TEXT-BOOKS

OF SCIENCE

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ADAPTED FOR THE USE OF

ARTISANS AND STUDENTS IN PUBLIC AND SCIENCE SCHOOLS

TELEGRAPHY

TELEGRAPHY

BY

W. H. PREECE, F.R.S., M.INST.C.E., &c.

Electrician Post Office Telegraphs

AND

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NINTH EDITION, REVISED AND ENLARGED

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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.

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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.

The present edition may fairly claim to be almost a new book. As indicating the extent of the revision it may be mentioned that twenty-four figures have been altered and forty-four excluded, and there are now 265 as compared with 194 in the last edition. Several chapters have been enlarged or entirely reconstructed; a chapter on the Multiplex System and another on Instruments for Testing have been added. In all cases the latest practice is described; and a few points that could not be conveniently dealt with in the body of the work, but which should be clearly understood by the student, have been inserted in an Appendix.

We have to acknowledge our indebtedness to Mr. J. Gavey, Superintending Engineer of the South Wales District, who kindly revised the chapters on Construction; and to Mr. Arthur J. Stubbs, one of the Technical Officers of the Post Office Telegraphs, who has taken general charge of the revision.

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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 gas-jet 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 electricity 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, when it has been excited by rubbing so as to exert attraction, is electrified. A glass rod, similarly treated, is electrified. In the two latter cases although the method of electrification may be precisely similar, 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 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.

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 that 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 rubbed glass to a rubbed comb, or a signal from Europe to America, may take place in different *times*; the path between A and B offers obstruction to the

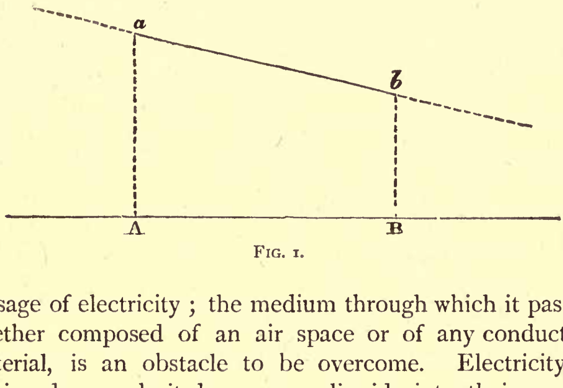


FIG. 1.

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 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 upon 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.*

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 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.

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

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 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 only 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, say pure zinc and platinum, be immersed in any acidulated solution, say sulphuric acid and water, then so long as the two metals are kept apart no action whatever is observed to take place between them. But immediately they are metallically connected together, whether by being brought into immediate contact at any point or by means of a wire, and so long as they remain so, the zinc is chemically attacked and eaten away, and the acidulated water is decomposed into its constituent elements, one of which unites with the zinc, forming a salt of that metal, and bubbles of the other—hydrogen gas—are seen to form upon and to rise from the platinum plate.

If a wire has been employed to connect the two plates it does not remain quiescent, but in various ways it gives evidence of molecular disturbance and of being imbued with electrical energy.

a. If it be dipped in a mass of iron filings, the particles of iron will cluster around and apparently adhere to it (see fig. 21).

b. 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.

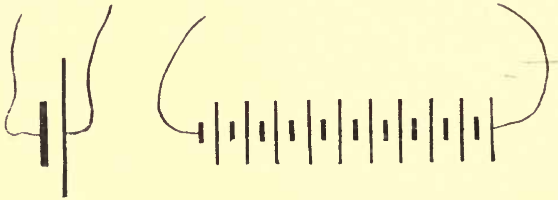
c. If it be placed in the immediate neighbourhood of a freely suspended magnetic needle, the needle will at once exhibit a tendency to place itself at right angles to it.

d. 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. 2. A battery is similarly represented by a combination of these, as shown in the same figure.

The action observed is said to be due to a current which is conventionally assumed to start from the 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.



A Cell. A Battery.
FIG. 2.

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. Volta was of opinion that it originated simply and wholly from the contact of the two dissimilar metals, and in this view he was supported (amongst others) by Ritter, Pfaff, Ohm, and Biot.

Faraday, on the other hand, maintained with Fabroni, who suggested the theory in 1792, that the prime cause was chemical action. He performed an enormous number of experiments in order to verify this opinion, and with the apparatus which he then had at his disposal they seemed to be convincing. This theory, known as the *chemical theory*, as opposed to Volta's *contact theory*, numbered amongst its supporters Wollaston, Davy, De la Rive, Daniell, and many others.

Now, however, by means of delicate apparatus invented since Faraday's time, it has been distinctly shown that the mere contact of two dissimilar metals does determine a difference of potential between them, and thereby (p. 6) gives the prime conditions of a current. Based upon this a theory has been advanced which goes far to unite the rival contact and chemical theories, and which has been adopted by Helmholtz, Sir William Thomson, and several of the leading physicists of the present day. It is this. When two dissimilar bodies are brought into contact a difference of potential is determined between them. In figs. 3 and 4

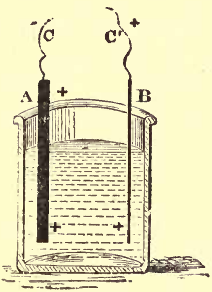


FIG. 3.

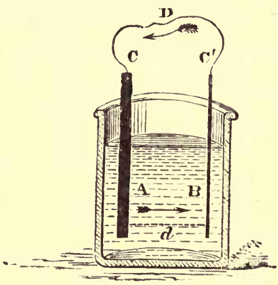


FIG. 4.

let A represent a zinc plate, B a copper plate, both immersed in acidulated water, and CC′ a connecting wire of copper, which is shown in fig. 3 as divided into two sections, CA and C′B. Taking fig. 3, CA being placed in metallic contact with

A, the latter has a positive potential at once determined in it relative to that of CA, and CA is therefore negative to A, B remaining in a neutral condition. A and B, which are separated from each other by a liquid, are therefore at first in different electrical conditions, but the conducting liquid at once reduces them to the same potential, so that A and B are now in the same electrical condition. C′B acquires the same potential as B, because it is the same metal, and is in metallic connection with it; it has therefore a positive potential relatively to CA. Thus the points C and C′ are at different potentials. Now suppose (fig. 4) C and C′ to be united; a current must flow because these two points are at different potentials. C retains the same potential relative to A, but the wire CC′ tends to reduce B to the same potential as C. The equilibrium being thus disturbed between A and B, the potential of B falls below that of A, a current flows, the liquid is decomposed, and this decomposition of the liquid exercises a counteracting influence, it endeavours to keep B at the same potential as A. The consequence is that B assumes a potential between that of A and that of C. Similarly any point D in CC′ has a potential between that of C and that of C′, and any point *d* in the liquid between A and B has a potential between that of A and B. Thus we have a constant fall of potential from the zinc through the liquid back to the zinc again through the connecting wire.

The result of all this is that what we may call a continuous flow of electricity is kept passing through the liquid from A to B, tending to keep the potential of the latter up to that of the former; and a continuous flow of electricity from C′ to C through C′C, tending to reduce the potential of B to that of C. A current, therefore, is said to pass in the direction of A B C′ C when the cell is at work. The first flow is determined by the difference of potential due to contact, and the continued flow is maintained by the energy of the chemical decomposition of the liquid.

The zinc is named the positive plate or element, the 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. Assuming first that pure water (H_2O) is made use of, the action which takes place may be symbolically represented thus:—

Before contact—

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

After contact—

$$\mathrm{CuH_2},\ \mathrm{OH_2},\ \mathrm{OH_2},\ \mathrm{OZn.}$$

But zinc oxide (ZnO), which is non-conducting, is insoluble in water, and so if pure water were used the action would at once cease, because the zinc plate would be covered with an insulating compound. Hence sulphuric acid is added (H_2SO_4), which instead of zinc oxide deposits the soluble zinc sulphate ($ZnSO_4$), so that the zinc plate is left clear for further action. This action is symbolically represented thus:—

Before contact—

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

After contact—

$$\mathrm{CuH_2},\ \mathrm{SO_4H_2},\ \mathrm{SO_4H_2},\ \mathrm{SO_4Zn.}$$

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 electro-motive force 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 though 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.

Another injurious effect which the hydrogen ultimately exercises upon the action of the battery is due to the facility which it possesses for reducing the metals from their salts. The zinc sulphate which in time accumulates by the action of the cell is reduced by the hydrogen as soon as they come into contact with each other; the zinc is then deposited upon the copper plate, and eventually therefore zinc is opposed to zinc, so that the current ceases to flow.

It will thus be seen how essentially important 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, 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 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 combining with the molecule 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—

$$Zn, SO_4H_2, \overline{SO_4H_2}, \| \overline{SO_4Cu}, \overline{SO_4Cu}, Cu.$$

After contact—

$$\overline{ZnSO_4}, \overline{H_2SO_4}, \overline{H_2SO_4}, \| \overline{CuSO_4}, \overline{CuCu}.$$

The electro-motive force of a Daniell cell is taken to be 1·079 volt, based upon British Association standards.

One of the most convenient of the various forms of Daniell's battery, and that which is generally employed in the English telegraph system, 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 throughout, including the slate partitions, with marine

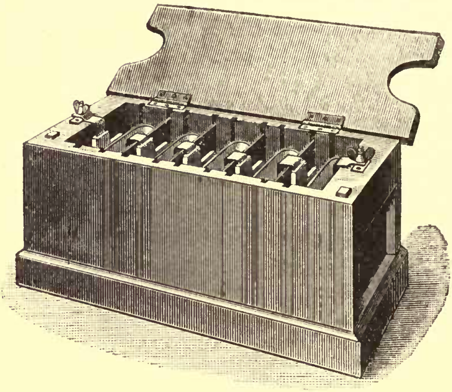


Fig. 5.

glue.[1] The object of this is to render the trough perfectly water-tight and prevent any leakage 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, in which is inserted a thin copper plate four inches square. Opposite the porous pot in each cell is placed the zinc plate, four

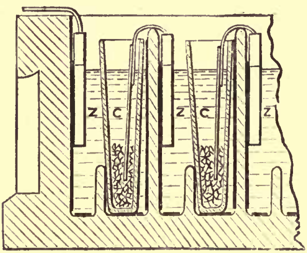


Fig. 6.

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

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]

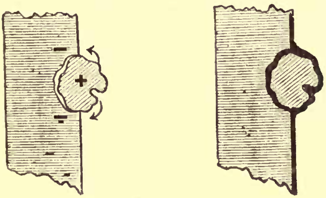
In setting up a Daniell's battery there are various points to which special attention must be given, a disregard of any one of which will more or less mar its action.

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

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

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 wasted, 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 (say lead) with zinc determines to the latter a positive potential ; 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 partially polarises the zinc plate (p. 13). The consequence is that the resultant[3] current may be materially weakened, at the same time that the battery is proportionately injured.



B

FIG. 7.

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

[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.

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 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. 15) that zinc sulphate is spontaneously formed in the action of the battery. Consequently if the action is 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.

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 the sulphuric acid contained in the copper sulphate (p. 15), which in time makes its way through the porous partition, 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, and immediately gives rise to a local action.

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 is carried off by capillary action, and short-circuits are 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 sulphuric acid leaves it and unites with the zinc, with which, as has been already observed (p. 19 *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 remain. 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 impurities contained in the zinc plate which have not been effectually got rid of, and partly to those 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.

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 should 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.

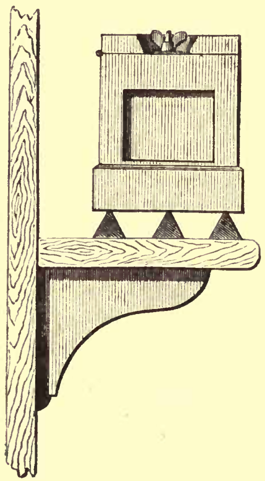


Fig. 8. ⅛th real size.

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.

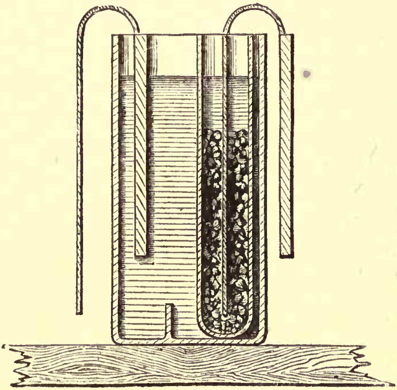


FIG. 9. ⅓rd real size.

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

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

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

3rd. That when the battery is not being worked, there should be no waste of the materials employed; in other words, there should 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. 19 *d*; 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 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. 20 *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 binoxide of manganese (MnO_2), the pyrolusite of mineralogists, as the negative element. 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 binoxide 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 peroxide 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 binoxide of manganese 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—

$$Zn,\ 2(NH_4Cl),\ \|\ 2(MnO_2),\ C.$$

After contact—

$$\overline{ZnCl_2},\ \overline{2NH_3},\ \overline{H_2O},\ \|\ \overline{Mn_2O_3},\ C.$$

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

Three sizes of cells are made; that which is generally adopted is of the form 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 binoxide 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.

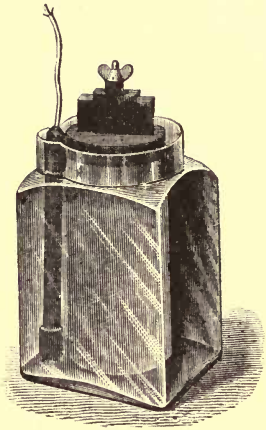


Fig. 10.

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 little more than half its height in the solution, as the drier its contents are the better for constant working.

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 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 binoxide 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.

The top of the carbon pot is covered with marine glue, or an asphalte composition. Care must 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

[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.

condition for a period varying according to the amount of work which it is called upon to do. If it is required only for occasional use, such as the ringing of bells for either signalling or domestic purposes; or, if it is 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 is taken to add every now and then a little water to the liquid in the zinc cells to compensate for evaporation, and if need be cleaning the zincs. Instances have occurred where a battery has been left for

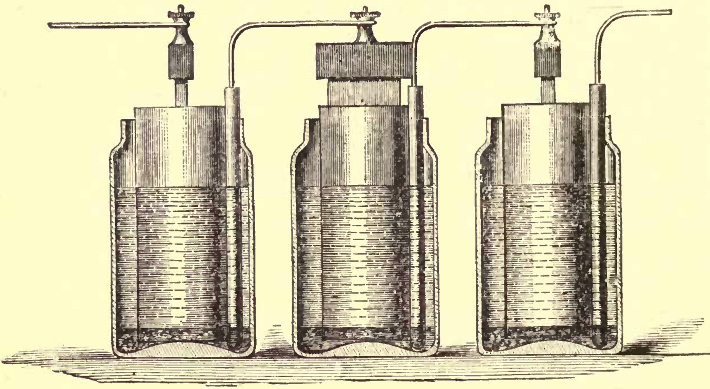


FIG. 11. ¼th real size.

periods ranging from nine to eighteen months, or even longer, without being so much as looked at, and yet no complaint of its working was heard. On busy circuits, however, it cannot be relied upon to anything like the same extent as the Daniell. 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 iron 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 has been made to get rid of this local action by welding or soldering the iron wire on to the lead top of the carbon plate, and issuing the elements in pairs, as is the case in the form of Daniell's battery, which has been described (p. 17). White lead is also speedily formed 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 manganic peroxide, 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.

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 rod with grooves to take six agglomerate cylindrical prisms which are placed around it; the combination is

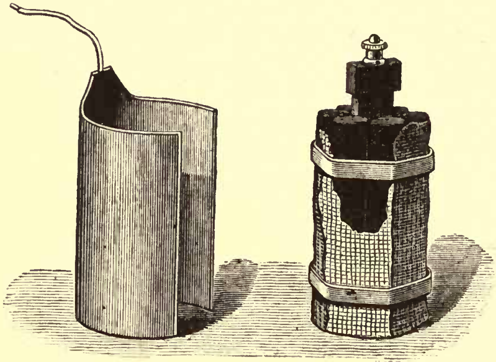


FIG. 12.

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. An earthenware jar is generally used for these cells.

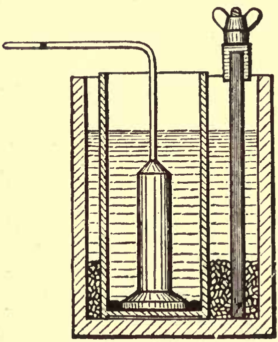


FIG. 13.

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.

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. 19). The carbon plate and porous pot are then inserted in a quart-size earthenware jar, into which are placed four ounces of bichromate of potash and four ounces of sulphuric acid. Both the outer jar and the porous pot are then filled up to within two inches of the top with water, a quarter of an ounce of sulphuric acid being added in the porous pot.

The exact action of this battery is rather complex, but it may be generally described thus. When the circuit is completed the sulphuric acid passes into the zinc cell, attacks the zinc and forms sulphate of zinc, while the liberated hydrogen reduces the bichromate of potash to a lower form. There is a secondary action in the battery when the solutions become saturated, which results in the formation of crystals of 'chrome-alum' on the carbon plate. Chrome-alum is a double salt—a sulphate of chromium and potassium. As soon as this secondary action is noticed the crystals should be removed and some of the liquid withdrawn and replaced with fresh solution of sulphuric acid.

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 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 (N_2O_5). When the circuit is completed the zinc is attacked, the soluble sulphate of zinc is formed, and the liberated hydrogen, before it can settle on the platinum plate, is oxidised to water by the concentrated nitric acid. The nitric acid is thereby reduced, and fumes of the peroxide of nitrogen arise in the form of a dark-brown vapour.

The action which takes place may be symbolically represented thus:

Before contact—

$$\text{Zn}\ \overline{\text{H}_2\text{SO}_4}\ \|\ \overline{\text{N}_2\text{O}_5}\ \text{Pt.}$$

After contact—

$$\overline{\text{ZnSO}_4}\ \|\ \overline{\text{H}_2\text{O}},\ \overline{\text{N}_2\text{O}_4}\ \text{Pt.}$$

The strength of current obtained from a Grove's battery upon short circuit is, compared with that from a Daniell's battery, roughly as 8 : 1; for this reason Grove's battery has been largely employed for experimental purposes where a powerful current is required. It is admirably adapted for this purpose, for which it was in fact originally designed.

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

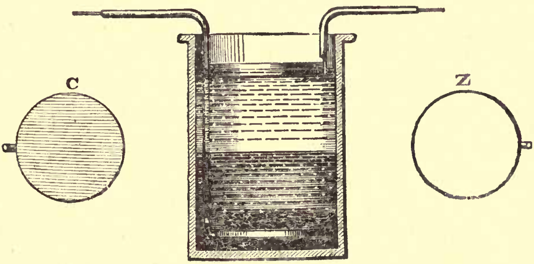


FIG. 14.

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.

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

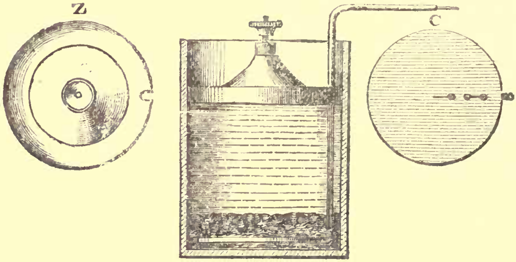


FIG. 15. ⅙th real size.

It consists of a round earthenware glazed 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, whose conductor 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.

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.'[5] To prevent local action between the zinc plate and the brass terminal, it is necessary to apply a coating of coal tar and resin to a point some little way above 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; and it is stated that upon what are important lines they last sometimes 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 do not form a portion of the general stock-in-trade of the country. The copper sulphate possesses this

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

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.

Another form of gravity battery is the Meidinger, which is largely used in Germany. It consists of a glass cell of the shape shown in fig. 16, containing 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 gutta-percha, is attached, and thence passes to the next cell. Into the cell a zinc cylinder is inserted and supported upon the projecting edges. 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 of it, is suspended, and reaches about halfway down into the smaller vessel.

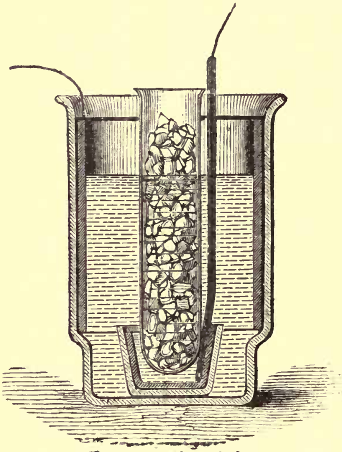


FIG. 16. $\frac{1}{6}$th real size.

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 should remain undisturbed, and every precaution be taken against their being shaken up and thereby mixed with each other.

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.

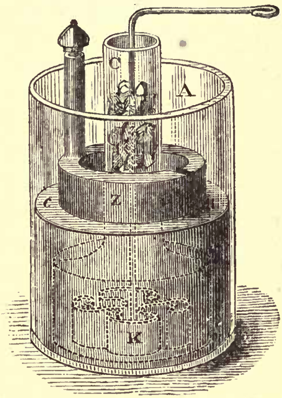


FIG. 17. ⅛th real size.

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 made to receive a current, 'polarisation' ensues from the electrolytic effect, and in consequence forms a battery which can yield an inverse current. This is a '*secondary*,' '*accumulator*,' or '*storage*' battery: it accumulates or stores energy under the influence of a primary current. 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 quantity of electricity could afterwards be evolved. 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, with a strip of insulating material between, the whole being placed in a 10 per cent. strength 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 produced there soft metallic lead. As peroxide of lead is a conductor of electricity, it follows that two dissimilar electrodes [6] were obtained, and conditions established analogous to those of an ordinary voltaic battery.

The amount of peroxide of lead formed, or, in other words, the quantity of electricity stored, determines the capacity of the battery for doing external work. Theoretically an equivalent supply of electrical energy 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 succeeded in raising the capacity of secondary cells and of expediting their formation by coating the lead plates with a paste of red lead (minium), which compound is readily

[6] 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*.

decomposed by electrolysis into peroxide of lead and spongy lead, a few hours by this means sufficing to accomplish results which previously required months to perform. The battery is said to be 'charging' when energy is being stored, and to be 'discharging' when the accumulated energy is being liberated. During either process the condition of the battery is ascertained by taking the specific gravity of the electrolyte with a hydrometer specially graduated for the purpose. The density of the dilute sulphuric acid at starting a new battery is usually 1·15, and it rises to about 1·20 when the battery is fully charged.

It is believed that the chemistry of the lead and dilute sulphuric acid secondary battery is due to the formation and decomposition of sulphate of lead ($PbSO_4$) on each plate. During the process of charging, the sulphate of lead is converted into peroxide of lead on the one electrode and metallic lead on the other, while the dilute sulphuric acid increases in strength. During discharge the electrolyte gradually decreases in strength until $PbSO_4$ ultimately covers the plates. The following symbols fairly represent the chemical changes :

(1) Before charge—

$$\overbrace{PbSO_4}^{\text{Plate}},\quad \overline{2OH_2},\quad \overline{SO_4H_2},\quad \overbrace{SO_4Pb}^{\text{Plate}}$$

(2) While charging—

$$\overbrace{PbSO_4,\quad O_2}^{\text{Plate}},\qquad \overline{H_2SO_4},\qquad \overbrace{2H_2,\quad SO_4Pb}^{\text{Plate}}$$

(3) And after charge—

$$\overbrace{PbO_2}^{\text{Plate}},\qquad \overline{SO_4H_2},\qquad \overline{SO_4H_2},\qquad \overline{H_2SO_4},\qquad \overbrace{Pb}^{\text{Plate}}$$

Although these formulæ imply that all the water in the cells is decomposed, and acid alone left, it must be understood that an excess of water is always present, but otherwise the formulæ depict with tolerable accuracy the products of electrolysis.

The normal electro-motive force of these lead cells when fully charged is about two volts, and their resistance is extremely low.

Secondary cells are not at present used to any considerable extent for telegraph purposes, but where there is an electric light system and spare dynamo power can be utilised, their introduction may in many cases be a distinct advantage, especially in connection with the universal battery system (see p. 116).

Many other forms of cells might be referred to, some of which have been devised for special purposes—such as De la Rue's chloride of silver cell, and Clark's standard cell for testing—or others which have only had a limited use, or which, like the several forms of so-called dry battery, have not yet attained a definite standing; but those described sufficiently indicate the general lines upon which the majority of batteries are based, and include all that are generally used for telegraph purposes.

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*;

[1] See footnote, p. 38.

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. 18) 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 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.

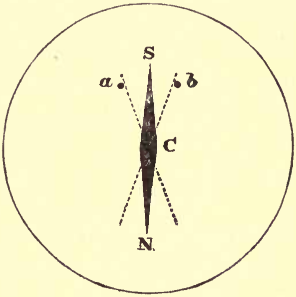


Fig. 18.

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, with a maximum combination of 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. 19), the little stroke ˎ representing a motion to the left and the longer stroke / a motion to the right.

Fig. 19.

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.

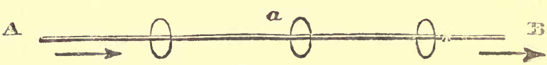


Fig. 20.

Thus, if the wire A B (fig. 20) is traversed by a current in the direction shown by the arrow, it is surrounded along its whole length by a magnetic field ; and if it be dipped while in this condition in a mass of iron filings, these filings will, if the current be strong enough, cluster around the wire, and adhere to each other in the manner shown in fig. 21.

FIG. 21.

This is due to the fact that each little piece of iron acquires magnetism, and assumes the direction with respect to the wire which its *polarity* imparts to it. 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, at any distance A *a*, were conceived to be surrounded by a ring of little magnets, all freely suspended by their centres, 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 the 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,

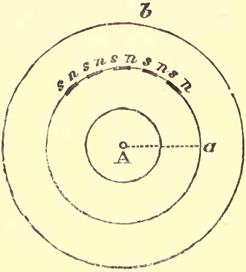


FIG. 22.

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

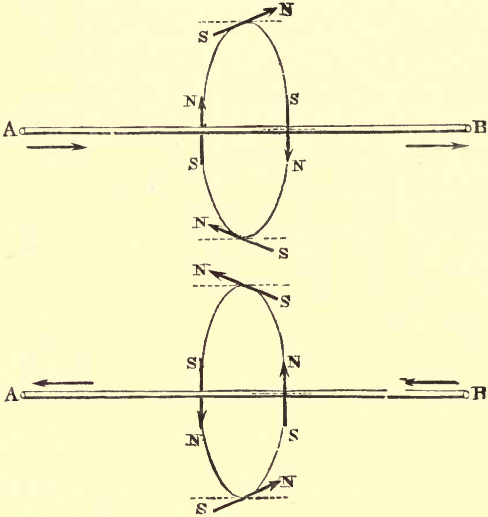


FIG. 23.

having that wire for a centre. There is no difficulty in remembering this direction of deflection. If you look at the face of a watch and conceive the current going *from* you, 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.

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

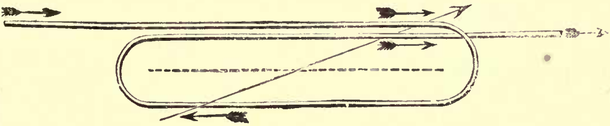


FIG. 24.

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 of the weakest possible current, and we can, by varying the direction of the current, vary its directive influence upon a

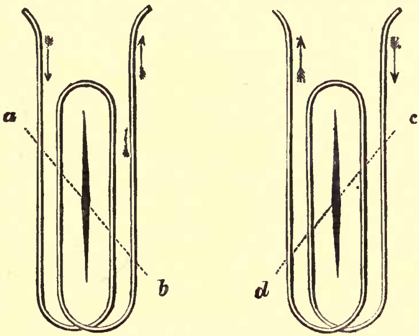


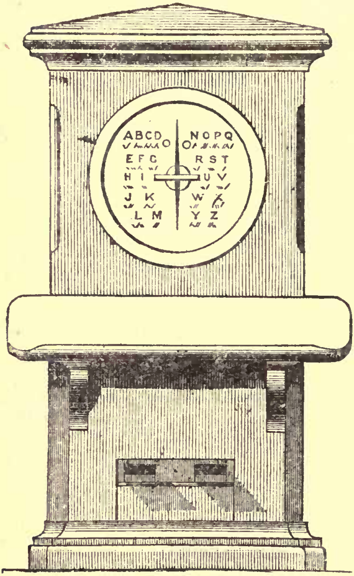
FIG. 25.

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 gives a view of a tapper form of instrument, and fig. 27 of a drop-handle single needle from which the case



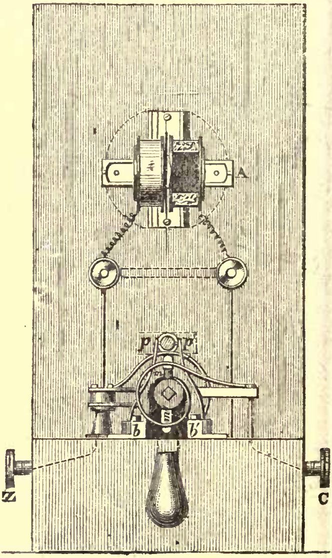


FIG. 26. 1/6th real size. FIG. 27.

and dial have been removed. A 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. One end of the coils of wire is connected to line, the other to earth. 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 regulated by two small ivory stops placed at a distance of about half an inch apart upon the dial, which is so constructed as to be capable of rotating upon its centre. If now a current of electricity pass through the coils of wire wound round the two small bobbins, the magnetic needle inside them will be deflected, and along with it the indicator outside. The direction of this deflection, whether to right or to left, will depend solely upon the direction in which the current is passing. The two coils are wound quite distinct from each other, but one end of the wire in each is soldered to the brass frame and

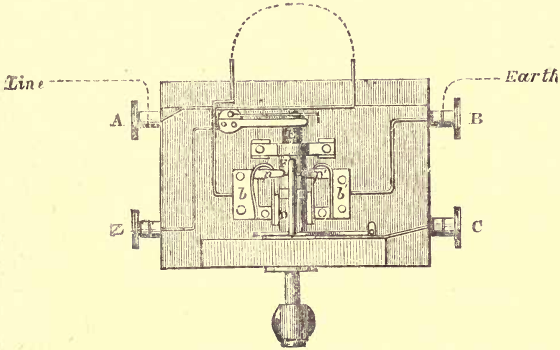


FIG. 28. ⅛th real size.

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 is 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 B is connected to earth. 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 box-wood, 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 means of one portion of brass-work *b*, *p* is in connection with terminal A through the coils, and *p′* is in connection 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 half of the arbor F carries over 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;

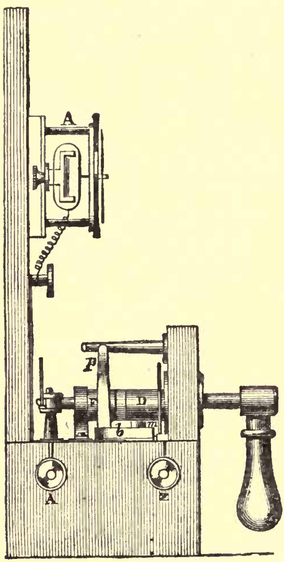


FIG. 29. ⅙th real size.

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 half 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 the half 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.

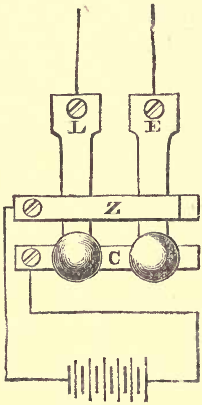


FIG. 30.

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 is 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.

The details of the construction of the pedal arrangement cannot be faithfully represented by a diagram, but no difficulty will be found in comprehending them if the principle stated above is clearly carried in the mind.

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 induced needles. Instead of the small permanent magnet, a soft iron needle of the shape shown in fig. 31, *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 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. 32. In this case the permanent magnets are of horseshoe form, one being placed above and the other below the axis of the needle. The

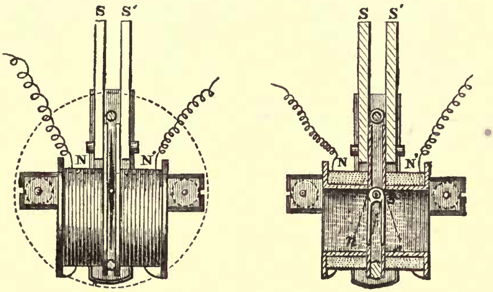


FIG. 31.

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

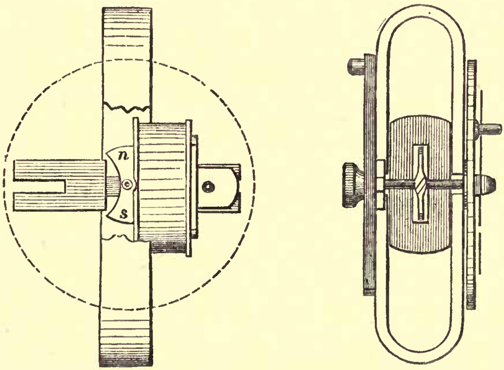


FIG. 32.

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 permanent magnets are adjacent, and thus the upper end of the central needle is induced with N polarity, and the lower end with S 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.* The latest pattern of tin sounder is shown in fig. 33. It consists of a small tin plate cut and bent as shown, and so fitted to the dial of the instrument beneath the heads of the screws which fix the pivot bridge 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.

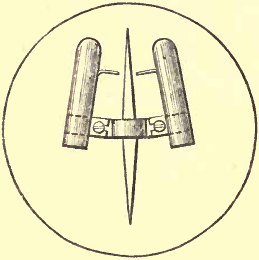


FIG. 33.

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 forms 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. 43), 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. 34) 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. 35; and as all these molecules have their polarities in

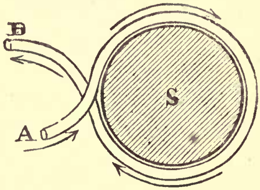


FIG. 34.

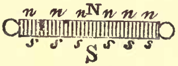


FIG. 35.

FIG. 36.

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

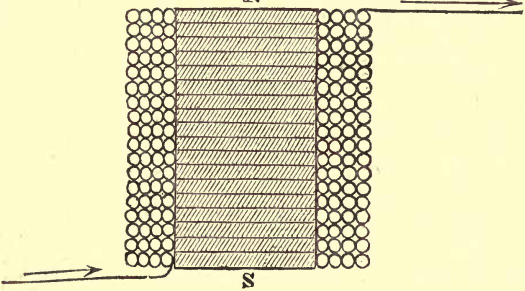


FIG. 37

were to surround the disc with several rings, the current flowing in the same direction in each ring, as shown by fig. 36, the effect would be magnified; and if we were to superpose several discs, as in fig. 37, 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. 38) 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

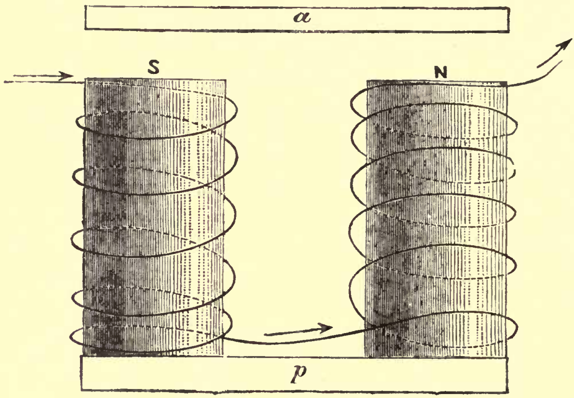


FIG. 38.

which therefore exerts attraction upon a bar of soft iron or *armature* 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]

The direction of the poles of the magnet is dependent

[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. 39, 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.

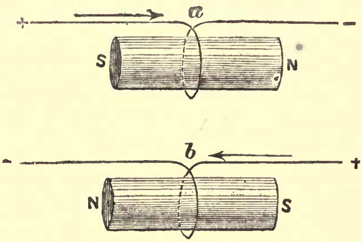


FIG. 39.

We can fix the armature of the electro-magnet at the end of a lever *a b* (fig. 40), 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 attrac-

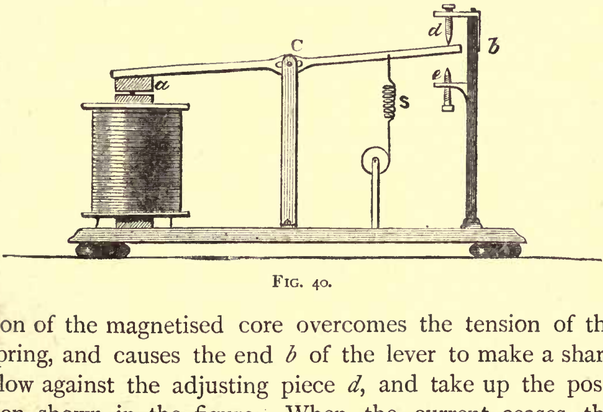


FIG. 40.

tion of the magnetised core overcomes the tension of the spring, and causes 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 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. 41) 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 affixing to each of the above four signals 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 ?	· · — — · ·
Stroke, or the divisional bar of a fraction..............	— — — — — —
Hyphen	— · · · · —
Apostrophe	· — — — — ·

There are many other signals in use, but they are exceptional. Some of those indicated above are rarely employed in England. *Ch,* for instance, has been abandoned because it is so much like '*to.*'

Fig. 41 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

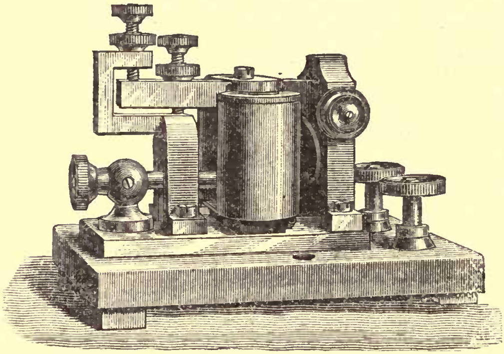


FIG. 41

armature is attracted, and the other forms the banking stop for the lever in its position of rest.

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. 42) consists of a simple brass lever K, 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 an insulating board of wood or ebonite. It is maintained in its normal position by a spiral spring which is not shown in the figure, causing the back of the lever to be held in contact with the back stop 3, which is in connection with earth, thus preserving the continuity of the line-wire to earth. One pole of the battery is placed in connection with the front contact piece 1, the other being put to earth. Thus, whenever the key is depressed, 2 is brought into contact with 1, and the current flows to line. The moment the key is raised 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. 55. 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.

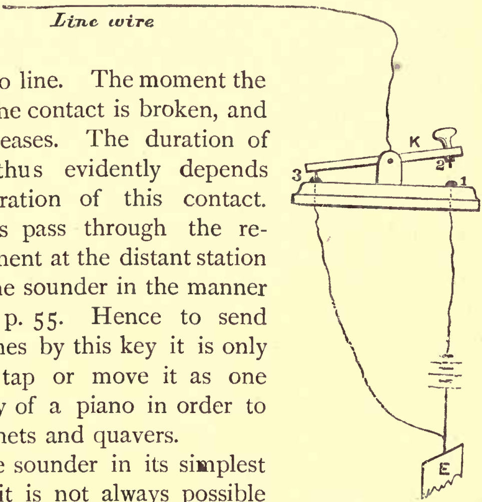


FIG. 42.

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 we have described other systems, we will draw a comparison between the advantages and disadvantages of the different plans in use, and show why it is that 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 practicable 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.

The relay is, in fact, nothing more nor less than a more delicate form of the electro-magnet and lever employed in

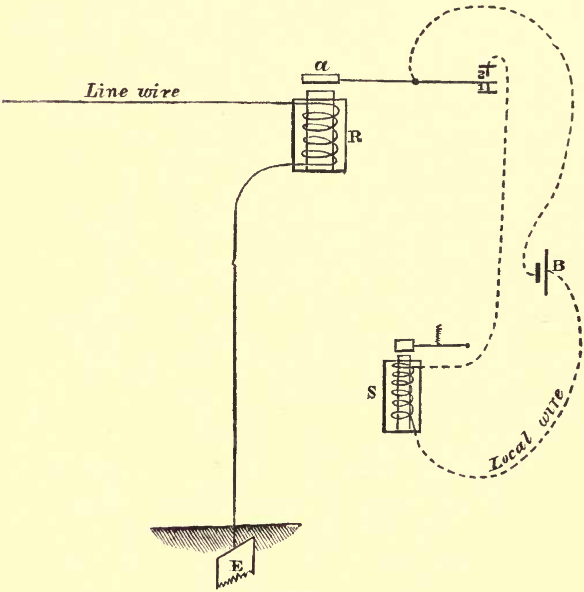


FIG. 43.

the sounder previously described. It is wound with a finer and longer wire, and all its parts are more delicately constructed, so that it will move with the weakest currents. 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. 43. 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 upper contact 2 of the relay. When a line current passes through R it attracts the armature *a*, brings the lever in contact with 2, so

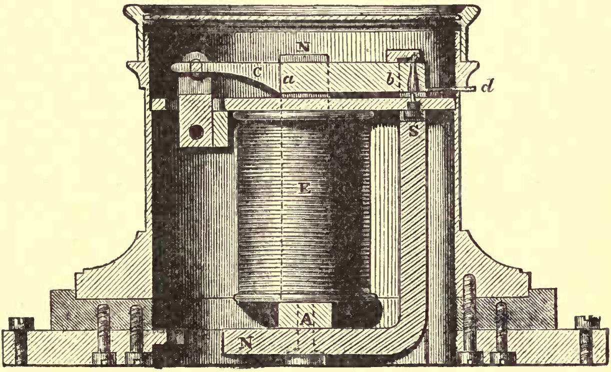


FIG. 44.

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.

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 because 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. 44, and a plan of the top by fig. 45.

N S (fig. 44) 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

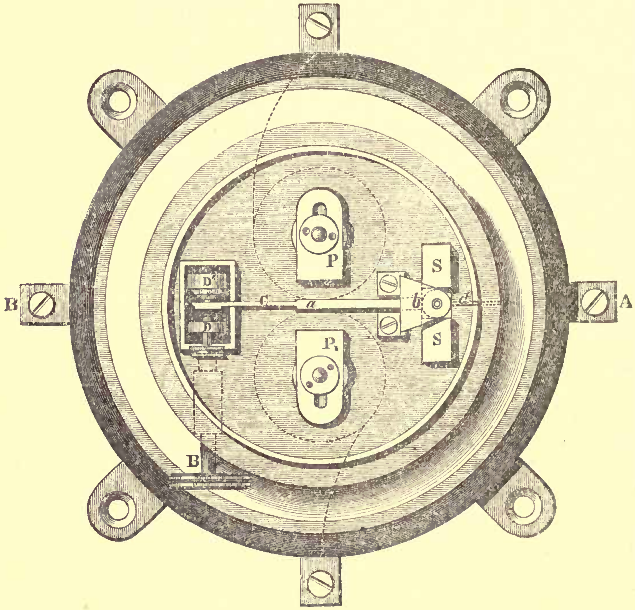


FIG. 45. ½ real size.

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. 45), 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 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 *a b*, 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 it is scarcely sensitive or light enough for very long lines, rapid sending, and extremely weak currents, on account of the comparative weight of the mechanism and the presence of electro-magnetic inertia. Fast-speed telegraphy has introduced 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, in England, through any weather. The sounder was introduced in America, and it has there

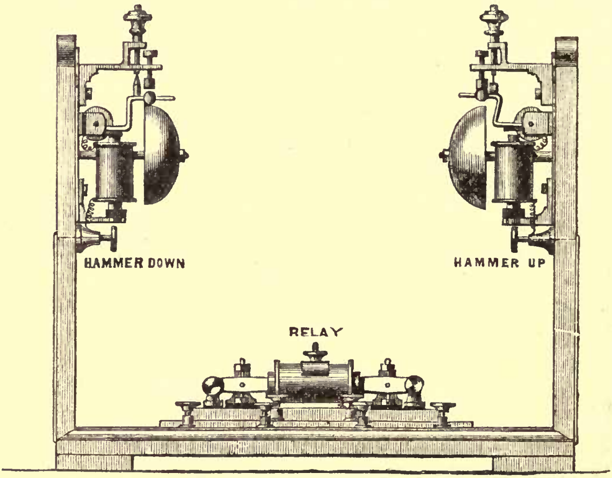


FIG. 46. $\frac{1}{5}$th real size.

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. The instrument is very quick in its action, probably the quickest of any non-recording instrument. The instru-

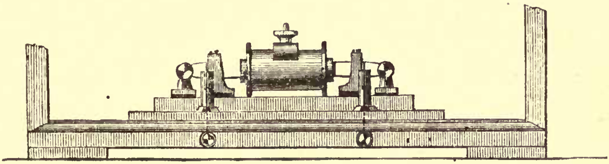


FIG. 47. $\frac{1}{6}$th real size.

ment is much liked, and is coming into greater use. Its general construction is shown by figs. 46 and 47, the former giving a back view of the relay. The relay here shown is being replaced by the Post Office Standard.

3. *The Double Plate Sounder.*

A modification of the Bright's Bell Instrument is shown in fig. 48. It is called the Double Plate Sounder, and consists of two sounders similar in arrangement to those of the bell, which are mounted, together with a relay, in a screen, which is useful in concentrating the sound in one direction. 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 spiral springs, 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.

4. *Neale's Acoustic Dial.*

The Neale's Acoustic Dial (fig. 49) is an elegant and most useful form of needle instrument. As its name suggests, it is really a sound-reading instrument, but the

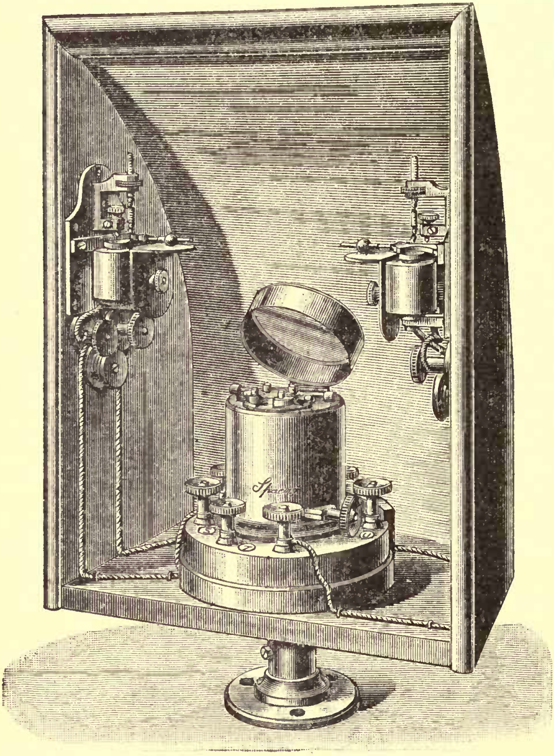


FIG. 48.

needle in front makes it equally available for reading by sight.

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.

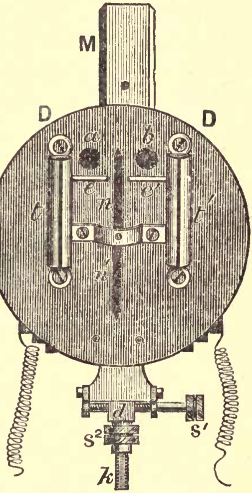


FIG. 49.

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 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. 50.

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. To the latter is attached 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 has now been 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 in place of the style a small metallic disc, which was kept constantly revolving in the inking fluid, and which was pressed 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.

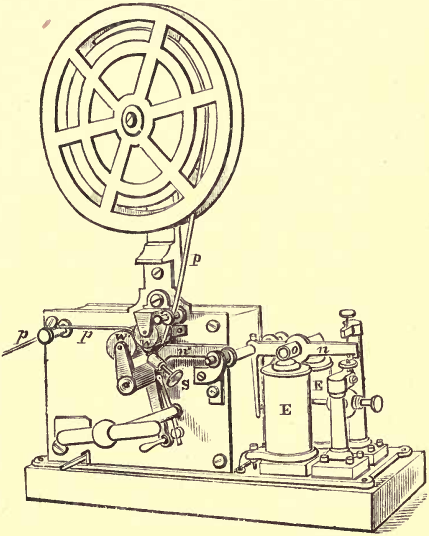


FIG. 50.

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 which was introduced by Messrs. Siemens and Halske, and is now almost universally employed wherever recording instruments of this class are in use.

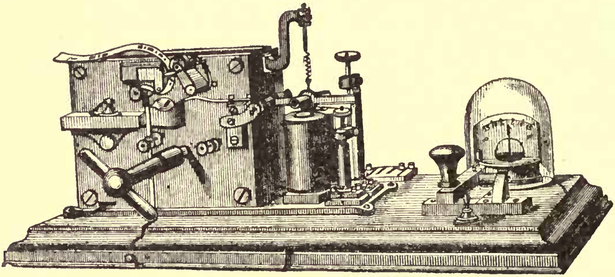


Fig. 51.

Fig. 51 shows one of the latest forms of these, and fig. 52 shows the details of the electrical portion of the receiving apparatus.

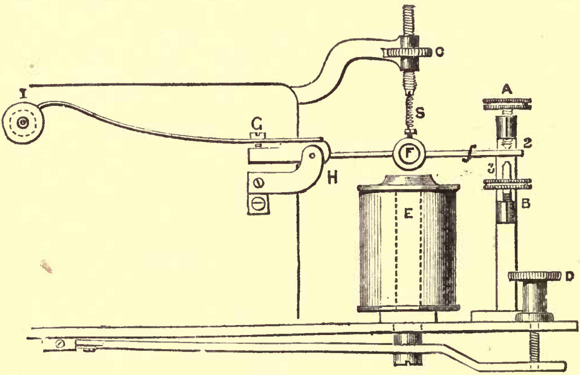


Fig. 52. $\frac{1}{4}$th real size.

E (fig. 52) 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. 51. It passes between two friction rollers, which are set in motion by means of an ordinary clockwork arrangement, which is enclosed in the case, and is liberated by the movement of a lever.

In addition to moving the friction rollers this clockwork arrangement 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 F therefore 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 is kept down for a longer time.

The paper which is employed is slightly coloured, and is cut into strips of about half an inch in width: the ink is a kind of printer's ink of good quality, diluted with olive-oil.

This instrument has four 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 distance between the poles of the electro-magnet E and the armature F, by raising and lowering the coils, so as to increase or diminish at will the attractive force between the two.

4. Screw G, 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 I gently touches the paper without pressing it too hard when the brass stop *f* is placed in contact with 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 — may become · — or – —.

(*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 *b*, 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 brass lever *f* is allowed 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, the coils should be lowered by means of D until marks are clear and distinct.

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 result 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 potassic iodide, iodine will appear at the positive pole and potassium 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. 53). 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 potassic iodide,
20 parts starch paste,
40 ,, water.

The solution usually employed in practice is composed

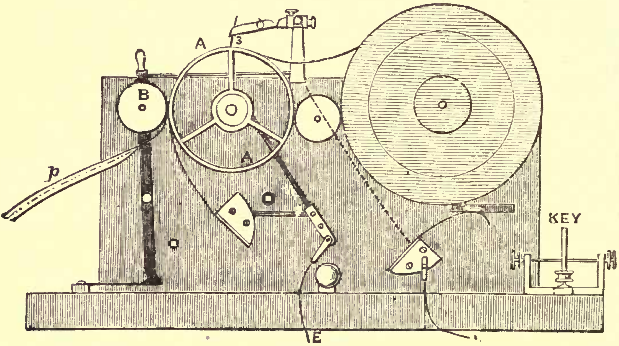


FIG. 53.

of one volume of a saturated solution of potassic ferrocyanide (prussiate of potash), one volume of a saturated solution of ammonic nitrate, and two volumes of water. The ammonic nitrate is a deliquescent salt,[3] and is used to keep the paper damp. The style 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 radical unites with the iron, and forms *Prussian blue*. Thus dots and dashes can be formed in bright clear blue.

The instrument is worked by a key in precisely the same

[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. 60), 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 underside of the paper. Hence a Bain's instrument must always be worked with the positive pole of the battery attached to the front contact of the key.

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 this it is invaluable, because it is very sensitive and it can register its signals with marvellous rapidity, being as it is quite 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.

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. 42) 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

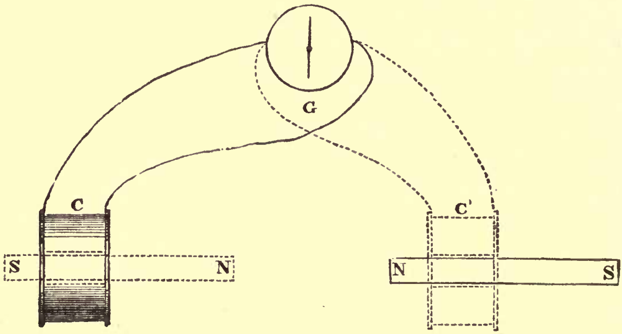


FIG. 54.

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.

Let N S (fig. 54) 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, 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 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. 54), 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. 55) 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

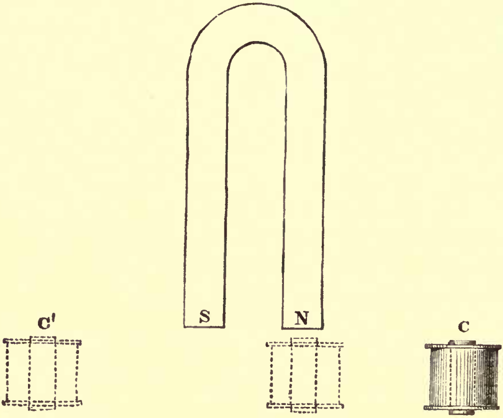


FIG. 55.

direction as the last, and as it leaves S a current is induced in the same direction as the first.

Let us take two coils wound like an electro-magnet, the two cores being connected by a piece of soft iron, *a b*, and rotating about their centre *c*, as shown in fig. 56; then, if the coils are made to take one quarter revolution, so that *a b* 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

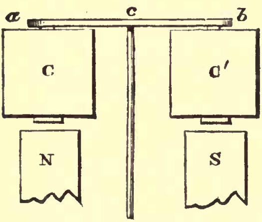


FIG. 56.

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. 57). 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

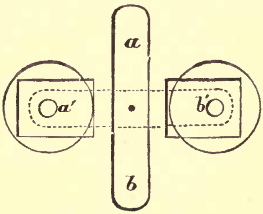


FIG. 57.

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

The most effective portion of each induced current is just

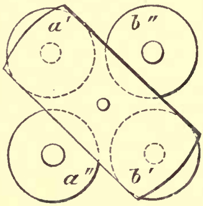


Fig. 58.

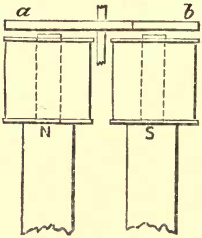


Fig. 59.

when the armature takes up its position across the cores, or leaves that position, so that the four currents due to one

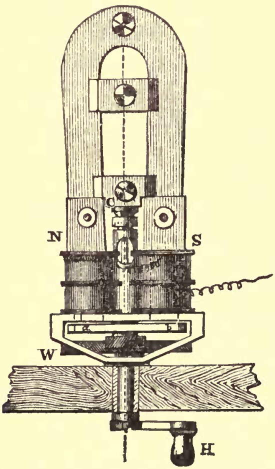


Fig. 60. Plan from below—¼th real size.

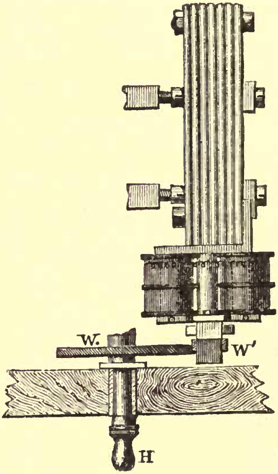


Fig. 61. Side elevation—¼th real size.

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. 58 and in elevation by fig. 59, 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. 60 and 61. 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. 58, and which

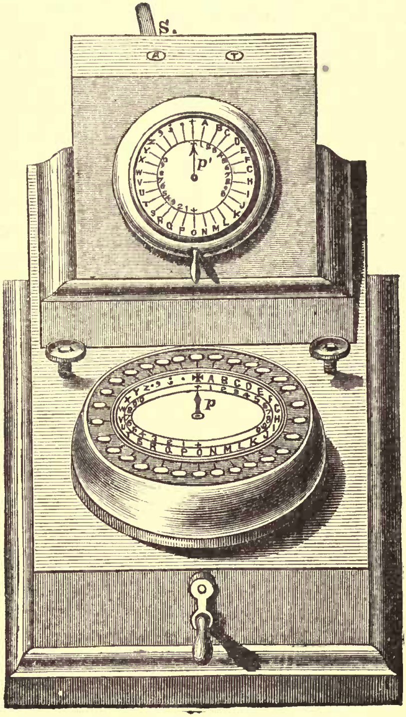


FIG. 62.

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. 62), 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. 63, 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. 64), and so arranged that only one key can be depressed at a time, one effect of depressing a key being to press in the chain at

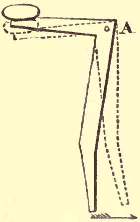


FIG. 63. ½ real size.

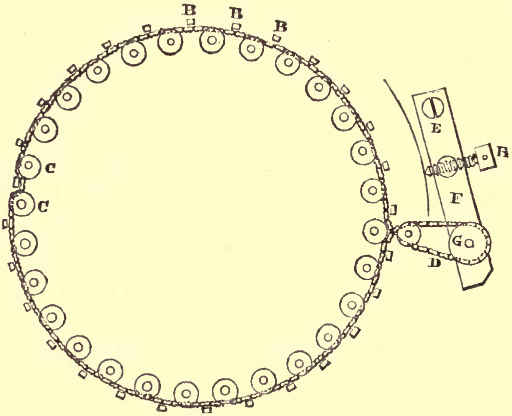


FIG. 64.

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.

If now the handle is 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. 65: 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.

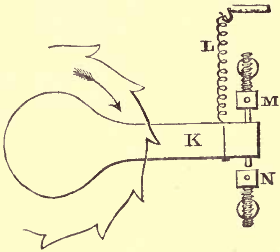


FIG. 65

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 it becomes so contracted 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. 64.

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

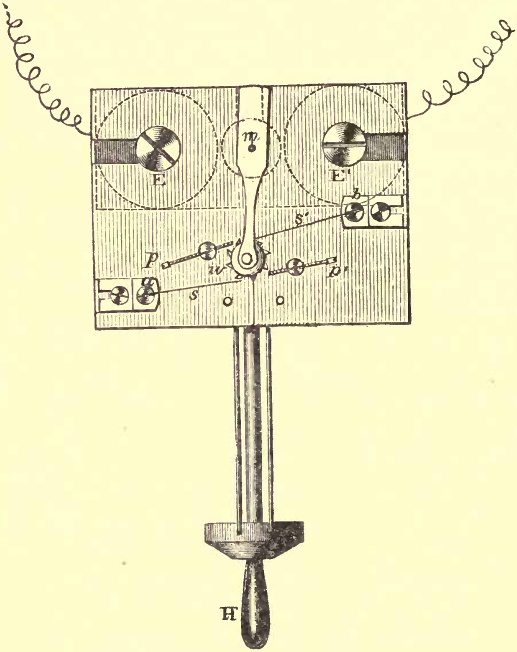


FIG. 66. Full size.

the chain being thus taken up in connection with it, 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.

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. 62) which indicates whatever letters are sent. The motion of this pointer is regulated by a small escape-wheel *w* (fig. 66), which is propelled by the electro-magnetic arrangement shown in plan in fig. 66 and in section in fig. 67. 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. 67) 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. 66), 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,

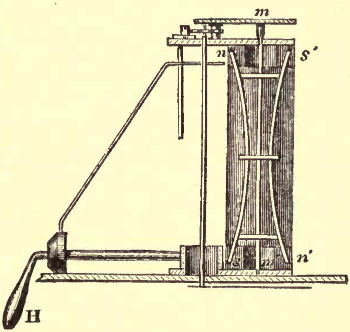


FIG. 67. ½ real size.

would carry the escape-wheel two teeth forward by four movements, and move the pointer through four spaces. H (figs. 66 and 67) 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 under these circumstances the zero key must be always kept depressed. The effect of leaving all the keys up is frequently to disconnect the circuit.

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. 62. When this switch is at A the alarum and indicator are both in circuit, when turned to T the alarum is cut out, 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. 66) 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

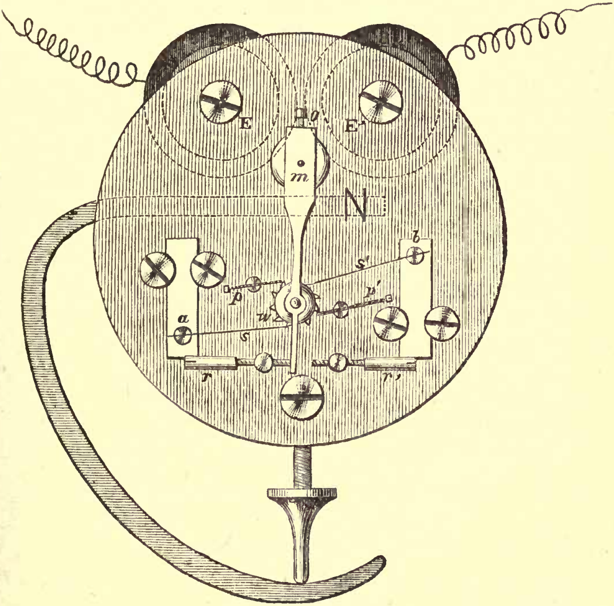


FIG. 68. Full size.

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.

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. 50), that is to say by employing induced instead of permanent magnets. Fig. 68 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. 67 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: instances, too, 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

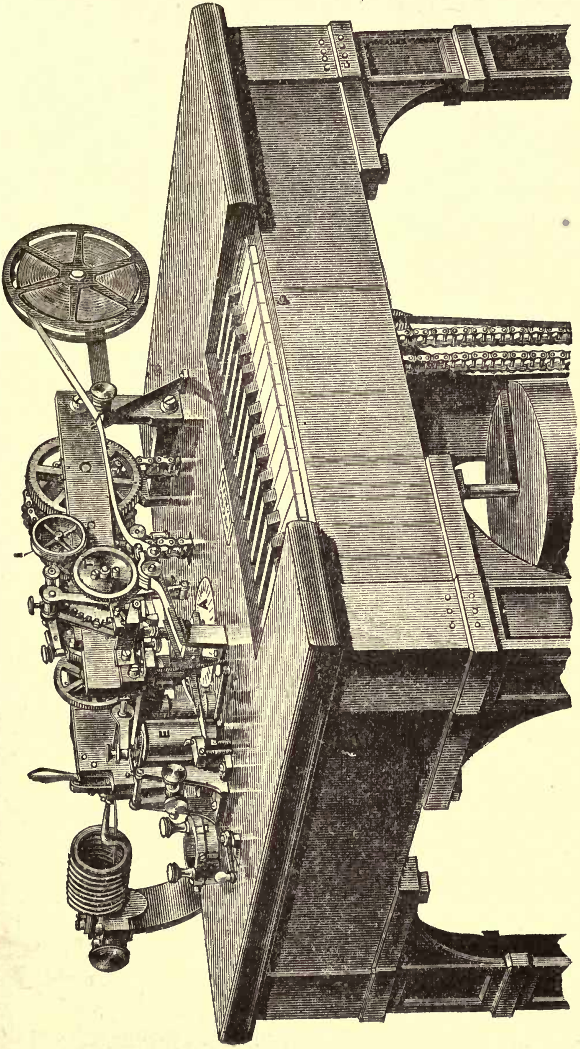


Fig. 69.

apparatus have been devised and practically used for this purpose, but only one has attained any considerable employment in ordinary telegraphy.

(1) *The Hughes Type-printer.*

This instrument, shown by fig. 69, 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. 69), 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-

ALLS WELL THAT ENDS WELL .

FIG. 70.

corded at both stations simultaneously. Fig. 70 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. 71). 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 heavy weight, the printing portion of which trainwork is brought into gear by the action of the spring *s* upon the armature when released.

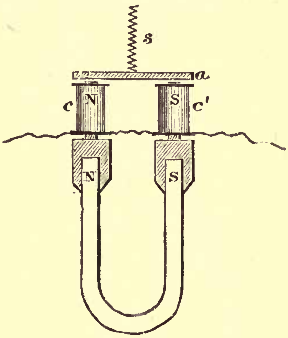


FIG. 71.

It is to be regretted that this beautiful instrument has not met with greater favour in England. It is very much used on the Continent, especially in France, where it is a great favourite. It is, however, expensive both in its prime cost and in the character of the labour required to work it ; for though, as a rule, it requires only one clerk at each end, and dispenses with writing altogether, this clerk must be of the most intelligent and experienced class, and therefore must be comparatively highly paid.

(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, 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

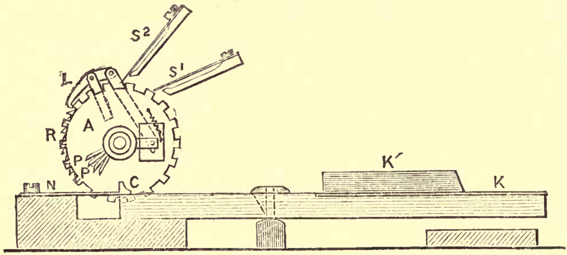


FIG. 72.

Hughes system. The general principle of the type of instrument 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.

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. 72. 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 normally when running 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. 72), 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

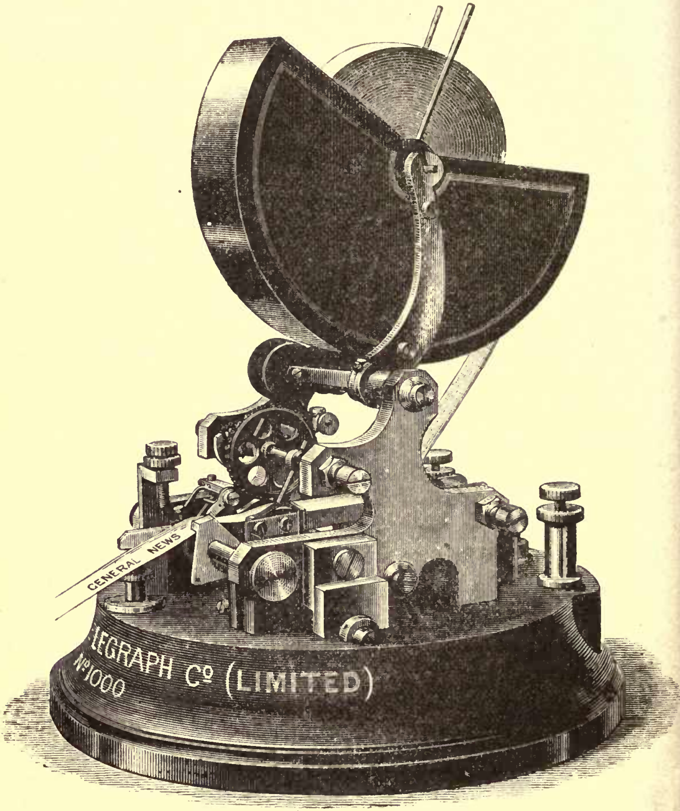


FIG. 73.

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.

A general view of one form of recording instrument is given in fig. 73, and fig. 74 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

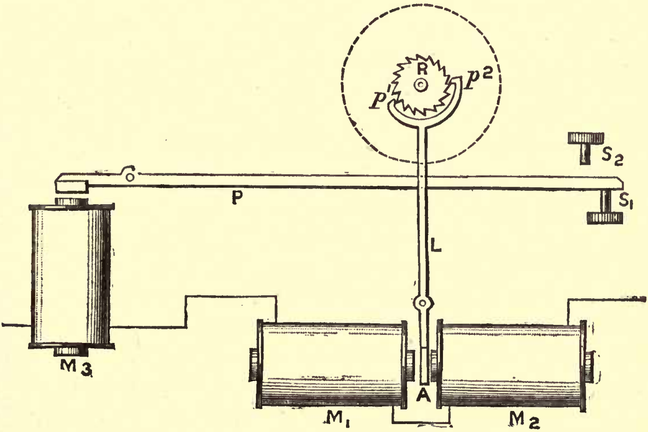


FIG. 74.

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.

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.

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 economy, 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, as generally employed, the Sounder is unquestionably 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 complicated; 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. 52.)

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. *Economy.*

The prices of the different instruments, and the cost of their annual maintenance, are dependent upon many varying conditions, but may be taken to be approximately as shown in the following list:

	Prime Cost			Annual Maintenance		
	£	*s.*	*d.*	£	*s.*	*d.*
A B C . .	25	0	0	2	10	0
Needle . .	4	10	0	2	10	0
Direct Writer .	15	0	0	4	10	0
Sounder . .	8	0	0	4	10	0

4. *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 follow 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 35 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	250
Morse	45	175
Needle	30	125
A B C	15	60

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 acknowledg-

[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 (1890).

ments. 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.

5. *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 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 specially 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 employment with untrained operators, has not hitherto been adopted 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 at present 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 the two cases in which the currents are flowing and in which they are not flowing. If we erect a wire between A and B (fig. 75), the end at each place being connected with the earth, then the whole path from A to B along the wire and back again from B to A through the earth is the *circuit*; 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.* There is a second condition of a circuit in which no current is flowing, called the *equilibrium* circuit, because every point of it is kept at the same potential by having

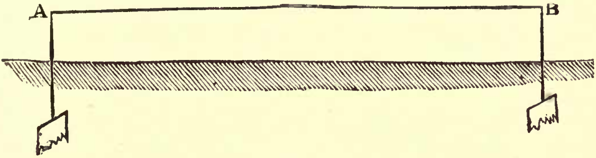


FIG. 75.

similar poles of different batteries of equal electro-motive force attached to it; but this is a form of circuit not used practically for telegraphic purposes.

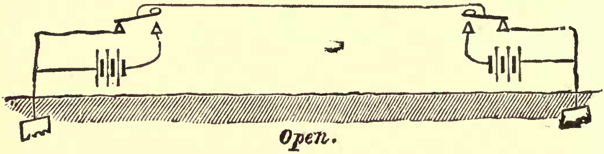
These three conditions of the circuit are shown in figs. 76, 77, and 78 respectively.

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, which can be measured, and which introduces peculiar disturbances that have to be eliminated or allowed for.

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.

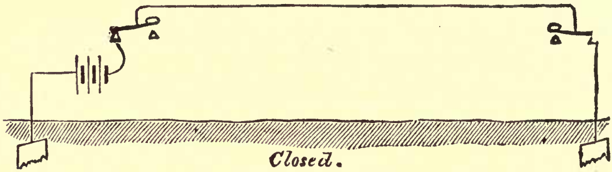
Thus we see that whatever is in the path of the current —whether it be in the battery itself, in the apparatus, in the line wire, or in the earth—whatever, in fact, offers any resistance to the passage of the electricity, is the *circuit*, and this circuit, for telegraphic purposes, may be either open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

The needle instrument is invariably worked on the open circuit system. The normal position of the needle when at rest being in the 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



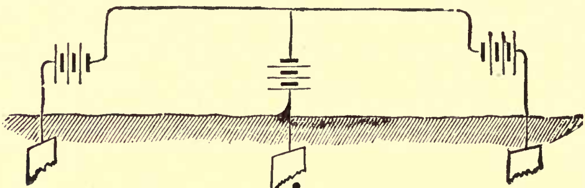
Open.

FIG. 76.



Closed.

FIG. 77.



Equilibrium.

FIG. 78.

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. 49. 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 make the needle at B deflect at will in either direction by depressing either *l* or *r*;

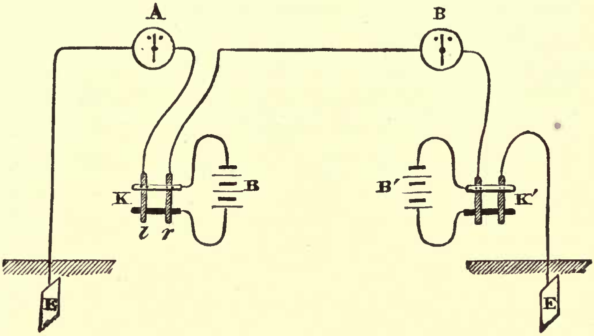


Fig. 79.

and similarly from B we can make the needle at A deflect in either direction at will.

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, so arranged that the current in the line always flows in the same direction, whichever station is sending. This is effected by the negative (zinc) pole being connected to the front contact of the key in one case, and the positive (copper) pole in the other. It is a conventional arrangement made for convenience, and not essential to the working of the apparatus. K is the key described on p. 60, 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, 1 is brought into contact with 2, which thus 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.

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.

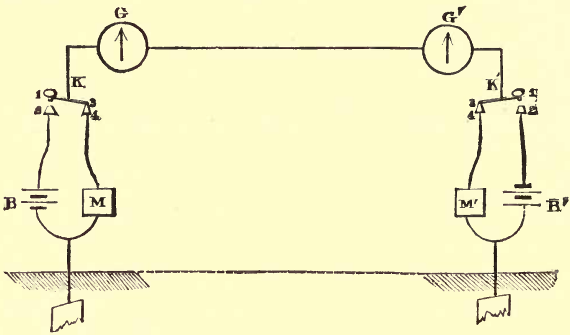


Fig. 80.

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 recorder in fig. 80; all the other connections are the same. When the key K at station A is depressed, 1 is brought into contact with 2, a current flows through 2, 1, G, G′, K′, 3, 4, R′, 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 when

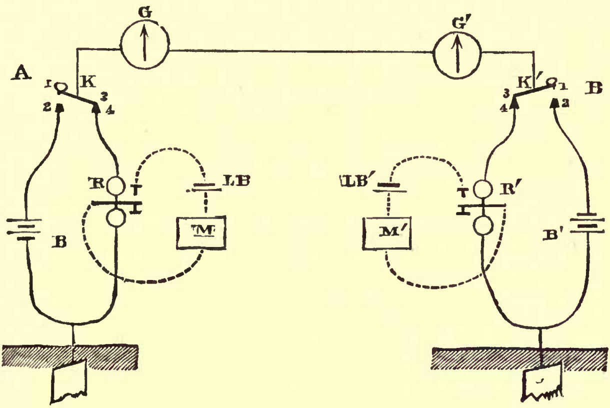


Fig. 81.

any one station worked every other station would be affected. The 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 3 and 4 of the key, and that when the key is depressed the currents flow through both the up and down line without affecting the recorder at the intermediate station itself, but operating those at the other stations. If simple line working be in use it is only necessary to replace R by M alone, and remove L B. The mode of connecting up a needle instrument intermediate is symbolically shown in fig. 83, where, for variety, drop-handle instruments are shown.

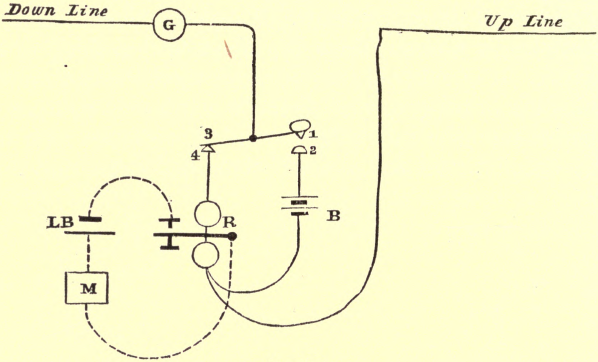


FIG. 82.

The closed circuit system has never been a favourite in England; it has been frequently tried, but, owing to the

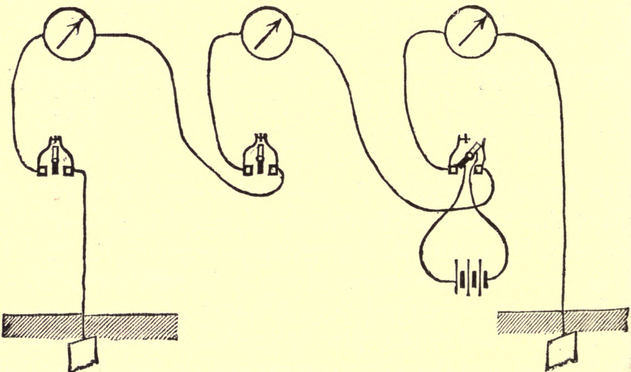


FIG 83.

greater consumption of materials in the battery compared with the consumption on the open circuit, and to the possible detrimental action of continuous currents on the gutta-percha covered wire, so much used in England, it has as frequently been abandoned. It is shown in its simplest form in fig. 84. M is the recorder, 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 when the circuit is idle the current is flowing.

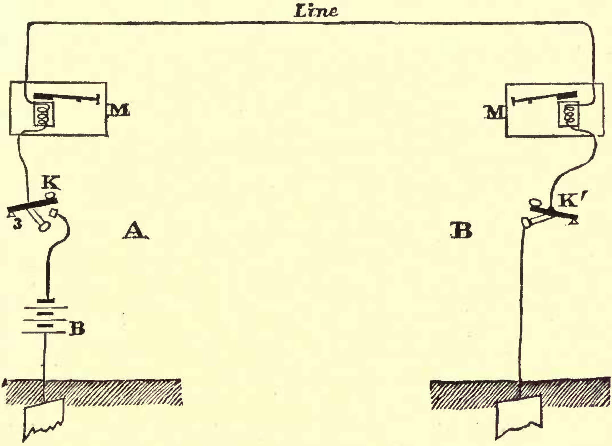


FIG. 84.

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 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 fig. 85.

There can be no doubt that where many intermediate

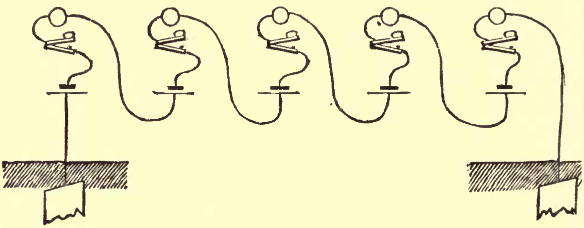


FIG. 85.

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, is 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. So that the necessity for employing the closed circuit system has not been experienced in England, while its extra cost, as compared with the open circuit, and its injurious action on gutta-percha-covered wires, have proved it to be really objectionable. We mention these facts 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.

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.

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. 128), 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, this effect of induction, as it is called, becomes evident. To overcome this distortion or abstraction of the currents, 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. The loss of speed is to a large extent 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

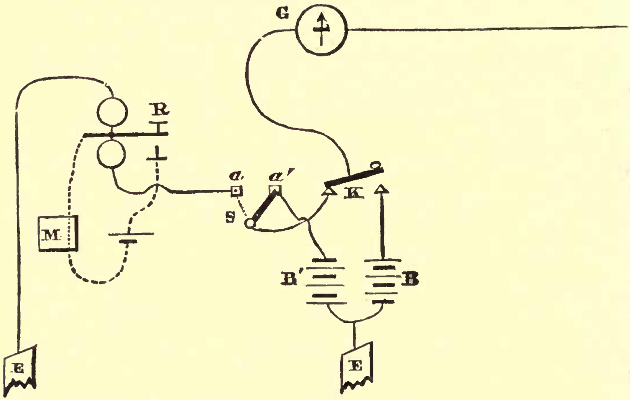


FIG. 86.

rapid position. This method of working is shown theoretically in fig. 86. G is the galvanometer, K the key, R the relay, and M the recorder or sounder ; but in addition to the ordinary line battery B there is a second battery B′, whose opposite pole to that of B is connected with earth, while its other pole is attached to the point *a*′ of a switch S, whose lever is movable at will from *a* to *a*′. The switch-lever itself is in connection with the back contact of the key K ; and in its normal position it is in contact with *a*, and it thus provides for the line currents received from the distant station to pass through the relay R, which is in connection with *a*, and work the instrument M. When it is desired to send, the switch-handle is moved to *a*′, which allows the current from B′ to go to line. This current passes through the relay at the distant station, and holds its tongue away from its contact point; hence all antagonistic springs or other forces are dispensed with, and the relay is in its most sensitive condition to respond to any change in the current. When the key is depressed this current ceases, and a reverse current is sent into 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. Polarised relays are necessarily employed with this system of working, for they alone are obedient to changes in the direction of the current.

In practice a double battery is not ordinarily used, but a double lever key is arranged to reverse the connections of the battery as regards line and earth.

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, 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 to satisfactory working that the resistance of the battery shall be less than the combined resistance of the several circuits, or, approximately, than their mean resistance divided by the number of circuits.[1]

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

[1] See Appendix, Section C.

to earth are required, and a single current key provided with a switch is sufficient for sending. In fact, the connections in fig. 86 show the actual arrangement of a double current circuit on the universal battery system. Similarly, single needle circuits require a double battery, and the commutators also require slight alteration. Accumulators, owing to their low resistance and the ease with which they can be kept at a normal electro-motive force, are peculiarly suitable for universal work. As many as 120 single needle circuits have been worked from the Central Telegraph Station in London for over three years from one double set of eighteen cells (see p. 40).

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.

The strength of current required to be sent in order to record the signals with the different forms of instrument used and on circuits of various lengths is a very important question. This 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 ,,

Hence the telegraph engineer has to regulate the number of cells so as to obtain the strength of current indicated above. Now, one Daniell cell through one thousand

[2] See Appendix, Section B.

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 wet weather and for 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 are 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

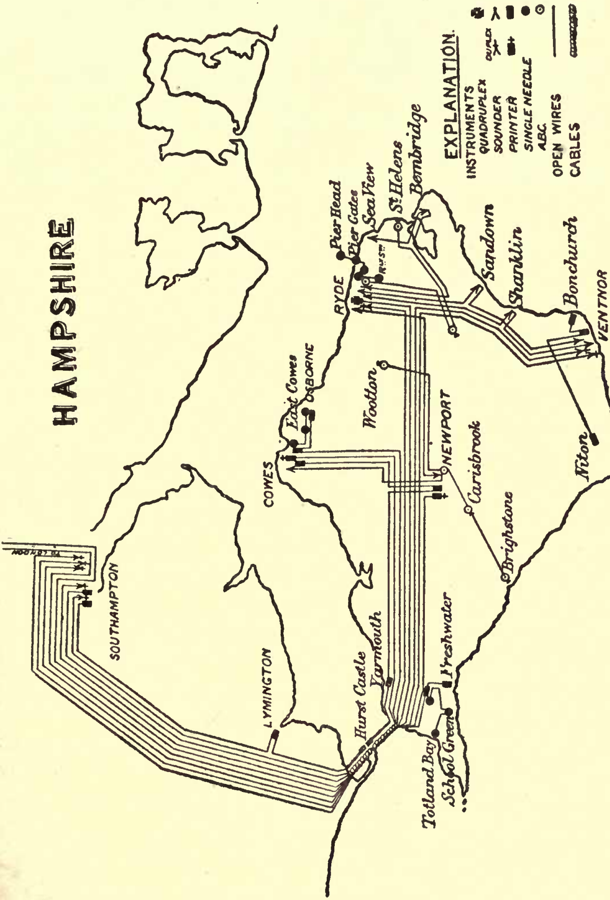


FIG. 87.

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., and it is imperative that all well-organised systems should 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 only affected 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*.

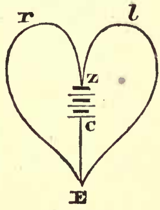


FIG. 88.

Now let the electro-magnet E (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*, it is evident that if the currents are equal the polarity induced by the one current must be exactly neutralised by that induced by the other

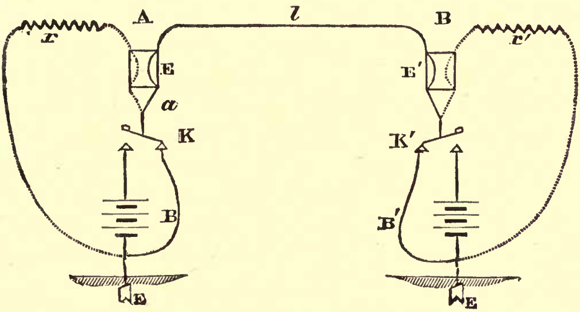


FIG. 89.

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* are interrupted, those in *l* will excite the electro-magnet, and if those in *l* are interrupted, the currents in *r* will excite the electro-magnet.

Assume A and B (fig. 89) to be two stations connected together by the line wire *l*. Let E be an electro-magnet at A, wound as just described, and E′ 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 *a*, the one half going through the wire in connection with *l* in E, through *l*, and at B, through the wire in connection with *l* in E′, 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 E through the wire in connection with *r*, through *r* and back to the battery. As these two currents are equal, their effect on E is *nil*, but the line current passing through one coil only of E′ 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 E′ in precisely the same way as if A's currents were received. Thus E and E′ 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 alone B 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 wire *l* over that in wire *r* of relay E, 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.

We have shown the keys K and K′ as putting the line to earth through the back contact, but there is an interval when 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 current 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 3, instead of going to earth through 2, 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* wires 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 2 altogether, but it introduces irregularities due to electro-magnetic inertia (p. 158), 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.

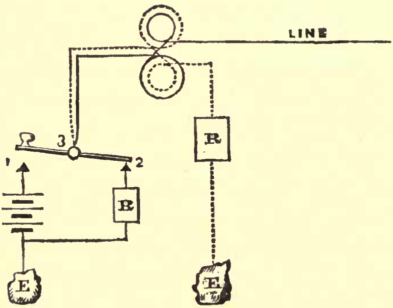


FIG. 90.

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-

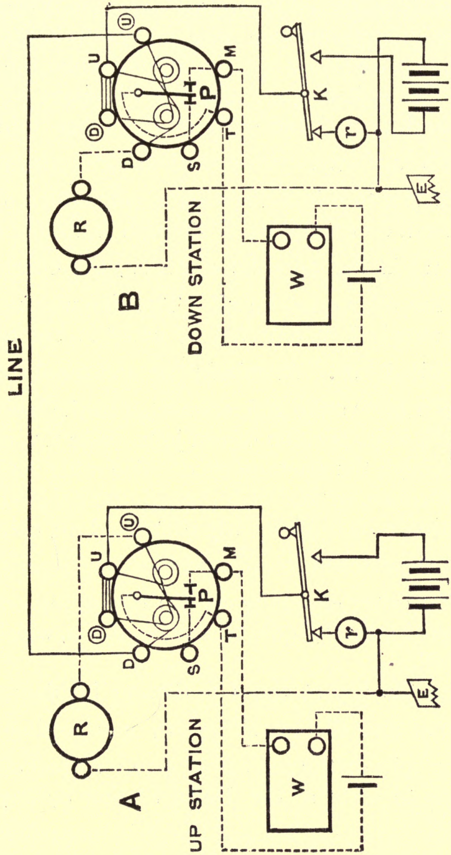


Fig. 91.

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 (D) (U) 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 small compared with that of the line, then the current passing through the compensating circuit will considerably exceed in strength 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 increasing 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. 123 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 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 4400ʷ. But in addition to this a coil offering a resistance of 4000ʷ 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 40ʷ being made, two other coils of 10ʷ and 20ʷ are also included, so that the range of the rheostat is really from *nil* to 8430ʷ, by variations of 10ʷ.

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

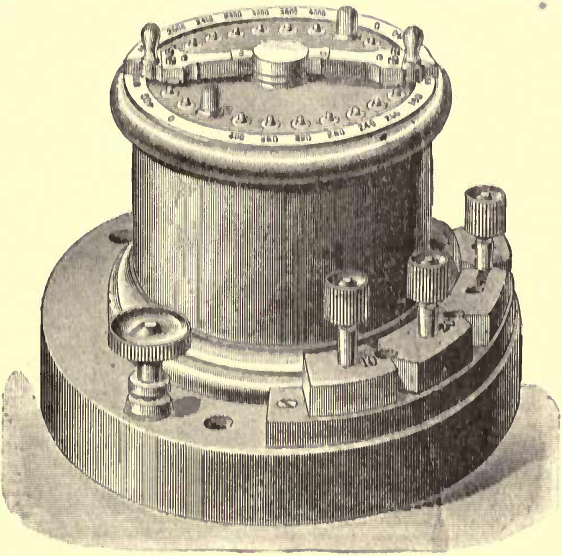


Fig. 92.

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. 126). 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 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

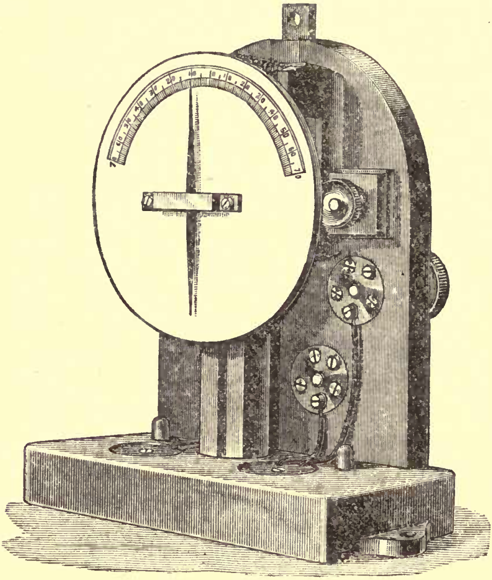


FIG. 93.

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 (3) upon the insulating medium that separates it from the earth. 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?

[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 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 within a certain range that may be required. a, a_1, a_2, b, b_1, b_2 (fig. 94), are square pieces of tinfoil separated by sheets of thin paper steeped

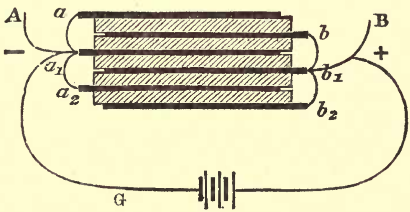


FIG. 94

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,

[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.

If now a very sensitive galvanometer be joined in circuit with the battery, say at G (fig. 94), and the battery (with galvanometer) be then 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

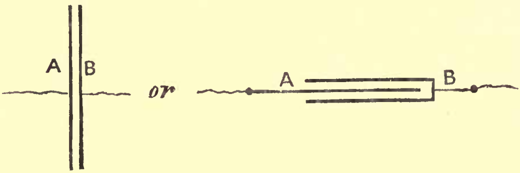


FIG. 95.

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.

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, when A (fig. 89) is working to B alone there is induction in the line, the return current will flow back through E 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 induction 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. 134, 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

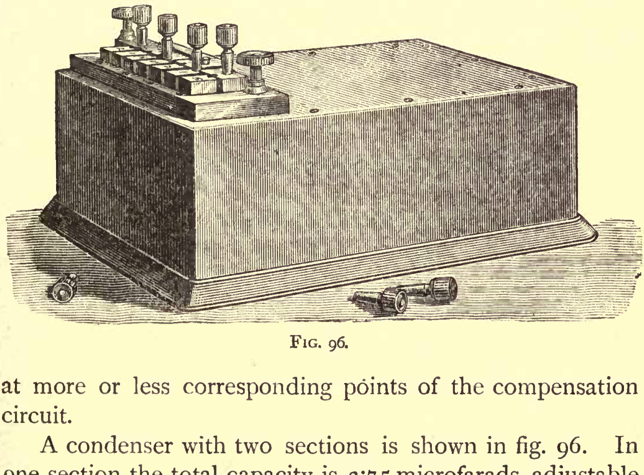


Fig. 96.

at more or less corresponding points of the compensation circuit.

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 the resistance in resistance coils 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 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

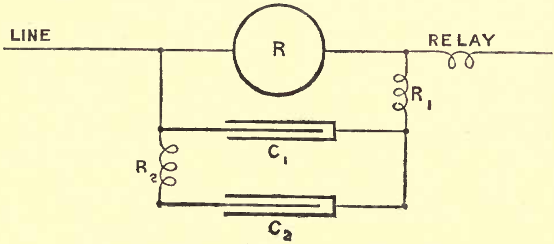


FIG. 97.

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.

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

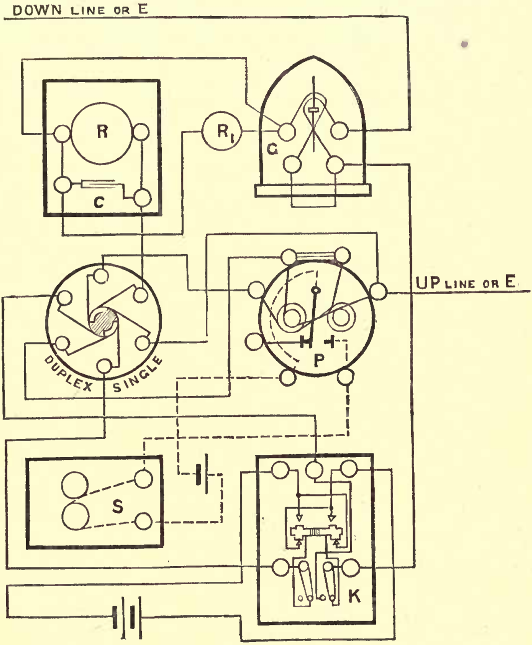


FIG. 98.

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 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 con-

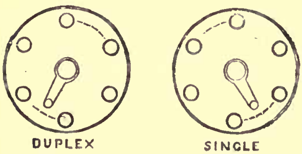


FIG. 99.

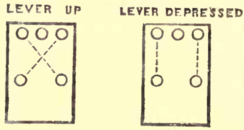


FIG. 100.

nection 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.

On analysing fig. 98, the fact will be noticed that there are two paths for the current to take, one 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; it is, in fact, only used because its introduction permits of the use of a simpler form of duplex and single switch than would otherwise be possible.

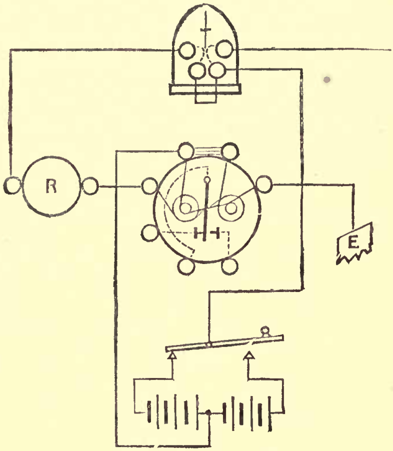


FIG. 101.

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.

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

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*, but the bridge principle depends on producing an *equality of potentials*. Fig. 102 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

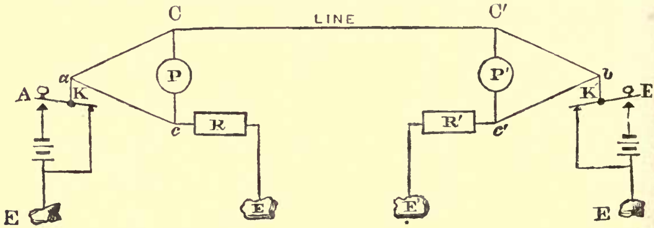


FIG. 102.

relay, is for the sake of simplicity not shown in the figure. The apparatus at B is precisely the same as that at A. Now when A depresses his key 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, since the resistances of the two circuits from *a* are equal, and as the points C and *c* are 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.

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 to each other, but it is not necessary for the resistances of the branches 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′ is 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 difference of potential between *b* and earth, and the strength of B's current to line is diminished to the same extent, 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 now 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

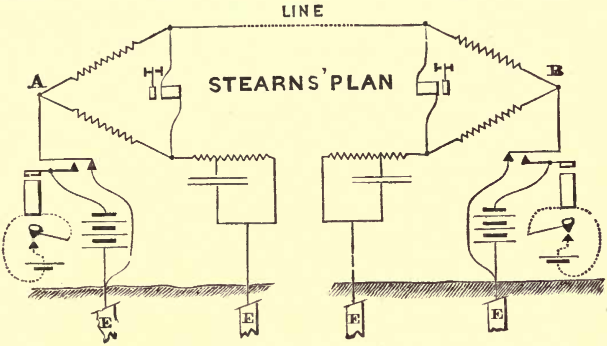


FIG. 103.

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. Thus 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. His plan is shown in fig. 103.

It will be noticed that in fig. 103 the key is used only for closing a local circuit through an electro-magnet. This electro-magnet forms part of an instrument known as a *Duplex Transmitter*, which is arranged to send the line signals without permitting a break in the circuit. It is clear that a suitable key for doing this direct might be devised, and indeed such a key is now in actual use for a similar purpose. (See fig. 134.)

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. Now 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 not only remove the defects inherent to manual labour, but 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, which thus 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. 75). 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,

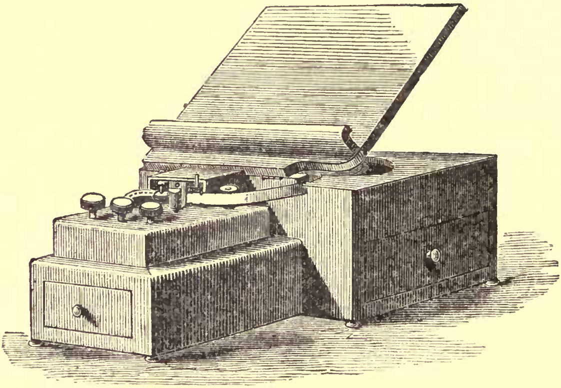


Fig. 104.

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 one vertical line thus : $\overset{\circ}{\underset{\circ}{\circ}}$; *b* causes 2 only to punch, thus : ∘ ;

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

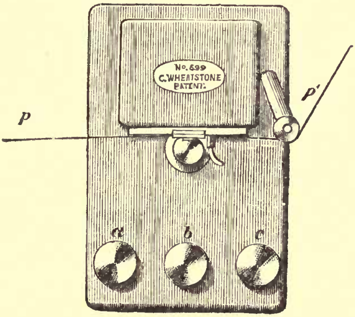


FIG. 105. ¼th real size.

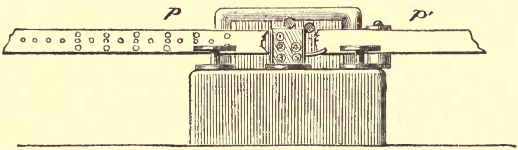


FIG. 106. ¼th real size.

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 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.

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 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

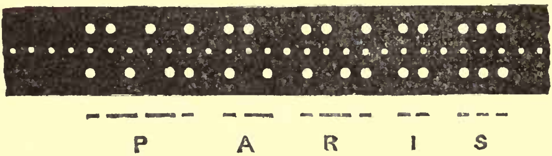


FIG. 107.

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 forty.

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

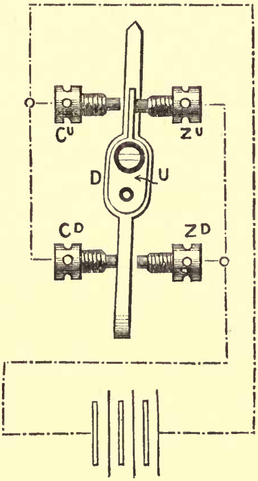


FIG. 108.

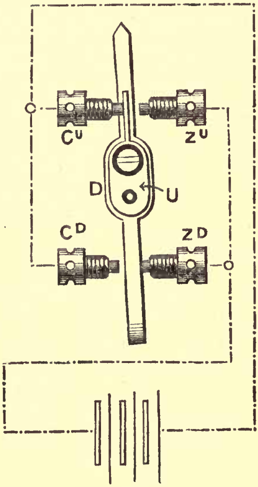


FIG. 109.

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 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

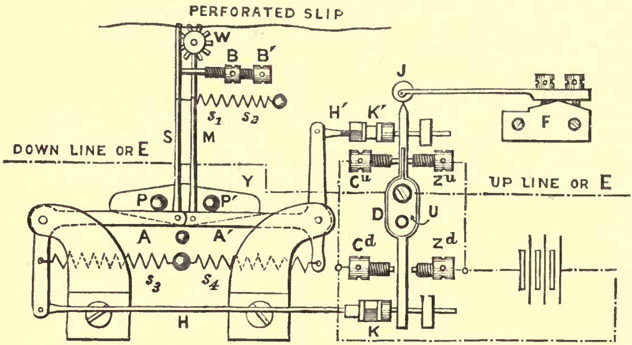


FIG. 110.

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

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 clock-work. 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.

oo
If now slip, perforated (say) with the letter ∘ ∘ ∘ (*a*) be
o o

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

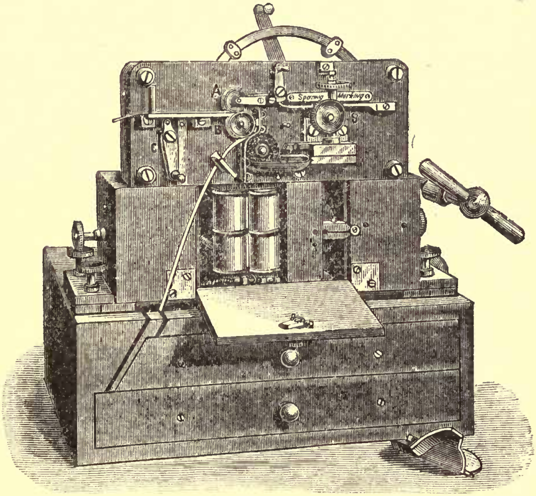


FIG. 111.

required Morse signals—dots, dashes, and spaces—can be automatically sent to the line.

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.

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 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.

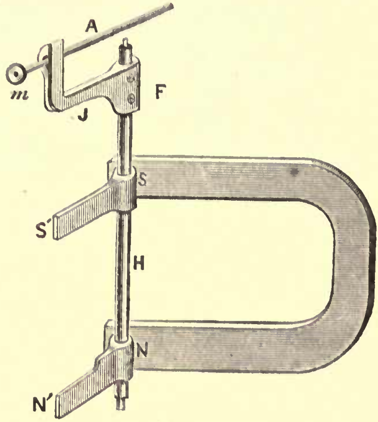


Fig. 112.

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 450 words per minute[1]; 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 core takes time to magnetise and to demagnetise, due to the fact that 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 to the originating current. This self-induction 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, 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 arising from it will, of course, be small or great in inverse proportion to the resistance through which it has to discharge. Hence, it is found that, other things being equal, a high-speed instrument will give better results with a

[1] English telegraphic 'words' are found to contain on an average five letters, and calculation of speed on the automatic system is based on the assumption that twenty-four possible reversals of the transmitter represent an average word.

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 resistance than it is through the low.

The effect of the shunted condenser will be understood from fig. 113. L represents the receiver coil, K R the shunted condenser (both condenser and resistance coil 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.

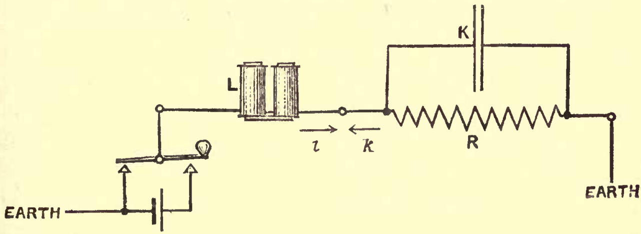


FIG. 113.

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 50$^{\omega}$ and that of the shunt 300$^{\omega}$ 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 shunt coils than through the much higher resistance 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, which consequently become oxidised, 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 450 words per minute so long as it is working only on a short line, but it has been already shown (p. 133) that as the length, or rather, as the resistance 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. 75), as 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

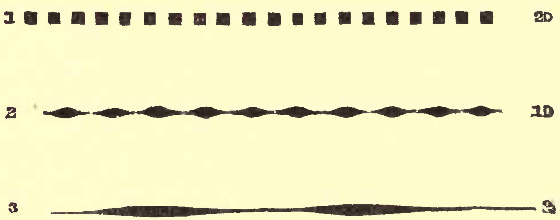


Fig. 114.

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 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 ordinarily be neutralised 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. 172).

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

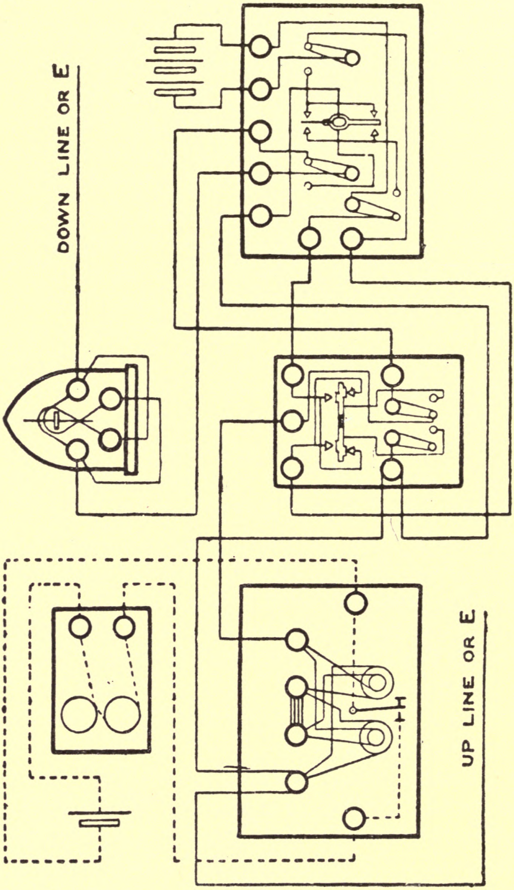


Fig. 115.

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 octuple the capacity of wires. The average rate of automatic working in England, due to the length of circuits, to the amount of inductive capacity present, and to the various causes that have been enumerated, is about 300 words per minute. 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.

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 retardation in such cases have been sufficiently dwelt upon (p. 158), 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, in a *metallic 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

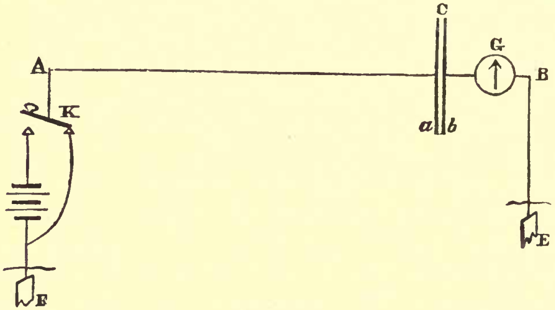


FIG. 116.

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 and release it, we affect the galvanometer with a reversal.

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. P, P′ are switches for connecting the cable to the sending or receiving instruments. The condenser may occupy any one of the positions marked c, c_1, c_2. When in the position c_1 the cable works with a condenser at each end;

when in either of the other positions there is a condenser in use at the receiving end only, but the signals from position c will be reverse as compared with those from position c_2 if other conditions are unaltered.

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

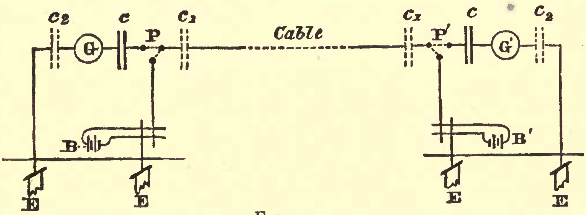


FIG. 117.

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 20 microfarads, which is equivalent to the capacity of about 60 knots of cable, and from four to ten cells of one or other of the forms of Daniell's battery—generally Minotto's (p. 34)—are 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 $\frac{3}{8}$-inch in length, cemented upon a small circular convex mirror of silvered glass, which is suspended by a short thread of cocoon silk without torsion. It weighs only $1\frac{1}{2}$ grain. This needle is suspended in the centre of a coil of very fine wire, giving a resistance of about 2,000ω. 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 a 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 condenser C, and the other 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. R is the resistance coil employed in connection with the condenser C, and inserted for adjusting to suit the varying conditions of the cable and strength of the currents. P is a small switch to which the cable is brought, and by means of which it 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 now it is never so placed.

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

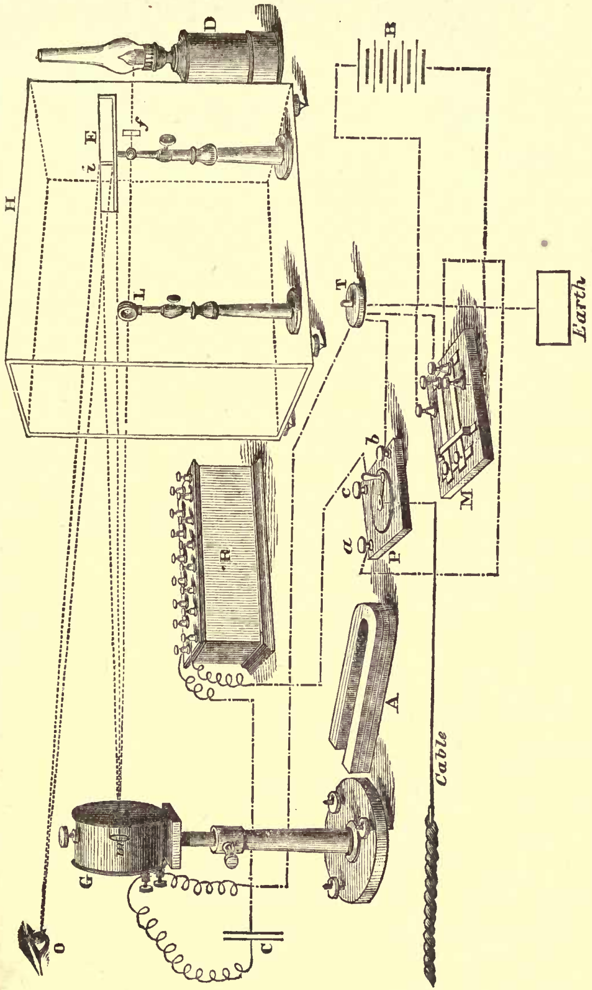


Fig. 118.

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 to the switch P, and if it is desired to put the cable direct to earth for testing or other purposes, the switch-bar is carried to *b*, which, by means of T, is in connection with the earth. When signals are to be received the switch-bar is placed in connection with *c*, and in this way the cable is connected to one side of the condenser through the resistance coils R: the other side of the condenser being in connection with 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 signals 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 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 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 its 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 upon the paper by rapid vibrations imparted to the tube.

A sentence sent by this *Syphon Recorder*, as it is called, is shown in fig. 119.

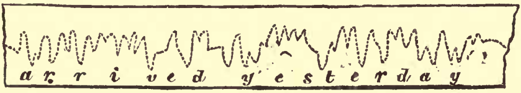


FIG. 119.

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 more felt upon cables than upon overground wires, since one mile of ordinary cable has a capacity equal to about twenty miles of open line.[1]

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 corre-

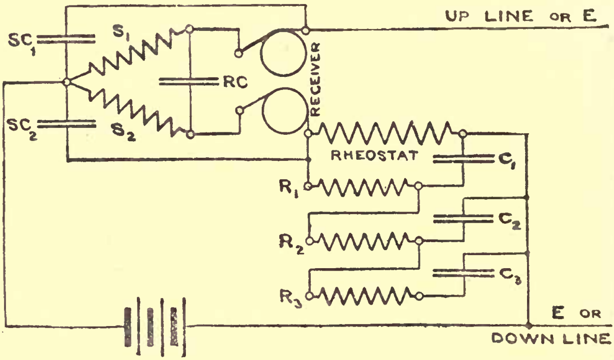


FIG. 120.

spond with the discharge from 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,

[1] The speed of working actually depends upon the product of the *capacity of the line multiplied into the resistance* (K R), 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.

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. 158), 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.

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 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 10 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.

Having the same working conditions, but applying the signalling condenser compensation described above, the possible speed at each end is equalised, and for the Amsterdam circuit becomes 116 words per minute either way, and for the Dublin circuit 120 words. (See p. 177.)

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 this to some extent, but it is clearly 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 transmit or relay 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 directly, without any retransmission by hand, by means of five 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

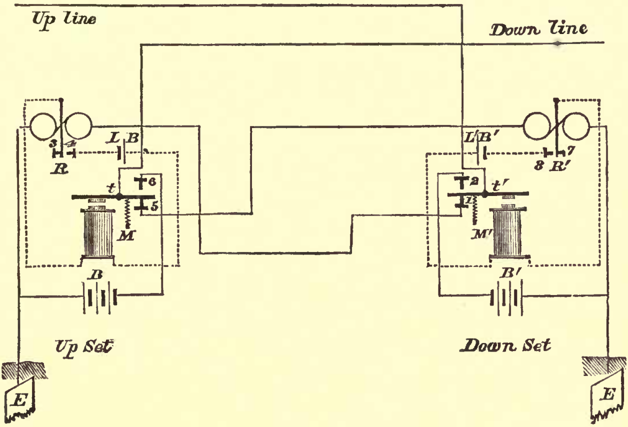


FIG. 121.

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 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 made 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 re-transmit 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. 173, 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. 114, 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

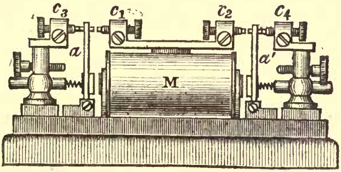


FIG. 122. ¼th real size.

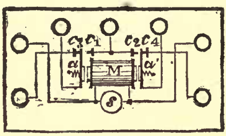


FIG. 123.

is an elevation which shows the actual construction of the instrument; the latter gives the electrical connections.

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

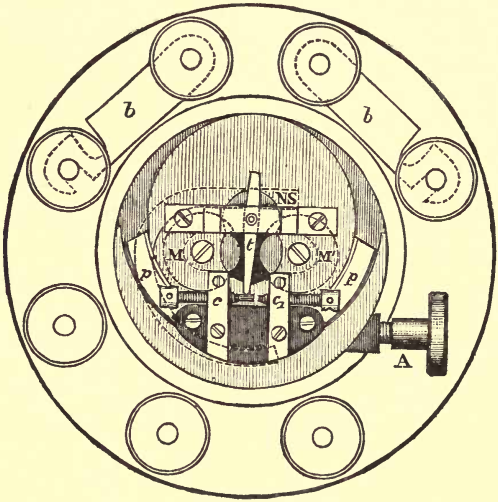


FIG. 124. ½ real size.

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

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.

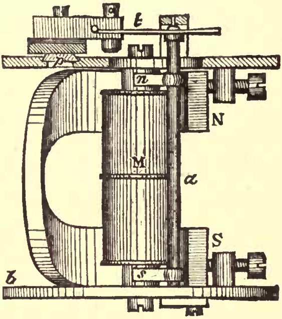


FIG. 125. ½ real size.

The brass straps *b b* are for the purpose of joining the coils of the relay in 'quantity' or 'series' at will. When the straps are as shown in fig. 124 the coils are joined up for quantity; when required in series both straps are joined across the two back terminals. The electrical connections of the relay are shown by fig. 126.

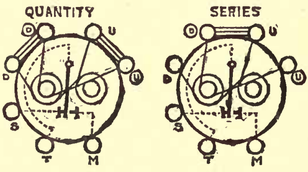


FIG. 126.

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.

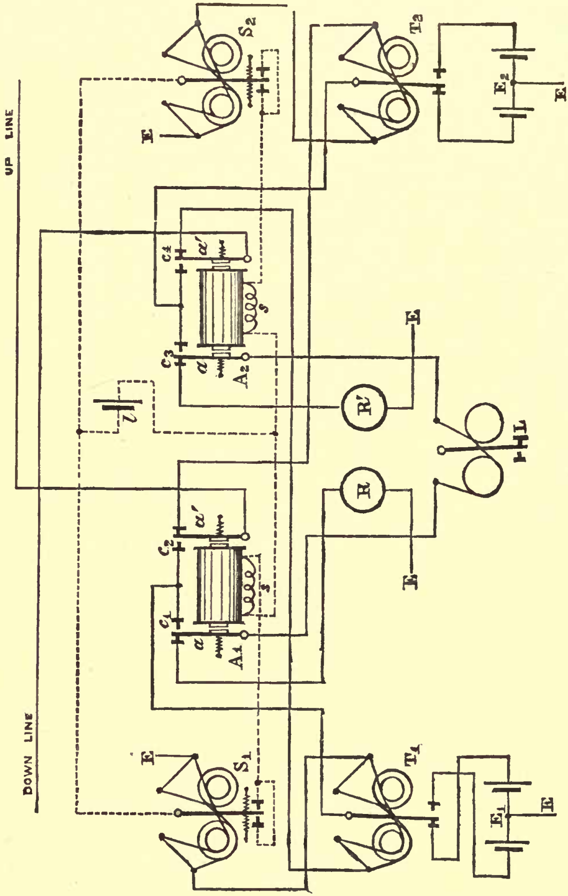


Fig. 127.

These relays (S_1 and S_2) are known as the 'automatic switch relays.' Their tongues are fitted with spiral springs upon each side, by 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 w th 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. 158). 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 drains off part of the current from the repeating battery 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 not sufficient to materially 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. 116, 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.

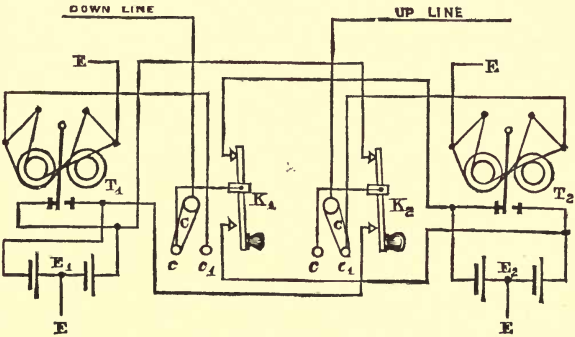


FIG. 128.

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. 121 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

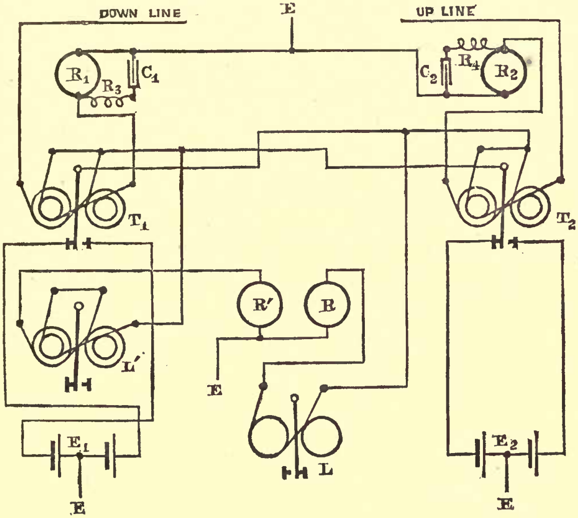


FIG. 129.

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.

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-

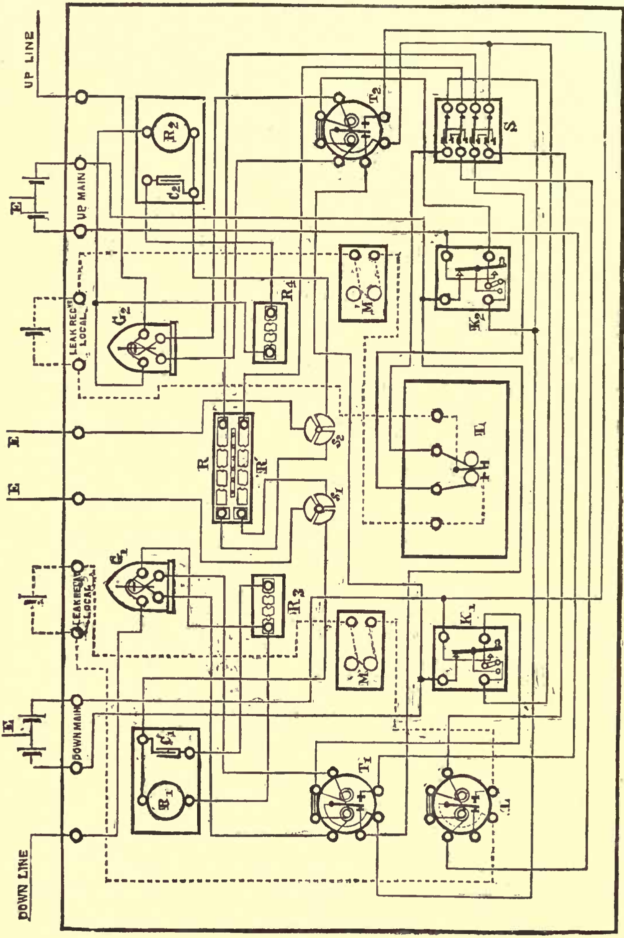


FIG. 130.

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.

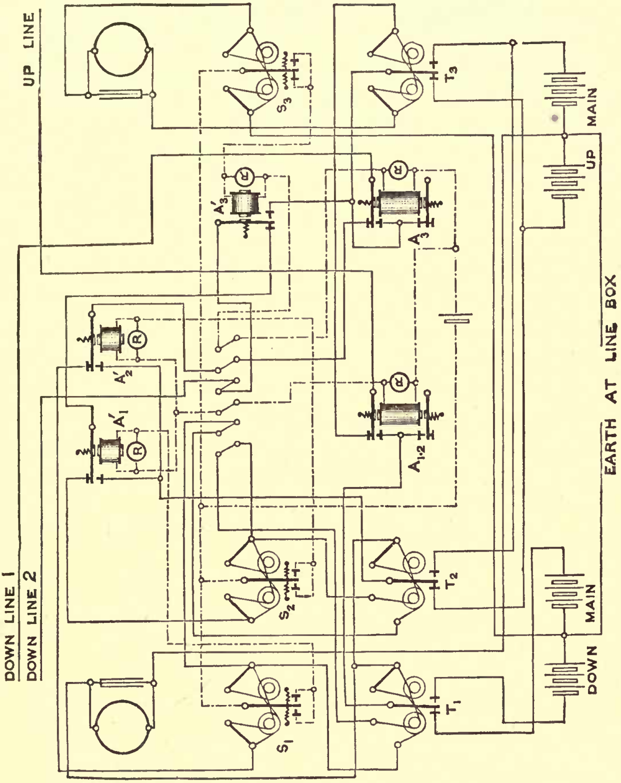


FIG. 131.

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 arranged to meet various requirements. 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. 197). The principle

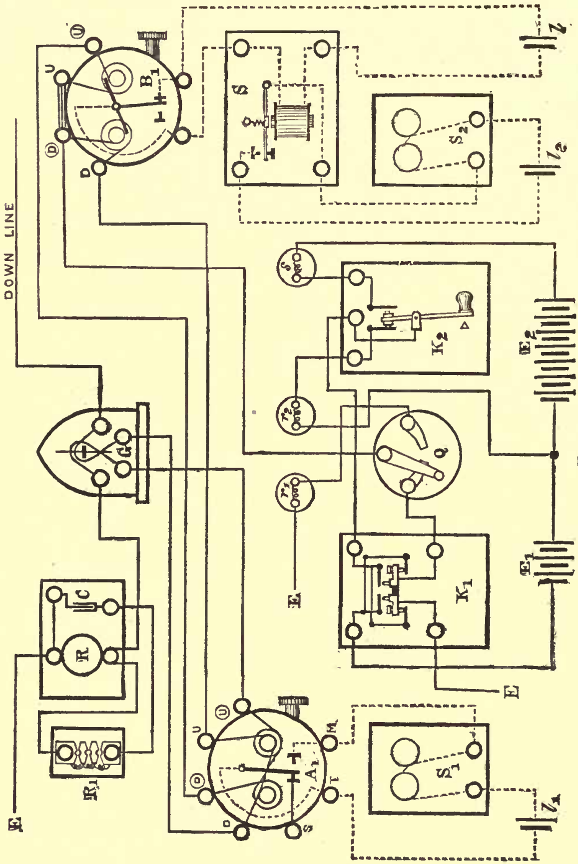


Fig. 132.

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;

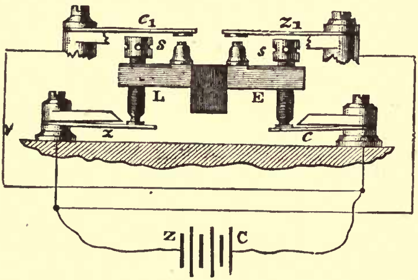


FIG. 133. ½ real size.

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.

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,

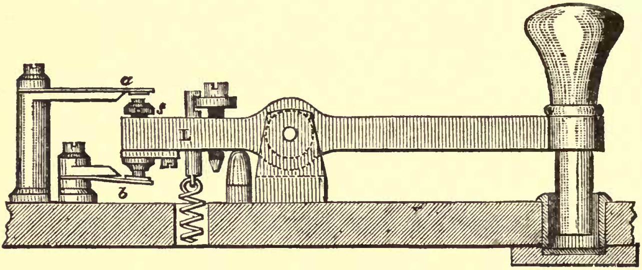


FIG. 134. ½ real size.

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*.

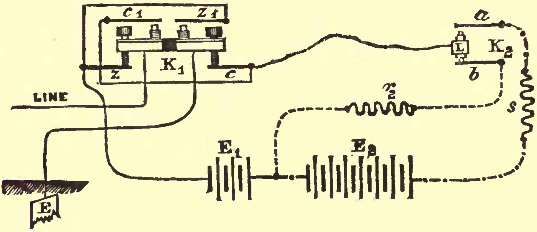


FIG. 135.

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_1 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 $3{\cdot}3\ E_1$, 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 $3{\cdot}3\ E_1$, 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

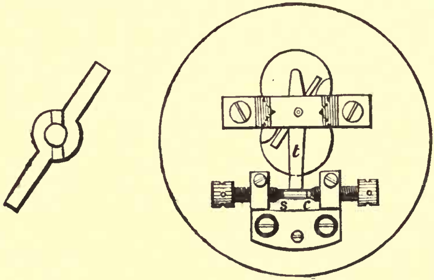


FIG. 136. ½ real size.

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

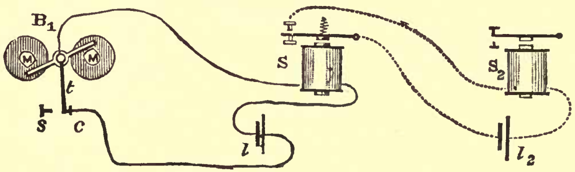


FIG. 137.

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. 51). 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).

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. 130).

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, which 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

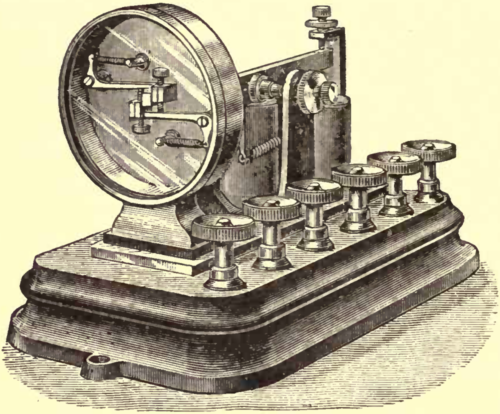


FIG. 138.

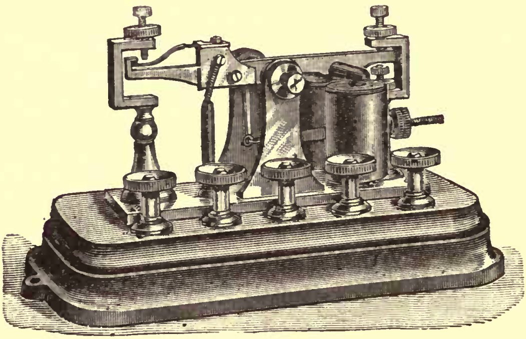


FIG. 139.

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

These transmitters perform the same function as the keys

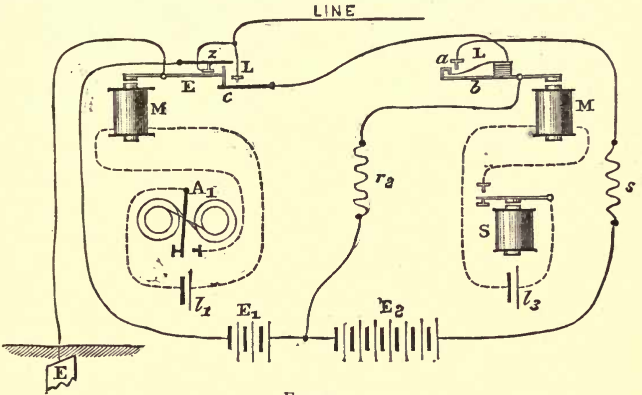


FIG. 140.

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 in some cases convenient 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 in America. The following is of great importance and is much used :

Let London be T (fig. 141), Leeds R (the repeating office), Stockton A′, West Hartlepool B′. 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 London works duplex on the A side to Stockton, and duplex on the B side to West Hartlepool.

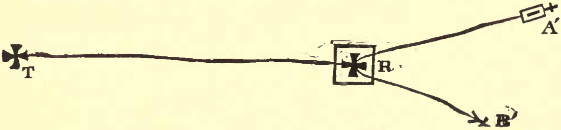


FIG. 141.

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

[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

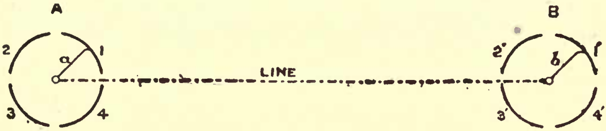


FIG. 142.

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

FIG. 143

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.

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, but still without success, the difficulty being in maintaining synchronism. 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.

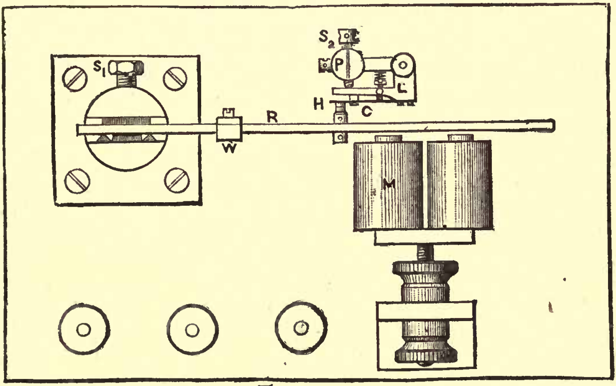


FIG. 144.

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. M is adjustable, and the motion of the wheel is most vigorous and firm 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 as well as effecting 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 capacity ($\frac{1}{2}$ microfarad) C, and a resistance coil r_2 of 100 ohms resistance, is joined across the electro-magnet M to prevent sparking at the reed contact. The reed rheostat (not shown) is inserted in the reed electro-magnet circuit (see fig. 149).

The motion of the wheel is regulated by a fly-wheel placed over it, but, as a dead weight would not accommodate itself to a sudden momentary variation of speed to which the motor may be subject, the fly-wheel consists of a circular

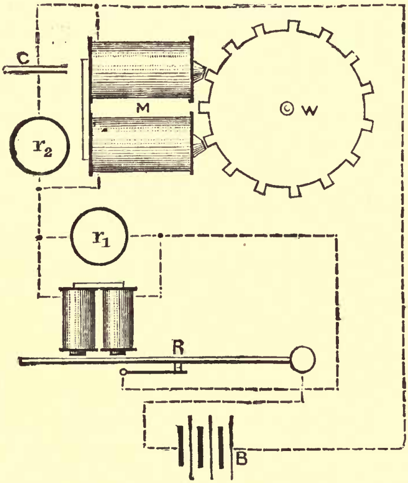


FIG. 145.

wooden block in which are two deep concentric grooves which are filled with mercury. It is thus really the rings of mercury that form the fly-wheel, and they are not readily influenced by irregularity of running; even if the wheel be actually stopped the mercury continues to move and will carry on the wheel if the period of stoppage is not too considerable. The axle of the phonic wheel carries the arm (*a* and *b*, fig. 143) upon which is fixed the trailer which moves over the segments of the distributor.

Now, assuming that the two ends of a line are both fitted with a distributor driven by means of a reed as described, and that these reeds are both carefully adjusted to have the same rate of vibration, it will be found that in practice they will not be absolutely isochronous; the deposition of dust or moisture, changes of temperature, variation of current and dirty contacts, all tend to affect the rate of motion. If, however, means can be adopted to insure that the lagging wheel shall be quickened or the fast wheel slackened if necessary, say three times during each revolution of the trailer, so as to tend to secure the accord of the two instruments at each correction, then it is clear that the

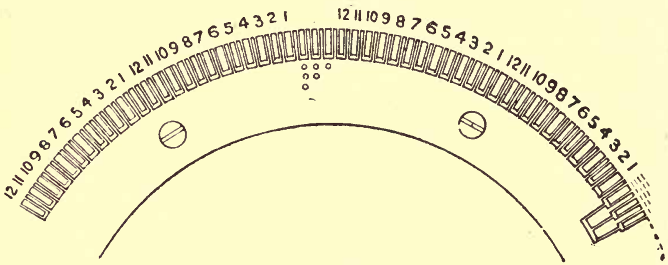


FIG. 146.

want of absolute isochronism in the reeds will be immaterial. This then is the principle adopted. A certain number of segments are set apart for the purpose of correcting, so that each time the trailer passes over such a segment it joins in circuit either a battery to send a correction or a relay to record one.

The general arrangement of the present form of distributor segments is shown in fig. 146, in which only one-third of the segments are shown, but the other two portions are exactly similar to this. The circle is divided into 162 equal spaces fitted with segments insulated from each other. These segments in fig. 146, reading from the right, are shown thus: three spaces for sending corrections; then consecutively 1 to 12; 1 to 12; three spaces for receiving corrections; and again 1 to 12; 1 to 12. The space between each two adjoining segments is partially filled by a tooth projecting from a brass centre-plate, the object of which is to prevent the trailer from bridging over two segments simultaneously. This applies to the sending correction segments (marked thus . : ⁝) as well as to the ordinary circuit segments, but at the three spaces set apart for receiving corrections the two teeth of the centre plate are removed and the whole space, equal to that occupied by three ordinary segments and two centre-plate teeth, is fitted with five insulated segments which are marked by dashes, thus — = ≡ ≣ ≣

These six groups of correcting segments, which occupy equidistant positions in the circle, are connected to form eight sets in the same way as the circuit segments, but each set consists of three segments only.

In fig. 147 are shown the complete connections of the reed and motor, including the arrangement for correcting. Of the three sending correction segments (.) is usually connected to the correcting battery; (:) is left disconnected and (⁝) is connected to earth. In some cases the correction is sent from (:), the first segment (.) being disconnected.

The relay R_1, which receives the correction current, is joined to one of the receiving correction segments, the proper one being determined by experiment. The remaining receiving correction segments are connected to earth.

When the trailer at station A is on one of the second sending correction segments (:) the trailer at B must be in or near the corresponding position in a receiving correction group. The correcting relay R_1 is connected at least one segment behind the required position, as the apparatus only wants 'correction' when it is actually out of synchronism. The particular sending and receiving segments to be used depend upon the retardation of the line. Thus, it is determined that corrections shall be sent to accelerate the slower of the two reeds; hence, if there be practically no retardation, the

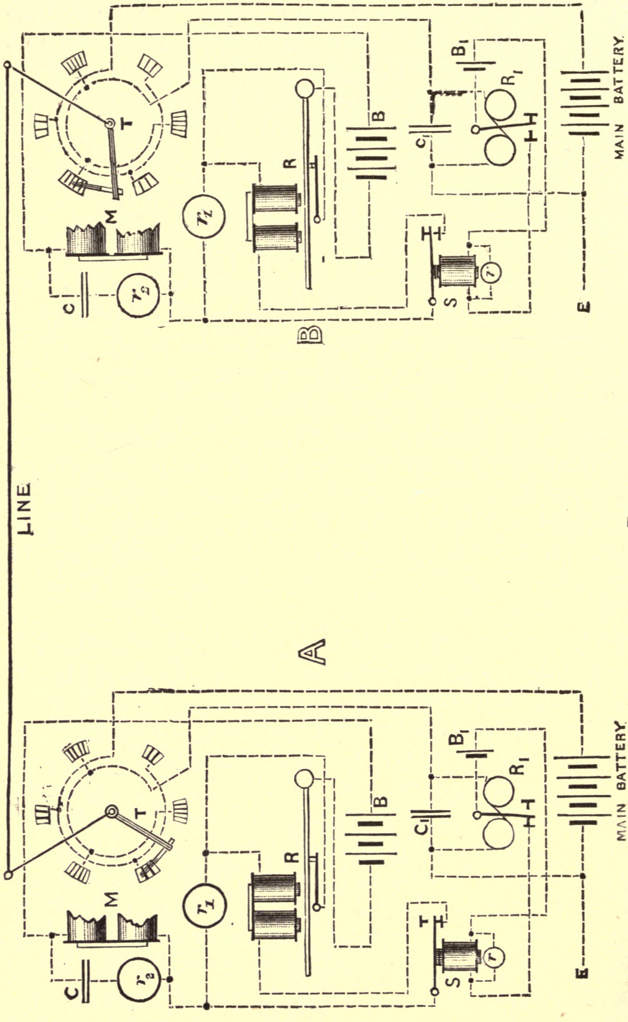


FIG. 147.

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 perfectly synchronous, 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 above explained 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 capa-

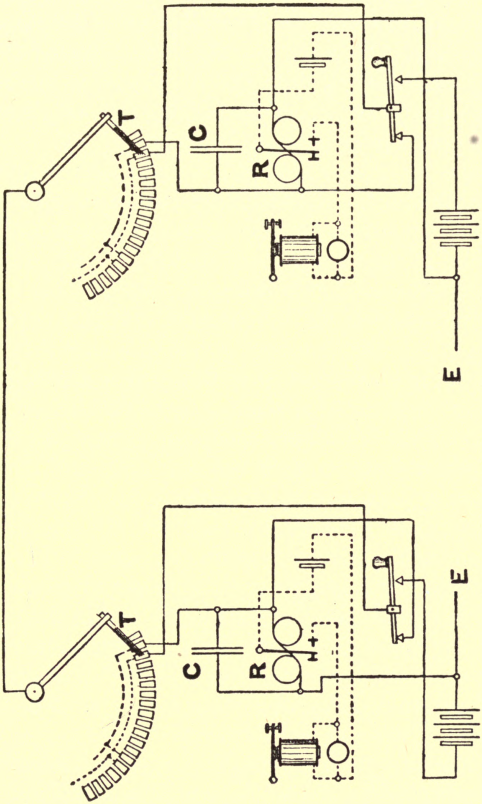


Fig. 148.

city (10 mf) is connected across the coils of the relay. One battery serves for all the arms, on the 'universal' principle (p. 116). This battery is also used for sending the correction currents.

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 140 and 80 bichromate cells respectively are generally used. For single-current working, about 140 cells 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

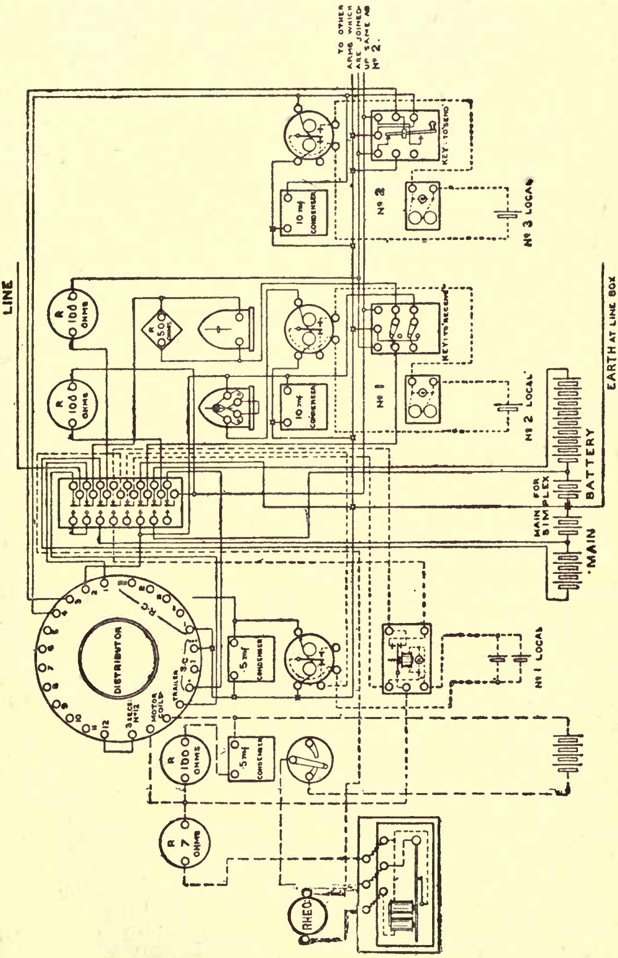


FIG. 149.

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. One great advantage which it possesses over the duplex or automatic system is that the actual work is done by the simple key and sounder with relay.

CHAPTER XI

THE TELEPHONE.

The telephone is an instrument employed for the reproduction of human speech at a distance. It is called by the Germans the '*Fernsprecher*,' or far-speaker. The production of sound by electricity, which was shown by Page in 1837 to be possible by the transmission of a rapid succession of currents around an electro-magnet, seems to have excited the conception of the possible transmission of speech. Farrar, in 1851, wrote: 'If the current power could be varied by some slight variation of a vibrator, to be affected by the atmosphere as the tympanum of the ear is, the supposition is that the sounds of the voice might be reproduced.' Bourseul, in 1854, said: 'What is spoken in Vienna may be heard in Paris. . . . Imagine that one speaks near a mobile plate flexible enough not to lose any of the vibrations produced by the voice; that this plate establishes and interrupts successively the communication with a battery. You may be able to have at a distance another plate, which would execute at the same time the same vibrations.' This was pronounced at the time to be a fantastic conception, and an idea that was no more than a dream. The conceiver himself seems to have contented himself with his magnificent idea.

Philip Reis, of Fredericsdorf, in 1861, was the first to put the idea into actual form. He thoroughly grasped the conditions of the problem, studied the action of the human ear, and devised an instrument that actually reproduced speech; but it was reserved for Mr. Graham Bell, in 1876, to produce a really practical and commercial instrument.

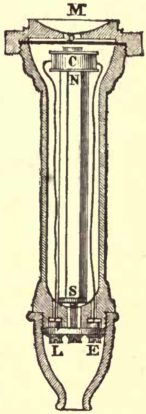


FIG. 150.
¼ real size.

Bell's telephone is constructed as follows. N S (fig. 150) is a hexagonal permanent bar magnet of the best steel that can be procured, $4\frac{1}{2}$ inches long and $\frac{1}{2}$ inch in diameter. Its N end is turned true, and over it is slipped a bobbin (C), wound with about 80 yards of fine copper wire 8 mils. in diameter, insulated with silk, and giving a resistance of about 40 ohms. The ends of this coil are connected to two terminals, L and E, fixed at the base of the ebonite casing that contains the magnet and coil, and which is made of a shape suitable for holding in the hand. The magnet is screwed to this ebonite case by the screw shown at S. In front of the N end of the magnet, but separated from it by an air-space of about $\frac{1}{100}$ of an inch, is a thin, flexible

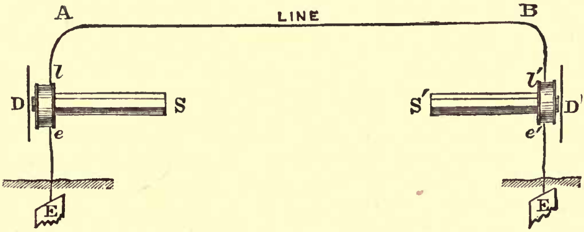


FIG. 151.

disc of iron, D, which is rigidly clamped at its periphery by the ebonite mouthpiece M screwed on to the ebonite casing. To complete a telephonic circuit there must be two of these instruments, and they must be connected up as shown in fig. 151.

To comprehend the action of the apparatus we must remember—First, that the character of a musical note, or of any sensible periodic sound, such as speech, is determined by three conditions, namely, *pitch*, *timbre*, and *intensity*. Second, that currents of electricity are produced in a wire whenever we alter the strength or character of the magnetic field in which that wire is placed. Third, that the passage of a current around the pole of a magnet varies or changes its attraction on magnetic masses in its neighbourhood.

The iron disc, being flexible, responds to any sonorous vibrations impinging against it in the same way as does the tympanum, or drum, of the ear. (1) It vibrates, and the rate of vibration is determined by the pitch or note sounded. A low note—the deep bass voice of a man—may cause 60 or 70 vibrations per second, while the high notes of a child may produce 1,000 or more vibrations per second. (2) The timbre of the note—that is, the quality which determines the difference between a man's voice and a woman's, between a fiddle and a flute, when they each sound the same note—imparts its characteristic vibration to the disc. Its movements may be jerky or smooth; they may be regular or irregular; although the vibrations are made in the same periodic time, they may advance and recede in very different ways; and it is this irregularity of movement that determines the timbre. (3) But the excursions of the disc to and fro, though they may have the same periodic time, and the same irregular movement, may vary in extent. Their amplitude of motion may be greater or less, and this is determined by the intensity or loudness of the originating sounds. Hence, when one speaks in front of an iron disc, such as that of a Bell telephone, the disc will vibrate, in number, way, and amplitude, exactly corresponding to the pitch, timbre, and intensity of the various sounds uttered.

It is necessary to remember also that the exact reverse takes place, viz. that while the disc will vibrate under the influence of sound, if it be made to vibrate by any other cause it will itself emit sound, the pitch, timbre, and intensity of which will be exactly determined by the nature of the originating cause. The disc D (fig. 151) is in the magnetic field of the magnet N S, and the coil C is in the same field. Any alteration of this field will result in a current induced in the coil C. If the disc D be moved inwards there will be a current in one direction, if it be moved outwards there will be a current in the other direction, because by each movement the field has been altered in exactly opposite ways. For every movement of D there is a current induced in the coil; its direction will be determined by the direction of movement of D, its length by the period of movement of D, its strength by the amplitude of movement of D, and form by the form or way of movement of D. Hence the character of the current induced in the coil C and flowing through the line will vary exactly with the pitch, timbre, and intensity of the sound uttered in front of the disc D.

Now these currents flow through the coil C′ which surrounds the pole of the magnet N′ S′, and they consequently either strengthen or weaken the attraction of the magnet N′ S′ on the iron disc D′. If the pull of the magnet N′ S′ upon the disc D′ varies, the disc must move, and if it moves it must move in exact obedience to the cause that moves it. Hence, as the currents which flow through C′ vary exactly in number, form, and strength with the pitch, timbre, and amplitude of the sonorous vibrations impinging upon the disc D, the pull on the disc D′ must vary in the same way, and it must vibrate in exact harmony with D. Moreover, as it thus vibrates in air it must itself produce sonorous vibrations, and these sonorous vibrations at D′ are an exact reproduction of those impinging upon D, and hence we have a reproduction of human speech.

It will be noticed that in the above arrangement (fig. 151) there is no battery; there are 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 strengthening the currents flowing through the line.

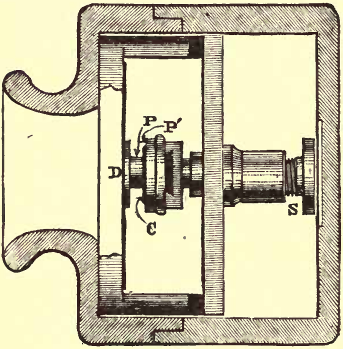


FIG. 152. ½ real size.

Edison did this in 1877 by the invention of the first form of carbon transmitter. This transmitter is constructed thus. An ebonite case contains a vibrating disc D (fig. 152), and a button of carbon, C, fixed between two discs of platinum, P and P′, which act as electrodes. The platinum electrode P is attached to the disc D by means of a cork pad, and the pressure between P and the carbon button C can be regulated by the screw S. Now, when the disc D is spoken against it vibrates, and its vibrations tend to lessen or increase the pressure upon the carbon button C in exact ratio to the pitch, timbre, and intensity of the sonorous vibrations impinging upon it. As the pressure varies, so does the resistance at the point of contact of the carbon button and the platinum, and if a current is flowing through the carbon its strength will vary with the resistance, and conformably with the sonorous vibrations impinging on the disc D.

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 necessary 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 generally of an iron core (usually made up of a bundle of soft iron wires) surrounded by a few turns of thick 'primary' wire, and over this are wound 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 (EMF) induced in each turn will be equal, and the total EMF at the ends of each 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 EMF.

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 I. The total resistance of this circuit is very low, being made up of the resistance of the

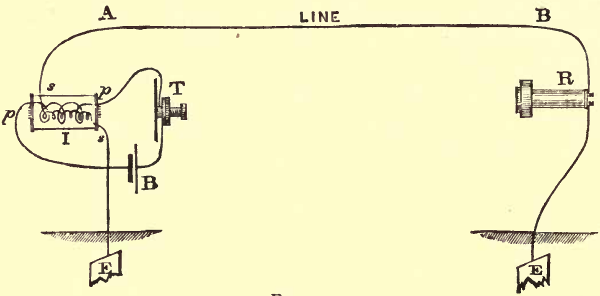


FIG. 153.

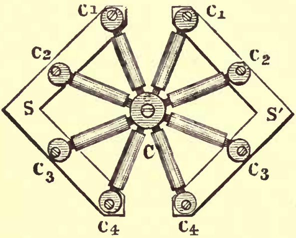
battery, the primary wire (less than 1 ohm), and the telephone transmitter itself. These constitute the sole resistance of the transmitter circuit, quite irrespective of the length of the line. Hence variation in the resistance of the transmitter itself will have a very considerable effect on the strength 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 currents, and as these vary 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 secondary currents are relatively stronger, and the defect of the Bell instrument as a transmitter thus ceases to be of importance.

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, which is so 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 as shown in the full-sized figure, 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.



¼ real size.

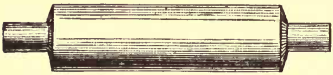


Fig. 154. Real size.

Fig. 155 gives a perspective view of a Gower-Bell telephone fixed in position; fig. 156 shows the several parts (the cover having been removed for convenience of inspection); and fig. 157 shows the various connections. I is the induction coil, the secondary wire of which, *s s*, is, for the sake of clearness, shown separate from the primary wire *p p*, although as a matter of fact it is wound over the primary wire. The primary wire has a resistance of $\cdot 5^{\omega}$, and the secondary wire

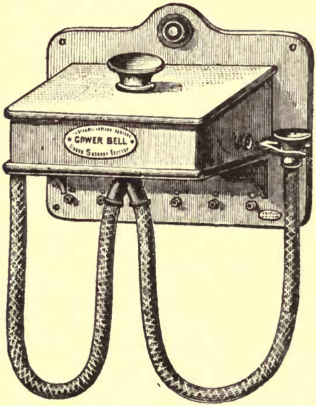


Fig. 155. ⅑th real size.

of 250ω. The receiver R is a Bell receiver, but it is made with a large and powerful horse-shoe magnet, the poles of which

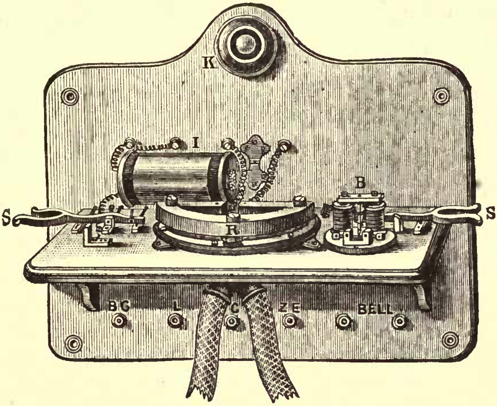


FIG. 156. ⅙th real size.

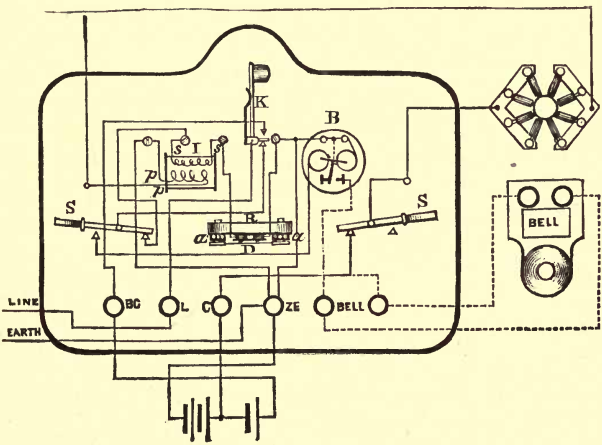


FIG. 157.

are provided with small soft iron cores, upon each of which a coil of wire of 125ω resistance is fixed. A disc of tinned iron, D, is fixed close to the ends of the cores, and opposite its centre a round hole is bored through the base board of the instrument, into which is screwed the brass socket supporting the two flexible hearing tubes shown in fig. 155. The distance between the iron disc and the pole pieces of the magnet is regulated by three screws, two of which, *a a*, are shown in the figure (157.)

S, S are two switches, which are maintained depressed when the hearing tubes are in their positions of rest, but which rise by the action of spiral springs when the tubes are taken out. When the tubes are in, the connections are arranged for ringing; when they are out they are arranged for speaking. The course of the currents may be easily traced.

K is a press-button, by the depression of which a current from the battery connected between the terminals Z E–B C is sent direct to line. The switches S S being depressed by the weight of the hearing tubes, a current from the line flows through the non-polarised relay B, the movement of the tongue of which completes the local circuit of the battery Z E–C, a current from which passing through the bell causes it to ring.

When the tubes are removed from the switches S S, the circuits of the induction coil are completed. If a person then speaks into the mouthpiece of the instrument, the board vibrates, and with it the carbon pencils; the resistance at the points of contact varies, secondary currents are induced in the induction coil and flow to line, the distant receiver responds, and so conversation is carried on.

The battery in the microphone circuit which is connected between terminals Z E–C should consist of two agglomerate Leclanché cells (p. 29).

An admirable form of transmitter and one very much used is that of Blake, which is shown in fig. 158.

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 the screw *s*. 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.

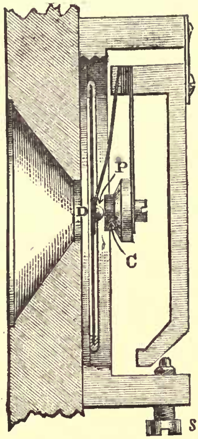


FIG. 158. ½ real size.

Representative of another distinct type of transmitter is Hunnings' transmitter. It is shown in fig. 159, 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. A modification of this instrument made by Charles Moseley forms one of the best transmitters yet introduced.

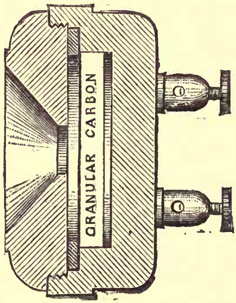


FIG. 159. ½ real size.

It is evident that some means must be provided on a telephone circuit to call attention between the two or more instruments on the circuit. This is done by means of an electric bell fixed in connection with each instrument. 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.

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 so 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. It may be noticed that in the bell shown, not only is there the possibility of adjusting the contact screw C, but the poles of the electro-magnet are so formed as to be adjustable by screwing forward or back. This is an improvement recently introduced by the Post Office.

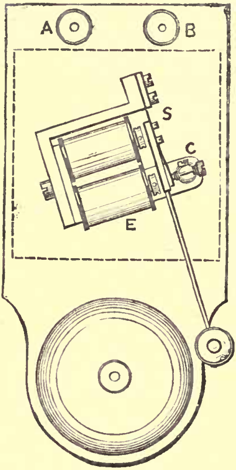


FIG. 160.

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.

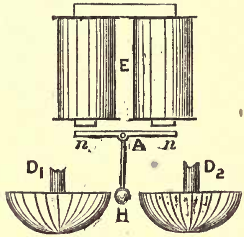


FIG. 161.

The magneto instrument used is not of the form described in connection with the Wheatstone A B C system (p. 83), but is based upon a design of revolving armature invented by Siemens.

The general arrangement of magneto calls 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 pole-pieces *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 points is insulated. From these two points the ends of the coils are connected to the lines.

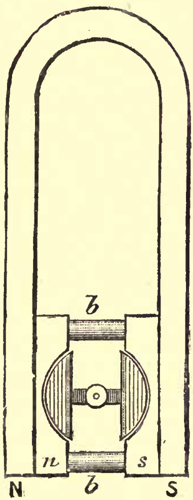


FIG. 162.

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 magneto machine will ring a call-bell through as much as 20,000$^{\omega}$ 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*.

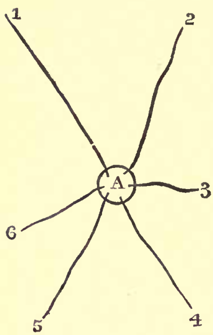


FIG. 163.

The telephone is used for ordinary telegraphic business in many countries, but in England it is principally as a convenient means of establishing communication between warehouse and office, between home and place of business, that it is used. It has also materially facilitated the transaction of business by improving the means of intercommunication between different houses and firms. Several circuits centre on one office called the Exchange, and there they are connected at will to one another. Supposing several wires, 1, 2, 3, 4, &c. (fig. 163) all terminate at A, which is in communication with each of them, and 1 wants to speak to 5, it requires but a very simple contrivance at A to enable him to do so.

The forms of switch are very various, but they are all equally simple. The construction of that used by the British Post Office for small exchanges with double wires (see p. 236) is shown in fig. 164. Each hole of the switch board is formed of two brass springs, *ss′*, which are normally in contact. The line, or A wire, is connected through the indicator to the top spring and the return (B) wire or earth to the lower spring. The indicator is fixed in the A wire. The upper brass piece is slotted (T, fig. 164). One hole is connected to another hole by a pair of pegs, such as are shown at P. Each peg has a top and bottom facing of brass *c c′*, to each of which an insulated wire within a flexible cord is attached, so that the circuit is maintained intact when pegs are inserted into two holes. In order to ensure that the through connection is properly made, there is a projecting piece on each peg to fit the slot in the upper spring. This prevents the pegs from being inserted upside down.

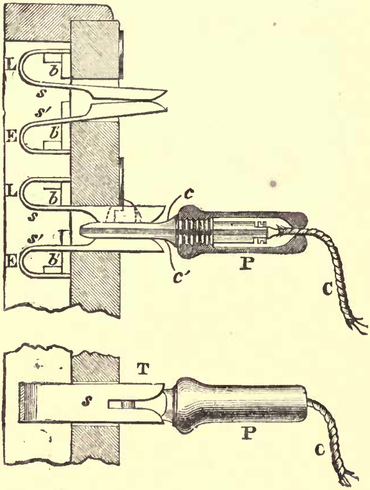


FIG. 164. ⅓rd real size.

Each subscriber's line is connected to an indicator in the Exchange by which he is able to attract attention. The form of indicator used is shown in fig. 165. M M is an electro-magnet, having as an armature a ring of iron, A A, which is hinged at *a* and so balanced that when no current flows through the coils it drops, thus attracting attention. This ring carries a label cut in the shape shown in the figure, upon which the number or name of the subscriber is engraved. A small magnet, or index (*i*), plays between the two poles of the electro-magnet, and is deflected to the one side or the other according to the direction of the current; S S′ is an insulated stud, by which, when the shutter falls, a local bell circuit is completed. This is used as a night call at exchanges where attendance is given at night.

Fig. 166 is a diagram which shows the connections of the switch board (s) and indicator tablet (i), and represents the method of effecting intercommunication.

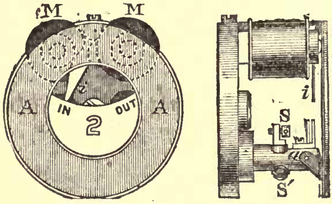


Fig. 165. ½ real size.

Every telephone instrument in connection with the Exchange is so arranged that a permanent current is sent to line when the instrument is not in use, and this current holds up the indicator shutter and deflects the needle at the Exchange. (Fig. 165 and Renter No. 2, fig. 166.) When a subscriber wishes to call he simply breaks the circuit by lifting the hearing tubes from their rests; this causes the shutter to drop and the needle to become vertical. Renter No. 1 (fig. 166) having done this, the Exchange clerk has

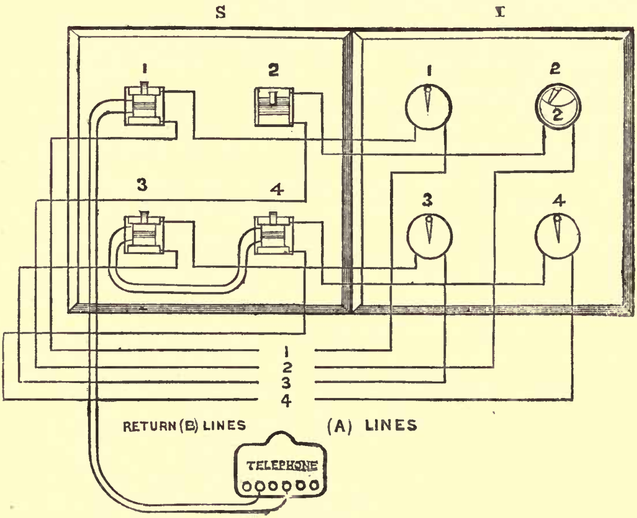


Fig. 166.

connected up the speaking telephone to find what is required. Nos. 3 and 4 are shown in communication; when their conversation is finished and the tubes are restored to their rests, the deflection of the needles of their respective indicators will show that this is so, and the operator will restore the shutters and remove the flexible connections.

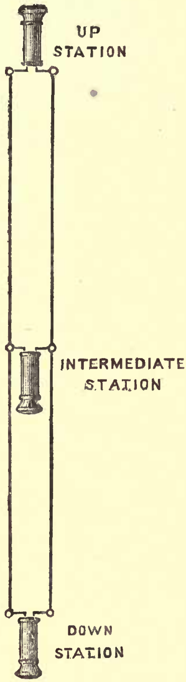


FIG. 167.

When there are more than two instruments on a double-line circuit it is often found that the introduction of an intermediate instrument in one line disturbs the inductive balance of the metallic circuit and so leads to noises from induction. This defect may be overcome by joining the intermediate instrument 'in bridge' across the two lines, which are kept continuous through the intermediate station. Such a plan is shown in fig. 167. Even six or eight stations may work satisfactorily on a circuit in bridge, if properly proportioned fixed resistances are placed in the different sections of the circuit. Each intermediate instrument acts as a derived circuit or 'shunt' on the rest, but the limit to the possible number is generally determined rather by the ringing current required than by the effect on telephonic communication. The bridge system is applied in many cases to exchange working, and in this case the lines are connected to the two springs and the indicators are connected across them, the springs being kept apart in such switches.

It is found that at a telephone Exchange it is scarcely possible for one operator to give proper attention to more than fifty subscribers, so the switches are usually made for

100 subscribers and placed in charge of two operators; it therefore becomes necessary to provide means by which subscribers under the charge of different operators may be placed in communication. This is effected for medium sized exchanges (say from 100 to 200 subscribers) by means of 'through tablets,' fitted with ordinary switch springs connected in pairs between the different switches. For instance, A and B of No. 1 switch might be connected to A and B of No. 2 switch; C and D of No. 1 to C and D of No. 3; and E and F of No. 2 to E and F of No. 3. Then, if subscriber No. 47 wishes to speak to subscriber 258, the operator at No. 1 places a pair of pegs in 47 and (say) C, and instructs the operator at No. 3 to similarly connect C and 258. This system works well for a limited number of subscribers, but when the number becomes considerable the delay in getting through is increased and the labour involved makes satisfactory working impossible. 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 co-operation 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. 168. Each switch, I, II, III, is arranged for a certain number of subscribers (usually 100), sufficient to require the attention of two operators. Each of these switches is fitted with switch springs to accommodate the whole number of subscribers to the Exchange, and the several lines are taken consecutively through each switch; but at only one switch is there any indicator by which a subscriber can gain attention. Thus each operator is able, by means of the switch springs at his own switch and without moving from his place, to put any subscriber directly into communication with any other subscriber, although he still has to attend only to the requirements of a limited number. For instance, if subscriber 2 wishes to speak to subscriber 5, the operator at No. I simply connects 2 and 5 at No. I switch 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 No. III switch would make a similar connection.

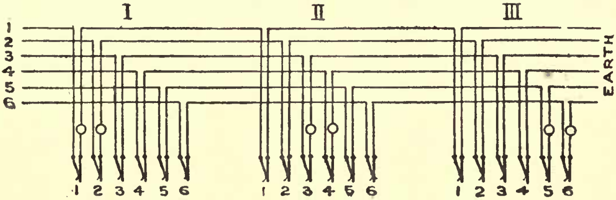


FIG. 168.

The construction of a multiple switch spring for single-wire working is shown in fig. 169. E, the main part of the switch hole, is fixed in position, with its cylindrical end projecting from behind into a hole in the switch board. A is an insulated spring to which the incoming line-wire is connected, and B is an insulated stop on which A normally rests and to which the outgoing line-wire is joined. The cylindrical front end of E is bored to admit the switch peg, which is shown in position at P in the lower figure. When the peg is inserted the incoming line wire is disconnected from the stop B. and joined through P to the body of the switch spring and to the conductor—the flexible cord.

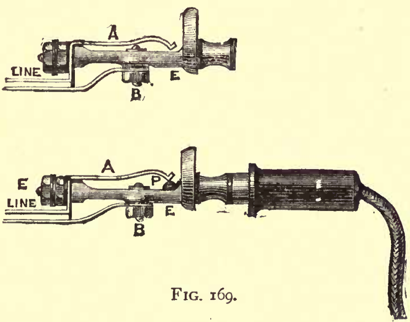


FIG. 169.

Fig. 170 shows the electrical arrangement of the switch for one line passing through three switches. From this it is seen that the line after passing through the switch springs is connected through an indicator to earth, and that a wire connects all the parts E of the corresponding hole at each switch.

When no outside connection is made the line-wire passes through the corresponding spring at each board without

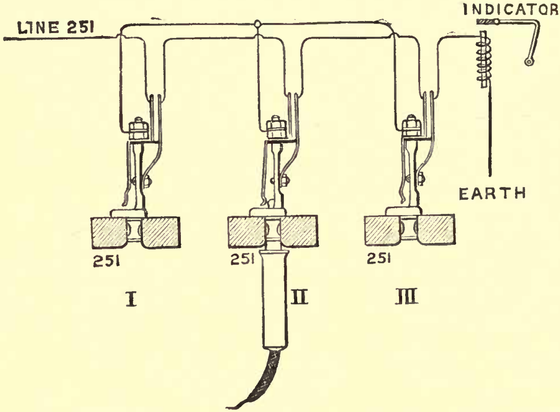


FIG. 170.

touching the mass E, and then goes through the electro-magnet of the indicator to earth. If now, a plug be inserted, say, at switch II, B at that switch, and consequently everything beyond it, is disconnected, and the line is joined to E and to the flexible cord. By means of the flexible cord connections 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, but on this system it is usual to have special 'ringing 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. 170, the clerk at No. I switch inserted a peg, it would interrupt the conversation already arranged for by No. II; whereas, if No. III inserted a peg, it would be simply disconnected. This difficulty is ingeniously provided against by means of the body of the switch springs, E. The insertion of a peg connects the incoming wire not only to the flexible conductor, but also to the piece E 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 his speaking instrument plug into the switch hole of the required subscriber, the operator simply touches the metallic mass E, and if there is no peg inserted in that circuit at another switch no sound will be heard at his telephone, but if there be a connection already made, E 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 a perfectly satisfactory solution of the difficulty in working large exchanges.

Attempts have been made with more or less success to secure multiplex telephony, but for a description of these as well as of the many and various other applications of the telephone the student must be referred to larger and more technical works.[1] In view of the rapid progress already made, there cannot be the least doubt that the future of the telephone will have a most important influence on the business and social conditions of life, and it is also probably destined to be of great service in medical and scientific research.

[1] *The Telephone.* By W. H. Preece, F.R.S., and Julius Maier, Ph.D. (Whittaker).

Owing to their extreme sensitiveness and delicacy, telephones are peculiarly liable to disturbances due to induction, 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. Many plans have been suggested to remove these disturbances, but only one effective plan has been adopted. This is shown in figs. 171 and 172. The use of the earth is entirely discarded, and return wires are employed, so that the circuit is entirely metallic : 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. Fig. 171 shows the plan where a single telephone circuit is erected amongst ordinary working wires. Fig. 172 shows two telephone circuits, each pair of wires diagonally situated being used for a circuit. The plan of using twisted double wires for telephone circuits is gradually coming to be recognised as a necessity by all telephone administrations.

In order to insure against inductive disturbance, twisted wires must be used throughout the circuit, including the underground wire.

At p. 160 is described the retarding influence of the electro-static 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, and the result is that the distance-limit of speaking by telephone upon a telegraph wire is not very great. It depends upon the product of the resistance of the circuit (in ohms) R, and the capacity of the circuit (in micro-farads) K, or K R. The following figures show approxi-

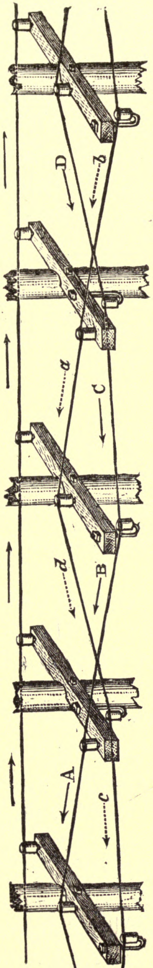


FIG. 171.

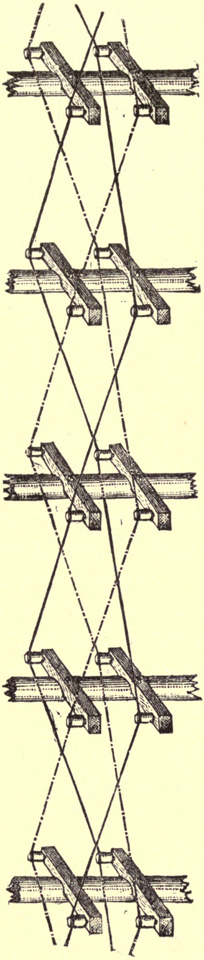


FIG. 172.

mately 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 long telephone circuits should be made of copper wire.

CHAPTER XII.

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 confirm 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 eleven wires, and the third for a maximum of twenty-one 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

[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 an angle approaching to 90°.

same 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	$4\frac{1}{2}$	$5\frac{1}{2}$	$5\frac{1}{4}$	$7\frac{1}{4}$	—	—
26	$4\frac{1}{2}$	6	$5\frac{1}{2}$	8	$6\frac{1}{2}$	$9\frac{1}{2}$
40	$4\frac{3}{4}$	$7\frac{3}{4}$	$5\frac{3}{4}$	$9\frac{3}{4}$	$6\frac{3}{4}$	$11\frac{1}{4}$

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 seven 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. These last answered the purpose on the whole well, and after the lapse of nearly twenty years the poles were reported to be in a very fair state of preservation, and to have required no renewal except in occasional instances where they had rotted near the sockets, owing probably to the latter being too deep in the ground or to the earth having been piled up over them so as to exclude the circulation of air and admit moisture. Such a combination, however, is not satisfactory either for economy or 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 eight 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 rapidly 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

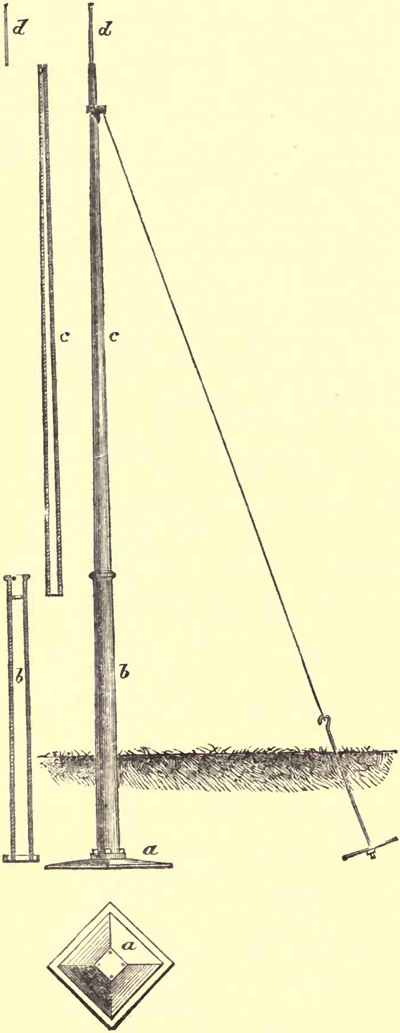


FIG. 173. $\frac{1}{45}$ real size.

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 which are given in fig. 173. It consists of four parts, viz.: 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, to which is welded an iron ring, for the reception of the lightning-conductor.

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.*

Another pattern of iron pole which has been largely introduced into India, where its employment for several years has given great satisfaction, and where it has been considerably modified and improved by Col. Mallock, is that known as Hamilton's Standard (fig. 174).

Each standard consists of—

2 or more galvanised wrought-iron tubes *a* and *b*,
1 cast-iron socket *c*,

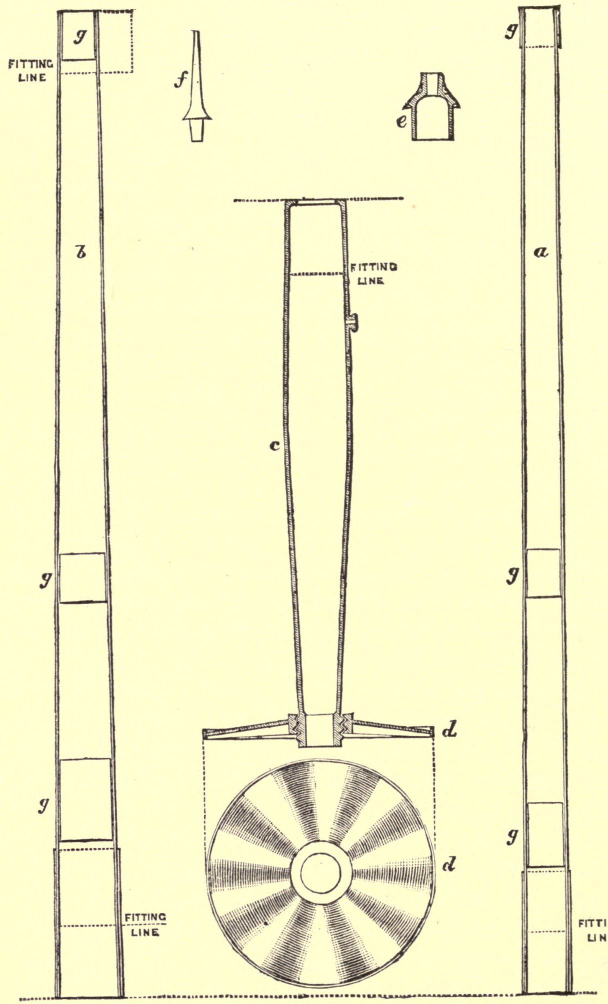

g
FITTING LINE
f
e
g
FITTING LINE
b
a
c
g
g
d
g
d
g
FITTING LINE
FITTING LINE

FIG. 174.

1 cast-iron disc-plate *d*,
1 galvanised cast-iron cap *e*,
1 galvanised cast-iron lightning-conductor *f*.

The wrought-iron tubes are, as a rule, each eight feet long, and are made in a series to one taper, so that two, three, four, or five may be joined together to form one pole in combination with corresponding sizes of caps, sockets, &c. Each tube fits into the size smaller and on to the size larger than itself, and is strengthened by broad rings *g g*. They are put together by simple hammering.

Wooden tops were tried upon similar poles in India, but proved a failure; the timber was speedily destroyed before the ravages of the white ants. The insects made their way up the hollow iron tube until they reached the top, which crumbled away under their attack.

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 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

[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 241 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). Wire 121 mils diameter is used for all short circuits of minor importance. For binding purposes a smaller wire (diameter 65 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 $1\frac{1}{2}$-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 $1\frac{1}{2}$ 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 in it.

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. 175. 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.

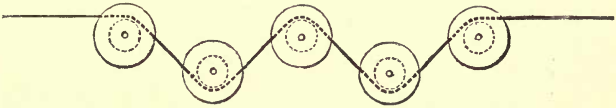


FIG. 175.

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. Good soft iron wire suitable for employment for telegraph purposes should be able to bear from 18 to 20 per cent. elongation in 10-inch lengths. The breaking strain will of course vary according to the gauge of the wire ; that for 400 lbs. should not be lower than 1,200 lbs., and for 200 lbs. not less than 650 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; 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 uniformly 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 given in the Table. Each piece must be warranted not to contain any weld, joint, or splice whatever, either in the rod before it is drawn, or in the finished wire.

(3) The wire is to be well galvanised, 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 coil or coils 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 coils of the 800-lbs. wire shall also bear bending round a bar $2\frac{1}{2}$ 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 $2\frac{1}{4}$ 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 $1\frac{1}{2}$ inches in diameter.

(4) After having been galvanised the wire is to be passed under and over four or more rollers or pulleys, placed at such distances and in

[1] The words in thick type are inserted only for charcoal wire.

such positions (fig. 175) as the Inspecting Officer shall from time to time determine, for the purpose of testing the quality of the wire as regards freedom from splits; and to be then 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. The wire to be smoothly and uniformly coiled so that the eye of the coil shall be not less than 26 inches or more than 30 inches in diameter.

(5) Should more than 5 per cent. of the coils break or show any defect during the straightening, the whole of the broken coils or 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) are not to 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 they may either be conveniently jointed on the work before being paid out, or that broken coils may be chosen for short lengths when required.

(6) Every piece may be gauged for diameter in one or more places. No deviation from the standard diameter greater than is shown in the Table will be allowed.

(7) Every piece may be tested for ductility and tensile strength, and 5 per cent. of the entire number of coils may be cut and tested in any part. Pieces cut for this purpose, or for weighing samples, are not to be welded or jointed together again, but to be treated as specified in Clause 5.

(8) 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 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.

(9) 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 is at first to 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.

(10) The electrical resistance of the wire is not to exceed the limit shown in the said Table, and the resistance of each test piece is to be reduced according to its diameter, such test piece being not less than one-thirtieth ($\frac{1}{30}$th) part of an English statute mile in length. 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.

(11) It must be understood that the tests referred to in paragraphs 3, 8, 9, and 10 are to be applied to the wire after it has been straightened, as specified in paragraph 4.

(12) If after the examination of any particular parcel of wire 10 per cent. of such wire does not meet the requirements of all or any of the foregoing stipulations, 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.

(13) Each piece of wire, when approved by the Inspecting Officer after examination and testing, is to be made up into a coil and separately bound, and in no case are two or more lengths of wire to be linked or otherwise joined together. The coils are to be made up in bundles within the limits of weight shown in the Table, and properly bound.

(14) Every bundle of approved wire is to be weighed separately and the weight (in English lbs. avoirdupois) stamped on a metallic label which shall be provided by the Contractors; the label to be firmly affixed to the inner part of the bundle. The Contractors shall also provide the necessary assistance 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.		ohms	lbs.
800	767 833	242	247 237	2,480	15	2,550	14	2,620	13	6·75	90 120
600	571 629	209	214 204	1,860	17	1,910	16	1,960	15	9·00	90 120
450	424 477	181	186 176	1,390	19	1,425	18	1,460	17	12·00	90 120
400	77 324	171	176 166	1,240	21	1,270	20	1,300	19	13·50	90 120
400	*377 424*	*171*	*176 166*	*1,025*	*23*			*1,075*	*20*	*12·00*	*90 120*
200	190 213	121	126 118	620	30	638	28	655	26	27·00	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 4,800, and for the best quality ordinary wire as specified above the constant is 5,400. For example, with 400 lbs. charcoal wire $400 \times 12 = 4{,}800$; or with 600 lbs. ordinary wire $600 \times 9 = 5{,}400$. 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. 251 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. The improvement effected of late years in the manufacture in this respect is shown by the fact that the conductivity of the last Atlantic cable laid (1883) was more than double that of the first, which was laid in 1856.

For overhead lines, however, 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. Attention was consequently directed to these matters, with the result 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 $22\frac{1}{2}$ 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 that of iron, its electro-magnetic inertia (p. 238) 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. 236). For long telegraph lines, therefore, and for most 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 diameters 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, and its weight (in English lbs. avoirdupois) stamped on a soft copper label which shall be provided by the contractors, the label being firmly affixed to the inner part of the coil. The contractors shall also provide the assistance necessary for properly affixing to each coil of approved wire, under the direction of the inspecting officer, a metallic seal which shall be provided by the Postmaster-General, 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.

(10) The approved wire shall be wrapped in canvas, and be delivered as required, securely packed in casks or cases.

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.		ohms	lbs.
100	$97\frac{1}{2}$ $102\frac{1}{2}$	79	78 80	330	30	9·10	50
150	$146\frac{1}{4}$ $153\frac{3}{4}$	97	$95\frac{1}{2}$ 98	490	25	6·05	50
200	195 205	112	$110\frac{1}{2}$ $113\frac{1}{4}$	650	20	4·53	50
400	390 410	158	$155\frac{1}{2}$ $160\frac{1}{4}$	1,300	10	2·27	50

[1] Except in the case of pieces cut for testing, as provided for in paragraph 3 of the Specification.

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 has recently taken the matter in hand, 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 as the square of its diameter—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 are adopted as a basis there is a ready means of correcting the gauge at all times. At the suggestion of Col. Mallock, the late Director-General, the Government Telegraph Department of India has 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;

[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 good material, when the glaze cracks moisture enters the mass, 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. 176 shows that usually 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

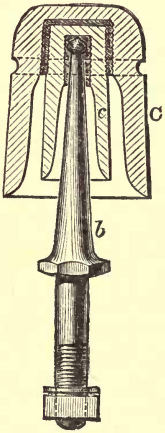


FIG. 176. ½ real size.

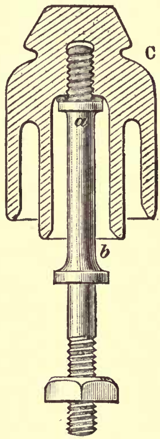


FIG. 177. ¼ real size.

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.

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 and the cement and earthenware under changes of temperature. This difficulty has been entirely removed by the introduction of Cordeaux's screw insulator, shown in fig. 177. The principle can, of course, be applied to any form of insulator, but fig. 177 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 XIII.

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.

SURVEY of from to

1 Number of Pole	2 Span	3 Distance from	POLES 4 Length	 5 Quality	6 Stay or Strut	7 REMARKS as to Consents, Obstacles, &c.

This schedule explains itself; yet it may be well to state that —

Column 1 contains the consecutive number of each pole, from one terminal station to the other.

Column 2 contains the span, or distance between each successive pole.

Column 3 gives the distance from some fixed object; the fence or ditch, for instance, in the case of a road line, or the metals for a line constructed upon the railway. This is to guide the hole-diggers in the event of the marks made by the surveying officer to indicate the position of the pole having been removed.

Column 4 gives the length of the poles.

Column 5 explains the character of the pole required, which will depend upon the work which it has to do. O is used to represent the pole of ordinary scantling, S for a stiff pole, and V S for a very stiff one. If A-poles or double poles are necessary, the fact should be indicated in this column.

Column 6 states whether a stay or strut is required, and, if so, whether single or double, and should give the strength or number of wires necessary for the stay, and the length of the strut.

Column 7 is intended to provide for any additional particulars which may be deemed necessary, such as shackling, crossing roads, noting any obstacles in the way, the names and addresses of those who will have to be consulted in the matter of way-leave, &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.

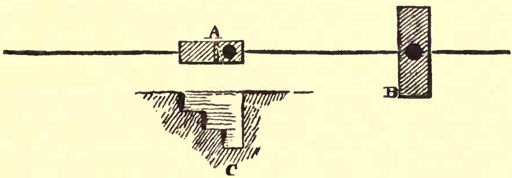


FIG. 178.

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. 178), 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 two 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 seen that there is room for improvement in this branch of telegraph construction.

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. 179.

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. 180. The cutting blade, a plan and elevation of which is given in fig. 181, 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

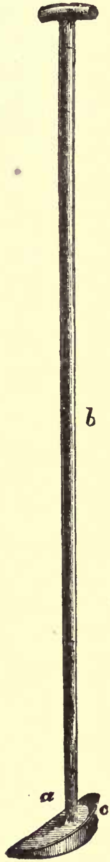


FIG. 179.
$\frac{1}{18}$ real size.

removed from time to time by lifting the apparatus out of the ground. The stock to which the blade is attached is

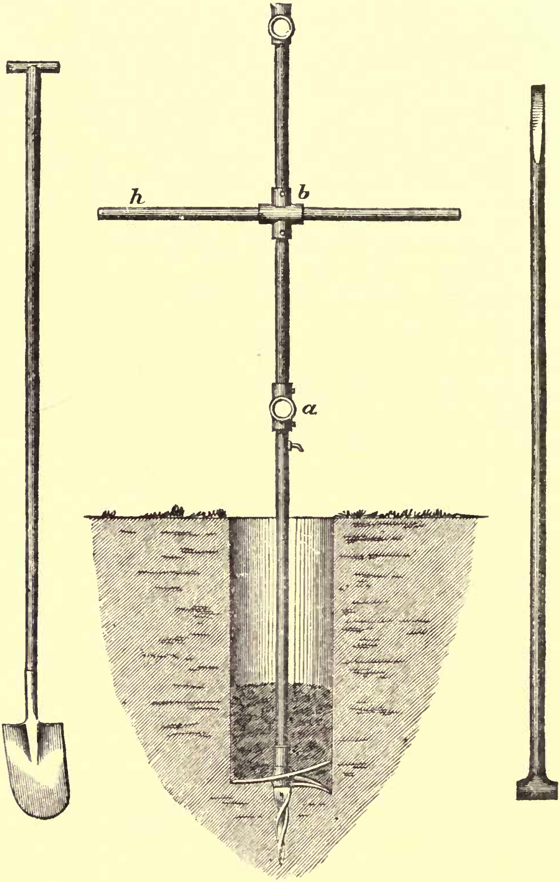


FIG. 180. $\frac{1}{24}$ real size.

squared at the end, and has screwed on to it a tapering metal point, which, in addition to serving as a nut, plays the 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. 180, to admit of the insertion of the handle *h*, which is employed for rotating and lifting the apparatus.

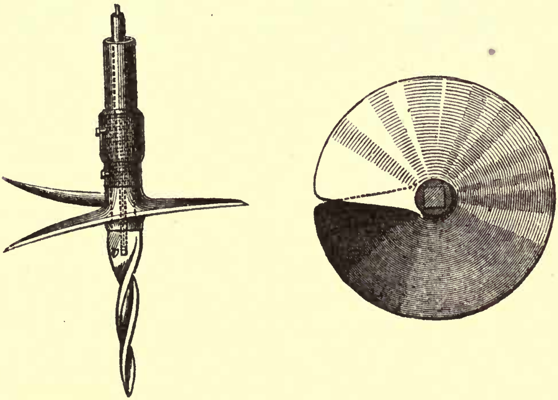


FIG. 181. $\frac{1}{15}$ real size.

The 'punner bar' forms an essential feature of Marshall's borer. It is shown to the right in fig. 180. 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. 180, 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 obtained : 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 *v* (fig. 181), 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 wait for 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.

Notwithstanding the advantages to be derived from the use of special appliances of the above type, they have fallen into general disuse in England. 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 into contact with

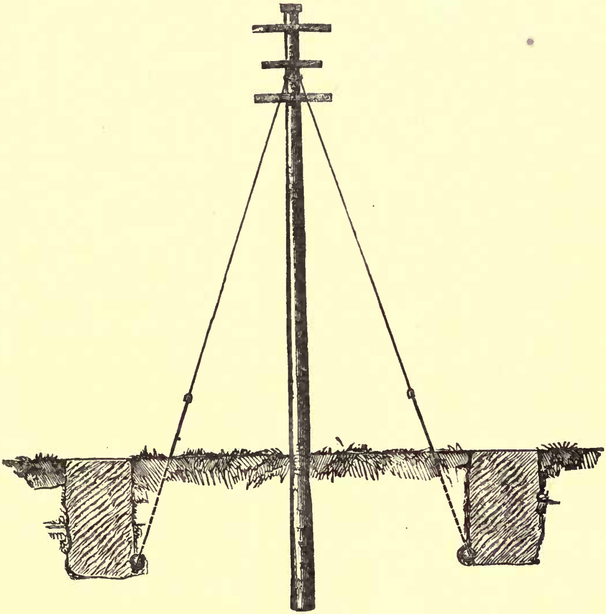


FIG. 182.

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. 182. 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.

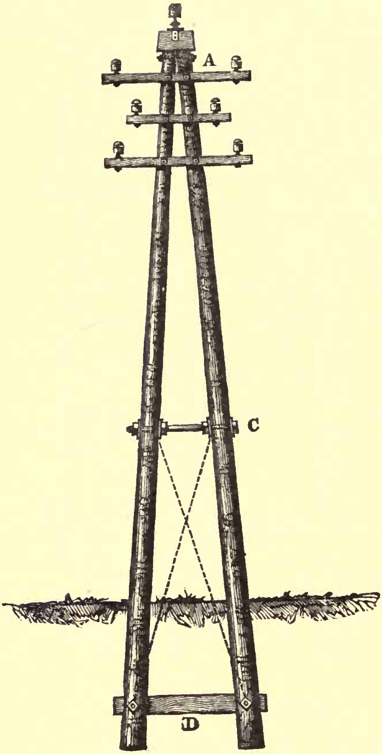


FIG. 183.

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

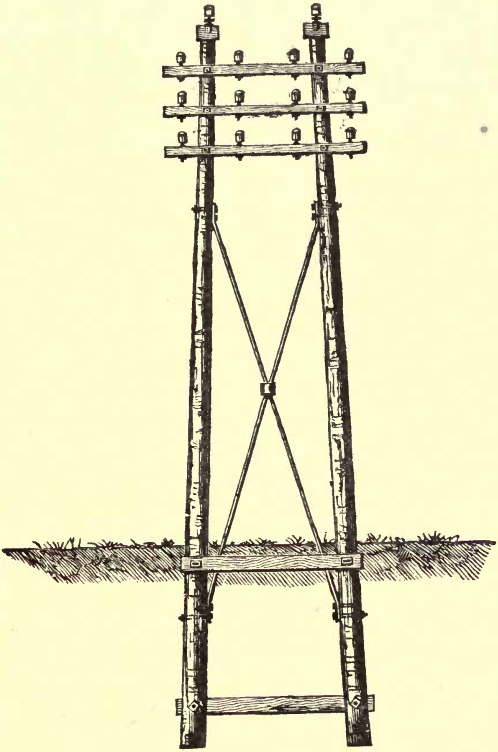


Fig. 184.

less danger results from taking this step than by leaving the wires to follow the outside of the curve.

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. 183. It consists of two ordinary poles scarfed at the top so as to fit into each other closely, and united together by means of a bolt, shown at 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. When the poles are long, or have to bear an exceptionally heavy strain, they are further strengthened by being braced together by two iron rods, indicated in the figure by dotted lines.

Where several lines converge, and the number of wires for the same line of poles thus becomes unusually great, *double poles* fitted together in the manner shown in fig. 184 are employed. Two ordinary poles are braced together by cross-pieces of wood bolted on to them on reverse sides. They are further strengthened by two iron rods placed diagonally in the manner shown in the figure, and securely attached by bolts to each pole.

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. 243); the following is the mixture for paint usually adopted in England :—

For 100 lbs. of paint—

White lead	70 lbs.
Driers	5 lbs.
Umber	5 oz.
Boiled oil	10 quarts
Turpentine	5 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. 277) that the stability and efficient working of a line depends 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. $7\frac{1}{2}$ (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 cf 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. $7\frac{1}{2}$'s will be sufficient, for ten wires five No. $7\frac{1}{2}$'s, and for thirteen wires seven No. $7\frac{1}{2}$'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 accepted 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.

The lower end of the stay is fixed to the eye of a galvanised iron rod (fig. 185) 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. 185, so that the stay-block may have firm solid earth to press against, and thus be prevented from drawing.

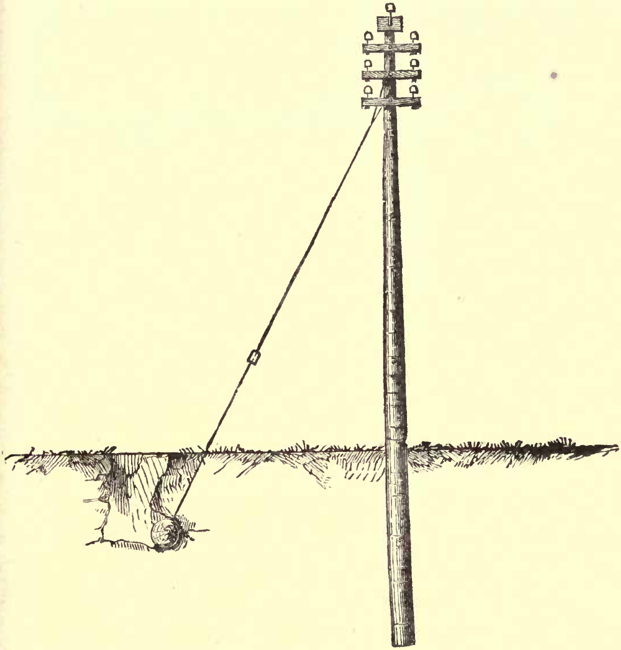


FIG. 185.

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. 186. Pick out one strand and lay the others symmetrically around the main stay as shown in the figure, the tool being placed 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

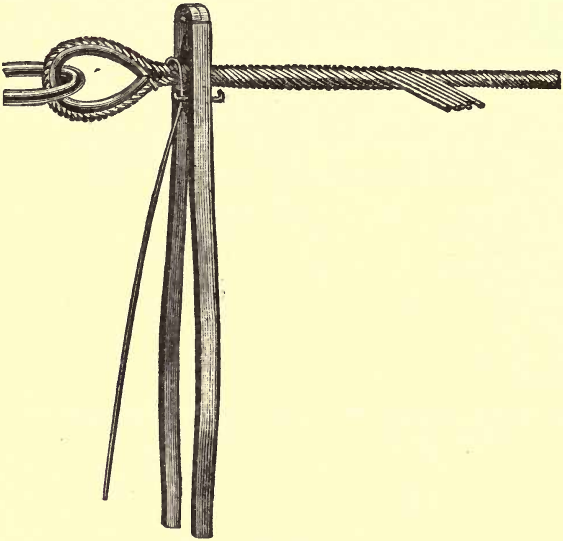


Fig. 186.

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. 187 should be employed, whose wires, coming from E and D and uniting at B, are continued on and fixed to

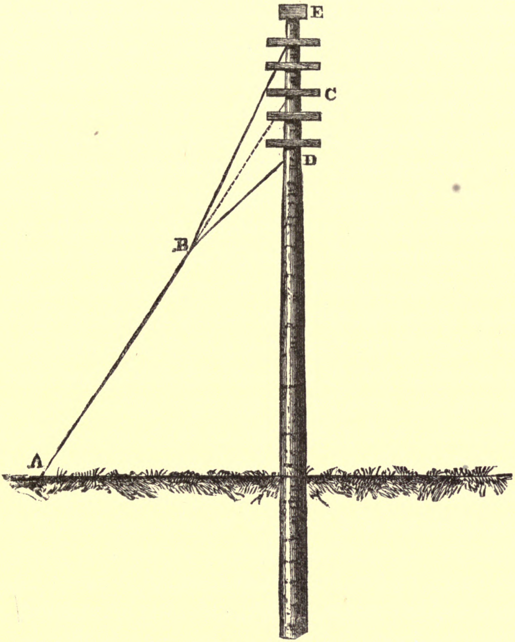


FIG. 187.

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 is 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. Should two rods and blocks be used, the stays should be placed symmetrically so as not to offend the eye.

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 extent 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 strains 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 strains of the wires terminated. Thus, with twelve wires, each having a breaking strain of 1,200 lbs., the maximum stress along the stay will approximately equal 1,800 lbs. for each wire; and a one-inch iron rod with a breaking strain of twenty tons per square inch would 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. 288)—from any sudden strain being thrown from either quarter upon the pole.

Struts.—It is more difficult to erect struts to satisfactorily withstand heavy strains 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 advisable to fix the strut at that point of the pole which, allowing for future requirements of the line, will ultimately be the resultant point. 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.

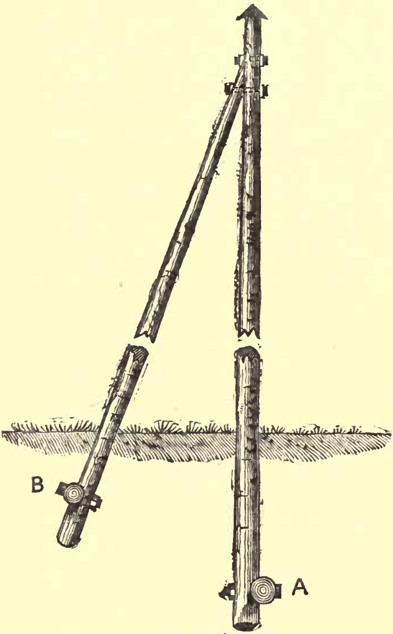


Fig. 188.

The proper method of fixing a strut is shown in fig. 188. 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 two bolts placed as shown in fig. 188. In the case of long poles a connecting tie-rod A (fig. 189) is bolted through about half-way down; and, as an extra precaution against the bottom of the pole being 'levered' out of the ground, a cross-piece of good stout timber, B, may be bolted on to both the strut and the pole about three feet six inches below the surface of the ground. It is needless to add that all stays and struts should be fixed before the wires are erected or any force whatever brought to bear upon the poles.

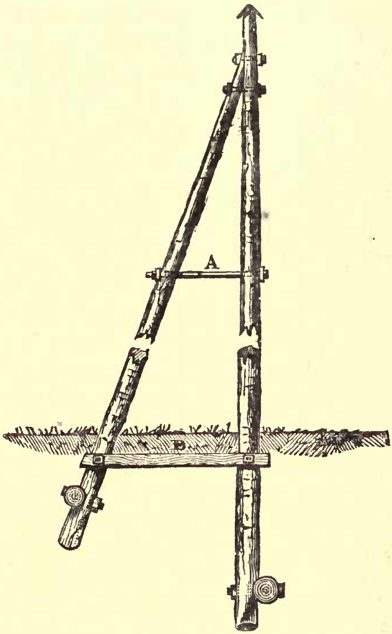


FIG. 189.

Fitting-up the Pole.—With the exception of placing the bolts 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. 190, 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 $1\frac{1}{2}$-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. 190, and 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 bolt 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. 190.

The supports for the insulators are either wooden *arms* or iron *brackets*, the latter being used only under exceptional circumstances. The arms in England are of oak, and ought to be thoroughly well seasoned previous to being issued. Where 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. $2\frac{1}{2}$ 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. Where four wires are erected upon each arm, the usual length for single poles is 44 inches; but longer arms are employed for double poles and in exceptional cases.

The first arm is placed 8 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 $1\frac{1}{2}$ 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 $7\frac{1}{2}$ inches upwards, according to the scantling of the timber. The head of the bolt on the 'down' side of a pole (fig. 192) beds upon a washer, whilst on the 'up' side in front of the arm, as shown in fig. 191, a nut with a washer clamps the arm in position.

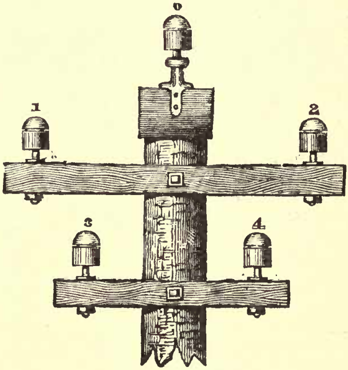


FIG. 191. Up Side of Pole.

Pole-brackets, except the saddle brackets already alluded to, are of a tubular form (fig. 193), and made of malleable iron. They are secured to the pole by means of three 3-inch nails. 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. 193, 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 is done the

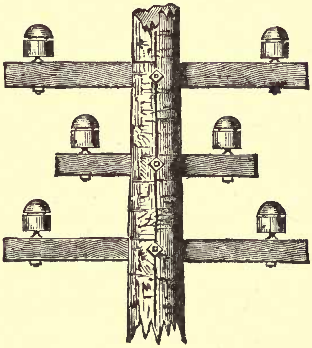


FIG. 192. Down Side of Pole.

risk of contact in the event of the insulators getting broken or proving faulty is incurred. The nails would often touch each other in the head of the pole, and so 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

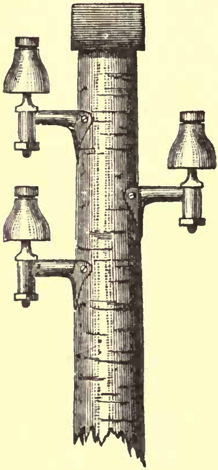


FIG. 193.

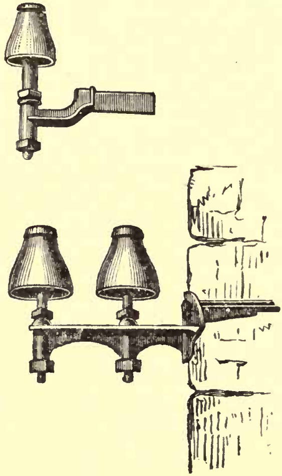


FIG. 194.

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. 194.

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 is no other wire upon the line, makes its way entirely to earth by means of the pole. The only evil resulting from this will be a weakening of the signals, which, until the defect is made good, can be remedied by increased battery power. But if there are 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 No. $7\frac{1}{2}$ 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 of the pole. In fig. 192 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 bolts 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 strain 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 terminated; 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. 195 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

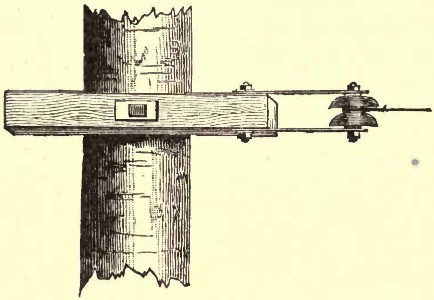


FIG. 195.

use on short lines where 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 bolts of extra strength, and made with a broad flange to give a considerable bearing upon the arm. For actual terminations, special large terminal insulators on extra strong steel bolts are employed. These are fixed upon arms three inches square, which are attached to the poles in the line of the wires.

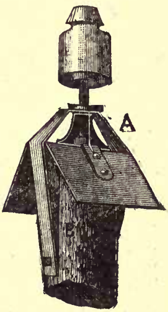


FIG. 196.

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. 196. 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 bolt 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 $3\frac{1}{2}$-inch coach screws.

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. 197. 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.

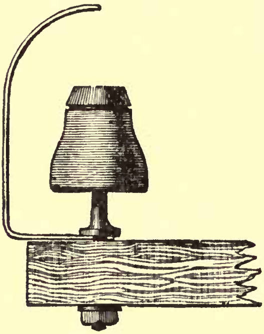


FIG. 197.

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, about a quarter of a mile, 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

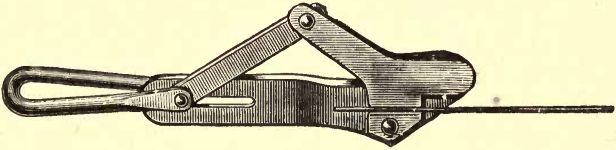


FIG. 198.

are then applied to the wire, a species of vice, technically known as the *draw-tongs* (fig. 198), being used to grip it. By means of this the wire is drawn as tight as may be required, and the actual strain 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

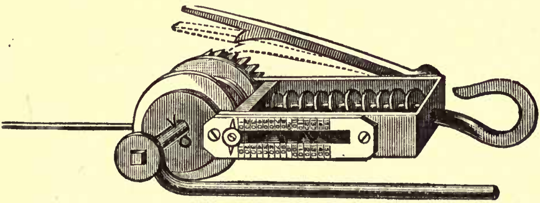


FIG. 199.

form shown in fig. 199. 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 strained-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 is pulled up too tightly it breaks; if it is left too slack, it is 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 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 are drawn is one-third of their breaking strain; for instance, 600 and 200 lbs. wire, whose breaking strains are respectively 1,860 and 620 lbs., should never be drawn up with a tension greater than 620 lbs. for the former and 210 lbs. for the latter. When this tension is employed it is found that the dip will be two feet in a span of 100 yards. Since copper has come into more general use for aerial wires, however, it has become necessary to make the factor of safety in erecting wires *four* instead of three; that is to say, the wires on all new lines are drawn up to only one-quarter of their breaking strain.

The following simple formulæ admit of the ready calculation of the sags and stresses, having given the weight of the wire and the length of the span:

Let

l = span in feet;
d = sag (or dip) in feet;
s = stress in lbs.;
w = weight of one foot of wire

Also,

w for 400 lbs. iron = ·075758 lb. per foot.
„ 150 „ copper = ·028409 „ „
„ 100 „ „ = ·018939 „ „

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

Thus, to calculate the sag of a 200 lbs. iron wire breaking strain 620 lbs.) in a 100 yards span, with a factor of safety of 3 :—

$$l = 300 \text{ feet}, w = \cdot 037878, \text{ and } s = 210.$$

Then $$d = \frac{300^2 \times .037878}{8 \times 210} = 2 \cdot 029 \text{ feet}.$$

To erect such wires with any given factor of safety it would appear at first as though it would be sufficient, disregarding the question of dip, simply to pull them up to one-third or one-fourth the breaking stress by means of the tension ratchet. The problem, however, is not so simple, for the effects of temperature modify the stresses and sags in a very material degree. Thus, if a 200 lbs. iron wire be erected at low winter temperature (say 22° Fahr.) with a stress of 135 lbs., it will have a dip of 3 feet $1\frac{3}{4}$ inch, and the length of the wire will be 300 feet $1\frac{1}{16}$ inch; but when the temperature has risen to 76° the length of the wire will be 300 feet $2\frac{7}{16}$ inches and the stress will have dropped to 90 lbs., whilst the sag will be increased to 4 feet $8\frac{7}{8}$ inches. Conversely, if the wire be pulled up to one-fourth its breaking strain at 76° Fahr. it would, through the effects of contraction, have reached its breaking strain, if it were perfectly inelastic, before the temperature had dropped to 22°, and breakage would only be avoided by the elongation of the conductor due to its elasticity.

In order to facilitate the erection of wires so as to avoid the difficulties referred to above, it is necessary to calculate the sags and stresses for various usual spans at varying temperatures, based upon the factor of safety to be adopted. The following table, issued by the British Post-Office, is based on a factor of safety of 4 at low winter temperature for the various wires used by the Telegraph Department.

Tables of Sags and Stresses to be observed in erecting Wires at various Temperatures.

Span	22° F. Low Winter temp.			40° F. Ordinary Winter temp.			58° F. Average Summer temp.			76° F. High Summer temp.		
	Sag		Stress	Sag		Stress	Sag		Stress	Sag		Stress
400 lbs. Iron Wire (No. $7\frac{1}{2}$).												
yds.	ft.	in.	lbs.	ft.	in.	lbs.	ft.	in.	lbs.	ft.	in.	lbs.
100	3	$1\frac{3}{4}$	270	3	9	227	4	$3\frac{1}{4}$	200	4	$8\frac{7}{8}$	180
90	2	$6\frac{5}{8}$	270	3	$1\frac{3}{4}$	219	3	$2\frac{3}{4}$	190	4	$0\frac{7}{8}$	169
80	2	$0\frac{1}{4}$	270	2	$7\frac{1}{8}$	210	3	$0\frac{3}{4}$	178	3	$5\frac{5}{8}$	157
70	1	$6\frac{1}{2}$	270	2	$1\frac{1}{4}$	198	2	$6\frac{1}{2}$	164	2	$10\frac{7}{8}$	143
60	1	$1\frac{5}{8}$	270	1	8	184	2	$0\frac{3}{4}$	148	2	$4\frac{3}{4}$	128
50	0	$9\frac{1}{2}$	270	1	$3\frac{1}{2}$	165	1	$7\frac{3}{4}$	130	1	$11\frac{1}{4}$	110
150 lbs. hard drawn Copper Wire (No. $12\frac{1}{2}$).												
100	2	8	120	3	7	89	4	$3\frac{7}{8}$	74	4	$11\frac{1}{2}$	64
90	2	2	120	3	1	84	3	$9\frac{1}{2}$	69	4	$4\frac{1}{8}$	60
80	1	$8\frac{3}{8}$	120	2	$6\frac{7}{8}$	80	3	$2\frac{1}{2}$	64	3	$8\frac{7}{8}$	$54\frac{1}{2}$
70	1	$3\frac{5}{8}$	120	2	$1\frac{3}{4}$	73	2	$8\frac{5}{8}$	$57\frac{1}{2}$	3	$2\frac{1}{2}$	49
60	0	$11\frac{5}{8}$	120	1	9	66	2	$3\frac{1}{8}$	51	2	$8\frac{1}{4}$	43
50	0	8	120	1	$4\frac{5}{8}$	58	1	10	44	2	$2\frac{3}{8}$	$36\frac{1}{2}$
100 lbs. hard drawn Copper Wire (No. 14).												
100	2	8	80	3	7	59	4	$3\frac{7}{8}$	49	4	$11\frac{1}{2}$	43
90	2	2	80	3	1	56	3	$9\frac{1}{2}$	46	4	$4\frac{1}{8}$	40
80	1	$8\frac{3}{8}$	80	2	$6\frac{7}{8}$	53	3	$2\frac{1}{2}$	$42\frac{1}{2}$	3	$8\frac{7}{8}$	36
70	1	$3\frac{5}{8}$	80	2	$1\frac{3}{4}$	49	2	$8\frac{5}{8}$	38	3	$2\frac{1}{2}$	33
60	0	$11\frac{5}{8}$	80	1	9	44	2	$3\frac{1}{8}$	34	2	$8\frac{1}{4}$	29
50	0	8	80	1	$4\frac{5}{8}$	39	1	10	29	2	$2\frac{3}{8}$	24

NOTE.—The Sag varies with the material, but not with the gauge; the Stress varies with both the gauge and the material. The Stress for 200 lbs. (No $10\frac{1}{2}$) Iron Wire is half that for 400 lbs. Iron Wire. The Stress for 200 lbs. (No. $11\frac{1}{2}$) Copper Wire is double, and for 400 lbs. (No. $8\frac{1}{2}$) is four times that for 100 lbs. Copper Wire.

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.

Binding.—The wire, having been duly stretched, is next placed in the groove of the insulator, and, if iron, is very tightly bound to it, in the manner shown in fig. 200. No. 16

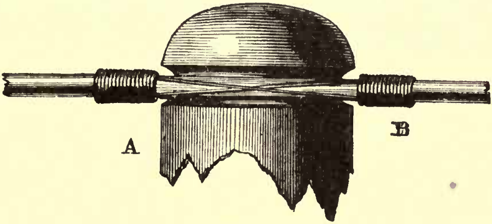


FIG. 200.

galvanised charcoal iron wire is always used for binding iron wire. It is cut up into lengths varying from 36 inches for a 200 lbs. wire to 50 inches for an 800 lbs. wire, and is used as follows: It is first of all lapped around the line-wire at A (fig. 200), then drawn as tightly as possible twice round the insulator, crossing the line-wire as shown in the figure, and again round behind the insulator to B. It is then lapped a few turns along the line-wire at B and back, and again taken behind the insulator back to A, where it is terminated by being lapped over the first lapping there.

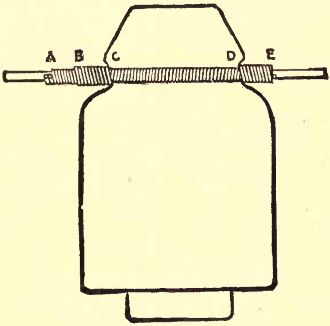


FIG. 201.

A modified form of binder, which is used for copper wire, is shown in fig. 201. *Two* wires are whipped round the line-wire from B to E, thence back to D, then, from the *upper* side of the line-wire they are taken around the neck of the insulator to the *under* side of the line-wire at C, back over the first layer to B, and then taken on as a single layer to A. The length of wire used in this case is 40 inches for 100 lbs. wire and 52 inches for 150 lbs. No. $17\frac{1}{2}$ soft copper wire, weighing 50 lbs. per mile, is used except for 400 lbs. line-wire, when 65 lbs. binding-wire is employed.

If the position of a pole has, either on account of renewal or from any other cause, 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 on to the wires. Should any portions be allowed to remain, they are apt, by taking up a swinging motion, to so wear down the line-wires that they break at the first touch of frost.

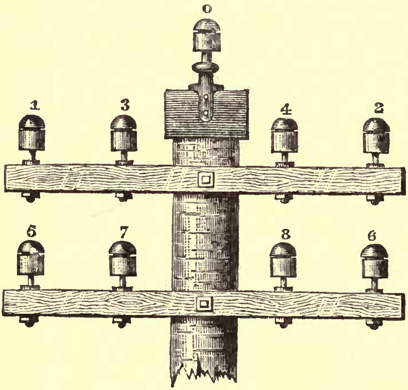


FIG. 202.

Numbering of Wires.—It is desirable that the wires when once 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 your 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. 191. Similarly, when there are four upon an arm they should be numbered as shown in fig. 202, so that at points where the wires are transferred to short arms, 3 and 4, 7 and 8 naturally fall into their proper places.

Joints.—Bad joints in telegraph wires have given rise to more trouble than any other defect, for not only have the faults caused by them been more numerous, but the time spent in localising them has been greater than is the case with faults of any other description; for, as each joint in open wires is generally at some little distance from the support, the examination of it is a tedious and difficult matter.

FIG. 203.

The first form of joint made in open telegraph wires was the common bellhanger's joint, which consists in merely hooking the two wires together. Binding-wire was next employed, and continued over the hooks in order to ensure the continuity, which, owing to oxidation, was frequently destroyed. This joint is shown in fig. 203. The vibration

FIG. 204.

to which the wire is constantly subject when erected in the air was found to act upon the binding-wire, and render the joint unsafe. A further modification was thus rendered necessary, and bolts and nuts were added as shown in fig. 204. These also proved a source of infinite trouble. The lapping wire was destroyed, and oxidation setting in between the bolt and the wire broke down the circuit.

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. 205, 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 as a flux chloride of zinc, formed by killing free hydrochloric acid (commonly known as

FIG. 205.

'spirit of salts'), by the insertion of a few small pieces of zinc; or preferably a prepared flux known as 'Baker's fluid' may be employed; 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. Any excess of the flux should be wiped off, so as to prevent its acting upon the wire, and no two joints should ever be made close together when terminating, for the flux, which may not be entirely removed from the space separating them, speedily eats through the wire; three inches at least should be allowed to intervene between them. 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; for the same reason no joints should be made more than fifty feet from the poles; when at a greater distance than this they are apt to hitch up when the wires are blown about by strong winds.

Terminating.—The wire is very often terminated on a shackle. This shackle is placed on an arm which is fixed in line with, not transverse to, the wire, and the method in which the wire is attached to the shackle is shown in fig. 195. It is simply bent round the porcelain and then bound in exactly the same manner as an ordinary joint, with the exception that it need not be soldered.

The present form of shackle is anything but well suited for its purpose : the current can escape either by the upper or lower portion of it ; and for this reason a strong porcelain insulator, similar in form to that shown by fig. 177, in which the bolt passes nearly to the top of the insulating material, is now more generally used, and acts much more efficiently as an insulator (p. 296).

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, so that the line-wire itself is continuous.

The leading-in wire from the terminal pole 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 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.

Shackles are almost invariably employed as the insulators, in order to lessen the friction which is inherent to the long spans that have to be taken, as well as to reduce to a minimum the risk arising from the breakage of the wires. The 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 roof of houses, the leads have been melted and the building 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 tried, and even in these brackets should never be inserted, 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, indiarubber, 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.

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 XIV.

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.

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 danger is always more or less 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, creosote 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 time gradually discontinued, and is now entirely abandoned. In place of boarding, cast-iron pipes are now universally 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 has been very extensively tried, but it failed owing to the difficulty experienced in maintaining sound joints. Roots from vegetation entered through the joints, and grew in the pipes until they became so thoroughly choked that it was impossible to withdraw the wires for repairs.

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 one inch, and the following may be accepted as a general rule for guidance upon the point :

From 1 to 8	No. $7\frac{1}{2}$ prepared	G.P. wires	1 inch pipe
,, 8 to 16	,,	,,	$1\frac{1}{2}$,, ,,
,, 16 to 24	,,	,,	2 ,, ,,
,, 24 to 48	,,	,,	$2\frac{1}{2}$,, ,,
,, 48 to 80	,,	,,	3 ,, ,,
,, 80 to 128	,,	,,	4 ,, ,,

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 to 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 depth 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. $7\frac{1}{2}$ 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. It has on occasion been accomplished by sending a rat through the pipe with a string attached. 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. 206, 207, and 208 show the construction of one of these boxes; being respectively a plan of the lid, a longitudinal section of the

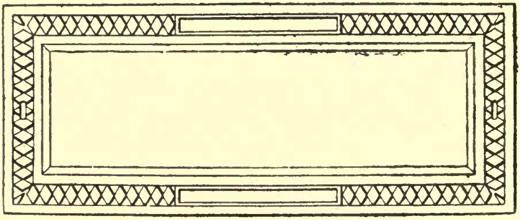


FIG. 206. $\frac{1}{12}$ full size.

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

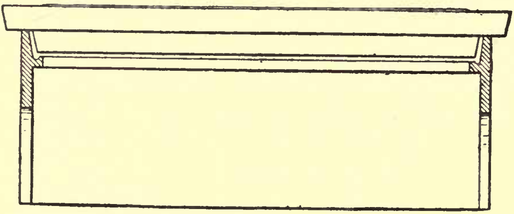


FIG. 207. $\frac{1}{12}$ full size.

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.

As a general rule the wire employed for tunnel and underground work in England is that known as No. $7\frac{1}{2}$ prepared gutta-percha. The copper conductor is No. 18 gauge, and is insulated with gutta-percha up to the gauge of No. $7\frac{1}{2}$; 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.

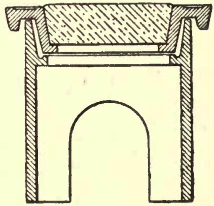


FIG. 208. $\frac{1}{12}$ full size.

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. 209): 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

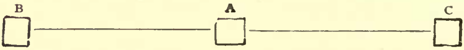


FIG. 209.

fig. 210, 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

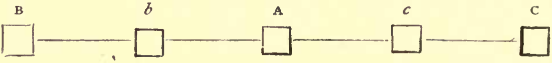


FIG. 210.

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.

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.

Jointing Covered Wires.—When the section of cable has been finally laid and the numbering of the wires correctly seen to, the jointing is proceeded with. It is impossible to lay too much stress upon the importance which attaches to the proper execution of this portion of the work. Of all the operations which are carried on in practical telegraphy there is none which requires more care and attention—none which if in the slightest degree neglected, or in any way slurred over, will prove a more fruitful source of trouble. Combined with much practice and experience, it demands a close attention to the minutest details, as well as some physical qualifications, the want of which renders a man unfit to be engaged for the work. Before entering into the details of out-of-door jointing of gutta-percha wires, it may be well to draw attention to the main points which should be most carefully seen to. Foremost amongst these stands *cleanliness.*

A lack of *cleanliness* is the cause of more bad joints than anything else. Not only should the jointer's hands be scrupulously clean, but he should see that the wires to be joined are equally so, the copper being scraped bright and clean, and the insulating covering freed from tar, dirt, and grease. The materials and the tools employed by him should receive the same careful attention, every trace of dirt, dust, or rust being removed from them.

Dissimilarity in the material supplied to the jointer must be guarded against; unless the materials are exactly the same as those employed in the manufacture of the wire, a perfectly homogeneous and thoroughly reliable joint cannot be made.

The physical qualifications alluded to consist first of all of perfect health. It is a well-known fact, proved by experience, that the work of even the best jointers cannot be relied upon when they are in an indifferent state of health. In some men, again, a greasy sweat is constantly issuing more or less from the pores of their hands, and this will of itself prevent the various coatings of the joint from firmly adhering to each other.

Again, *patience* is a very necessary virtue in gutta-percha jointing, especially in the open air. The difficulty of keeping the lamp alight and in applying the requisite amount of heat, especially in rough weather, must be steadily encountered. It is better to wait, and abandon the making of a permanent joint altogether for a time, until the weather moderates, rather than run the risk of making an imperfect one.

The following instructions, based upon a very large experience in the making and superintending the making of joints in gutta-percha covered wire, should be most carefully attended to, even to the minutest details :—

Preparatory.—The joint-box where the joints are to be made is first opened, the jointer's box, containing his tools, placed on one side of it, and then a tent placed over the box so that the opening in the tent is opposite the jointer's box.

Attached to the box should be two low stools for the jointer and his assistant to sit on, to keep them clear from the wet pavement or damp ground.

The box should be opened and the various tools, spirit-lamps, furnace, &c., placed where most handy; the spirit-lamp for the furnace should be lighted and the soldering-iron heated ; the gutta-percha tools should, if dirty or sticky with compound, be filed and cleaned.

Great care must be taken to keep the gutta-percha sheeting perfectly clean and dry.

The wires leading in one direction are then taken out and prepared for jointing ; the dirty work in all cases being done by the assistant.

If the wires are in a multiple cable, first strip off the tape about fifteen inches back and fasten it round the cable ; then loosen the numbers and pass them down the wires to the tape and fix them there. (N.B.—Great care must be used in passing the numbers down, for unless they are quite loose they will damage the percha.) When each wire has been served in this way, the whole of them should be cut to exactly the same length.

The same plan should be adopted with single wires.

When the above has been done to the one side, the jointer should do the same to the other side.

Cleansing Wires.—The wires at both sides must then be thoroughly cleaned with white cotton waste soaked in naphtha, until each wire is thoroughly clean, free from tar, dirt, and grease.

Cleansing Hands.—After cleaning the wires the jointer should very carefully clean his own hands, and dry them well. Naphtha will be found best for this purpose. Its disadvantage is that it has a tendency to harden the hand.

The wires are then ready for jointing.

Trimming Ends.—No. 1 wire should then be taken up on both sides (it is best to begin with the lowest number and proceed in regular order), and the gutta-percha carefully

FIG. 211.

trimmed off each end for about two inches (fig. 211), care being taken that the knife does not 'nick' the copper ; if this should happen, the copper must be cut off at the 'nick,' and the percha trimmed back.

Making Copper Joint.—The copper wire left bare should be scraped carefully, and then the two ends, being brought together so as to overlap each other about half-an-inch from the percha, may be held by the pliers as shown by fig. 212, and one side twisted, then (changing over the grip of the pliers) the other. The superfluous ends should then be carefully and closely cut and, being lightly touched with the pliers, turned in, so as not to leave an edge sticking up.

Soldering.—The twisted joints should then be soldered, care being taken to knock off superfluous solder, leaving the twist as shown by fig. 213. Great care must also be taken,

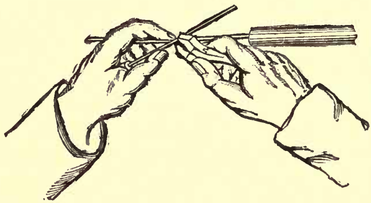


FIG. 212.

when soldering a joint, that no wires be immediately under it, but that the space underneath be quite clear. Hot solder dropping on gutta-percha at once heats and penetrates it.

Corresponding Numbers.—The remainder of the wires should then be jointed and soldered. Great care must be taken to join the right wires; the jointer should himself

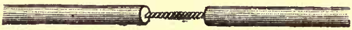


FIG. 213.

see that the numbers correspond, and not trust to his man giving him the numbers without himself seeing that they are correct.

The gutta-percha jointing may then be commenced, the second spirit-lamp having been previously lighted for warming the material; great care must always be taken that the spirit-lamps and the furnace are so placed that they cannot injure the gutta-percha.

Clean Joint.—The ends and soldered joint should first be thoroughly cleaned.

First Cover.—The ends of the gutta-percha are then slightly warmed and the actual ends nipped off with the fingers. One side of the percha should be well warmed for about two inches back, and then brought forward half-way

FIG. 214.

over the joint, as shown in fig. 214; the opposite end, after heating, should then be brought forward over the other part in a similar manner (fig. 215).

FIG. 215.

Then tool down the raised end of the second half over the end of the former half with a heated iron. Warm all up again with the lamp and work round over the whole

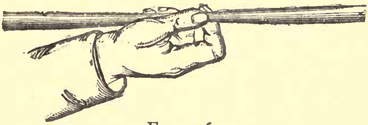


FIG. 216.

of the draw-down with the thumb and forefinger, as in fig. 216.

Second Coating Gutta-percha.—Next, rough the draw-down with a knife and put on a thin coat of Chatterton's

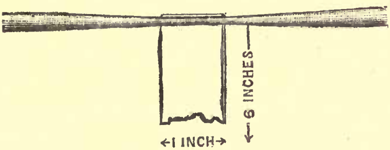


FIG. 217.

Compound for about one inch in the centre of the draw-down. Let it set before proceeding.

Then cut a strip of thick G.P. about six inches long and one inch wide; warm this well through from both sides with the lamp and attach one end to the centre of the draw-down, (fig. 217): and quickly wrap it round the draw-down, giving form as shown by fig. 218.

FIG. 218.

Work the wrapping both ways quickly, but carefully, with finger and thumb until it extends about $4\frac{1}{2}$ inches.

Then tool down the ends where the new G.P. meets the old; warm all up again and work with the finger and thumb as before.

Wet and soap the hand and rub it over the joint, leaving the finished joint smooth and round, thus (fig. 219):

FIG. 219.

The following notes respecting the joint and its manipulation should be carefully attended to:

Holding Core.—The jointer and his assistant should hold the wire carefully and firmly between the thumb and forefinger at such a distance from the joint as to be beyond the influence of the heat; the percha should always be held where it is firm; if the hand be too near the joint the man will probably be pressing the material where it has been softened by the heat, and will consequently damage it.

Twisting Joints.—In turning the joint over for the purpose of heating or cooling, the jointer and his assistant should turn it over carefully together, so as not to put a twist in the short portion, but to distribute it over the wire. The next turn should be in the opposite direction, so as to bring it into its original position. As, in making a joint, this turning has to be done very often, it is essential that this plan should be attended to, instead of turning the joint always the same way. Wires are sometimes seen, which, owing to carelessness in this respect, have a series of twists made outside the joint. A jointer should bear in mind that good work is known by the unaltered state of the core outside the joint, as well as by the excellence of the joint itself.

The application of the fingers to the joint is frequently necessary; they should invariably be well moistened before touching the warm material.

Whenever a joint has been touched by the moistened finger the joint should *always* be warmed with the spirit-lamp, in order to drive away any moisture. *This is very important.*

If in warm weather the hand should perspire, it ought to be dried. Naphtha will do this best, especially as its rapid evaporation produces coldness.

Cleanliness in every operation is essential to the making of a good joint.

The main faults in gutta-percha joints, which all beginners exhibit more or less, and which nothing but experience and careful attention to the foregoing instructions can surmount, are—

Bad twist in the copper.

Nicks in the copper, leading to a disconnection of the conductor.

One end of the twist left sticking up—the result of the trimming having been carelessly performed.

Indifferent soldering.

Eccentricity—*i.e.* the wire and joint being out of the centre of the core, due to bad kneading and tooling.

Burning, due to carelessness in the use of the lamp.

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. 209) 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.

CHAPTER XV.

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.*

Each of these is further subdivided, according as they are (a) *Total*, (b) *Partial*, or (c) *Intermittent.*

Disconnections are indicated by the total or partial cessation of the current.

1 a. *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.

1 b. *Partial disconnection* results from an unsoldered or badly soldered joint, a dirty contact, a loose terminal, bad earth, &c.

1 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 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.

2 a. *Full earth*—or, as it is 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.

2 b. *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.

2 c. *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 expanding and dropping upon them under the influence of heat.

Contacts are indicated by the signals from one wire passing into another wire.

3 a. *Full contact*—or, as it is 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.

3 b. *Partial contact* is that which is produced by imperfect conductors being thrown across the wires, by bad earths or by defectlve insulation on lines not earth-wired.

3 c. *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 can be caused by 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. 220. A battery wire, again, may be broken either mechanically or by the chemical action of the cell; as already mentioned (p. 29), the free ammonia in Leclanché's battery not infrequently eats through the wire.

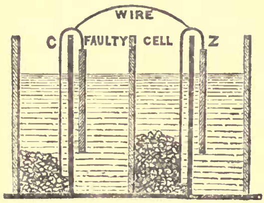


Fig. 220.

Intermittent disconnections in the battery—that is, only intermittent currents obtainable from it—are usually to be attributed to the wires being loosely fixed instead of being firmly connected by the terminals.

Apparent partial disconnections, indicated by weak currents, are often really 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; while dirty plates, cracked porous cells, corroded and dirty terminals, all tend to diminish the strength of the current. A similar result is also produced by the battery finding earth.

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. Partial disconnection, resulting in weak currents sent to line, may be due to the axles of the tappers being oxidised, but loss of magnetism in the permanent magnets of the induced coils will also cause an apparent partial disconnection (the carrying power of these should never be less than $\frac{1}{4}$ oz.; in the event of its falling below this, the magnets should be re-magnetised). Lightning is a source of trouble not only in this but in every form of instrument. Apart from the de-magnetisation or the reversal of the magnetism of the permanent magnets, the coils of the instrument are liable to be fused, and special measures have to be taken, which will be described further on (p. 342), in order to guard against this.

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 instruments 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; and a partial disconnection, resulting in weak currents to line, caused by the axle of the key being loose or dirty.

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 induced by 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 clean piece of paper should from time to time be gently passed between them for the purpose of removing any metallic dirt that may have gathered there. Small pieces of roughened watch spring are often used for cleaning contacts and prove of great convenience. 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^{ω}.

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 improperly put together again, so that the teeth do not properly fit into 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 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. 88), 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. 65) 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 is an extremely troublesome one, as it may come on by any one of the stations in the circuit giving a very slight motion to the handle of their communicator, and it frequently disappears without its locality being ascertained, owing to the station which caused it being in ignorance of its existence.

Duplex Apparatus.—The causes of the irregularities in duplex telegraphy have been already dwelt upon (p. 128 *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 rollers 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 rollers, 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 pole reverser, the duplex transmitter, 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. 194), 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 or pole reverser ; 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 working well on another multiplex circuit.

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 and the rate of vibration will thus be increased.

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.

Partial and *intermittent disconnections* on the line are invariably the result of bad joints; attention has been already drawn (p. 305) 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. 221, 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.

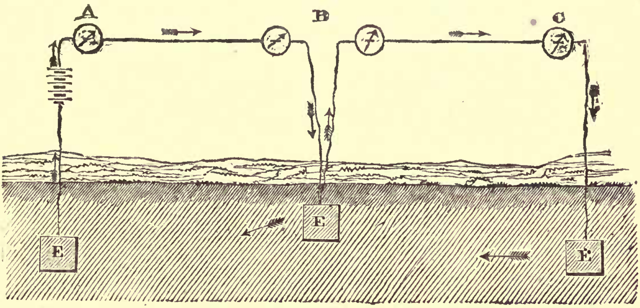


FIG. 221.

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. 308 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.

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.

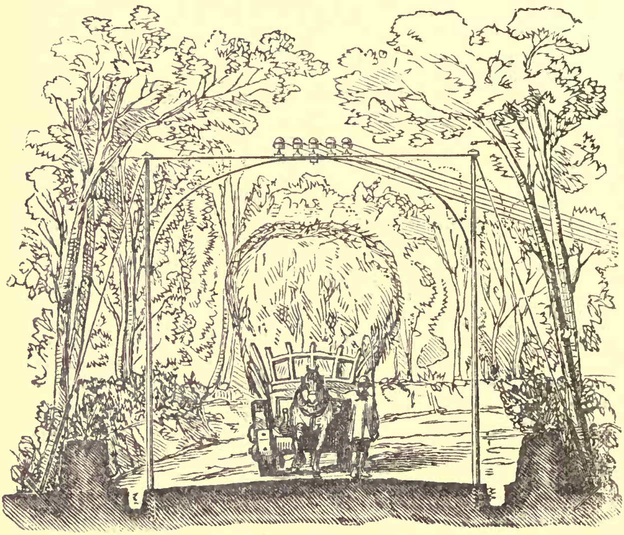


FIG. 222.

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, and when permission to lop the branches where necessary cannot well be obtained, the arrangement indicated in fig. 222 is sometimes adopted. Two poles are erected, one on each side of the road, and stayed or strutted, as may be required ; between these is fixed a bar of iron supported by an arch, as shown, and into it the insulators are fixed. In this way the middle of the road, which is the part least liable to be affected by the branches, is obtained. The wires should be doubly bound and soldered at each insulator, so as to prevent their running back, and thus to reduce to a minimum the danger of an accident occurring from a broken wire.

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 flush-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 zinc current is the reverse of this ; its effect being to keep the wire clean, and thus to maintain the leakage. For this reason the zinc current should invariably be used in testing covered wires, for leakages will be brought to light by it which, with the copper current, 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 the 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. 295 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 to earth-wire at least the last five supports on each side of every office, as a protection against the effects of lightning.

The dangers of damage to instruments which arise from the powerful currents which are induced by lightning discharges have been practically surmounted of recent years 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 non-conductor, such as dry air, at the moment of discharge the resistance along the line of discharge is so far reduced as to allow the passage of the greater part, if not the whole of the 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. 223), 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

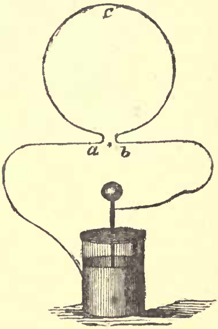


FIG. 223.

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 metal plates superposed, and separated from each other by a thin air-space. The line is connected to the upper plate, while the earth connection is made to the lower. 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. It consists 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. The protectors should be examined after every thunderstorm, and removed if the surface of either of the plates has been disturbed by a discharge.

One form of this protector is shown in fig. 224, the plates of which are circular and about two inches in diameter. The line-wire is clamped beneath the fixed brass washer C, so as to be attached to the upper disc L, while the lower disc is joined to 'earth' by the lower screw. C is driven over an ebonite collet on the clamping terminal T, which is the means by which the upper disc is held in position, but L is quite insulated from T.

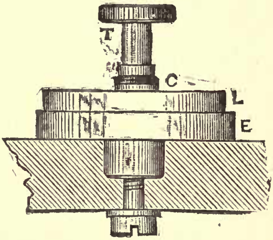


FIG. 224.

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. 224, and the design also embodies a special form of 'reel' protector, besides which in the cable 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 usually protected by means of 'vacuum' protectors, they being found to answer the purpose 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, which are fused into a glass tube in which a partial vacuum has been made. This offers a ready path for the discharge of electricity of high potential. 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, or other generator of electricity of high potential. If they show a bright violet glow they are in good condition.

CHAPTER XVI.

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 are really rather for indicating than for measuring the 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. 225. 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. 44, 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,

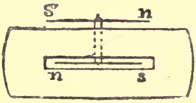


Fig. 225.

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 and the tendency to turn in a certain direction results then from this difference. 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-

[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. 226, 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 $\frac{\sqrt{3}}{2}$ and 1, so that a current which gives a deflection of 45° is $\frac{2}{\sqrt{3}}$ times the strength of one which gives a deflection of 30°.

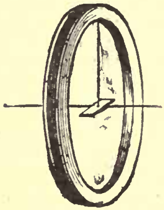


FIG. 226.

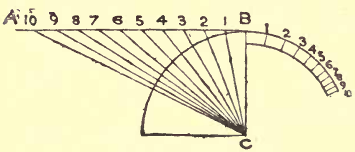


FIG. 227.

If a line A B (fig. 227) 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.

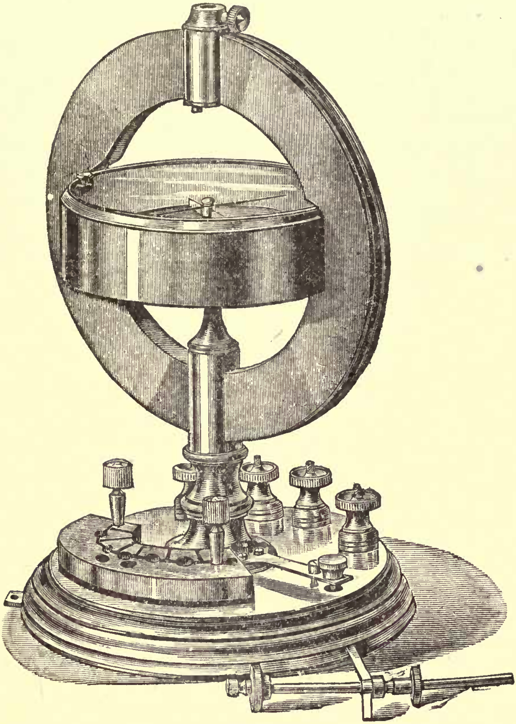


FIG. 228.

The latest pattern of the Post Office form of the instrument is shown by fig. 228. 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 north, whereas if it is desired to increase the sensitiveness, the N pole should point south. 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. 229.

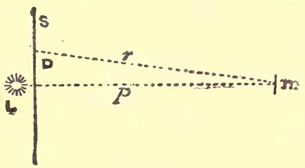


FIG. 229.

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. 350). 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 are made various arrangements of *resistance coils* for testing purposes. 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

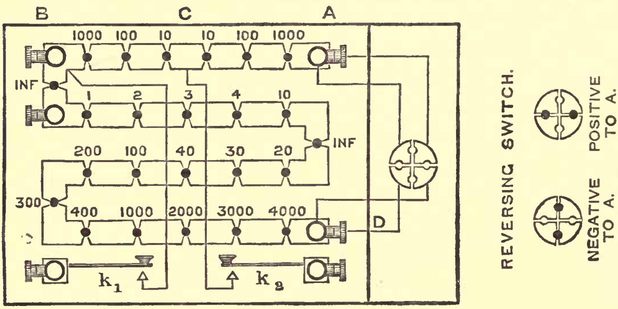


FIG. 230.

silk-covered platinum-silver 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 the outer ends

[1] A *megohm* is one million ohms. [2] See Appendix, Section D.

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. 230. 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. 231). Suppose *a*, *b*, *d*, and *x* to be resistances, some of which are adjustable. It is evident that the difference of potential between the ends C and D of *a* and *x* is precisely the same as that between the same two points of *b* and *d*; also, that the difference of potential between C and any intermediate point, say A, in *a x*, as compared with that between the same point A and D, will be in direct proportion to the relative resistances: for instance, if *a* be three times *x*, then the difference of potential between C and A will be three times that between A and D. The same applies of course to *b* and *d*. Hence, if the two proportions $a : x$ and $b : d$ are equal, that is, if as

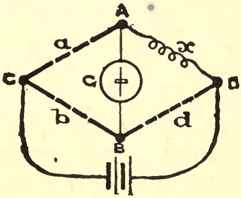


FIG. 231.

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

the points A and B will be at similar potentials, and no current will pass between them if they are joined (p. 5). The converse of this is, of course, also true; namely, that when no current will pass between A and B, the potentials of those points must be similar, and the above proportion must exist. If then, this condition be obtained, and the galvanometer G be inserted between A and B, no deflection will be given, but if the proportion be ever so slightly upset, a current will pass between A and B (assuming the galvanometer to be sufficiently sensitive), which will be indicated on G. Suppose the resistance x is not known, the other resistances being known and adjustable, when balance is obtained by adjusting the value of the other resistances, the actual value of x can easily be calculated, for if

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

then $$x b = a d, \text{ or } x = \frac{a d}{b}.$$

Now, by referring to fig. 230, where the lettering corresponds with that of fig. 231, the resistances a and b will be seen to be adjustable coils, each arm consisting of 10$^\omega$, 100$^\omega$, and 1,000$^\omega$. Between B and D is a series of coils, giving a range of adjustment from 1 up to 11,111. 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 $x = \frac{a d}{b}$ 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 b is only 100$^\omega$ or 10$^\omega$ (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 $\frac{1}{10}^\omega$ and $\frac{1}{100}^\omega$ respectively; for measuring small resistances, therefore, it is advisable to have b smaller than a, but when x is more than 1,000$^\omega$ or 100$^\omega$, the limited range of d precludes the possibility of this ratio being more than 10 or 100 times respectively.

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 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. 230). 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 self-induction of the galvanometer coils acts upon the needle. The galvanometer key should at first be only momentarily depressed, as 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 I N F (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. This instrument, however, is not used for ordinary telegraphic testing.

CHAPTER XVII.

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. 232). 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.

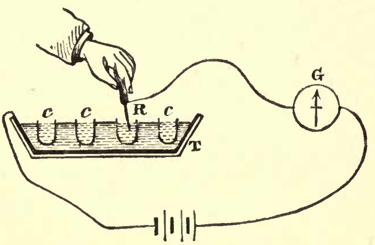


FIG. 232.

A powerful testing-battery, consisting of from 200 to 300 Daniell 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 96 per cent. of the conductivity of pure copper according to Matthiessen's standard. The *inductive 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 he fails to gain the attention of any or all of them, he concludes that there is a fault upon the circuit, and reports accordingly to the responsible officer.

Every important circuit is tested every morning between 7.30 and 7.45, in order that the condition of the wire may be ascertained before the day's work commences.

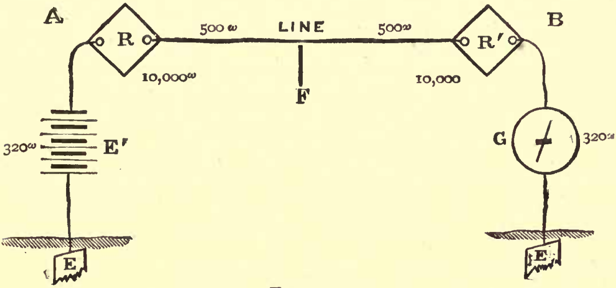


FIG. 233.

The method of 'Daily Testing' is shown by fig. 233.

First, the tangent galvanometer G at the receiving station B is adjusted to give a constant deflection of 80 divisions on the tangent scale with one milliampère of current, so that any given deflection D represents a definite strength of current C. That is,

$$C = \frac{D}{80} \text{ milliampères.}$$

Such being the case, the line A B, which is to be tested, is connected as shown. R R′ are resistance blocks, each of 10,000ω; E′, at the sending end A of the line, is a Daniell battery of 50 cells; and G is the tangent galvanometer at B, the receiving station. Under these circumstances, if the line, both as regards insulation and continuity, were perfect —conditions unattainable in practice—the whole of the current sent from the battery would be received at the distant end, but the less perfect the insulation of the line the less current will be received at B, because the more will pass to earth along the line. Now as the actual resistance of any section of line that is tested is small compared with the inserted resistance blocks of 10,000$^{\omega}$ each, there will no material error arise if the total amount of leakage that takes place along the whole length of line be assumed to be one fault in the middle; and the lengths of the different sections tested throughout the system are so arranged that their resistances do not vary so greatly from 1,000$^{\omega}$, that to assume them to be that amount in every case will not affect the working accuracy of the test. This then is the plan adopted. The fault is assumed to be in the middle of a line the total resistance of which is 21,640$^{\omega}$ (resistance of battery E′ + R + resistance of line + R′ + G). It will be seen that if under these conditions a certain deflection of the galvanometer G be obtained, it will be easily calculated what proportion of the current must have leaked off at the fault; or, in other words, what is the resistance of the assumed fault, and this represents the *total insulation resistance* of the circuit. In applying this system, therefore, the various resistances at F which would cause such variations of the current received at B as would produce deflections varying by half a division upon the galvanometer G have been calculated and put into tabular form, so that by reference the testing officer may see at a glance the resistance of the assumed resultant fault F, which really represents the total insulation resistance of the section tested.

For purposes of comparison, however, it is evident that this total insulation resistance must be reduced to a standard, and consequently it is usual to show the *insulation resistance per mile*; and this is obtained by *multiplying* the total insulation resistance by the length of the circuit in miles. That this multiplication is correct will be clear upon considering that if the leakage along the line be supposed uniform, and that there be no specific fault, the leakage along n miles will be n times greater, and the insulation consequently n times worse than upon *one* mile of the same circuit. The insulation of an open wire when in proper working order should never fall below 200,000$^{\omega}$ per mile in England, except under such circumstances as dense fogs, continued heavy rain, or proximity to the sea for a considerable distance. It is very necessary that the state of the weather at the time of taking the test should be given; the value of the record greatly depends upon this, seeing that the tests are largely comparative.

By this method the continuity of the line as well as its insulation resistance is tested, and, whatever the fault may be, it is shown as a fault, so that if necessary the testing officer can at once take steps to trace it.

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. 234, 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. 230 '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

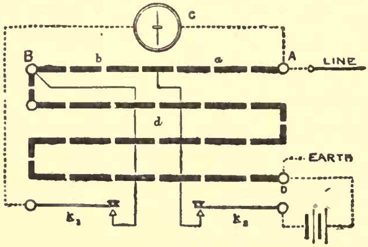


FIG. 234.

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. 308), 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. 235) 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

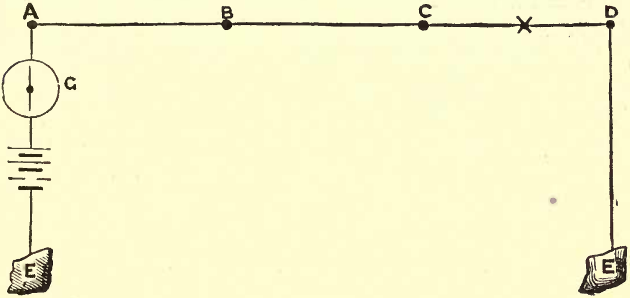


FIG. 235

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,

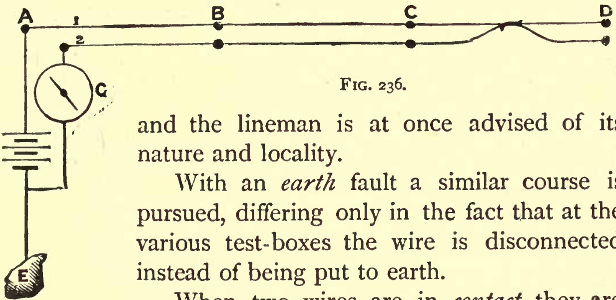


FIG. 236.

and the lineman is at once advised of its nature and locality.

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. 236) 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

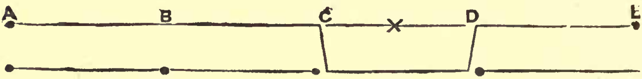


FIG. 237.

crossing the wire with any other of less importance which may happen to exist be ween the two stations where the fault has been localised. Suppose that A E (fig. 237), 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 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

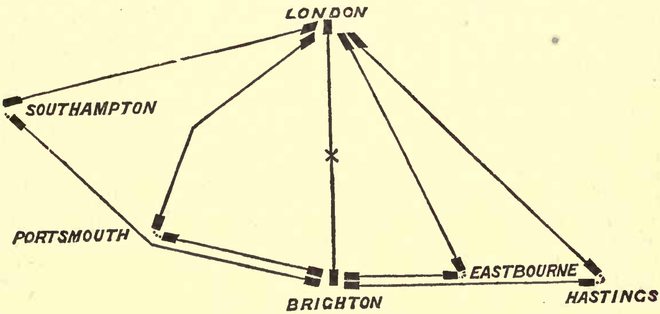


FIG. 238.

line of communication being broken down, an outlet may be found for the traffic. Thus (fig. 238), 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.

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. 237) 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 on 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. 340, *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. 235) 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. 239 will show the connections which have to be made in one method of taking

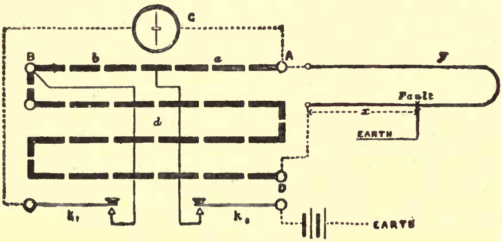


FIG. 239.

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 distance of the fault from terminal D, and y the distance 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—

$$a(d + x) = b(L - x)$$

$$\therefore x = \frac{b \times L - a \times d}{a + b} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

And the values of *a*, *b*, *d*, and L being known, the resistance of x is obtained : this divided by the resistance per

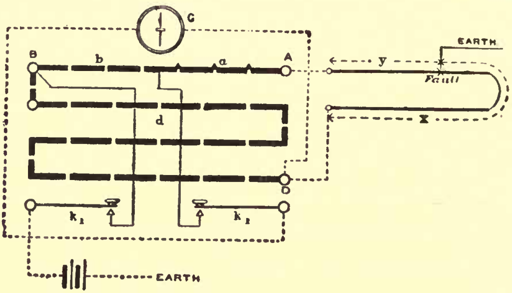


FIG. 240.

mile of the wires gives the distance in miles of the fault from the testing station.

If the two arms of the bridge *a* and *b* be made equal to each other the above equation becomes—

$$x = \frac{L - d}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Second Method.—A second method of taking the loop test is shown by fig. 24c. 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 $$x = L - y$$
$$\therefore b(L - y) = d \times y$$
that is $$y = L \frac{b}{b + d}$$

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. 239, 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

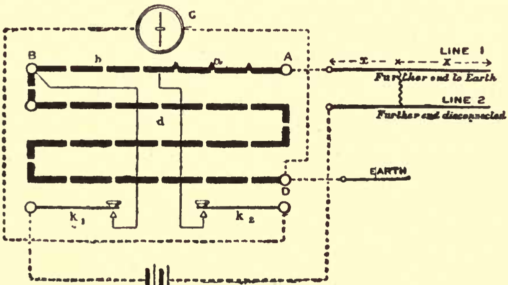


FIG. 241.

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.

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. 241. 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 :

$$b \times \text{X} = d \times x$$

but $\text{X} + x$ is known, let it be L,

then $$\text{X} = \text{L} - x$$

therefore $$b\,(\text{L} - x) = d \times x$$

that is $$x = \text{L}\frac{b}{b + d}$$

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

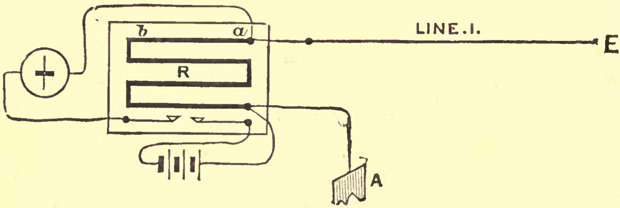


FIG. 242.

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. 242, 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.

The battery is now reversed and the other connections are altered as shown in fig. 243. 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

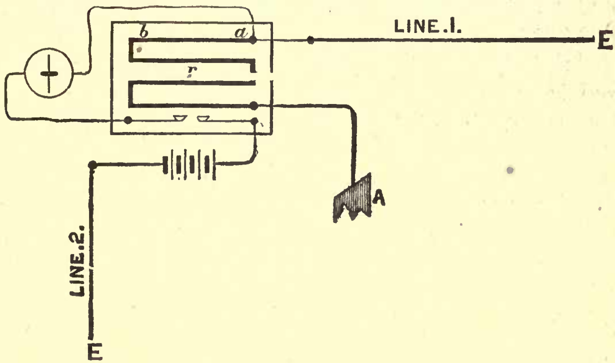


FIG. 243.

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

$$\frac{a(R - r)}{a + b} \quad \text{(General Case).}$$

Or, if the two arms *a* and *b* of the Bridge are equal, then the resistance of the earth is

$$\frac{R - r}{2} \quad \text{(Special Case)}$$

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 places 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

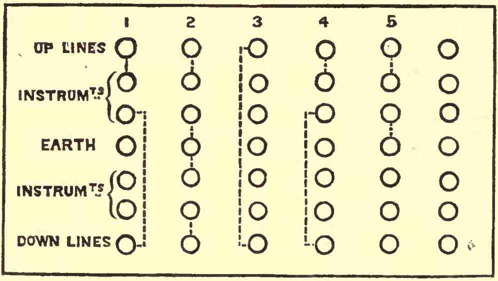


FIG. 244.

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. 244, but this is frequently departed from to meet local requirements.

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

[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. 244 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

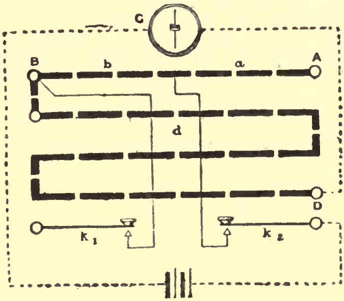


FIG. 245.

of these may be determined are very numerous. It is proposed to describe only the simplest of these.

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. 245 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

$$r = R_2 - (G + 2\,R_1) \qquad (1)$$

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

$$r = R_2 \qquad (2)$$

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 absolute standard it is usual to compare the electro-motive force with that of a recognised standard cell (see p. 40), 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. 245, 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. 228, 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. 245, 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.

The British Post Office authorities have introduced a 'Battery-testing Instrument' by means of which the resistance and the electro-motive force are obtained by direct readings.

APPENDIX

SECTION A.—OHM'S LAW.

(References, pp. 6, 378.)

THE functions of electricity which determine and regulate the flow of *current* between any points are *electro-motive force* and *resistance*. 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 present 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

$$CR = E, \qquad (2)$$

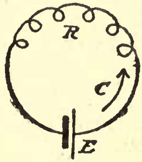


FIG. 1.

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?

$$E = 1{,}079 \times \frac{20}{1000} = 1 \cdot 079 \times 20 = 21 \cdot 58 \text{ volts.}$$

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

$$CR_1 = E_1. \qquad (3)$$

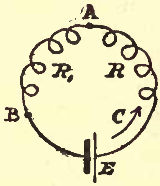


FIG. 2.

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, 117.)

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)?

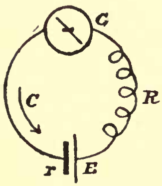


FIG. 3.

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. 116, 159, 160, 330, 349, 352.)

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.

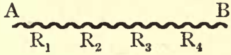


FIG. 4.

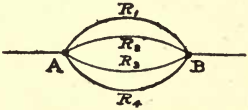


FIG. 5.

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* also *vary as the square of their diameter*; thus the relative resistances of equal lengths of circular wires whose diameters are d_1 and d_2 will be respectively $(d_1)^2$ and $(d_2)^2$. 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 or inversely as the square 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?

$$\text{As } \frac{1}{4^2} : \frac{1}{5^2} \text{ or } \frac{1}{16} : \frac{1}{25} = 25 : 16;$$

that is, the resistance of the wire of diameter 4 is 25 if that of the wire of diameter 5 be taken as 16.

SECTION D.—SHUNTS.

(References, pp. 159, 160, 330, 349, 352.)

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.

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,

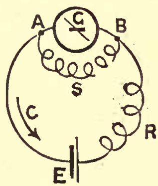


FIG. 6.

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 c rtain 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), $S = \dfrac{G}{m - 1}$, m being the multiplying power of the shunt; therefore

$$R = \frac{G \times G}{G + \dfrac{G}{m - 1}} = \frac{G}{\dfrac{(m - 1) + 1}{m - 1}} = \frac{G\,(m - 1)}{m}. \qquad (2)$$

(Ex. 2.) In Ex. 1 what compensation resistance (R) should be inserted?

$$R = \frac{32\not{0}\,(99)}{10\not{0}} = 316{\cdot}8^{\omega}.$$

SECTION E.—THE WINDING OF ELECTRO-MAGNETS.

(References, pp. 45, 53, 54, 55.)

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 $\frac{2}{5}$ 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. 54) 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. 135, 166, 358.)

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. 223). 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,[1] 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

[1] *Dielectric* is the term generally used to express the insulating medium when dealing with static electricity.

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

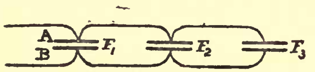


FIG. 7.

$$F = F_1 + F_2 + F_3. \qquad (1)$$

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

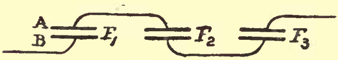


FIG. 8.

$$F = \frac{1}{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3}}. \qquad (2)$$

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. 372, may be explained thus ;

FIRST TEST.

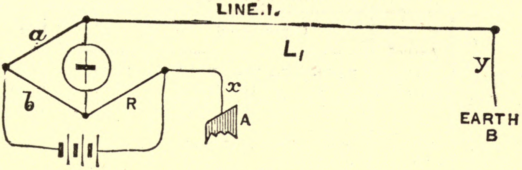


FIG. 9.

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,

$$a\,R = b\,(L_1 + y + x)$$

or

$$a\,R = b\,(L_1 + y) + bx. \qquad (1)$$

SECOND TEST.

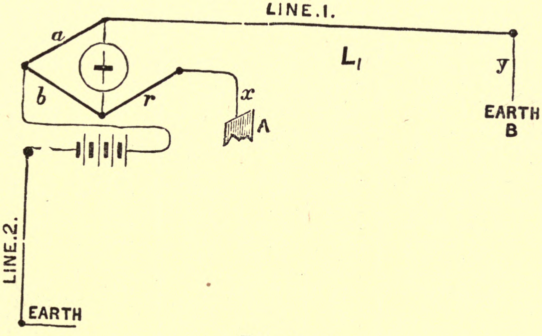


FIG. 10.

In this case, when balance is obtained,

$$a\,(x + r) = b\,(L_1 + y);$$

that is,

$$ax + ar = b\,(L_1 + y). \qquad (2)$$

Then, by subtracting (2) from (1)

$$a\,R - ax - ar = bx,$$

or

$$x\,(a + b) = a\,(R - r);$$

that is,

$$x = \frac{a\,(R - r)}{a + b} \qquad (\textit{General Case});$$

and, if a and b are equal,

$$x = \frac{R - r}{2} \qquad (\textit{Special Case}).$$

SECTION H.—BRITISH 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	.0032	.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.
,, ,,	×	·91075	=	ozs. ,, ,,
,, ,,	×	4·7	=	grs. ,, ,,
Length 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

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