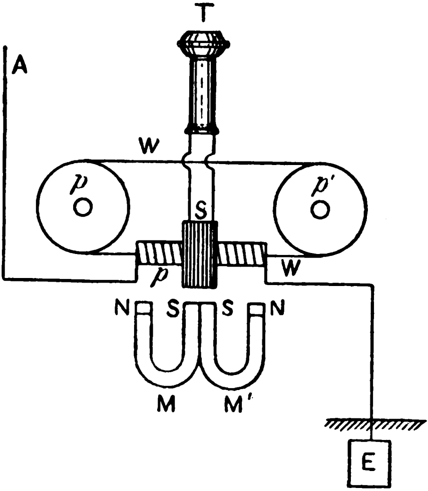

FIG. 270.

Steel or iron when magnetised directly or by induction is singularly sensitive to changes of magnetism when electrically disturbed. M M' are fixed permanent magnets, and W is a continuous moving band of iron wires passing over the pulleys P P', and thread the coils (P the primary and S the secondary) of a transformer.

The antenna A is connected to earth through the primary, and the secondary has a telephone T in its circuit. The delicate received currents are sufficient to vary the magnetic condition so that distinct and clear sounds are heard in the telephone. The apparatus is reliable and sensitive.

The Germans have been working very earnestly to make wireless telegraphy practical, and we are much indebted to them and particularly to Dr. Slaby for the light he has thrown on the theory of the subject and the use he has made of these conclusions to practical purposes. To Dr. Slaby we are indebted for the multiplier (fig. 271), which utilises to the best advantage the currents in the antenna. A is the antenna, L a regulating inductance, M a coil representing electrically the antenna. This places the coherer T where it is subject to its maximum action.

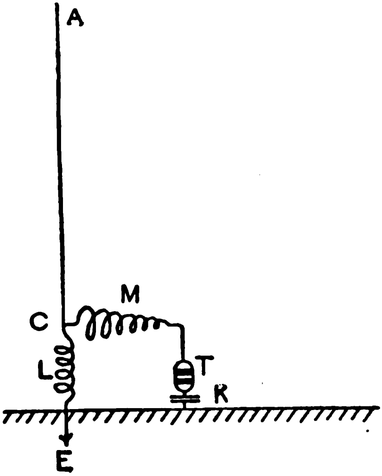

FIG. 271.

The chief feature of this multiplier M makes that portion of the circuit equal in L and K to the antenna A, so that the waves set up in the antenna and receiving apparatus are such that the centre C is a node and the two ends loops.[1]

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[1] *Vide* p. 459, fig. 260.

Thus the maximum potential differences act with great advantage to the signals received.

Duddell's thermo-galvanometer (fig. 272) gives us an instrument which measures the strength of the very minute currents in the receiving circuit. A short fine wire R is fixed to two bars immediately below a bismuth-antimony thermo-junction T. This fine wire R carries the currents to be measured, and being thus warmed the radiant heat falls

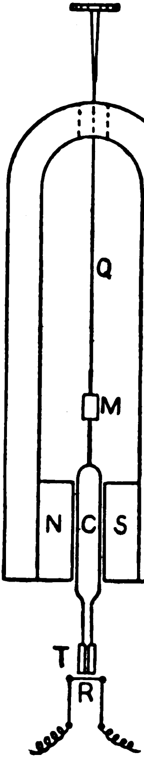

FIG. 272.

on the thermo-junction which forms part of a coil or loop C which deflects in a strong magnetic field N, S. The coil is suspended by a quartz fibre Q to which is attached a mirror M. It measures currents of ·00016 ampere. Coherers as a rule require for their operation a steady potential difference of the order of a volt, but no careful experiments have yet been published on this point.

4. *The Earth.*—It must be clearly understood that in ætheric telegraphic circuits we are dealing with currents in conductors and waves in dielectrics. Each in its turn represents the energy in circulation. At each station the antenna and apparatus are actuated by currents; the æther between the two conveys the energy in the form of electric waves. The earth completes the circuit and conveys the energy back to the source as current. The part played by the earth is as important as any other part of the circuit, and its functions have been much neglected. A very small fraction of the energy excited at the sending station reaches the receiving station. What becomes of the missing energy? How much is radiated into space? How much enters the earth from neighbouring systems? What do houses, trees, hills, mountains do to divert the energy?

It is quite clear that much depends on the resistance of the earth. Sea is the best earth we have. Land is the worst unless it is thoroughly moist. Indeed the sand of the desert and the dry cracked parched earth of South Africa are fatal to ætheric telegraphy unless moisture can be reached. It has been possible to send messages by the De Forest system from St. Louis to Chicago, three hundred miles apart, but the river connects the two places to make a good earth. Signals have been sent by the Marconi system from Cornwall to Bari on the Adriatic, one thousand miles apart, but each place is on the sea.

Many failures in this system of working are undoubtedly due to 'bad earth.'

It is usual to make direct contact with the earth by burying a plate of copper either in the sea or in the ground. But this is not imperative, for a flat surface of metal or a large strip of network of wire laid flat on the surface acts well (fig. 262). It increases the capacity of the system and acts upon the earth by induction. This system is used largely by Lodge, especially for military purposes (p. 461).

A condenser of sufficient capacity is very useful when the 'earth' is bad. Ætheric telegraphy can thus be carried out over short distances without direct contact with the earth. This is valuable for the soldier; the sailor always has the sea.

5. *Disturbances.*—We have already referred to the troubles due to bad earths, but we have also troubles in the atmosphere. Marconi has found a great difference in the strength of signals sent by day and by night. Daylight whips out of the waves so much of their energy that they fail to excite the receiver when the distances exceed five hundred miles. Even at shorter distances between Poldhu and Poole, about two hundred miles, signals failed in daylight, but they were restored by increasing the energy at the transmitting end.

In the Royal Navy it has been found that the interposition of high land reduces the distance considerably by absorbing the waves. There is no doubt that houses and trees have the same effect. The influence of trees has been admirably studied by Captain Squier, of the U.S.A. engineers. But atmospheric electricity is the worst enemy, for it sends false signals. The approach of lightning is often indicated by impulses affecting the receiver in the manner of the Morse signals giving the letters E, I, S, R, etc. It also diminishes the distance to which signalling is possible. Captain Jackson, R.N.,[1] says the fine weather signalling distance is reduced by lightning from 30 to 70 per cent. Whatever tends to absorb the energy contained in the æther waves must necessarily diminish the range

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[1] Re *Proc. R. S.*, May 1902.

of signalling. Even material particles like sand, salt, or even water globules, such as are brought from Africa by the sirocco in the Mediterranean, or such as produce the khamsin in Egypt, reduce the working distance.

Wireless Telegraphy is still in its experimental stage, but great progress has been made and undoubtedly will be made in the near future. The sea is its domain. Here it is practical and even commercial, but not reliable for continuous periods. It has not yet been proved effective overland excepting for comparatively short distances where the earth is moist. Secrecy is impractical and attainable only by codes. It is still complicated, and it needs skilled experts at each end.

The fascination of Marconi's operations has obscured the merits of the Preece system, but given a receiver as sensitive to the magnetic waves as the coherer is to the electric waves, there is no reason why the latter system should not be as successful as the former. Indeed there are reasons why, under certain conditions, it should be superior, for it would render unnecessary the very uncertain and capricious spark gap, it would be independent of the vagaries of the atmosphere, and it would eliminate the evil influence of trees and vegetation.

APPENDIX

SECTION A.—OHM'S LAW.

(References, pp. 6, 454.)

The flow of electricity between any two points is regulated by the *electro-motive force* of the generator, and the *resistance* of the conductor between them. It is therefore necessary to know the relations which exist between these, and this Law of the Current was determined by the great physicist Ohm early in the nineteenth century. He found that the strength of current which flows in a circuit varies *directly* as the electro-motive force and *inversely* as the total resistance. The law thus expressed is called, after the discoverer, 'Ohm's Law.' It may be shown thus:

$$\text{Current varies as } \frac{\text{Electro-motive Force}}{\text{Resistance}}.$$

Thus, if the electro-motive force be doubled, the current will also be doubled; but if the resistance be doubled, the current will then be halved.

Now, when the standard units of these functions are applied to the above expression, it may be stated as an equation, thus:

$$\text{Current in ampères} = \frac{\text{Electro-motive force in volts}}{\text{Resistance in ohms}};$$ and this may be shortened to

$$C = \frac{E}{R}. \qquad (1)$$

Giving numerical values to these letters (Ex. 1), if the electro-motive force (E) be 10 volts and the total resistance of the circuit (R) be 25 ohms, what will be the strength of the current?

Here, $C = \frac{10}{25} = \cdot 4$ ampères,

or this may be stated in the sub-unit milliampères,

$$C = \cdot 4 \times 1{,}000 = 400 \text{ milliampères.}$$

But formula (1) $C = \frac{E}{R}$ may be rewritten

$$CR = E, \qquad (2)$$

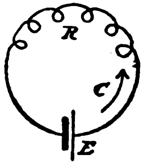


FIG. 1.

which shows that the electro-motive force (E) in a circuit is proportionate to the product of the current strength and the resistance. Thus (Ex. 2) if the strength of current in a circuit of 1,079 ohms resistance (including resistance of the battery) is 20 milliampères, what is the electro-motive force?

$$E = 1{,}079 \times \tfrac{20}{1000} = 1\cdot 079 \times 20 = 21\cdot 58 \text{ volts.}$$

As 1·079 volts represents the highest electro-motive force of a Daniell cell, the above conditions would result from a battery consisting of 20 Daniell cells, presuming the total resistance in circuit, $1{,}079^{\omega}$, included that of the battery.

Equation (2) also indicates, what is the fact, that the electro-motive force for *part* of a circuit may be calculated. Thus (fig. 2), the current strength C is due to $\frac{E}{R + R_1}$, that is to say, the strength of current throughout the circuit is C, and therefore E_1, the electro-motive force, or, as it is more usually expressed, the *difference of potential* between A and B through R_1 will be

$$CR_1 = E_1. \qquad (3)$$

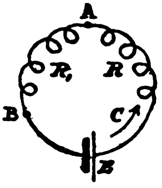


FIG. 2.

N.B.—This equation is not correct when there is a source of electro-motive force in the section of circuit dealt with; for instance, it would not apply to the difference of potential between A and B if the resistance between those points through R were substituted for R_1.

Again, $C = \frac{E}{R}$ may be written $R = \frac{E}{C}$, . . (4)

from which it is clear that, having given a fixed electro-motive force, the resistance through which it is made to act will be indicated by the reciprocal of the currents $\left(\frac{1}{C}\right)$.

SECTION B.—CALCULATION OF STRENGTH OF CURRENT.

(References, pp. 7, 10, 122.)

As seen in the previous section, the strength of an electric current flowing in a circuit depends upon the electro-motive force of the generator (whether that be a voltaic battery, a magneto machine, a dynamo, or a secondary battery) and upon the resistance through which the electro-motive force is applied. In calculating the strength of current it is necessary that the *total* resistance included in the circuit be taken. For example (fig. 3), with a battery of electro-motive force E and resistance r, joined in circuit with resistance coils R and galvanometer of resistance G, what is the strength of the current (C)?

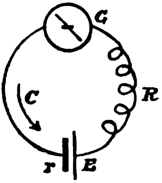


FIG. 3.

Here,
$$C = \frac{E}{R + G + r},$$

and if E = 21 volts, R = 1,416 ohms, G = 250 ohms, and r = 84 ohms, then

$$C = \frac{21 \times 1{,}000 \text{ (millivolts)}}{1{,}416 + 250 + 84} = \frac{21{,}000}{1{,}750} \text{ milliampères}$$
$$= 12 \text{ milliampères.}$$

SECTION C.—COMBINED RESISTANCES.

(References, pp. 121, 163, 165, 388, 406, 409.)

For any given conductor of uniform section the electrical conductivity varies directly in proportion to the transverse sectional area, and inversely in proportion to the length; that is to say,

$$\text{Conductivity varies as } \frac{\text{Sectional area}}{\text{Length of conductor}}.$$

Now resistance is the converse of conductivity, so that

$$\text{Resistance varies as } \frac{\text{Length of conductor}}{\text{Sectional area}}.$$

For instance, a piece of copper wire of certain sectional area and ten yards long will give double the resistance of five yards of similar wire, and the resistance of equal lengths of wire whose sectional areas are in the proportion of 1 to 3 will be respectively as 3 to 1.

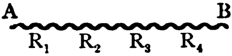


FIG. 4.

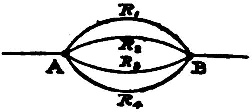


FIG. 5.

It is clear that if a series of resistances be joined up successively, as R_1, R_2, R_3, R_4 (fig. 4), the total resistance between A and B will be $R_1 + R_2 + R_3 + R_4$; that is, the total resistance of a series of resistances joined successively is the sum of the separate resistances.

But if the same four resistances be joined, as shown in fig. 5, what will be the resistance? These are said to be joined 'in multiple,' or 'for quantity.' It will be at once seen that there are here four ways for the current between A and B, and the resultant resistance must therefore be reduced. Now we may assume that each wire, R_1, R_2, R_3, R_4, is equal in length, and that if they vary in resistance (or conductivity) it is owing to their varying sectional areas. The relative conductivities of these wires are $\frac{1}{R_1}$, $\frac{1}{R_2}$, $\frac{1}{R_3}$, and $\frac{1}{R_4}$; so that, relatively, the total conductivity between A and B is $\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$; and the total resistance (R) is the reciprocal of this, namely,

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}; \qquad (1)$$

that is, *the joint resistance of two or more resistances joined for quantity is the reciprocal of the sum of the reciprocals of the several resistances.*

The case where there are only two resistances, R_1 and R_2, may be reduced to simpler form, for

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{R_2 + R_1}{R_1 R_2}} = \frac{R_1 R_2}{R_1 + R_2}; \qquad (2)$$

that is, *the joint resistance of two resistances joined for quantity is the product of the two divided by their sum.*

(Ex. 1.) (*a*) Four resistances, respectively 40^{ω}, 60^{ω}, 80^{ω}, 100^{ω}, are joined in series; what is the total resistance?

$$R = 40 + 60 + 80 + 100 = 280^{\omega}.$$

(*b*) What is the joint resistance when joined in multiple?

$$R = \frac{1}{\frac{1}{40} + \frac{1}{60} + \frac{1}{80} + \frac{1}{100}} = \frac{1}{\frac{30 + 20 + 15 + 12}{1{,}200}} = \frac{1}{\frac{77}{1{,}200}}$$

$$= \frac{1{,}200}{77} \text{ ohms} = 15{\cdot}58^{\omega}.$$

(Ex. 2.) What is the joint resistance of two resistances respectively 40^{ω} and 60^{ω}?

$$R = \frac{40 \times 60}{40 + 60} = \frac{2{,}400}{100} = 24^{\omega}.$$

It should be observed that the sectional areas of circular or square conductors vary as the square of their diameters or sides respectively, and that, consequently, *resistances of equal lengths vary inversely as the squares of their diameters*; thus the relative resistances of equal lengths of circular wires whose diameters are d_1 and d_2 will be inversely proportional to $(d_1)^2$ and $(d_2)^2$ respectively. [The actual areas would of course be $(d_1)^2 \times {\cdot}7854$ and $(d_2)^2 \times {\cdot}7854$.]

Suppose now that there are two wires of equal length whose areas are as 2 to 1; their weights will of course be in the same proportion, and their resistances as 1 to 2. If the length of the thinner wire be doubled the resistance will also be doubled, and will hence be *four* times that of the thicker wire, while their weights will be equal. Again, suppose the area to be as 3 to 1 and the lengths 1 to 3, then the resistance of these equal weights will be as 1 to 9; hence, *for equal weights of similar uniform conductors, the resistance varies directly as the square of the length and inversely as the square of the area or as the fourth power of the diameter.*

(Ex. 3.) Two wires of equal weight are respectively 10 yards and 15 yards in length; what are their relative resistances?

$$\text{As } 10^2 : 15^2, \text{ or } 100 : 225 = 4 \text{ to } 9.$$

(Ex. 4.) The respective diameters of two circular wires of equal weight are 4 and 5; what are their relative resistances?

$$\text{As } \frac{1}{4^4} : \frac{1}{5^4}, \text{ or } \frac{1}{256} : \frac{1}{625} = 625 : 256;$$

that is, the resistance of the wire of diameter 4 is 625 if that of the wire of diameter 5 be taken as 256.

SECTION D.—SHUNTS.

(References, pp. 165, 166, 388, 406, 409.)

It sometimes happens in measuring a current by means of a galvanometer that the deflection which the current would give is too great to be conveniently measured, and in such case recourse is had to the use of a *shunt*. The application of the term is not strictly limited to galvanometers, but to any form of resistance which is arranged to divert or take off part of a current flowing in a section of a circuit. In dealing, however, with the more restricted case, the general principle will be also explained.

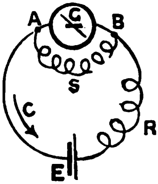


Fig. 6.

If the needle of the galvanometer G when placed in circuit with the battery E be deflected to an inconvenient extent, a second way for the current may be made by joining the resistance S in multiple with the coil of the galvanometer. As indicated by the previous section (C) this will reduce the resistance between A and B (fig. 6) to $\frac{G \times S}{G + S}$. Incidentally this will have the effect of increasing the actual current flowing from the battery, but this may either be compensated for by correspondingly increasing the resistance of the other part of the circuit, or it may be ignored. Now, the *conductivity* of these two paths between A and B are as $\frac{1}{G}$ to $\frac{1}{S}$ or as $\frac{S}{G \times S}$ to $\frac{G}{G \times S}$; that is to say, the proportion of current which will flow in the two sections, the galvanometer and the 'shunt,' will be respectively as S is to G; so that, if the current be supposed to be subdivided into S + G parts, S parts will pass through the galvanometer and G parts through the shunt. It will now be evident that, by giving S certain definite values as compared with G the resistance of the galvanometer, and then measuring the current passing in G, the total current of the undivided circuit may be calculated. Suppose, for instance, that S be equal to G, then S + G = 2 S, and it is clear that the current flowing through G is only $\frac{S}{S + G}$ or $\frac{S}{2\,S}$ that is, one-half of that flowing in the undivided circuit. Again, if S + G be made equal to 10 S, 100 S, or 1,000 S, then the current flowing through G will be $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ of that flowing from the battery, and the *multiplying power of the shunt* in these cases will be respectively 10, 100, and 1,000. But it is clear that these proportions may be obtained by giving S a value equal to $\frac{1}{9}$, $\frac{1}{99}$ or $\frac{1}{999}$ G, from which may be deduced the general rule that, calling the multiplying power of the shunt m,

$$S = \frac{G}{m - 1} \qquad (1)$$

(Ex. 1.) A $\frac{1}{100}$ shunt is to be applied to a galvanometer of 320^{ω} resistance; what must be the value of the shunt?

$$\text{Here, } S = \frac{320^{\omega}}{99} = 3{\cdot}232^{\omega}.$$

It was remarked above that the introduction of a shunt has the effect of reducing the total resistance of the circuit, and reference was made to compensating for this decrease. This compensation (R) must be equal to G less the combined resistance of G and S, that is

$$R = G - \frac{G \times S}{G + S} = \frac{G\,(G + S) - G \times S}{G + S} = \frac{G \times G}{G + S};$$

but, as was seen in (1), $S = \frac{G}{m - 1}$, m being the multiplying power of the shunt; therefore

$$R = \frac{G \times G}{G + \frac{G}{m - 1}} = \frac{G}{\frac{(m - 1) + 1}{m - 1}} = \frac{G\,(m - 1)}{m}. \qquad (2)$$

(Ex. 2.) In Ex. 1 what compensation resistance (R) should be inserted?

$$R = \frac{320\,(99)}{100} = 316{\cdot}8^{\omega}.$$

SECTION E.—THE WINDING OF ELECTRO-MAGNETS.

(References, pp. 45, 54, 55, 56, 57.)

For telegraphic purposes the (copper) wire used on electro-magnets is invariably covered with silk.

As a general rule it may be taken that the diameter of the bobbins should not exceed $\frac{2}{3}$ of the length of the electro-magnet core.

It is usual to specify the *resistance* to which electro-magnets are wound, as this is important for purposes of calculating strength of current, &c.; but this must not be taken absolutely as indicating the efficiency of the electro-magnet. It has been pointed out (p. 56) that the efficiency depends upon the number of convolutions around the core; that is, virtually, upon the actual *length* of wire used, and for a given resistance the length of wire will vary directly as the square of the diameter; hence the larger the wire the more convolutions there will be and the greater the efficiency of the electro-magnet. Therefore the largest possible wire which the bobbin will take for the specified resistance should be used in winding electro-magnets. Incidentally it may be noted that the larger the wire the less likely it is to be fused by currents of unusual strength: for this reason the rule applies also to ordinary resistance coils.

SECTION F.—CONDENSER.

(References, pp. 140, 176, 416.)

The principle of the Leyden jar was discovered in 1746, probably by Von Kleist, although the discovery is more commonly associated with the name of Muschenbroek, or of Cuneus of Leyden. It consists of a wide-mouthed bottle coated inside and out with tinfoil to about three-fourths its height. Connection with the inside coat is generally obtained by means of a chain attached to a metal rod which terminates in a knob (see fig. 232). The two coats of the jar thus separated by the glass have a power of retaining a certain quantity of electricity in the form of a charge, and the amount held depends upon the surface of the coatings, and the thickness of the glass. When, however, we come to deal with the more convenient method of obtaining capacity —the condenser—where the customary glass of the Leyden jar is abandoned in favour of some more convenient dielectric, the electrostatic capacity is found to vary in conformity with three conditions, namely: (1) Directly, as the surfaces of the opposing conducting plates; (2) inversely, as the distance between the opposing conducting plates; and (3) directly, as the *specific inductive capacity* of the dielectric. This last is a property inherent to all non-conducting substances, in virtue of which they have the power of effecting induction to a specific extent. Comparatively, if air be taken to have a specific inductive capacity of 100, then that of glass is 190, that of paraffin 198, of gutta-percha 420, and of mica 500. For use in making condensers glass is inadmissible, except for very small capacities, on account of its fragility; gutta-percha cannot be relied upon because in thin sheets it soon becomes brittle; and, in fact, the only dielectrics ever used for condensers under ordinary conditions are mica and paraffined paper. Mica, from the fact that it can be so readily split into very thin sheets and that its specific inductive capacity is very high, is most suitable, but its high price prevents its use except for special purposes, such as standard condensers. All ordinary condensers, therefore, are constructed with paraffined paper.

As stated above, the capacity varies directly as the surfaces of the opposing plates. If now three condensers, F_1, F_2, F_3, be joined up, as shown in fig. 7, the effect is clearly to connect all the A plates together, so that, practically, they become one plate of large area, and so also with the B plates ; hence, by such an arrangement, the total capacity (F) becomes

FIG. 7.

$$F = F_1 + F_2 + F_3. \qquad (1)$$

Again, the capacity varies inversely as the distance between the plates. Assume the distances in fig. 8 are $\frac{1}{F_1}, \frac{1}{F_2}, \frac{1}{F_3}$; then, if the three condensers be joined as shown, the B plate of F_1 is practically brought opposite that of F_2 by the connection of the A plates of F_1 and F_2, but at distance $\frac{1}{F_1} + \frac{1}{F_2}$, and similarly with F_2 and F_3, so that the distance between plate B of F_1 and plate A of F_3 is $\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}$, and the capacity (F) is therefore

FIG. 8.

$$F = \frac{1}{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}}. \qquad (2)$$

The special case of two capacities works out similarly to that of the law of combined resistances (section C), and becomes

$$F = \frac{F_1 F_2}{F_1 + F_2}. \qquad (3)$$

SECTION G.—TESTING 'EARTHS.'

The theory of the method of finding the actual resistance of an 'earth,' which is described at p. 448, may be explained thus :

FIRST TEST.

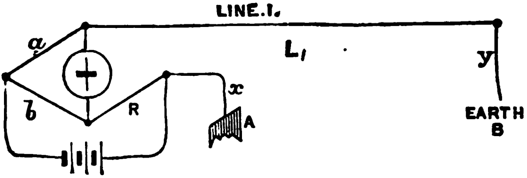


FIG. 9.

Let x be the resistance of the earth A (the resistance required),
,, y ,, ,, ,, B (not known),
and L_1 ,, ,, line 1 ; then, when balance is obtained,

$$aR = b(L_1 + y + x)$$

or $$aR = b(L_1 + y) + bx. \tag{1}$$

SECOND TEST.

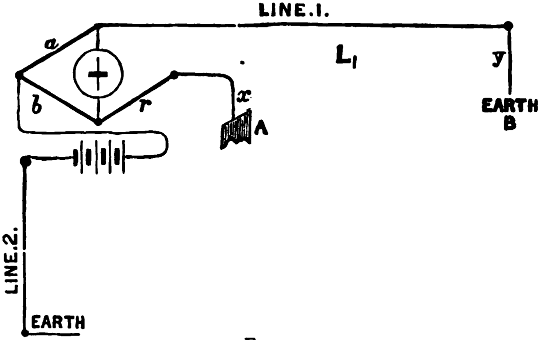


FIG. 10.

In this case, when balance is obtained,

$$a(x + r) = b(L_1 + y);$$

that is, $$ax + ar = b(L_1 + y). \tag{2}$$

Then, by subtracting (2) from (1)

$$aR - ax - ar = bx,$$

or $$x(a + b) = a(R - r);$$

that is, $$x = \frac{a(R - r)}{a + b}$$ (*General Case*);

and, if a and b are equal, $$x = \frac{R - r}{2}$$ (*Special Case*).

SECTION G (1).—FAULTS IN SUBMARINE CABLES.

Mr. E. Raymond-Barker has developed Jona's graphic method and has successfully extended the same to the localisation of 'Partial Earths'; also to the graphic treatment of Mance bridge readings where current from a fixed battery is varied by succeeding equal ratio coils in the fork of the bridge, the resultant plottings of bridge readings with corresponding $\frac{1}{\sqrt{\text{m.a.}}}$ being utilised for the production of a curve the lower extremity of which points approximately to a figure repre-

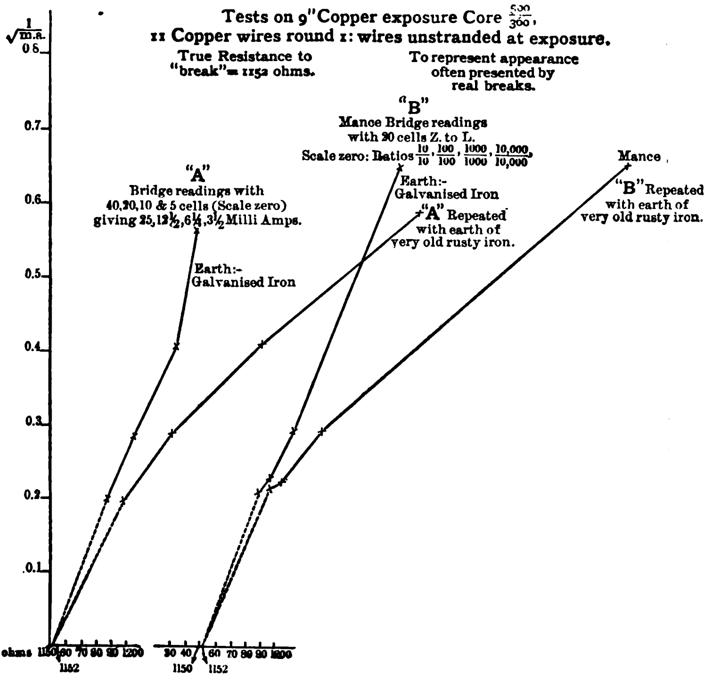


FIG. 11.

senting ***true resistance up to break or fault.*** Fig. 11 illustrates this method as applied to an artificial fault and fig. 12 exhibits the localisation of an actual fault in one of the Atlantic cables.

Graphs of actual Localisation tests to broken ends
Core $\frac{400}{360}$

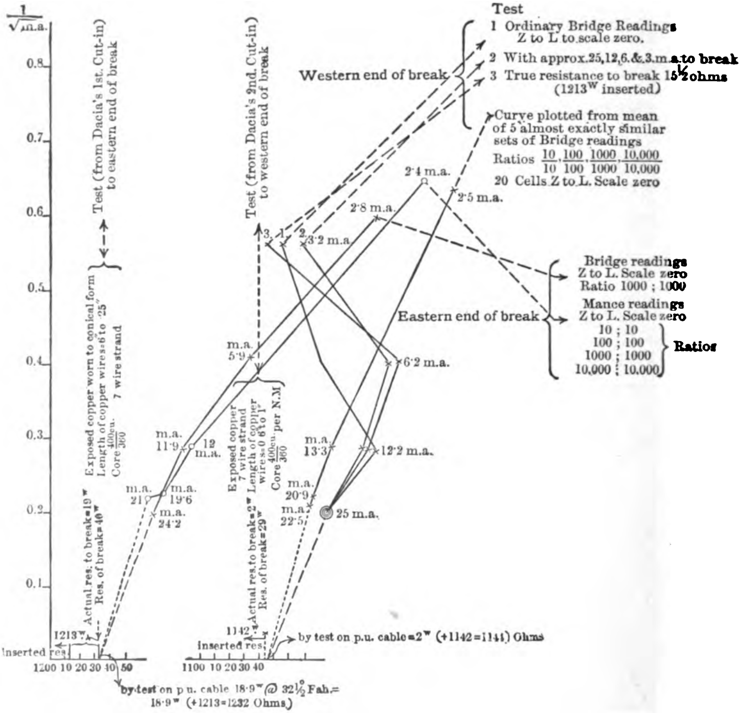


FIG. 12.

SECTION H.—STANDARD WIRE GAUGE.

Table showing Areas of Cross Section of Round Wire, and Resistance, Conductivity and Weight for Copper and Iron Wire.

No. of British wire gauge	Diameter		Area of Cross Section, square cms.	Copper (pure)			Iron		
	Ins.	Cms.		Resistance, ohms per metre	Conductivity, metres per ohm	Weight, grammes per metre. Density 8.90	Resistance, ohms per metre	Conductivity, metres per ohm	Weight, grammes per metre. Density 7.79
7/0	.500	1.270	1.267	000135	7402.1	1127.4	.00080	1245.3	986.8
6/0	.464	1.178	1.090	.000157	6370	970.2	.00093	1071.8	849.0
5/0	.432	1.097	.945	.000181	5521	840.8	.00106	943.4	735.9
4/0	.400	1.016	.811	.000211	4736	721.3	.00125	800.0	631.3
3/0	.372	.945	.701	.000244	4098	624.2	.00145	689.7	546.3
2/0	.348	.884	.613	.000279	3584	545.9	.00166	602.4	477.8
0	.324	.823	.532	.000322	3107	473.2	.00191	523.6	414.2
1	.300	.762	.456	.000375	2666	406.1	.00223	448.4	355.5
2	.276	.701	.386	.000444	2253	343.2	.00264	378.8	300.5
3	.252	.640	.322	.000532	1881	286.5	.00316	316.5	250.8
4	.232	.589	.273	.000628	1592	242.5	.00373	268.1	212.8
5	.212	.538	.228	.000751	1331	202.7	.00446	224.2	177.4
6	.192	.488	.187	.000916	1092	166.3	.00544	183.8	145.6
7	.176	.447	.157	.00109	917.8	139.8	.00648	154.3	122.4
8	.160	.406	.130	.00132	757.2	115.3	.00784	127.6	100.9
9	.144	.366	.105	.00163	614.9	93.7	.00968	103.3	82.0
10	.128	.325	.0829	.00206	484.6	73.8	.0122	81.97	64.6
11	.116	.295	.0682	.00251	398.3	60.7	.0149	67.11	53.1
12	.104	.264	.0548	.00312	320.3	48.8	.0185	54.05	42.7
13	.092	.234	.0429	.00398	250.6	38.2	.0236	42.37	33.4
14	.080	.203	.0324	.00528	189.5	28.9	.0314	31.85	25.3
15	.072	.183	.0263	.00651	153.5	23.4	.0387	25.84	20.5
16	.064	.163	.0208	.00824	121.3	18.5	.0489	20.45	16.2
17	.056	.142	.0159	.0108	92.7	14.1	.0642	15.58	12.3
18	.048	.122	.0117	.0147	68.2	10.4	.0873	11.45	9.10
19	.040	.1016	.00811	.0211	47.4	7.19	.125	8.000	6.29
20	.036	.0914	.00657	.0260	38.4	5.84	.154	6.493	5.11
21	.032	.0813	.00519	.0330	30.3	4.62	.196	5.102	4.04
22	.028	.0711	.00397	.0431	23.2	3.54	.256	3.906	3.10
23	.024	.0610	.00292	.0587	17.05	2.60	.349	2.865	2.28
24	.022	.0559	.00245	.0698	14.32	2.18	.415	2 410	1.91
25	.020	.0508	.00203	.0845	11.84	1.80	.502	1.992	1.58
26	.018	.0457	.00164	.104	9.59	1.46	.618	1.618	1.28
27	.0164	.0417	.00136	.125	7.97	1.21	.742	1.348	1.06
28	.0148	.0376	.00111	.154	6.48	.988	.915	1.093	.865
29	.0136	.0345	.000937	.183	5.46	.834	1.087	.9200	.730
30	.0124	.0315	.000779	.220	4.55	.693	1.307	.7651	.607
31	.0116	.0295	.000682	.251	3.98	.607	1.491	.6707	.531
32	.0108	.0274	.000591	.290	3.45	.526	1.723	.5804	.460
33	.0100	.0254	.000507	.338	2.96	.451	2.080	.4808	.395
34	.0092	.0234	.000429	.398	2.51	.382	2.364	.4230	.334
35	.0084	.0213	.000358	.478	2.09	.318	2.839	.3522	.278
36	.0076	.0193	.000293	.585	1.71	.260	3.475	.2878	.228
37	.0068	.0173	.000234	.730	1.37	.208	4.336	.2306	.182
38	.0060	.0152	.000182	.943	1.06	.162	5.601	.1785	.142
39	.0052	.0132	.000137	1.248	.801	.122	7.412	.1349	.107
40	.0048	.0122	.000117	1.466	.682	.1038	8.708	.1148	.0909
41	0044	.0112	.0000982	1.742	.574	.0874	10.350	.0966	.0765
42	.0040	.0102	.0000811	2 109	.474	.0721	12.530	.0798	.0631
43	.0036	.00914	.0000656	2.611	.383	.0584	15.510	.0645	.0511
44	. 032	.00813	.0000519	3.300	.303	.0462	19.600	.0510	.0404
45	.0028	.00711	.0000397	4 310	.232	.0353	25.600	.0391	.0309
46	.0024	.00610	.0000292	5.848	.171	.0260	34.740	.0288	.0228
47	.0020	.00508	.0000203	8.475	.118	.0180	50.340	.0199	.0158
48	.0016	.00406	.0000129	13.23	.076	.0115	78.580	.0127	.0101
49	.0012	.00305	.0000073	23.42	.043	.00650	139.100	.00719	.0057
50	0010	.00254	.0000050	33.78	.030	00451	200.600	.00499	.0040

NOTE.

Area in square cms. × ·155 = area in square ins.
Ohms per metre × ·305 = ohms per foot.
Metres per ohm × 3·28 = feet per ohm.
Grammes per metre × ·000672 = lbs. per foot.
,, ,, × ·01075 = ozs. ,, ,,
,, ,, × 4·7 = grs. ,, ,,
Lengths in millimetres × ·03937 = length in ins.
,, centimetres × ·3937 = ,, ,,
,, metres × 3·2809 = ,, feet.
,, ,, × 1·0936 = ,, yards.
,, kilometres × ·62138 = ,, miles.
Weight in grammes × 15·432 = weight in grains troy.
,, kilogrammes × 2·2 = ,, lbs. avoirdupois.

SECTION I.

COPPER CONDUCTORS.

The following standards for copper conductors have been agreed upon by the Engineering Standards Committee in London as from August 1904.

(1) A wire one metre long, weighing one gramme, and having a resistance of 0·1539 standard ohm at 60° Fahr. (15·6° C.) is taken as the standard for hard-drawn high-conductivity commercial copper.

(2) Hard-drawn copper is defined as that which will not elongate more than 1 per cent. without fracture.

(3) A wire one metre long, weighing one gramme, and having a resistance of 0·1508 standard ohm at 60° Fahr. (15·6° C.), is taken as the standard for annealed high-conductivity commercial copper.

(4) Copper is taken as weighing 555 lbs. per cubic foot (8·89 grammes per cubic centimetre) at 60° F. (15·6° C.) which gives a specific gravity of 8·90.

(5) The average temperature co-efficient of 0·00238 per degree Fahr. (0·00428 per degree C.) is adopted for commercial purposes.

(6) A variation of 2 per cent. from the adopted standard of resistance is allowed in all conductors.

(7) A variation of 2 per cent. from the adopted standard of weight is allowed in all conductors.

(8) An allowance of 1 per cent. increased resistance, as calculated from the diameter, is allowed on all tinned copper conductors between diameters 0·104 and ·028 (Nos. 12 and 28 S.W.G.) inclusive.

(9) In cables, for the purpose of calculation of tables, a lay, involving an increase of 2 per cent. in each wire, except the centre wire, for the total length of the cable is taken as the standard.

(10) The legal standard wire gauge is adopted as the standard for all wires.

SECTION J.

WORKING CURRENT OF POST OFFICE INSTRUMENTS.

(References, pp. 56, 477.)

In Section E of the Appendix the relation which exists between the resistance of an electro-magnet and its efficiency is explained, and the principle there pointed out is always insisted upon in all instruments used in the Postal Telegraph Service. With this object—that is, to secure that the resistance shall as nearly as possible represent a certain number of convolutions of wire around the electro-magnets—the size of wire to be used, as well as its resistance, is invariably specified in connection with the manufacture of instruments. Hence all instruments of one form may be safely relied upon to be of fairly equal efficiency.

The following Table shows (1) the resistance of the coils of some of the standard instruments in general use; and also (2) the 'figures of merit' (that is to say, the *minimum* current with which the instrument is expected to work when tested before being issued from the Stores); and (3) the range of current allowed when calculating for battery power.

	Resistance of Coils. Ohms.	Figure of Merit. Milliampères	Working Current. Milliampères	
			Minimum	Maximum
Wheatstone A B C (magneto):				
Communicator	800	Must work well on short circuit, and also through an external resistance of 7000^{ω}.		
Indicator	250			
Bell	250			
Single Needle (Induced Coils)	200	3·06 Needle to deflect to stop pins	15	20
Bright's Bell:				
Relay	200	3·2	15	20
Sounders (20^{ω} electro magnet with 500^{ω} shunt coil; see p. 166)	19·2	73	—	—
Relays:				
Standard A	400	·5	14	17
„ B	200	·5	14	17
„ C	1200	·087	14	17
Non-polarised B	400	6	—	—
Siemens	400	1·13	15	20
Sounder (20^{ω} shunted with 500^{ω}. Used for local circuits only)	19·2	55	60	80
Direct Inker (including galvanometer, 30^{ω})	330	4·9	15	20
[Speed of slip between 6 and 7 feet per minute.]				
Local Inker (40^{ω} with 500^{ω} shunt)	37	69	—	—
Automatic Receivers	200	10 (key)	—	—
[Speed of slip to range from 8 to 60 feet per minute.]		17·5 (400 words per minute)	20	25
Telephone:				
Post Office Telephones:				
Induction Primary Coil	1	—	—	—
Induction Secondary Coil	25	—	—	—
Induction Primary Coil for Trunk Lines	1	—	—	—
Induction Secondary Coil for Trunk Lines	250	—	—	—
Receiver (joined in multiple) each	120	—	—	—
Relay	100	6	16	—
Bell, Trembler	100	13·5	20	—

SECTION K.

I. ELECTRO-MOTIVE FORCE OF BATTERIES.

Bichromate Battery (p. 29)	2·14 volts	(approximate).
Grove (p. 30)	1·96 ,,	,,
Bunsen (p. 31)	1·96 ,,	,,
Leclanché (pp. 23, 29)	1·60 ,,	,,
Smee (p. 12)	1·10 ,,	,,
Daniell (p. 12)	1·07 ,,	,,
Secondary (p. 36)	2·00 ,,	,,

The electro-motive force of a cell depends solely upon the chemical action which takes place, and is quite independent of the internal resistance between the poles.

II. RESISTANCE OF BATTERIES.

The resistance of a cell depends upon its chemical constituents and their density, and the construction, shape, and size of the cell, the thickness and density of porous pot (if one is used), &c. Hence it is difficult to indicate any standard, but the following gives the range of resistance permitted for Post Office Batteries :—

		Standard. Ohms	Highest allowed. Ohms
Bichromate, Fuller's quart size (p. 29)		2	3
Daniell (p. 14)		4	6
Chamber (p. 21)		5	7½
Leclanché, Porous Pot (p. 24)		2	3
,, Agglomerate (p. 28)	(about)	0·5	—

So-called *Dry* Leclanché cells are made which possess lower internal resistance than the Wet cells.

SECTION L.

ACTUAL SPEED OF WORKING OF POST OFFICE INSTRUMENTS.

The following Table, showing the maximum speed observed in *actual working* with the principal forms of apparatus employed in the British Postal Telegraph Service, has been prepared as a record.

	No. of Messages per hour	No. of Telegraphists at each end of the wire	No. of Messages per Telegraphist per hour
Morse :			
Simplex Sounder . .	61	1	61
Duplex Sounder . .	112	2	56
Quadruplex Sounder .	249	4	62·25
Hughes	106	2	53
Wheatstone Automatic .	412	9	45·77

It should be noted that there is no essential difference in the speed of Sounder working in different systems ; the differences shown above arise from conditions of actual practice.

As an indication of the perfection to which the Wheatstone Automatic apparatus has now been brought, it may be stated that on February 3, 1892, 550 and 600 words per minute were printed at Birmingham on the racing circuit from Leicester, serving simultaneously Birmingham, London, Manchester, and Liverpool.

SECTION M.—SAGS FOR COPPER AND IRON WIRES.

At various temperatures which provide for a factor of safety of 4 at 22° Fahr.

Temperature in Degrees F.	Sags for various Spans									
	Copper Wire					Iron Wire				
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
22	0 8	0 11⅝	1 3⅝	1 8⅝	2 1⅞	0 9⅛	1 1⅛	1 6⅛	2 0¼	2 6⅝
25	0 9⅞	1 2¼	1 5¾	1 10⅛	2 4	0 10¾	1 2⅞	1 7⅞	2 1⅛	2 8
30	1 0⅝	1 4¼	1 8⅜	2 1⅝	2 7⅛	1 0½	1 4¾	1 9¾	2 3⅜	2 10
35	1 2¼	1 6⅜	1 11⅛	2 4⅜	2 10	1 2	1 6⅛	1 11⅝	2 5⅝	2 11⅞
40	1 4⅛	1 8⅜	2 1⅝	2 6⅞	3 0⅝	1 3⅛	1 8	2 1¼	2 7⅛	3 1¾
45	1 6¼	1 10⅜	2 3¾	2 9¼	3 3⅛	1 4¾	1 9⅜	2 2⅞	2 8⅞	3 3⅛
50	1 7¾	2 0¼	2 5¾	2 11⅜	3 5⅛	1 6	1 10⅞	2 4¼	2 10⅜	3 5⅛
55	1 9⅜	2 2¼	2 7⅝	3 1⅜	3 7¾	1 7	2 0⅛	2 5¾	2 11⅞	3 6¾
60	1 10⅝	2 3⅞	2 9¼	3 3¼	3 10	1 8⅛	2 1¼	2 7	3 1⅜	3 8¼
65	1 11¾	2 5⅛	2 11	3 5¼	3 11¾	1 9⅛	2 2⅜	2 8⅜	3 2¾	3 9¾
70	2 0⅞	2 6⅝	3 0⅛	3 7	4 1¾	1 10⅛	2 3⅜	2 9⅛	3 4⅛	3 11¼
75	2 2	2 8	3 2⅜	3 8⅝	4 3⅝	1 11	2 4⅝	2 10¼	3 5⅝	4 0⅝
80	2 3⅛	2 9⅛	3 3⅛	3 10⅛	4 5⅜	1 11⅞	2 5⅝	2 11⅞	3 6⅜	4 2
85	2 4¼	2 10⅛	3 5	3 11⅞	4 7⅛	2 0¾	2 6⅝	3 1	3 7⅞	4 3¼
90	2 5¼	2 11⅜	3 6½	4 1⅜	4 8¾	2 1⅝	2 7⅝	3 2⅛	3 9⅜	4 4⅝
95	2 6¼	3 0⅜	3 7⅝	4 3⅜	4 10⅝	2 2⅝	2 8⅝	3 3⅛	3 10¼	4 5⅛
100	2 7⅛	3 1⅜	3 9	4 4⅜	5 0	2 3⅛	2 9⅝	3 4⅛	3 11⅜	4 7⅛

The sag varies with the material and not with the gauge.

SECTION N.—STRESSES. COPPER WIRES.

Temperature in Degrees Fahr.	Stresses in lbs. for various Spans in yards																				Temperature in Degrees Fahr.
	150 lbs. per mile (97 mils diameter, No. 12½ S.W.G.)					200 lbs. per mile (112 mils diameter, No. 11½ S.W.G.)					400 lbs. per mile (158 mils diameter, No. 8 S.W.G.)					600 lbs. per mile (193 mils diameter, No. 6 S.W.G.)					
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
22	120	120	120	120	120	160	160	160	160	160	320	320	320	320	320	480	480	480	480	480	22
25	96	102	106	109	111	129	136	142	145	148	258	272	284	290	296	386	409	425	436	444	25
30	76	84	91	96	99	102	113	121	128	133	204	226	242	256	266	306	338	364	383	399	30
35	65	74	71	86	91	87	98	108	115	122	174	196	216	230	244	262	295	323	346	365	35
40	58	66	73	79	84	77	88	96	106	113	154	176	192	212	226	232	265	294	318	338	40
45	52	61	68	74	79	70	81	90	98	105	140	162	180	196	210	211	243	271	296	317	45
50	48	56	63	69	75	65	74	84	92	100	130	148	168	184	200	194	223	253	277	299	50
55	45	53	59	65	71	60	70	79	87	94	120	140	158	174	188	182	211	238	262	284	55
60	42	50	56	62	67	57	66	75	83	90	114	132	150	166	180	171	200	226	250	270	60
65	40	47	53	59	65	54	63	71	79	86	108	126	142	158	172	162	189	214	238	260	65
70	38	45	51	57	62	51	60	68	76	83	102	120	136	152	166	153	181	205	229	249	70
75	37	43	49	55	60	49	58	66	73	80	98	116	132	146	160	147	173	197	220	240	75
80	35	41	47	53	58	47	55	63	71	77	94	110	126	142	154	141	166	190	212	232	80
85	34	40	46	51	56	45	53	61	68	75	90	106	122	136	150	136	160	183	205	225	85
90	33	39	44	49	54	44	52	59	66	73	88	104	118	132	146	131	155	177	199	218	90
95	32	37	43	48	53	42	50	57	64	71	84	100	114	128	142	127	150	172	191	212	95
100	31	36	42	47	52	41	48	56	62	69	82	96	112	124	138	123	146	167	188	207	100
Poles per mile	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	Poles per mile

SECTION O.—STRESSES. IRON WIRES.

Temperature in Degrees F.	Stresses in lbs. for various Spans in yards									
	200 lbs. per mile (121 mils diameter, No. 10½ S.W.G.)					400 lbs. per mile (171 mils diameter, No. 7½ S.W.G.)				
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80yds.	90yds.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
22	135	135	135	135	135	270	270	270	270	270
25	120	124	127	128	130	239	247	253	256	259
30	103	110	115	119	122	205	219	230	238	243
35	91	100	107	112	115	182	199	213	223	230
40	83	92	99	105	110	165	184	198	210	219
45	77	86	94	99	105	153	172	187	199	210
50	72	81	89	95	101	143	161	177	190	201
55	67	77	85	91	97	134	153	169	182	194
60	64	73	81	88	94	127	146	162	175	187
65	61	70	78	85	91	121	139	155	169	181
70	58	67	75	82	88	116	134	149	163	175
75	56	64	72	79	85	111	129	144	158	170
80	54	62	70	77	83	107	124	140	153	165
85	52	60	68	75	81	103	120	135	149	161
90	50	58	66	73	79	100	117	132	145	157
95	48	56	64	71	77	97	113	128	142	154
100	47	55	63	69	75	94	110	125	138	150
Poles per mile	35	29	25	22	19½	35	29	25	22	19½

Factor of safety of 4 at 22° Fahr. for all wires.
The stress varies with both the gauge and the material.
The stress for 100 lbs. (No. 14) copper wire is half that for 200 lbs. and the stress for 800 lbs. (No. 4½) copper wire is double that for 400 lbs.

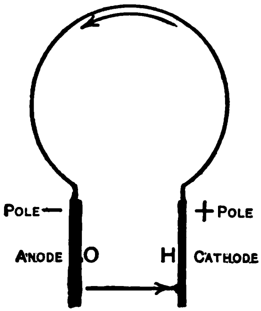
SECTION P.

ACCUMULATORS.

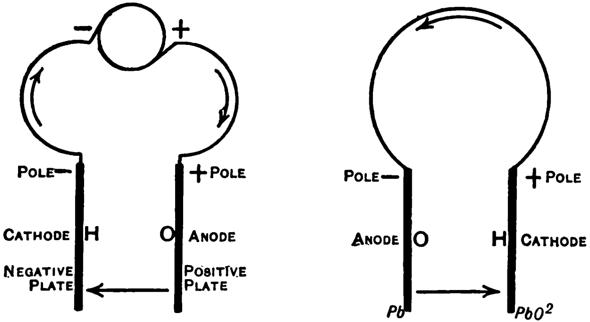
So many mistakes are made in naming the poles, plates of cells, and electrodes, from which currents start and towards which they flow, that the following figures (p. 495) have been drawn, which give at a glance the correct information, as used in this text-book.

Diagrams illustrative of the Nomenclature conventionally applied to the Poles and Plates of Cells, etc.

VOLTAIC CELL



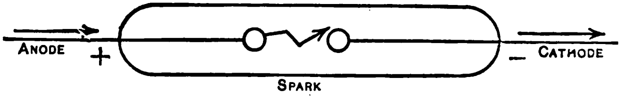
ACCUMULATOR



CHARGING

DISCHARGING

VACUUM TUBE



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