ELEMENTARY ELECTRO-TECHNICAL SERIES

ELECTRIC TELEGRAPHY

BY

EDWIN J. HOUSTON, Ph. D.

AND

A. E. KENNELLY, Sc. D.

Second Edition

NEW YORK
McGRAW PUBLISHING COMPANY
1906

PREFACE.

It requires but little thought to perceive the vast civilizing influence which has been exerted on the human race by the electric telegraph, an influence which has been active during but little more than half a century. Extended civilization is impossible without the co-operation that can only come through speedy and ready intercommunication. While giving full credit to the part played by the steamship and the railroad in effecting material transportation, a still greater share is due, perhaps, to the facility with which the intercommunication of intelligence is achieved by the aid of telegraphy. Before the development of the telegraphic art, the oceans, and even mountain chains, formed the natural boundaries that separated peoples and differentiated their language. Now metallic wires annihilate space and practically cause these natural boundaries to disappear. Wherever the telegraph has gone, civilization has advanced.

So potent and universally employed an agent as the telegraph cannot be disregarded by the general public, and information concerning the principles of its operation becomes a matter of public necessity. While it is true that the detailed operation of many of the complicated systems of telegraphy, such, for example, as the quadruplex, require careful study for their thorough comprehension, yet even here the general principles on which these operations are based are readily grasped by the non-technical reader.

It is with the view of presenting these principles to the general public, in a manner which will enable them to be comprehended without technical training, that the authors have prepared this book.

So vast is the field covered by telegraphy that the authors have thought it advisable to explain the principles of the art as practiced in America only. Special attention has, however, been devoted to submarine telegraphy, which necessarily includes international practice.

The book is copiously illustrated by figures, many of which have been prepared specially for the work. A full index will aid the reader.

The authors desire to specially acknowledge their indebtedness to Messrs. H. D. Wilkinson and J. E. Young, and also to Dr. F. B. Herzog for cuts and photographs.

PHILADELPHIA, *November*, 1896.

PREFACE TO THE SECOND EDITION.

SINCE the first edition of this little volume was written, comparatively little change has occurred in the methods or uses of wire telegraphy. A very great stride has, however, been made in the direction of electric wireless telegraphy; that is, in signalling over the conducting surface of the earth or sea. The whole earth's surface in this sense has become a vast wire over which electric waves can be radiated in a manner that human intelligence can detect at remote distances, and can spell into letters, words and sentences.

It is believed by the authors that the additions made in this edition will enable the reader to become acquainted with the salient principles of this fascinating and lately developed branch of telegraphy.

MAY, 1906.

CONTENTS.

ELECTRIC TELEGRAPHY.

CHAPTER I.

INTRODUCTORY.

Puck's boast that he could put a girdle around the earth in forty minutes, has, in our nineteenth century, been more than realized. Witness, for example, the recent telegraphic feat at the opening of the Electric Exposition in New York City, on the 16th of May, 1896, when a message, sent by Dr. Chauncey Depew to Mr. E. G. Adams, traversed 42,872 miles of telegraph circuit from New York to San Francisco, London, Tokio, London, and New York, in 57 minutes. And this is by no means an unique record as to speed; for, every day, at Greenwich noon, time is telegraphically signalled from the Greenwich Observatory to Bombay, while Washington noon is signalled daily over the length and breadth of the North American continent. In point of fact, it is impossible actually to girdle the earth telegraphically at the present time, since a gap exists in the telegraphic connection between Siberia and Alaska, but, were this gap completed, it would be possible to send a message around the earth in a few seconds of time.

Both business and social life have been profoundly modified by the advent of the electric telegraph. The new means of communication once established, old methods necessarily became effete. By the electric telegraph both time and space are practically annihilated. The telegraph creates new markets for the merchant, and greatly extends his old ones. It gives ruling powers instant and accurate information as to what is going on in distant portions of their domains, as well as in neighboring districts. It gives the inventor, the writer, the profound thinker, the world for their audience. All this it has done, and it promises to do even more in the future; for, is it not already rendering the world so small, so far as regards the transmission of thought, as to herald the dawning of the millennium?

The transmission of intelligence to greater distances than can be reached by the human voice was practiced long before electricity was applied to this purpose. Such methods were entirely visual or semaphoric. They consisted essentially in the movements of conspicuous objects such as torches at night, or flags by day. The semaphoric method is still adopted to-day, in the communication between vessels at sea, or by army signal corps.

It was natural, as soon as the high speed at which an electric impulse travels from one end to the other of a conducting wire was recognized, that the idea was conceived of employing this agency in transmission of intelligence to a distance; since, by its means messages could be transmitted to distances far exceeding those to which rays of light could be sent. As early as 1747, Watson constructed an electric telegraph consisting of a wire stretched, for a distance of two miles or more, over the chimney tops of London, employing the discharges from a frictional electric machine. Numerous other attempts were made with telegraphs employing the frictional electric machine or Leyden jar, but all these systems naturally failed to come into commercial use, owing to the difficulty of insulating the high electric pressures employed on the lines. It was not until after the invention of the voltaic pile that the practical electric telegraph may be regarded as having been introduced.

Even then, although the principles of electric telegraphic communication were founded upon a definite basis, progress was necessarily slow until the discovery and introduction of the electromagnet, about the year 1820. After this date the electric telegraph was rapidly improved, and was introduced commercially about the year 1838 in Europe, and the year 1840 in America. So rapid has been the development of electric telegraphy since that time that there are now about 900,000 miles of overhead wire in the United States employed for telegraphic purposes. Over these lines about 80,000,000 of telegraphic messages are sent annually between about 23,000 offices, and this in spite of the fact that the telephone has robbed the telegraph wire of many of its communications. The average toll for these messages is in the neighborhood of 30 cents. In 1894, the total length of telegraph wire in the world reached, approximately, 3,000,000 miles, and the total length of pole line about 1,250,000 miles. The length of the first submarine telegraph cable, which was that of 1835, was about 30 miles. The present total length of submarine cables over the world is about 150,000 miles.

CHAPTER II.

ELEMENTARY ELECTRICAL PRINCIPLES.

All the effects which are employed in electric telegraphy are produced by the electric current; that is, by the flow of electricity. In every telegraphic line an electric current is caused to flow in a predetermined manner, and the effects of this current are recognized, at the distant end of the line, in the signals received. Since, therefore, all the important phenomena of electric telegraphy depend upon electric currents, it is necessary to examine into the elementary principles controlling such currents.

Fig. 1, represents diagrammatically an

ideal hydraulic circuit arranged for the transmission of signals to a distance. *P*, is a rotary pump, continuously driven by suitable machinery at a constant speed, so as to maintain between its inlet and outlet pipes a constant pressure of say 10 pounds-per-square-inch. A pair of small pipes

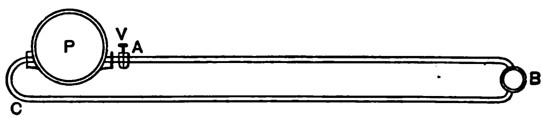


Fig. 1.—Hydraulic Circuit.

C B and *A B*, are carried from the pumps to the signal apparatus *B*, which enables any flow of water to be detected. The *hydraulic circuit* is, therefore, *closed* or *completed* through the pump, pipes and signal apparatus. *V*, is a valve by which the circuit may be opened or closed at will. Shutting off the valve *V*, will stop the flow of water through the pipe and affect the signal apparatus *B*. Opening the valve *V*, on the contrary, thus permitting the flow of water, will again operate the apparatus *B*. Consequently, intermittently opening and closing the valve *V*, will produce correspondingly intermittent indications at the apparatus *B*, which might be read off in signals according to a predetermined code. It will be seen that the pump *P*, constantly maintains a *water driving* or *water-motive force* between its terminals *A* and *C*, whether the valve *V*, be closed or not, although there is a *water current* only when the valve *V*, is opened.

Fig. 2, represents diagrammatically an ideal electric circuit arranged for the transmission of signals to a distance. *P*, is a *voltaic cell* which continuously maintains a constant electric pressure between its terminals. *A B* and *B C*, are two electric conductors; *i. e.*, metallic wires extending from the cell to an *electric indicator m*, at the distant point. *K*, is a *key* so arranged that when depressed by the hand, the *electric circuit P A B C*, is *closed*, and an electric current will flow through this circuit operating the apparatus *m*. On lift-

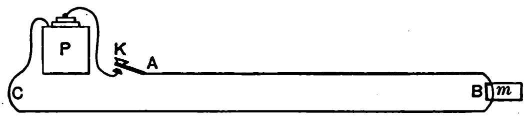


FIG. 2.—ELECTRIC CIRCUIT.

ing the key *K*, the circuit is *opened* or *broken* and the electric current ceases to flow, as indicated by the instrument *m*. Consequently, by intermittently depressing and lifting the key *K*, the instrument *m*, will give corresponding intermittent indications which may be read off as signals according to a predetermined code. The voltaic cell *P*, maintains a steady electric pressure or E. M. F. whether the key *K*, be depressed or not, but a current will only flow when the key is depressed.

The electric circuit of Fig. 2, thus offers a very fair analogy to the hydraulic circuit of Fig. 1. In each there is a source of constant pressure, a pair of conductors, a receiving or indicating instrument, and a circuit opening and closing device. It must be remembered, however, that while a gross fluid material, *i. e.*, water, flows in the hydraulic circuit, there is no flow of gross material in the electric circuit; that is to say, although electricity is sometimes described as an electric fluid, it is not a material fluid in the same sense that water is. Consequently, the analogy between the electric and hydraulic circuits must only be employed to the extent that the phenomena presented in one facilitate the comprehension of those presented in the other. The analogy must not be carried too far, since the exact nature of electricity is not yet known, although many of its laws are well understood.

The rotary pump *P*, in Fig. 1, has already been alluded to as possessing the capability of maintaining a steady difference of pressure of 10 pounds-per-square-inch between its terminals. In the same way the electric pump or voltaic cell *P*, in Fig. 2, is capable of maintaining a steady *difference of electric pressure* between its terminals. This difference of electric pressure, or *electromotive force*, usually abbreviated E. M. F., is measured in *units of E. M. F.* called *volts*. The bluestone cell represented in Fig. 3, has an E. M. F. of a little more than one volt.

A voltaic cell consists essentially of two substances, generally metals, called the *voltaic elements*, and constituting a *voltaic*

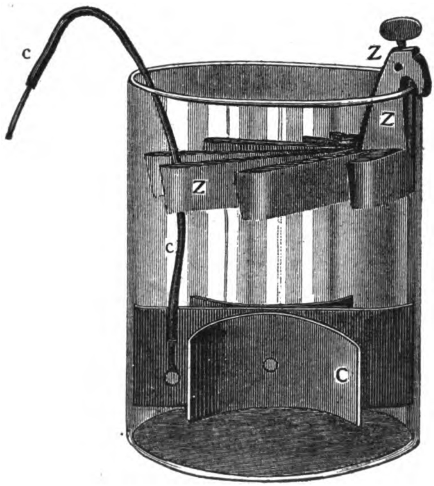


FIG. 3.—BLUESTONE VOLTAIC CELL

couple. The elements are immersed in an electrically conducting liquid or liquids called *electrolytes.* This is shown diagrammatically in Fig. 4, where *Z*, is a zinc plate; *C*, is a copper plate, and *L*, is an electrolyte consisting of dilute sulphuric acid. So long as the wires connected to

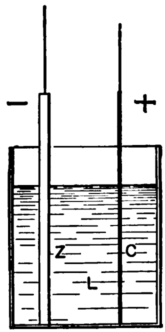


Fig. 4.—Simple Voltaic Cell.

the plates are separated as shown, so that the conducting path or circuit is open, no chemical change is effected, provided the plates are pure, and that the sulphuric acid solution is not too strong. There will, however, be a constant E. M. F. of roughly one volt between the wires + and — connected to the plates *Z* and *C*. A very great number of voltaic couples may be employed in connection with suitable electrolytes to produce an E. M. F. The value of this E. M. F. will depend upon both the couple and the electrolyte, but will not usually exceed 1 1/2 volts, although in rare instances 3 1/2 volts have been reached. A voltaic cell should continue to maintain its E. M. F. indefinitely while on open circuit.

The effect of closing the circuit of the cell is to produce a current which is maintained by the chemical activity in the elements and electrolyte. For convenience it is assumed that the current flows as shown by the arrows in Fig. 5, from the copper plate through the external wire to the zinc plate, and from the zinc plate through the electrolyte to the copper plate, thus completing the electric circuit. The terminal or pole connected to the copper plate *C*, is called the *positive pole*, and that connected with the zinc plate is called the

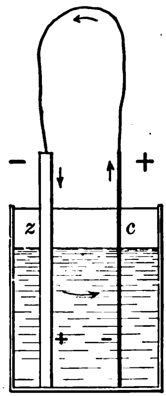


Fig. 5.—Voltaic Cell on Closed Circuit.

negative pole, because the electric current is assumed to flow from the positive pole to the negative pole in the external portion of the circuit. Within the electrolyte, the current flows from the zinc plate to the copper plate. The former is, therefore, considered as the *positive plate* and the latter as the *negative plate*. Consequently, the plate which forms the positive pole of the cell is the negative plate, and that forming the negative pole is the positive plate. The polarity of any metal, such as copper, depends both on the nature of the other metal or element with which it forms a couple, and also, upon the nature of the electrolyte in which it is dipped. There are some couples in which the polarity is reversed by substituting one particular electrolyte for another.

The passage of the electric current is invariably attended by a decomposition of the electrolyte and a consumption of the positive plate. Thus, in Fig. 5, the electrolyte is decomposed, the zinc combining with a portion of the electrolyte forming zinc sulphate, and the hydrogen being liberated in the form of bubbles of gas at the surface of the negative or copper plate. The presence of this hydrogen is deleterious to the action of the cell, since it tends to establish a new element, namely hydrogen, covering the copper plate, and, therefore, tending to produce a zinc-hydrogen couple, the E. M. F. of which is counter, or opposed, to the E. M. F. of the cell on open circuit. This E. M. F. is, therefore, called the *counter E. M. F. of polarization.* usually abbreviated *C. E. M. F.* It is the presence of this polarization which has led to the development of a large number of voltaic cells of special design with the object of overcoming the difficulty. The early voltaic cells employed in telegraphy were of the type indicated in Figs. 4 and 5, but have been altogether replaced by more complex types in which polarization is almost entirely obviated.

We have seen that it is the presence of hydrogen upon the surface of the negative plate which gives rise to polarization. Consequently, if this hydrogen be prevented from making its appearance, the C. E. M. F. will be prevented from developing. This is done by surrounding the negative plate by a substance capable of entering into combination with the hydrogen as rapidly as it is developed. When this substance is in the form of a liquid, it becomes necessary to employ some means for preventing the commingling of this liquid with the other liquid electrolyte. This is accomplished either by the use of *porous cells*, or the two liquids are kept apart by reason of their difference in density.

The bluestone cell already referred to in connection with Fig. 3, is of the latter type, and is, therefore, frequently called a *gravity cell.* In this cell the voltaic couple consists of zinc and copper. The zinc is made in the form of a grid, shaped as shown, and supported by a tripod near the top of the liquid. The negative element consists of a copper star-shaped plate, provided with an insulated wire as shown. The two liquid electrolytes are a saturated solution of bluestone, or copper sulphate, and a solution of zinc sulphate. Owing to their differences in density the lighter zinc sulphate solution floats on the surface of the denser copper sulphate solution. Consequently, the zinc plate is surrounded by the solution of zinc sulphate, and the copper plate by a saturated solution of copper sulphate. In order to maintain the strength of the copper sulphate solution, crystals of bluestone are heaped around the copper plate. If the cell were allowed to remain on open circuit, these two liquids would slowly diffuse through the cell and thus tend to produce irregular and deleterious chemical action, called *local action*, that is, a wasteful consumption of the zinc without the production of useful current. The zinc in such cases attacking the copper sulphate solution, and having a layer of copper deposited over its surface. If, however, the cell be steadily worked on closed circuit, the consumption of the chemicals holds the diffusion in check, so that comparatively little local action takes place.

During the action of the gravity cell the zinc plate is slowly dissolved, forming zinc sulphate, and tending, therefore, to increase the strength of the solution surrounding the plate, the rate of consumption being proportioned to the electric flow. The copper plate becomes coated with freshly deposited copper and the copper sulphate solution is weakened, so that fresh crystals of copper sulphate become dissolved. The cell, therefore, supplies an electric current under an E. M. F. of about one volt by the consumption of the zinc plate and of copper sulphate crystals.

Fig. 6, shows a form of bluestone cell in which the zinc plates are arranged for complete consumption. In the ordinary bluestone cell the zinc plates have to be thrown away when only partially consumed. In the form shown in Fig. 6, the zincs are provided with a conical head, so that as one is consumed it is driven like a wedge into the lower portion of the surface of the new zinc above it. On the right hand of the figure is a cross-section of a new zinc plate with two other zinc

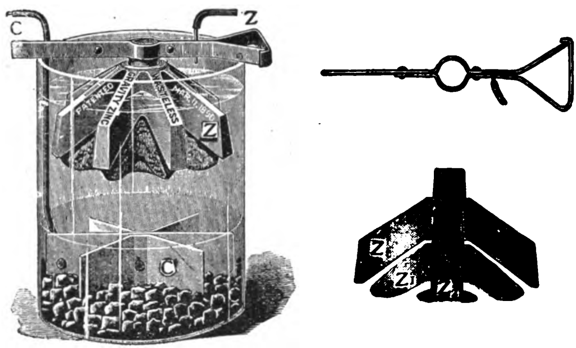


FIG. 6.—GRAVITY DANIELL CELL WITH WASTELESS ZINC.

plates at its centre in different conditions of consumption.

Another form of gravity cell is shown in Fig. 7. Here the copper plate is formed of spiral copper wires with a central screw shaft. The space between the spirals is arranged to be packed with bluestone crystals.

Fig. 8, shows a form of *double-fluid cell* called the Fuller cell. Here the couple is

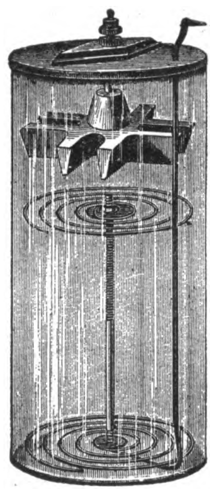


FIG. 7.—GRAVITY CELL.

zinc and carbon. The electrolyte around the zinc is dilute sulphuric acid; that around the carbon, is bichromate of potash, sulphuric acid and water. The zinc is cast in the form shown, and is thoroughly

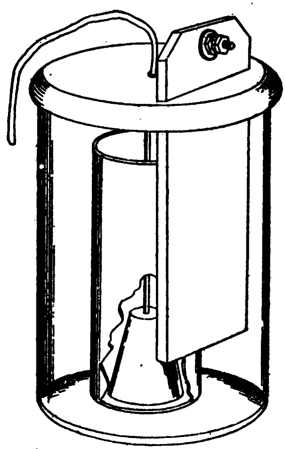


FIG. 8.—FULLER CELL.

amalgamated by being placed in a porous cell with a little free mercury. The E. M. F. of this cell is slightly in excess of

2 volts, so that it has about twice the E. M. F. of the Daniell cell.

Another type of cell is shown in Fig. 9, This is called the Leclanché cell. It con-

Fig. 9.—Leclanché Cell.

sists of a zinc-carbon couple immersed in an electrolyte of sal-ammoniac dissolved in water. Although apparently of the single-fluid type, it in reality employs a solid depolarizing substance consisting of manganese peroxide, which is packed around the negative carbon. The positive plate has the form of a zinc rod. The E. M. F. of this cell is, approximately, 1 1/2 volts. Although the cell is provided with a depolarizing substance, polarization sets in if the electric current supplied by the cell exceeds a certain strength and duration, so that the cell is unsuited for continued active current supply. The cell is frequently employed, however, on circuits where its current delivery is intermittent, that is to say, for *open-circuit work*. For *closed-circuit work*, that is, on circuits which are maintained closed, either the bluestone or the Fuller cell are generally employed and these are usually described as *closed-circuit cells*.

A single bluestone cell will, as we have already seen, only supply an E. M. F. slightly in excess of one volt, but if two of them be connected *in series*, as shown in Fig. 10, that is with the zinc pole of one

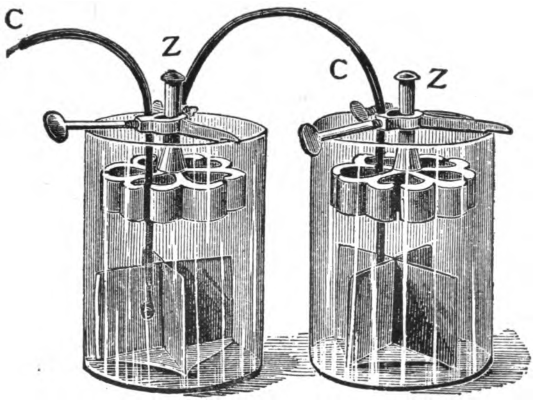


FIG. 10.—BLUESTONE BATTERY.

connected to the copper pole of the other, the total E. M. F. between the free poles at the ends of the battery so formed will be a little more than 2 volts, or twice that of a single cell. In the same way a battery of 100 such cells, connected in series, would supply a total E. M. F. of a little more than 100 volts

In Fig. 1, the *hydraulic flow* or flow of water which the pressure produced by the rotary pump is able to maintain in the hydraulic circuit, when the valve *V*, is open, depends upon what may be called the *hydraulic resistance* of the circuit. It will be evident that a very long, small pipe would offer a considerable resistance to the flow of water through it, and possibly only a few gallons-per-hour could be driven through it. On the other hand, a very short, large pipe would enable a considerable water current to be maintained through the circuit.

In the same way, in Fig. 2, the *electric* *flow* which the E. M. F. or electric pressure generated in the voltaic cell could maintain through the electric circuit, when the key *K*, is closed, would depend upon the *electric resistance* of the circuit. A very long, thin wire would offer a considerable resistance to the flow of electricity through it, while a short, thick wire would offer a comparatively small resistance.

Electric resistance is measured in terms of a *unit of electric resistance* called the *ohm*. The ohm is the resistance of about two miles of ordinary trolley wire, No. 0 A. W. G. (American Wire Gauge) 0.325″, or about one foot of No. 40 A. W. G. copper wire, 0.0031″ in diameter. Consequently, one foot of very fine copper wire, three-thousands of an inch (3 mils) in diameter, has about the same resistance as two miles of large trolley wire about one-third of an inch (325 mils) in diameter.

The resistance of any conductor depends upon three things: its length, its cross-sectional area, and the material of which it is composed. If we double the length of a wire we double its resistance. For example, if two miles of trolley wire have a resistance of one ohm, four miles will have a resistance of two ohms. In other words, the resistance of a uniform conductor is proportional to its length.

If we double the cross-sectional area of a wire, we double its conducting power to an electric current, that is, we halve its electric resistance. In the same way if two wires of similar material have the same length, but one has three times the area of cross-section of the other, or is three times as heavy, the resistance of the heavy wire will be one-third of that of the lighter wire. In other words, the resistance of a wire is inversely proportional to its cross-sectional area.

The resistance of a conductor of given length and cross-sectional area depends upon the nature of its substance. Wires having the same dimensions and composed either of copper or silver have less resistance than if composed of any other metal. A wire of iron has about 6 1/2 times as much resistance as a wire of copper of the same dimensions.

The resistance of a wire also depends upon its temperature and physical condition. If the wire be hard, as for example if it be taken after passing through a draw plate, its resistance will be slightly reduced by annealing, or softening it. Thus, hard copper has about 2 1/2 per cent. more resistance than softened or annealed copper. Hard copper is, however, usually employed for overhead telegraph wires in preference to soft copper, owing to its greater tensile strength. The resistance of a metallic wire also increases with the temperature. A copper wire has about 40 per cent. more resistance at the temperature of boiling water, than at the temperature of melting ice.

A wire of soft copper, one foot long, and having a diameter of one-thousandth of an inch (one mil) a cross-sectional area which is arbitrarily defined as one *circular mil.* In other words, its area may be considered unity for purposes of convenience in computation. Such a wire is called a *circular-mil-foot* and has a resistance at 20° C. of 10.35 ohms. The area of the wire increases as the square of the diameter. If we square the number of mils in the diameter of any wire we obtain its cross-sectional area expressed in circular mils. For example, a soft copper wire of standard conductivity, and at 20° C., one mile long (5,280′) and 0.325″ in diameter (325 mils) would have a resistance of

$$\frac{10.35 \times 5{,}280}{325 \times 325} = 0.5175 \text{ ohm.}$$

Every electric circuit must possess a certain amount of resistance, however large the conductors of which it is composed. This resistance resides in the generator or source, in the connecting wire or wires, and in the receiving apparatus. Besides these, however, resistance is sometimes artificially added for various purposes, and it is often necessary to add it in definite amounts. *Resistance boxes* containing spools of insulated wire so arranged that the amount of resistance which they offer may be regulated are called *rheostats*. One of these is shown in Fig. 11. Here

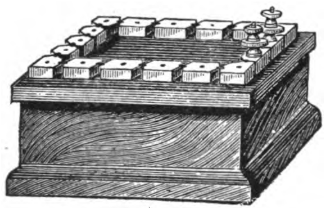


FIG. 11.—RHEOSTAT.

a number of brass pieces secured to the top of the box are separated by gaps into which brass plugs can be tightly inserted. The arrangement of the interior of such a box is represented diagrammatically in Fig. 12. Here the resistances *C*, *C'*, of a definite number of ohms, are connected between adjacent plugs in such a manner that when the plug between these blocks is removed, the current has to pass through the spool and encounter its resistance, whereas when the plug is restored practically all the current passes through the

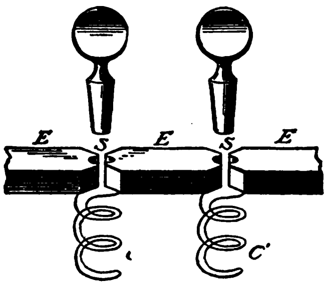


FIG. 12.—CONNECTIONS OF RHEOSTAT.

brass shank, and the resistance is short-circuited or cut out.

As regards their ability to carry electric currents, all substances may be divided into two classes; namely, *conductors*, and *non-conductors* or *insulators*. To the former belong all metals though in different degrees, and to the latter gases and many non-metallic substances, such as glass, rubber, porcelain, wood, paraffin, mica, etc. Non-conductors vary greatly in their insulating properties. No solid insulator is perfect; all conduct to a greater or less extent. There is, moreover, no dividing line between a very imperfect insulator and a very imperfect conductor. It would, of course, also be possible to arrange all substances in a table of conducting powers. Such a table would also be a table of insulating powers of materials if read in the reverse order. The resistance of a prism of glass at ordinary temperatures is, however, roughly 10,000 millions of millions of millions of times the resistance of a prism of copper of the same dimensions.

Since telegraph conductors are usually composed of bare insulated wires supported on poles, it is necessary to support them on insulators. In America insula-

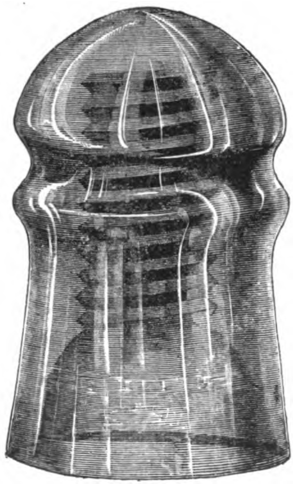


FIG. 13.—GLASS INSULATOR.

tors are usually of glass. A form of glass insulator is shown in Fig. 13.

The current strength which will flow in a circuit of known resistance under the action of a known E. M. F. is determined by a very simple law first enunciated by Ohm of Berlin and known as *Ohm's law.* This law may be expressed as follows. The current strength in amperes in a circuit is found by dividing the E. M. F. in the circuit in volts by the resistance of the circuit in ohms; or, briefly, in any circuit the

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

Fig. 14, represents a simple telegraphic circuit, employing two line conductors,

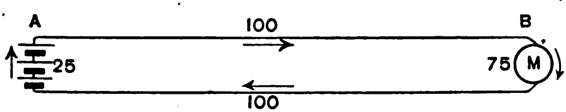


FIG. 14.—SIMPLE METALLIC CIRCUIT.

each ten miles long, having a resistance of 10 ohms per mile. The total resistance of each conductor is, therefore, 100 ohms. At the end *A*, is a battery of 10 bluestone cells, of which only three are indicated, each cell having an E. M. F. of say 1 volt, and a resistance of 2 1/2 ohms. At the end *B*, is a receiving instrument, having a resistance of 75 ohms. The total resistance will, therefore, be

Battery	25 ohms
Two line wires	200 ohms
Receiving instrument . . .	75 ohms
Total	300 ohms

The total E. M. F. in the circuit will be 10 volts, and the current strength will be 10 volts ÷ 300 ohms = 1/30th ampere = 33 1/3 milliamperes, or 33 1/3 thousandths of an ampere.

The early telegraph circuits were

formed in the manner indicated in Fig. 14, with two wires; *i. e.*, with *metallic circuits.* Steinheil, in 1825, endeavored to employ the two rails on a railroad track for telegraphic purposes, and discovered that the earth formed such a good conductor

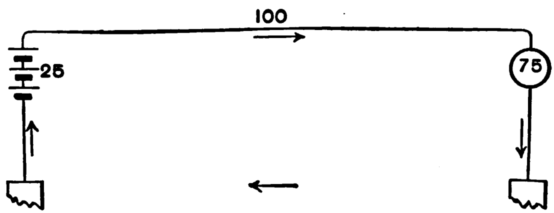


FIG. 15.—SIMPLE GROUND-RETURN CIRCUIT.

that a single conductor would be sufficient, employing the earth as a return. This is almost invariably the plan adopted in telegraphic practice since that time. Fig. 15, represents the circuit of Fig. 14, employing, however, a *ground-return circuit* instead of a metallic circuit. Here the resistance of the circuit may be expressed as follows:

Battery	25 ohms
10 miles of line wire . .	100 ohms
Receiving instrument . .	75 ohms
Ground, practically negligible, and therefore	0 ohms
	200 ohms

The current in this circuit would, therefore be 10 volts ÷ 200 ohms = 1/20th ampere = 50 milliamperes. In this case we have assumed that the resistance of the ground is zero. This would never be strictly true; the resistance of the ground would always have some magnitude. It might be supposed that since the materials constituting the earth's crust, in small masses, are generally of very poor conducting power, that the resistance of the earth would be high, but, as we have seen, the resistance of a conductor decreases with its area of cross-section; and, since the cross-section of the conductor formed by the earth is enormously great, the resistance is so low that when proper ground connection is secured, it is negligible for telegraphic purposes.

In a hydraulic circuit, such as represented in Fig. 1, the rate-of-flow of current may be expressed in gallons per second. In this case the unit of quantity would be the gallon. In an electric circuit, such as is represented in Fig. 2, the rate-of-flow of current is always expressed in *amperes.* The ampere is a rate-of-flow equal to one *coulomb* of electricity per second, corresponding in the hydraulic analogy to a rate of flow of one gallon per second, so that the coulomb represents a unit of quantity corresponding to the gallon. If, therefore, a current of one ampere be flowing through a circuit, one coulomb of electricity will pass through the circuit in each second of time. In an hour the total quantity of electricity which will have passed through the circuit will be 3,600 coulombs, and with one milliampere, one thousandth of this amount, or 3.6 coulombs.

When a pound of matter, say water from a reservoir, falls through a distance of one foot, as in flowing through an outlet pipe, an amount of *work* is done equal to one *foot-pound;* that is, equal to that which must be expended in order to raise one pound of water against the force of gravity through the vertical distance of one foot. In a similar manner, when one coulomb of electricity flows through a circuit under a pressure of one volt, an amount of work is expended in the circuit equal to one *volt-coulomb*, more frequently called one *joule*. A joule is a unit of work somewhat smaller than a foot-pound, being, approximately, 0.738 foot-pound; or, a foot-pound is, approximately, 1.355 joules. When, therefore, in a telegraph circuit, an E. M. F. of say 50 volts, supplied by a dynamo or battery, sends a current strength of 30 milli-amperes through the circuit, or $\frac{30}{1,000}$ coulomb-per-second, the work done by the generator is $50 \times \frac{30}{1,000} = 1\ 1/2$ joules in each second of time; or, approximately, 1.1 foot-pounds in each second.

A rate of working of one joule per

second is called one *watt*, and is employed as a *practical unit of activity*, or rate of working. Consequently, the circuit just considered would have an electric activity of 1.5 watts. If we multiply the current strength in amperes by the pressure under which it is delivered in volts, we obtain the electric activity in watts. Thus a telegraphic apparatus which receives a steady current of half an ampere under a pressure at its terminals of 10 volts, receives an activity of $10 \times 1/2 = 5$ watts, or 3.69 foot-pounds-per-second. The mechanical work which this machine can perform cannot possibly exceed this amount, or indeed, even equal it; since some loss of power necessarily occurs in friction. If the machine delivers more work than this, it must receive this work from some other source of power, as for example a local electric battery.

CHAPTER III.

ELEMENTARY PRINCIPLES OF MAGNETISM.

It is well known that a permanent magnet possesses the power of attracting or repelling the poles of other magnets in its vicinity or of attracting light particles of iron and steel. A copper wire through which no current passes possesses on the contrary no such power. If, however, an electric current be passed through the copper wire, it acquires magnetic properties as long as the current is passing, and loses these properties immediately on the cessation of the current. In other words, the active conductor acquires magnetic polarity by reason of the flow of the electric current through it. The direction of this polarity depends upon the direction of the current.

Deflection of a magnetic needle by means of an active wire is represented in Fig. 16. Here a copper wire *A B*, is suspended over a magnetic needle *N S*, in a North and South Direction; that is to say, when no current passes through the wire, the needle comes to rest parallel to the wire. When, however, a current passes through the wire, say from *A* to *B*, the needle is deflected to the left of the observer standing over the needle and facing the North pole. The pencil shown in the figure indicates the original direction of the needle before the current passed through the wire. The amount of the needle's deflection depends upon the strength of the current, the local strength

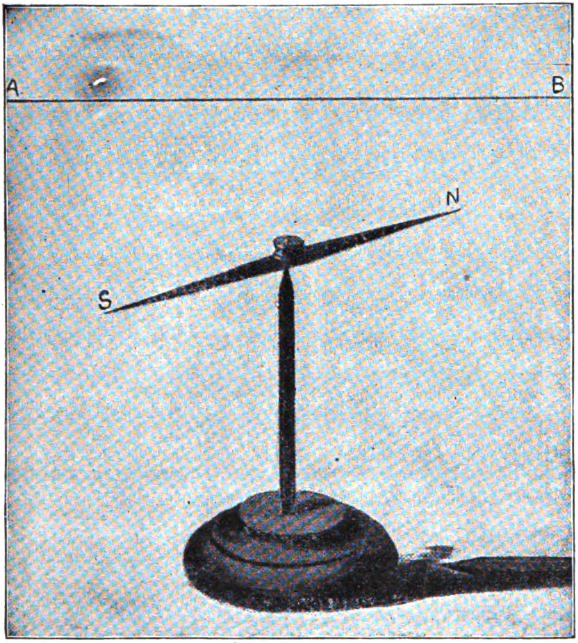


FIG. 16.—DEFLECTION OF MAGNETIC NEEDLE BY ACTIVE CONDUCTOR.

of the earth's magnetism and the distance of the wire from the needle. If the current were powerful and very close to the needle the deflection would amount to nearly 90°.

When a conductor becomes magnetized by the passage through it of an electric

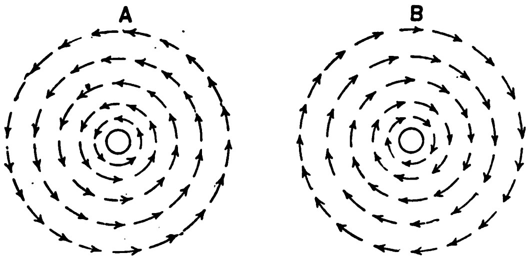


FIG. 17.—DIAGRAM OF MAGNETIC FLUX SURROUNDING ACTIVE CONDUCTORS.

current, the conductor is assumed to be surrounded by an invisible flow, called *magnetism*, or *magnetic flux*. This is represented diagrammatically in Fig. 17, where the arrows indicate the direction of the magnetic flux surrounding an electric current, flowing through a very long straight wire at the centre. At A, the current is coming toward the observer, and at B, the current is passing through the wire in a direction away from the observer. A small magnetic needle brought near the wire tends to assume the direction of the flux at that point, its North pole pointing in the direction of the arrow. The arrows are only drawn for a short distance from each wire, but the magnetic flux in reality continues for an indefinitely great distance from the wire, but with a constantly diminishing intensity, so that beyond a certain distance it cannot be detected. The *intensity* of the magnetic flux at any point will depend upon the strength of the current and the distance of the point from the wire; the greater the current strength, the greater the intensity of the magnetic flux in direct proportion, and the nearer the point to the surface of the wire, the greater the intensity in direct proportion.

If a conductor carrying a current be bent into a loop, such as is shown in Fig.

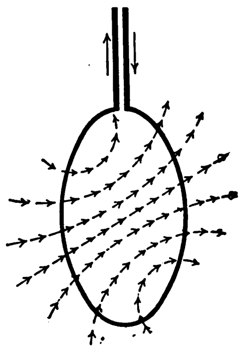


FIG. 18.—FLUX PASSING THROUGH SINGLE LOOP OF CONDUCTOR.

18, the magnetic flux will be so directed from all parts as to enter the loop on one side and emerge from it at the other side. The amount of flux which will pass through the loop will depend upon the size of the loop and upon the strength of the current which circles around it. If two such turns be placed as shown in Fig. 19, the flux from each turn will unite in

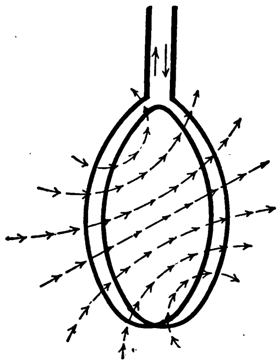


FIG. 19.—FLUX PASSING THROUGH DOUBLE LOOP OF CONDUCTOR.

passing through both, and the magnetic flux produced at any point in the neighborhood of the loops will be, approximately, twice as intense as if one loop only with the same current were employed.

When a number of turns of insulated wire are associated together in a common helix, or coil, the arrangement is called an *electromagnetic coil*, or *helix*, and the magnetic flux, which may be produced by such a coil on the passage of an electric current through it, may be considerable, owing to the co-operation of all the turns in producing the flux through the coil in the same direction. This is represented diagrammatically in Fig. 20, where a current passing through the left-handed helix wound on a cylindrical wooden block or core enters at the wire *A*, and leaves at the wire *B*. The magnetic flux leaves the core at the face marked *N*, and, after passing through the surrounding air, enters it on the face marked *S*. In this case, the face *N*, of the wooden core behaves like the *North-seeking pole* of a permanent bar magnet; *i. e.*, if the coil were suspended freely by a cord through its centre of figure, it would, when the current passed through the coil, tend to come to rest with the face *N*, facing the North pole of the

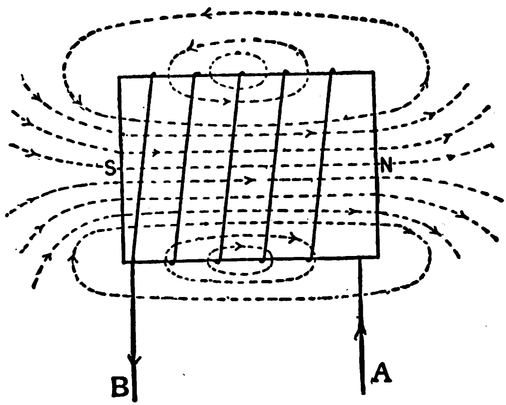


FIG. 20.—FLUX PASSING THROUGH ELECTROMAGNETIC COIL.

earth. If the direction of the current through the coil be reversed, the direction of the magnetic flux will be reversed, so that the end marked *N*, will become the

South-seeking or *South pole* of the coil, and the end marked *S*, the North pole.

If we increase the current strength passing through the coil we shall correspondingly increase both the total amount of magnetic flux passing through it, and also the intensity of the flux at any point. Since every line or path along which the magnetic flux is directed, that is every stream line, forms a completely closed path through the core and coil, each *magnetic stream line* constitutes an individual magnetic circuit, but the aggregation of all the stream lines passing through the coil is usually spoken of as the *magnetic circuit* of the coil. In this magnetic circuit, the total amount of magnetic flux corresponding to the magnetic current is the analogue of the electric current in the electric circuit. The number of turns of active conductor in the coil, multiplied by the number of amperes which these turns carry, gives the number of *ampere-turns* in the coil, and this corresponds to the E. M. F. which produces the electric current in the electric circuit. If we double the number of ampere-turns in the coil we double the amount of magnetic flux, or magnetic current, in the magnetic circuit, provided that no iron be included in the circuit.

We have seen that in the electric circuit it is the E. M. F. which produces the electric flow or current; so, in the magnetic circuit it is the *magnetomotive force*, usually contracted M. M. F., which produces the magnetic flux or current. There is this difference, however, between the two circuits; viz., that when an E. M. F. is set up there will be no permanent electric current until a complete conducting path is provided in which the E. M. F. may act; that is to say, the current will not flow until the circuit is closed. In the magnetic circuit, however, the existence of a M. M. F., due to the presence of turns of active conductor, invariably produces a magnetic flux. In other words, there is no known magnetic non-conductor or insulator. All substances with the exception of the magnetic metals, iron, nickel and cobalt, offer practically equal resistance to the flow of magnetism. Another difference between the electric and magnetic circuits is found in the fact that an electric flow can only be sustained by the expenditure of energy, whereas magnetic flux, once established, can be sustained without an expenditure of energy although energy is required to establish the magnetic flux at the outset.

If instead of winding the coil of wire upon a wooden core, it is wound upon a core or rod of soft iron, the arrangement is called an *electromagnet.* The effect of introducing the iron core into the coil is to greatly increase the amount of magnetic flux produced.

The reason for the great increase in the total magnetic flux through the magnetic circuit of the coil, which is effected by the introduction of an iron core, may for purposes of convenience be regarded as owing to the greater *magnetic conductivity* of iron than of air or wood. Soft iron has a conductivity for magnetic flux which may be hundreds of times that of air, wood or other non-magnetic material, and if a magnetic circuit be wholly composed of soft iron, the magnetic flux passing through the iron may be hundreds, or even thousands of times as great as that which the same M. M. F., expressed in ampere-turns, would force through the same magnetic circuit if composed of air. The *magnetic resistance* of iron, or, as it is termed, the *magnetic reluctance* of iron, varies with the intensity of magnetic flux passing through it. To a comparatively feeble flux its reluctance may be extremely small by comparison with air, while to a very dense magnetic flux its reluctance may be nearly as great as that of air. In other words the iron becomes *magnetically saturated.*

The simplest form of electromagnet is that shown in Fig. 21, where a straight bar or core of soft iron is wrapped with a coil of insulated wire. Here the magnetic circuit consists of two distinct parts; namely, of the interior of the core which is of iron, and the air outside through which the circuit is completed. One end of the core becomes of north polarity, the other

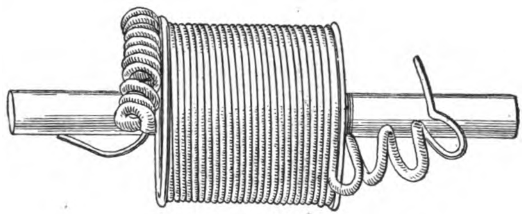


FIG. 21.—BAR ELECTROMAGNET.

end south, the direction of the polarity depending upon the direction of the current.

For most practical purposes it is desirable to bring the two ends of the bar together. This may be done by bending the iron core into a U, or horseshoe shape, and mounting a coil of wire upon each leg of the U, as shown in Fig. 22. Here the current passes first through one coil and then through the other, the M. M. Fs. of the two coils being virtually added together. The magnetic resistance of the

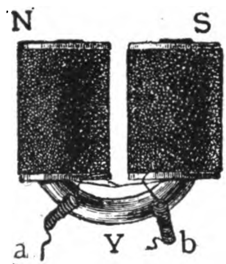


FIG. 22.—HORSESHOE ELECTROMAGNET.

circuit is now reduced, since the length of the flux paths through the air between the poles is shortened.

For convenience in mechanical construction, the *horseshoe electromagnet* is usually constructed as shown in Fig. 23, where the parallel cores *N*, *S*, are secured together to a common yoke piece *Y*.

Referring to Fig. 23, the magnetic flux produced by the M. M. F. of the magnetizing coil is assumed to issue from the pole marked *N*, to traverse the air space between these and the pole marked *S*, and then to complete the circuit through the

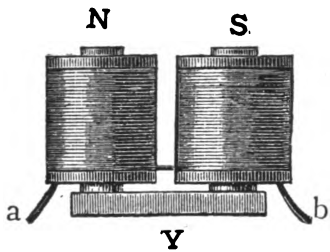


FIG. 23.—HORSESHOE ELECTROMAGNET.

cores and yoke, so that the magnetic circuit is partly composed of iron and partly composed of air. When the current flowing through the magnet coil ceases, the M. M. F. disappears and with it the magnetic flux. A piece of iron introduced into the magnetic circuit between the poles *N*, *S*, is attracted to them. A piece of iron so constructed as to be capable of being attracted by and moved towards the poles, under the influence of the magnetic flux passing through the circuit, is called an *armature*. This iron armature, when attracted to the poles, completes the magnetic circuit through its mass, thus providing an iron path for all parts of the magnetic circuit. Such a circuit is called a *ferric magnetic circuit*, in contradistinction to an *aëro-ferric magnetic circuit*, in which the magnetic circuit is completed partly through iron and partly through air, as in Fig. 23; or, to the *non-ferric magnetic circuit*, in which no iron enters, as for example, in the case of the copper wire or coil carrying an electric current.

The electromagnet owes its practical

value in telegraphy to the rapidity with which it can acquire and lose the magnetism produced by a current sent through its coils. In all cases it operates by the attraction which its flux exerts on a movable armature. The core and armature of the electromagnet are always made of very soft iron, so that the magnetic flux may as far as possible promptly disappear after the cessation of the electric current through the coils. If the iron were hard, the magnetism acquired would tend to be retained after the cessation of the current. In other words, the iron becomes in a greater or less degree permanently magnetized instead of being temporarily magnetized.

Fig. 24 shows a simple form of electromagnet and armature employed for ringing a bell. Here *M*, *M*, are the magnetizing coils whose terminals are connected to the binding posts *b*, *b*. *A*, is the soft iron armature, suitably supported on the pivot screws *V*, *V*, and carrying a hammer for

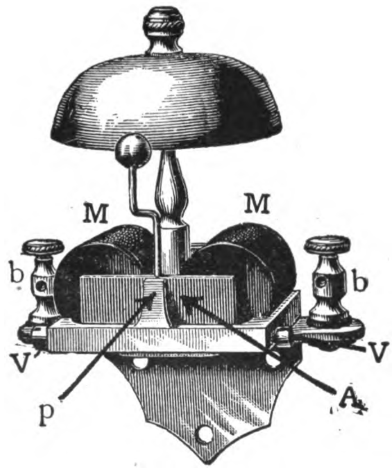


FIG. 24.—ELECTROMAGNETIC BELL.

striking the bell. The weight of the hammer is so disposed relatively to the armature, that when no current traverses the coils *M*, *M*, the armature falls away from the poles as far as the stop *p*, will permit. When a current is passed through the coils, they exert a M. M. F. on the magnetic circuit. The magnetic flux generated in this circuit traverses the air spaces between the poles and armature and passes through the mass of the armature itself. The armature is thereby attracted toward the poles and comes forward until arrested by the hammer striking the bell. The armature will remain in this position so long as the current passes through the coils. If now the circuit be opened, the armature will fall back, and this to and fro movement of the armature will occur as often as the circuit is made and broken. For this reason the bell is called a *single-stroke bell.* It is evident that the number of strokes delivered by the hammer on the bell will be under the control of a distant operator who makes and breaks the electric circuit at will, and that, by a suitably arranged code of signals, such a bell might be employed in telegraphy.

Fig. 25, shows an electromagnetic bell differing from the preceding. Here the magnetizing coils *m*, *m*, are connected with their terminals to the binding posts T_1 and T_2, so that if these binding posts be connected with a suitable E. M. F., and the circuit be closed, the armature *A*, will be attracted, and will bring the hammer *H*, upon the bell. When the armature *A*, is attracted the spring *s*, leaves the screw contact *c*, against which it rests. This screw contact is connected with the binding post T_3, in such a manner that if the binding posts T_1 and T_3, are connected with the circuit, instead of T_1 and T_2, the circuit will be automatically interrupted, as soon as the armature leaves the contact *c*.

This will cause the M. M. F. and magnetic flux to disappear, and the armature *A*, to

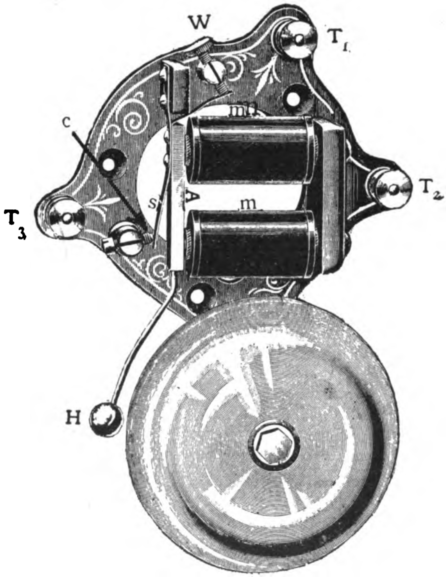


FIG. 25.—ELECTROMAGNETIC BELL.

return, again closing the contact at *c*. The re-establishment of the contact will restore the electric current, M. M. F., magnetic flux, and attraction, so that the armature will periodically be attracted and released. With this action a bell is called a *vibrating bell*, in contradistinction to a single-stroke bell. This bell is therefore single-stroke or vibrating, according to the pair of terminals employed. *W*, is a small screw adjustment serving to vary the tension of the spring *s*.

The magnetic flux developed in the magnetic circuit of any electromagnet, depends, as we have seen, upon the M. M. F., and this depends upon the number of ampere-turns. If the current supplied through the coils be powerful, a comparatively small number of turns will be sufficient to produce a considerable M. M. F. If, on the contrary, the current strength passing through the coils be feeble, a greater number of turns will be necessary to develop the same M. M. F. For this reason electromagnets, which have to be employed in telegraphic circuits where the current strength is quite feeble, say 1/50th of one ampere, are wound with many turns of fine wire so as to make up in the number of turns what they lack in the number of amperes.

CHAPTER IV.

BRIEF HISTORY.

Attention has already been called in the introductory chapter to the fact that the electric telegraph remained an uncommercial device until after the discovery and application of the voltaic pile about the year 1800. In 1809, Sömmering of Munich availed himself of the ability which the electric current possesses of decomposing acidulated water to produce a form of apparatus represented in Fig. 26. Here *V*, is a *voltaic pile; i. e.*, a series of voltaic cells arranged in a column so connected as to produce a considerable total E. M. F. *T*, is a transmitting apparatus connected with the voltaic pile on one side, and on the other, with the receiving apparatus *R*, through the cable *c c*,

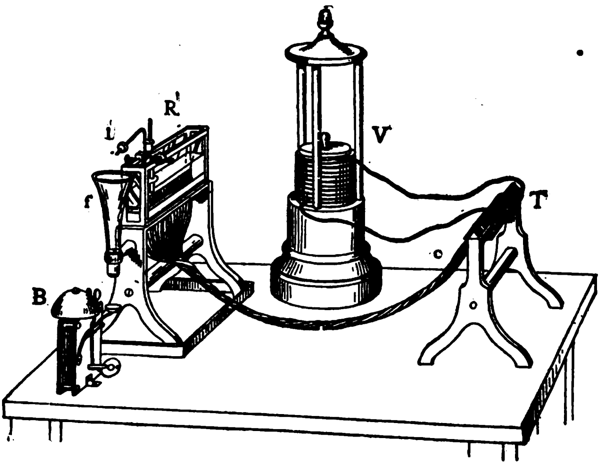


FIG. 26.—SÖMMERING'S TELEGRAPH.

containing 27 wires, one wire for each letter of the alphabet, with one extra wire. These wires are so arranged that by pressing the appropriate contact under the letter of the alphabet at *T*, an electric current from the voltaic pile *V*, was sent through the wire into the bath of acidulated water at *R*, and gave evidence of its passage by a stream of small gas bubbles from the extremity of that particular wire. The observer at *R*, watching these bubbles, was able to recognize the particular letter of the alphabet to which that particular wire corresponded, and, by suitable intervals or spaces between words, was enabled to spell out a message. A crude form of alarm apparatus, or call bell, designed to call the attention of the operator at the distant end, is also represented in the figure. A spoon-shaped gas collector was inverted in the acidulated water over one wire, in such a manner that by causing the current to flow steadily through that wire a considerable quantity of gas would be liberated and would accumulate in the inverted receptacle until the buoyancy of the gas caused the receptacle to rise and release the ball *i*, through the funnel *f*, on to a platform connected with the alarm bell which was thus set in motion. This system was never introduced into commercial practice owing to the number of conductors which it employed.

The discovery of electromagnetism by Oersted of Copenhagen in 1820, and the production of an electromagnet in 1825, gave a new stimulus to electric telegraphy.

One of the earliest forms of telegraphic apparatus employing electromagnetism was that devised by Gauss and Weber, in 1833. The receiving apparatus employed in this device is represented in Fig. 27.

Here a permanent bar magnet *M M*, is suspended within the coil *H H*, from a thread, and carries the mirror *N*. When the electric current passed around the coil, the magnets became deflected, the direction

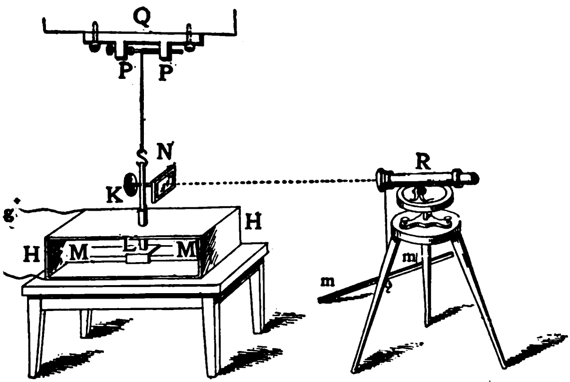


FIG. 27.—GAUSS AND WEBER'S TELEGRAPH.

of deflection depending upon the direction of the current. This deflection was noted by an observer at the telescope *R*. A series of signals was sent through the two wires forming the line and the observer watching the movements of the suspended magnets was able to spell out the letters and words so formed.

The year 1837, witnessed important developments in the telegraphic art, three distinct inventors presenting systems that may be regarded as available for commercial use. These three inventors were Steinheil of Munich, Wheatstone of London, and Morse of New York. Without entering into a description of the systems, it will suffice to say that the Steinheil apparatus constituted an improvement upon that of Gauss and Weber.

The Wheatstone instrument was of the needle type, the movement of a magnetic needle to the right or left being employed in much the same manner as Gauss' bar magnet, the combination of movements to the right and left being employed to spell out the letters of the alphabet, the telescope of Gauss being rendered entirely unnecessary.

Morse employed an electromagnet to move a pen across a band of paper moved steadily forward by clockwork. This apparatus is represented in Fig. 28. Here a weight *W*, drives clockwork *C*, to move forward a band of paper *p p p*, over a roller *R*, beneath the point of a pencil held in a suspended frame. The magnet *m*, in circuit with a voltaic cell *V*, and the transmitter *H*, was so arranged that when the current passed through the circuit, the magnet attracted the suspended frame and moved the pencil across the paper band. The signals were sent by moving forward a board *b b*, with the aid of a handle *H*.

Pins were inserted in the port-roll or board, so as to cause the wires at the free end of

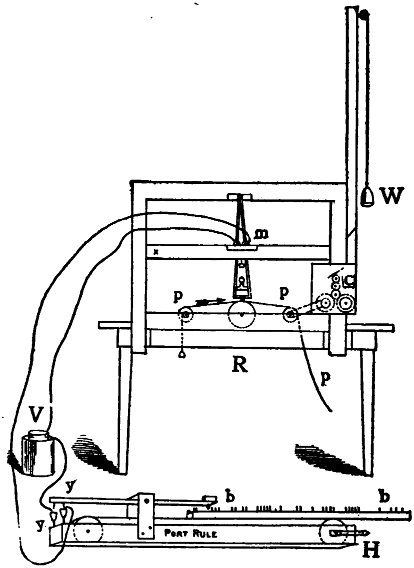


FIG. 28.—EARLY FORM OF MORSE APPARATUS.

the lever to dip into mercury cups *y*, *y*, at suitable intervals and so close the circuit. It is evident that at this time Morse had not conceived the idea of sending signals by a hand key and considered that it was necessary to space the contacts by mechanism. The pin contacts were set in the port-roll by type such as represented in Fig. 29. These letters were called *tele-*

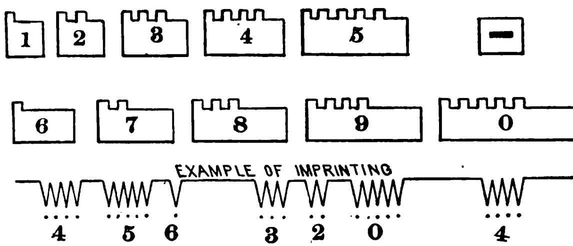


FIG. 29.—EARLY MORSE TELEGRAPHIC TYPE LETTERS.

graphic type letters. The manner in which the signals were received on the band of paper is also represented in this figure, and at a later date Morse discovered that it was unnecessary to send the signals from type characters and the Morse key was introduced.

The first telegraphic line in the United States was opened in 1844, between Baltimore and Washington. It was constructed under an appropriation by Congress. The first dispatch was transmitted on the 27th

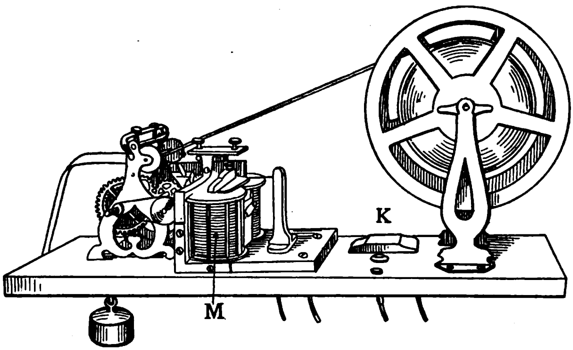


FIG. 30.—EARLY MORSE TELEGRAPH.

May from Washington to Baltimore. The apparatus employed on this line is represented in Fig. 30. *M*, shows the electro-magnets with their armatures which emboss the moving strip of paper when these armatures are attracted. *K*, is the key whose knob projects above the surface of the base. The relay employed with this instrument is not shown in the figure. It weighed about 180 pounds.

After the date of Morse's first telegraph circuit, improvements were rapidly introduced, and the system used soon simplified to that which is found throughout the country to-day.

CHAPTER V.

THE SIMPLE TELEGRAPH CIRCUIT.

We have seen that when an electromagnet is connected in the circuit of an E. M. F., a current will pass through the coils of the electromagnet as soon as the circuit is closed. Whether or not the electromagnet is able to attract its armature under these circumstances will, of course, depend upon the current strength passing through its magnetizing coils, as well as upon the character of the electromagnet and the amount of force it must exert in order to move its armature against the action of its retarding forces. In accordance with Ohm's law, the resistance in the circuit will determine the magnitude of the E. M. F. which must be applied to it in order to obtain the requisite current strength. The length of the line connecting the E. M. F. with the electromagnet has no influence whatever upon the strength of the current which can be maintained through the magnet coils, beyond the effect of the electric resistance which the line wire introduces. Thus if the resistance of the line wire be 100 ohms, and the insulation of this wire be assumed as perfect, so that no current escapes by leakage, it is a matter of indifference whether the length of the line be 100, or 1,000 miles, the strength of current which will pass through the electromagnet coils will in each case be the same.

Fig. 31, represents a telegraphic circuit reduced to its simplest elements. *L L'*, is the line wire connecting the two stations *A* and *B*, which may be many miles apart. A ground-return circuit is established between the two *ground-plates* *G*, *G'*. *E*, is a voltaic battery furnishing

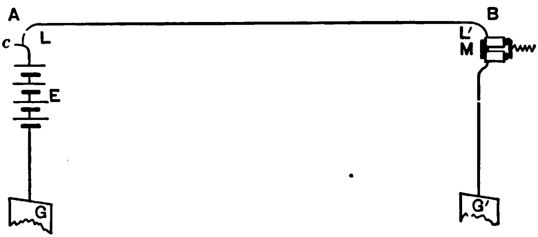


FIG. 31.—SIMPLE TELEGRAPHIC CIRCUIT.

a suitable E. M. F. This battery is represented as connected with the circuit at *A*, but it may be connected at station *B*, or at any point intermediate between *A* and *B*. *M*, is an electromagnet, so wound that the current strength passing through the circuit, when closed, is sufficiently strong to operate it properly and cause it to attract its armature against the force of a retractile spring. *c*, is a device for readily making and breaking the circuit. This might be done by taking the two ends of the wire in the hands, connecting them and disconnecting them at suitable intervals, but, for convenience, a special device is always employed, called a *telegraphic key*, which will be presently considered.

As soon as the operator at *A*, closes the circuit at *c*, by bringing the wires together, a current will flow through the circuit, the strength of which will be determined by Ohm's law in the manner already described. Let us suppose that the total resistance of the circuit amounts to 1,000 ohms, and that the E. M. F. of the battery is 25 volts, then the current strength which will pass through the circuit will be 25 volts ÷ 1,000 ohms $= \frac{25}{1,000}$ ampere = 0.025 ampere, or 25 milliamperes. A certain small fraction of time will be needed for the development of this current through all parts of the circuit, but, for present practical purposes, this time is so brief that the current may be considered as rising instantaneously to its full strength. Consequently, the closing of the circuit at *c*, is followed by the passage of the current through the magnetizing coils at *M*, and this is immediately followed by the attraction of its armature. If we assume that no leakage exists in any portion of the circuit, the current strength will everywhere be the same, but if considerable leakage takes place between the line and ground through the insulators supporting the wire, the current strength passing through the magnet *M*, may be considerably less than the current strength leaving the battery *E*.

As soon as the circuit is broken at *c*, the current ceases and the armature of *M*, is released. Consequently, the movements of the contact at *c*, determine the movements of the armature of *M*. If the wire at *c*, remain in contact for, say 30 seconds, the armature of *M*, will remain attracted for an equal length of time, and so for any other period of contact, so that any succession of makes and breaks at *c*, is accompanied by a corresponding succession of to-and-fro motions at the armature of *M*.

The telegraphic circuit shown in connection with Fig. 31, is only provided with the circuit-closing arrangement at *A*, and the electromagnet at *B*. Consequently, while *A*, could send signals to *B*, *B*, would be unable to send signals to *A*. Fig. 32, represents the same line with a

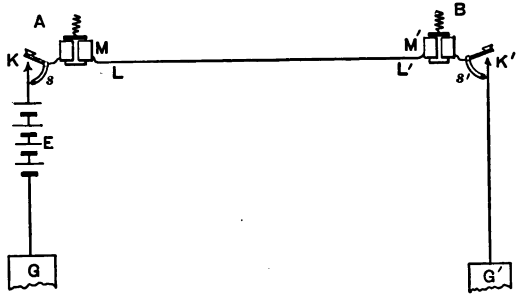


FIG. 32.—TELEGRAPHIC CIRCUIT.

circuit-closing arrangement and an electromagnet at each end. Under ordinary conditions the keys *K*, *K'* are either depressed or short-circuited by the *switches* *s*, *s'*, so as to close the circuit at both ends of the line, and enable the current to pass steadily through it. Since the resistance of the entire circuit in Fig. 31, was 1,000 ohms, the introduction of the additional electromagnet in Fig. 32, may increase the total resistance of the circuit to say 1,100 ohms, and in order to produce the same current strength through the circuit as before, the E. M. F. will have to be increased to 27 1/2 volts, since 27.5 ÷ 1,100 ohms = 25 milliamperes.

If *A*, desires to signal *B*, he breaks the circuit at his switch *S*, and produces a series of makes and breaks which are immediately followed by a similar series of movements on the part of the armature of the electromagnets *M*, *M′* at *A* and *B*. When *A*, ceases to signal, he restores the circuit at *A*, by permanently closing his switch *s*. *B*, may now signal to *A*, by opening the circuit at *s′*, and producing a series of makes and breaks with his key which are followed by the armatures of both electromagnets. In this case the signals which are sent at one end of the line are repeated at both ends, so that the sender may know by the action of his own electromagnet's armature that the same signals are being received at the distant end.

A form of telegraphic key in extensive use, for purposes of making and breaking the circuit in the manner described, is represented in Fig. 33. A metal base *D D*, is firmly screwed down to the operator's table by long screws *W*, *W'*, which pass through the table's surface. The ends of the wire which are to be brought into connection with the screws are clamped securely to the binding screws *W*, *W'*, so that one wire is in contact with the screw *W*, and the other wire with W'. The latter is in metallic connection with the base D D. The former is insulated from D D, and termi-

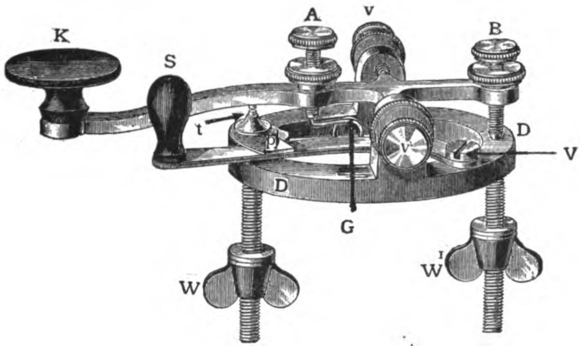


FIG. 33.—MORSE TELEGRAPHIC KEY.

nates in a platinum contact point at t, which also supports a metallic strip p. Under these circumstances the screws W and W', remain insulated from each other. They may, however, be electrically connected in either of two ways. First, by the key K, which is pivoted at the line v v, and connected through these pivots with the base

D. On depressing *K*, the contact is closed at *t*, thus connecting the base *D*, with *W*, and, therefore, *W'*, with *W*; or, secondly, the circuit may be closed by pushing the switch *S*, under the metallic spring *p*, as shown in the drawing. The metallic switch *S*, is movable about the axis of the screw *V*, and is, therefore, electrically connected with the base *D*. When the key is not employed for signalling, the switch *S*, is left permanently in the position shown, thereby closing the circuit of *W W'*. On opening the switch the circuit is broken until pressure at *K*, re-establishes the circuit at the contact *t*. The screw *A*, adjusts the tension of the brass spring *G*, which forces the key *K*, upward and against the back stop of the screw *B*. The play, or distance between the platinum points of the screw, can be regulated by the screw and nut *B*.

Another form of telegraphic key is represented in Fig. 34. This key is screwed to the surface of the table and not through the table. Consequently, the

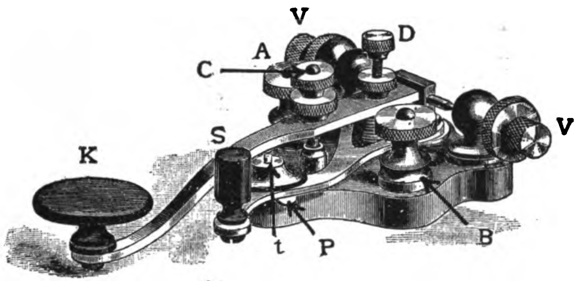


FIG. 34.—MORSE TELEGRAPHIC KEY.

wires closing the circuit are connected to the terminals *A* and *B*, above the key, instead of to the wing nuts *W*, *W'*, of Fig. 33, beneath the table. The tension of the spring is regulated by the screw *D*, the play by the screw *C*, while *t*, is the contact and *P*, the strip making contact with the switch *S*, as before. The manner in which this key operates is the same as in the preceding case, although the form is slightly different.

We have hitherto spoken of the receiving instrument *M*, as a simple electromagnet. In actual practice, however, special forms are given to the receiving electromagnet. One of these is represented in Fig. 35. The magnetizing coils are enclosed in hard rubber cylinders *M*. The terminals of the wire wound on these coils are connected to the binding posts *B*, *B'*. *A*, is a soft iron armature, rigidly attached to the metallic lever *L*, pivoted on the line *v v*, and maintained at this upper contact stop by the tension of the spring regulated by the screw *S*. The play of the lever is adjusted by the screws *W*, *W'*. When the armature is attracted it brings the lever down until arrested by the screw *W'*, and when the armature is released, the spring beneath forces the armature upward until arrested by the

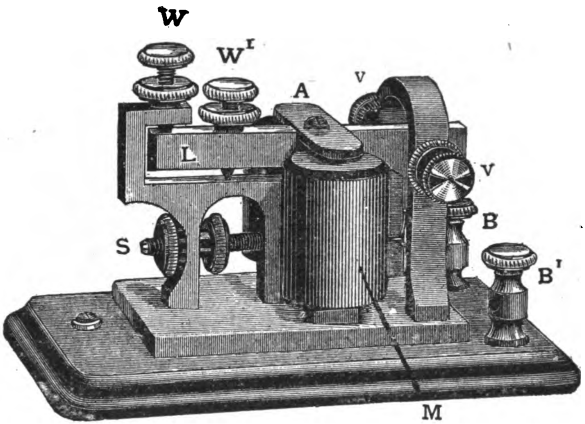


FIG. 35.—TELEGRAPHIC SOUNDER.

screw *W*. This form of magnet is called a *telegraphic sounder*, because the sound made by the armature in its movements, between the upper and lower stops, serves to convey the signal sent on the line to the ear of the operator.

Another form of sounder is represented

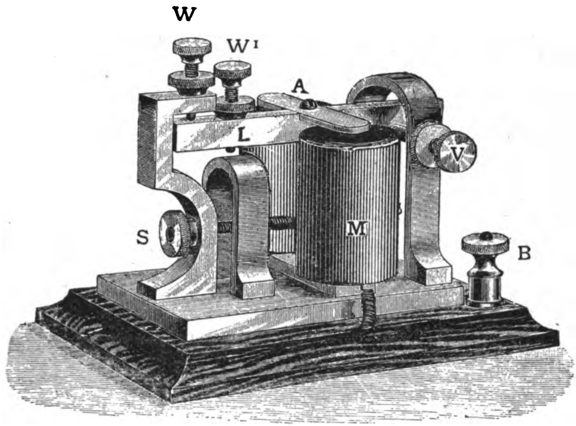


FIG. 36.—TELEGRAPHIC SOUNDER.

in Fig. 36, similar letters corresponding to similar parts.

Messages are transmitted by the use of

three independent characters; namely, short signals or *dots*, long signals or *dashes*, and dividing intervals or *spaces*, between adjacent signals. Thus, a dot followed by a short space and then by a dash represent the letter *A*, while a dash followed by a short space and three dots, separated by short spaces, represent the letter *B*. Five of the letters of the alphabet employ spaces of extra length and are called *spaced letters*. As will be seen in Fig. 37, these letters are *c*, *o*, *r*, *y*, *z*. The letter *l*, consists of a dash twice the length of an ordinary dash.

The unit of length in this system or code of signals is the dot, and the space separating the signals in the letter has the length of one dot. The space between the letters of a spaced letter is two dots in length. The dash has a length of three dots. The space between adjacent letters is three dots, and the space between adjacent words six dots.

When an operator desires to send a

a	-—	o	- -	1	-——-
b	—---	p	-----	2	--—--
c	-- -	q	--—-	3	---—-
d	—--	r	- --	4	----—
e	-	s	---	5	———
f	-—-	t	—	6	------
g	——-	u	--—	7	——--
h	----	v	---—	8	—----
i	--	w	-——	9	—--—
j	—-—-	x	-—--	0	——
k	—-—	y	-- --	.	--——--
l	——	z	--- -	?	—--—-
m	——	&	- ---	!	———-
n	—-				

Fig. 37.—Morse Code.

letter *A*, he depresses his key for a short interval, then releases it, and, after an interval equally brief, depresses it again, holding it down for a period three times as long before releasing it. Corresponding to the closing of the circuit caused by the depression of the key, currents flow through the line, the one caused by the depression corresponding to the dash being of three times greater duration than that corresponding to the dot. The effect of these currents passing through the magnetizing coils of the telegraphic sounder is to produce corresponding movements of its armature as already explained.

The movements of the armature lever of the electromagnetic receiving apparatus were originally employed by Morse for producing a permanent record on a band of moving paper. An instrument for accomplishing this is called a *Morse register*. A form of such instrument is shown in Fig. 38. In this instrument the electromagnet *M*, is provided with a lever *L*, armed at its extremity with a stylus or adjustable screw point *p*, so placed relatively to a moving band of paper tape *TT*,

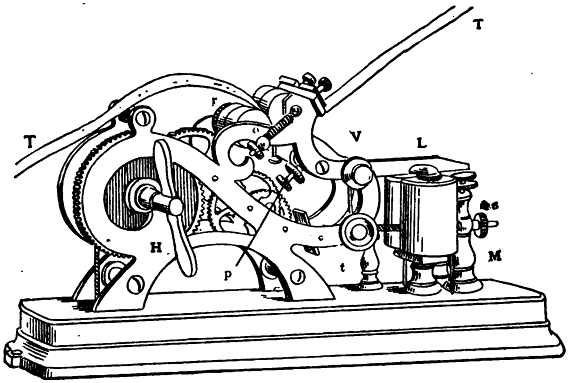


Fig. 38.—Morse Register.

as to emboss or indent the paper on the downward movement of the lever *L*, consequent on the passage of the current through the magnetizing coils of the electromagnet. The paper is drawn through the reels *r*, *r*, by the aid of clockwork, at a regular rate. If the armature lever *L*, is depressed momentarily, a dot is made in the paper tape. If, on the contrary, the lever *L*, be continuously depressed, a long dash will be indented or furrowed in the paper. When, however, no current passes through the magnets, the paper tape runs through unindented. Consequently, by sending over the line impulses of current corresponding to dots and dashes of the Morse alphabet, the characters will be embossed on the moving tape, thus producing a permanent record.

A more modern form of Morse register is represented in Fig. 39. Here *t*, *t*, are the terminals or binding posts connected with the magnets, which in this case are within the instrument. The lever is pivoted at *V*, and carries the stylus *p*, close beneath the roller, over the surface of which is drawn the moving tape. *S*, is the adjusting spring for varying the tension on the armature lever whereby it is restored to its

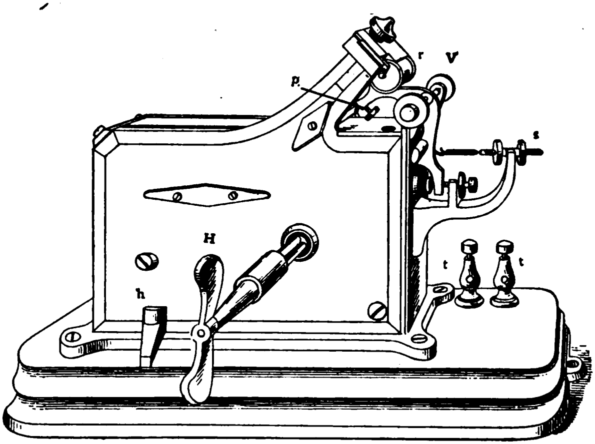


FIG. 39.—MORSE REGISTER.

original position when unattracted by the electromagnet. *h*, is a small lever for stopping the paper band when no signals are being received.

In the early history of the Morse system of telegraphy, registering instruments were solely employed. It was soon found, however, that the sounds produced by the movement of the recording lever were sufficiently characteristic to enable the operator to read the message directly by sound without the use of the recording slip or tape. This led to the practical abolition of the register, which is to-day but little employed, sounders of the general type shown in Figs. 35 and 36, having taken its place.

Outside the United States and Canada a somewhat different system of Morse alphabet is employed. When the electromagnetic telegraph was first introduced on the European Continent, different alphabets were employed in different countries. By an international European conference it was agreed to adopt a uniform code which is now known as the *Continental code.* This code differs from the Morse in the fact that it contains no spaced letters. The alphabet is formed of various com-

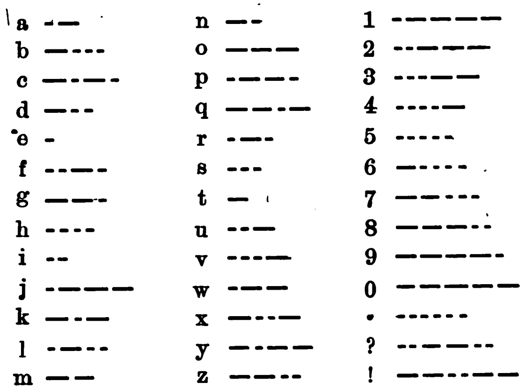


FIG. 40.—CONTINENTAL MORSE CODE.

binations of dots and dashes, but the intervals between the signals in each letter are the same. The Continental Morse code is shown in Fig. 40.

On a comparison of the Continental and Morse codes it will be seen that the 15 letters *a, b, d, e, g, h, i, k, m, n, r, t, u, v* and *w*, are the same in both. The remaining 11 letters *c, f, j, l, o, p, q, r, x, y, z*, are different, as also are the numerals and the various punctuation marks. It has been found in practice that the *American* or *Morse code* is more rapid, because it requires fewer dot intervals for the transmission of any given message. In other words, there are fewer dashes in the Morse code than in the Continental code. This difference in speed may amount to say five per cent. In order to indicate this the following short sentence is analyzed in both codes in Fig. 41.

Here the sentence "Great is Diana of the Ephesians" is printed in both Morse and Continental codes. It will be found on counting that the total number of unit spaces in the Morse code sentence is 222, while the total number of units in the Continental code sentence is 210, thus

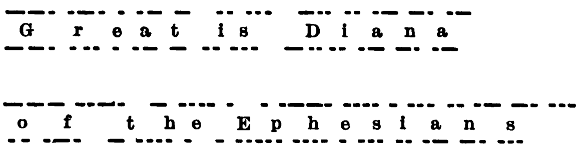


FIG. 41.—COMPARISON OF MORSE AND CONTINENTAL CODES.

showing a gain in this case of about five per cent.

While, however, the Morse code is the more rapid, it possesses a greater liability to errors of transmission, owing to the spaced letters which are apt to be mistaken for double letters; for example, the letter *o*, in the Morse code is apt to be read *ee*, and so on. Moreover, the Morse code is ill adapted to signalling through long submarine cables, as will be explained in a subsequent chapter.

In order to give some idea of the skill which may be acquired by the Morse operator, it may be interesting to note that an expert operator can send from 35 to 40 words per minute, although for steady working a rate of 25 words per minute may be regarded as good. The highest recorded speed of legible telegraphing with the ordinary Morse code, in a five-minute trial, is 53 words per minute.

Telegraphic circuits may be divided into two kinds; namely, the *closed-circuit system* and the *open-circuit system.* In the United States and Canada the former is used almost entirely. The latter is employed in other parts of the world.

The closed-circuit system is illustrated in Fig. 42. It corresponds to the system

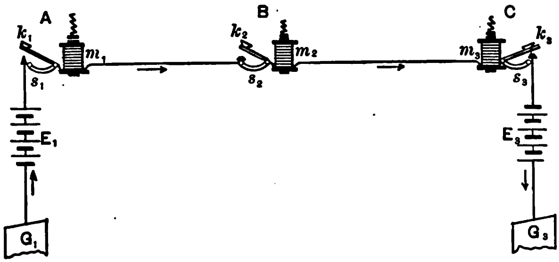


FIG. 42.—CLOSED-CIRCUIT MORSE SYSTEM.

already shown in Fig. 32, except that it represents the introduction of an intermediate station at *B*. It will be seen that when no signals are being sent along the line, a current steadily flows through the circuit from the batteries E_1 and E_3, which are arranged in series so as to assist each other. In other words the circuit is normally closed, and from this is derived the term closed-circuit system. When any station say *B*, desires to communicate with *C*, he opens the switch s_2, thus breaking the circuit and releasing the armatures of all three sounders m_1, m_2, m_3. *B*, now calls *C*, by sending *C's* calling signal, generally consisting of one or two letters. *C's* attention is thus called to his instrument. Although *A*, can hear the signals passing over the line yet he knows by listening to them that it is *C*, that is wanted and not his station. *C*, then answers and receives the message which *B*, may desire to send. As soon as *B*, ceases to transmit he must close his switch, otherwise he will leave the line open and prevent *A* and *C*, from using it. Consequently, on the closed-circuit system it is necessary for each operator to close the circuit the moment they have ceased to use the line, otherwise they would prevent the entire circuit from being used.

The batteries in Fig. 42, are shown as being connected to the circuit one at each end, and this is the most usual practice. It is possible, however, on a short line to introduce a single battery, at any point, or it may be desirable in the case of long lines to employ several batteries inserted at several points.

Fig. 43, represents an open-circuit Morse

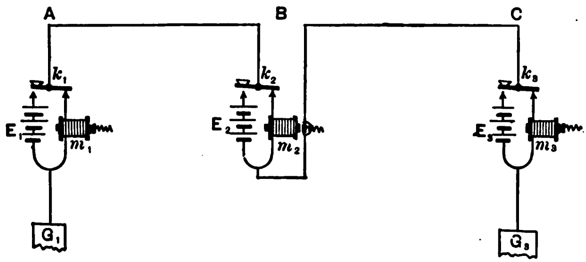


FIG. 43.—OPEN-CIRCUIT MORSE SYSTEM.

telegraphic line with three stations *A*, *B* and *C*. Here each station is provided with a battery. It will be seen that when no message is being sent, the circuit of the line is closed but the circuits of the batteries are all open, so that no current is normally sent along the line. When any operator such as *B*, desires to communicate with another operator say *C*, he depresses his key, which in this case is unprovided with a switch, and changes it from the back contact to the front contact, his key being pivoted at or near its centre. The current from the battery E_2, is then sent to line through the instruments m_1 and m_3, but not passing through the instrument m_2. *C*, hearing that he is called answers and receives the message.

It will be seen that in the open-circuit system there are as many batteries as there are stations on the line, while in the closed-circuit system there may be only one main battery, or a convenient small number, such as two batteries, say one at each end. When an operator sends a message on the open-circuit system he employs a current from his own battery, whereas when an operator sends a message on the closed-circuit system he employs the current from the main battery or batteries in the line.

Both the open- and the closed-circuit Morse systems possess certain advantages, and each is adapted to a particular character of work. The advantage of the closed-circuit system is the readiness with which an office or station can be introduced into a circuit; for, without carrying any battery, all that is necessary is to cut the telegraphic wire at some point and insert a receiving instrument and key into the circuit. Consequently, in cases where a number of stations have to be inserted on a single line, as for example, along a considerable length of railway, a number of offices can be operated with a comparatively small expense in the installation of batteries.

On the contrary, the open-circuit system has the advantage of not working the batteries when the line is idle. Although this system requires the introduction of a separate battery for each station inserted in the line, yet, in cases where a very great number of stations are not required on the line, it may possess advantages over the simpler closed-circuit system.

CHAPTER VI.

BATTERIES AND DYNAMOS.

The current strength required to operate an ordinary Morse circuit is about one-fortieth of one ampere; *i. e.*, about 25 milliamperes. The resistance of a telegraph circuit, 200 miles in length, may be 2,000 ohms, and if say 12 stations are connected up in the circuit, each with a relay of 150 ohms resistance, the total resistance of the line and instruments will be 3,800 ohms. It will, therefore, be necessary, in order to obtain a current strength of one-fortieth of an ampere, to provide an E. M. F. in the circuit of 95 volts without making any allowance for the additional resistance, which will necessarily be included in the batteries supplying this E. M. F., or for any loss by leakage occurring over the line. If, say, a battery of 100 gravity cells, having, therefore, a total E. M. F. of approximately 100 volts, be connected to the line at one end *A*, the leakage will be greatest, and the current strength through the circuit will be a maximum at this end, and a minimum at the distant end *B*, where the line is grounded. With considerable leakage the relays will be working feebly near *B*, owing to the weakened current, while at or near *A*, the relays will be working with strong current but with a variable adjustment: for, if an operator at *B*, is sending a message to *A*, when he opens the circuit at his key he will cut off from the battery at *A*, all the current which flows through the line wire, relays and ground, but he will not cut off the leakage current which flows through the line and some of the relays to ground. Consequently, the relay at *A*, has to be adjusted so as not to attract its armature upon the leakage current but only upon the leakage and line current combined.

An analogous series of conditions to those above described would be presented by a long india rubber water pipe or hose connected to a pump at one end and to a discharge pipe at the other. If the pipe is free from leakage it is evident that the flow at the pump end must be the same as the flow at the discharge end, provided both are steady, and any instruments inserted in the pipe at different points to indicate the amount of flow would register alike throughout its length. As soon as the discharge is shut off, the flow subsides throughout the pipe and none would be indicated on any of the meters in the hydrostatic circuit. If, however, the pipe be uniformly leaking at each joint, the flow at the pump end will always be greater than the flow at the discharge end when the discharge pipe is open; and, moreover, this difference will increase with the number and leakiness of the joints; or, in other words, with the length and leakage of the line. If the discharge pipe be shut off, the flow will cease close to the discharge end, but will only be lessened at or near the pump end, where the flow in leakage will still be comparatively strong. The amount of leakage will evidently increase with the hydrostatic pressure under which the water is forced through the pipe.

A better distribution of the E. M. F.

over a circuit is obtained by dividing the battery into two equal portions and inserting these in the line, one at each end. In this case the leakage is a maximum at each end, and is a minimum at the centre. The most perfect arrangement would be a uniform distribution of the voltaic cells along the line, but this is impracticable.

Until within the last few years voltaic batteries were entirely relied upon for the source of current in telegraphic service, and several thousands of gravity cells were sometimes employed for this purpose in a single large office. The dynamo-electric machine has, however, of recent years largely supplanted the voltaic cell, so that there are scarcely any voltaic cells in the central telegraph offices of large cities. Along the line and in sub-offices generally, voltaic cells are still employed for the local circuits of the sounders.

The reason for the introduction of dynamo-electric machines in place of batteries is the fact that batteries necessarily occupy a large amount of space, need considerable care and inspection, and necessitate a comparatively large outlay in installation. Voltaic cells require to be periodically replenished and their plates renewed; moreover, they require continued attention in order to maintain their E. M. F. even approximately constant. It is found impossible to work more than two or three circuits from a single voltaic source, so that a large number of circuits terminating in an office require a correspondingly large number of separate batteries. On the other hand a dynamo-electric machine is capable of supplying a considerable number of independent telegraphic circuits and is less expensive in first cost, as well as in maintenance, when introduced on a large scale.

A dynamo-electric machine is a machine for the production of electric energy at the expense of mechanical energy. The dynamo is so constructed that when its moving part, usually the *armature*, is driven by power, an E. M. F. is developed in the machine. Dynamo-electric machines are constructed in a great variety of types. Some of these supply currents which are *alternating*, or alternately flow in opposite directions, and as such are not available for ordinary telegraphy. Others supply currents suitable for arc lamps and are equally inapplicable for telegraphy. What is required for telegraphic purpose is a *uniform continuous E. M. F.* of the requisite voltage.

A dynamo of the type commonly employed in telegraphy is represented in

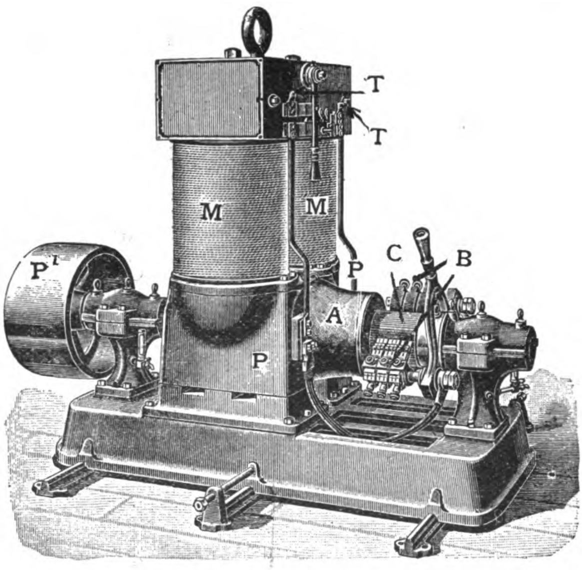


FIG. 44.—DYNAMO-ELECTRIC MACHINE.

Fig. 44. *M*, *M*, are two large *field magnets*; *i. e.*, coils of wire wrapped around

iron cores. The passage of a continuous current through these coils produces a powerful magnetic flux between their poles *P*, *P*, in the same manner that the passage of an electric current, through the coils of a relay or sounder magnet, produces a magnetic flux between its poles. The armature *A*, is supported in bearings, one at each end, and is revolved by a belt upon the pulley *P′*, through the magnetic flux. This armature consists of a cylindrical core of laminated soft iron carrying a number of insulated wires upon its surface. The revolution of these wires, through the magnetic flux produced by the field magnets, causes E. M. Fs. to be generated in them. The loops of wire on the armature are connected with the *commutator C*, which consists of a number of copper segments insulated from one another and from the armature shaft. Copper brushes

B, *B*, bear upon the surface of the revolving commutator at diametrically opposite points, and the continuous E. M. F. of the armature is delivered to these brushes, and from them through the flexible cables to the main terminals *T*, *T*, of the machine.

The voltage of a dynamo-electric machine depends upon the speed at which it is rotated, upon the strength of the magnetic flux passing through the armature, and upon the number of turns of wire on the armature. Consequently, if the magnetic flux and the number of loops on the armature are fixed, the E. M. F. delivered by the armature will depend upon the speed at which it is rotated, and, if the speed be uniform, the E. M. F. will be uniform.

If we suppose that such a dynamo produces an E. M. F. of 100 volts, and that it has a possible output of 1,000 watts, or about 1 1/3 horse-power, it can continuously deliver a current of 10 amperes through suitable resistances. Such a machine could theoretically supply the electric current required for about 300 ordinary telegraph circuits.

Dynamos for telegraph purposes are usually wound to supply about 60 volts, as 100 volts would be considerably in excess of what is required for short lines. Where more than 60 volts are needed, dynamos are connected in series so that a battery of five such dynamos would produce a total E. M. F. of 300 volts, and this is, approximately, the highest E. M. F. in use at any single point of a telegraphic circuit.

Just as dynamos are used in the main

line instead of main-line voltaic batteries, a dynamo is also used for local service instead of local voltaic batteries. The E. M. F. of such a dynamo is about 6 or 7 volts. One such dynamo in an office is sufficient to operate all the sounders that have yet been collected into a single building. The resistance of such sounders is from 25 to 100 ohms, while the resistance of a sounder employed with two cells of local battery is only about 4 ohms. Consequently, sounders worked from a dynamo employ a finer wire, and take a current from 1/8th to 1/15th of an ampere, while the current supplied to a sounder on a local voltaic battery circuit, is about 1/4th of an ampere, and its coils are wound with coarser wire.

The arrangement of dynamos in a main telegraph office is represented in Fig. 45.

D_1, D_2, D_3, D_4, D_5, are five dynamos, all driven by the same engine, and with their armatures connected in series as shown. The total E. M. F. is the sum of all the

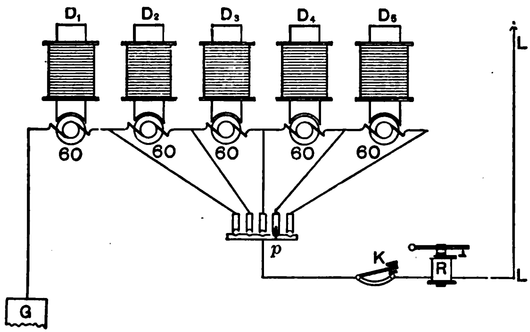


FIG. 45.—ARRANGEMENT OF BATTERY OF DYNAMOS IN CENTRAL TELEGRAPH OFFICE.

separate E. M. Fs., and amounts in the case considered to 300 volts. The first dynamo D_1 is grounded at G. The plug switch p, enables any desired E. M. F., in multiples of 60 volts, to be connected with a circuit such as that shown at L, L, in which *R*, is the main-line instrument, and *K*, the key. The plug is represented as being inserted between the bar and fourth strip of the switch, thereby connecting a pressure of 240 volts to the line. The local circuit of the relay is not indicated in the figure but employs a separate dynamo for its supply.

CHAPTER VII.

RELAYS.

The current which is required to pass through the magnetizing coils of a sounder to give a distinctly audible sound is comparatively strong. Over a long line of considerable resistance, apart from the loss of current by leakage, the current strength is necessarily limited by Ohm's law, so that either a very great number of voltaic cells have to be employed in the circuit, or the click of the sounder will become so feeble as to be practically inaudible. In order to remedy this defect, instruments called *relays* are employed.

Telegraphic relays are electromagnets

whose armature levers move between stops, as in the case of the ordinary sounder; only, instead of being obliged to give a distinctly audible blow, they are merely employed to open and close a contact in a local circuit. This is illustrated in Fig. 46, where *R*, indicates the electromagnet of the relay which is inserted instead of the sounder in the main line circuit *A B*. The armature lever *L*, plays between two stops t_1, t_2, under the influence of electromagnetic attraction and the retractile spiral spring. When attracted by the electromagnet the lever closes the circuit, through the battery *e*, called the local battery, the stop t_2, and the sounder *S*. It is evident that the movement of the relay armature may be so slight and feeble as to give comparatively little sound, while the movement of the sounder armature will have full amplitude and power, being limited only by the strength of the local battery and its magnetizing coil.

A common form of telegraphic relay is

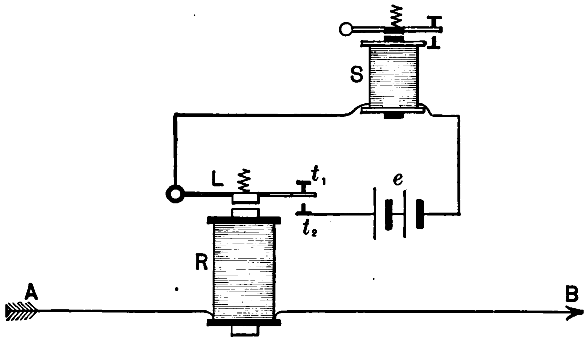


FIG. 46.—CIRCUIT OF RELAY AND SOUNDER.

shown in Fig. 47. The electromagnet *M*, *M*, is placed horizontally, and, under the control of the screw *W*, is advanced or retreated from the light armature *A*, mounted on a vertical lever whose upper extremity plays between the stops p^1 and p^2. The former is insulated, while the latter is uninsulated and connected by an insulated wire to the binding post t^2. The armature is normally withdrawn from the poles of the electromagnet by the action of the

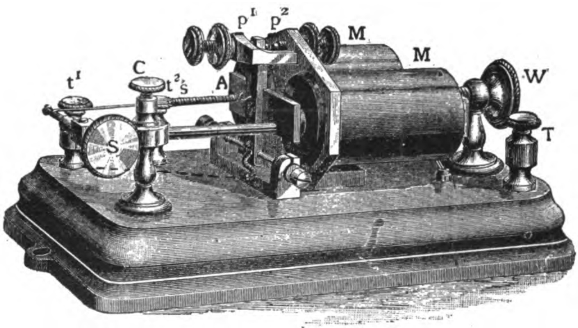


FIG. 47.—TELEGRAPHIC RELAY.

retractile spring *s*, under the control of the screw *S*, for fine adjustment, and also under the action of a clamp *C*, on a base holding the screw, for coarse adjustment, One of the two binding posts connected with the coils *M*, *M*, is shown at *T*. These binding posts are connected to the main-line circuit. The other pair of binding posts t^1, t^2, are connected to the local circuit, which is closed by the lever *A*. The resistance of a relay of this type is usually about 150 ohms, but it may be wound for any resistance between 50 and 5,000 ohms, by suitably choosing the size of wire. The finer the wire, the greater will be the resistance in the relay coils but the greater the number of turns around the core and the greater the M. M. F. which a given current strength will produce. Consequently, a very feeble current requires a high resistance relay in order to develop the necessary amount of M. M. F.

Fig. 48, shows a smaller form of relay sometimes called a *pony relay*. Here the magnets *M*, are fixed in their frame. The instrument therefore differs from that shown in Fig. 47, in that here only the retractile force is adjustable under the influence of the spring *s*, and its screw *S*. The relative position of the magnet poles

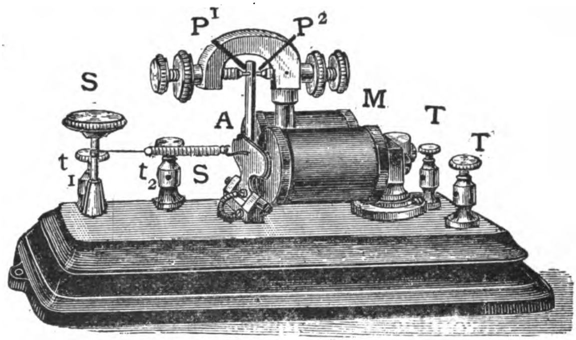


FIG. 48.—PONY RELAY.

and armature is, however, adjustable as well as the amplitude of the motion by the screw points P^1 and P^2. *T*, *T*, are the line terminals leading to the magnet coils, and t_1, t_2, are the local terminals leading to the front contact p_2, and the armature *A*, through the small spiral of copper wire at its base.

Another form of relay differing only in details of construction from the preceding

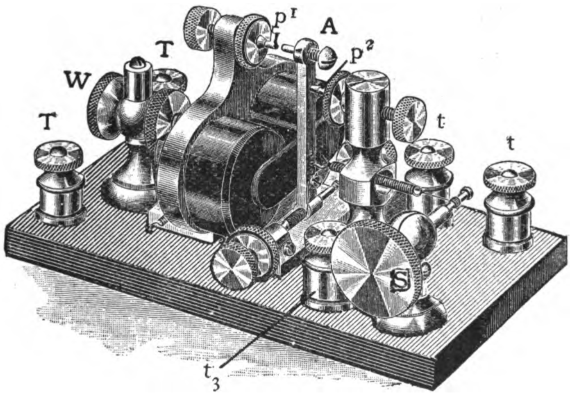


FIG. 49.—SHORT COIL RELAY.

is shown in Fig. 49. Here the coils are shorter and are held in a frame in such a manner that their position relatively to the armature can be adjusted as in Fig. 47, by the screw *W*. The tension on the retractile spring is also adjustable by the screw *S*. *T*, *T*, are the main terminals and *t*, *t*, the local terminals. A third local

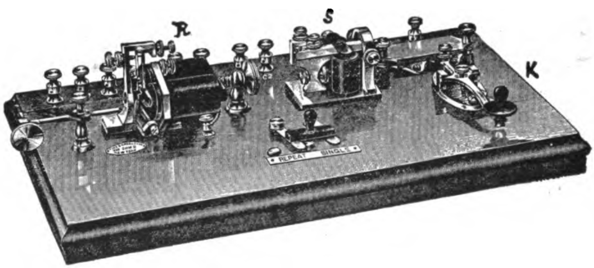


Fig. 50.—Telegraphic Set.

terminal t_3, is in this case provided. It is connected to the back stop p^2, and permits the relay to close a local circuit through its back contact when desired, in addition to the local circuit closed through its front contact p^1.

Fig. 50 shows an office set consisting of key, relay, and sounder mounted upon one board. Here *R*, is the relay, *S*, the sounder, and *K*, the key. This set is also capable of being employed as an *automatic*

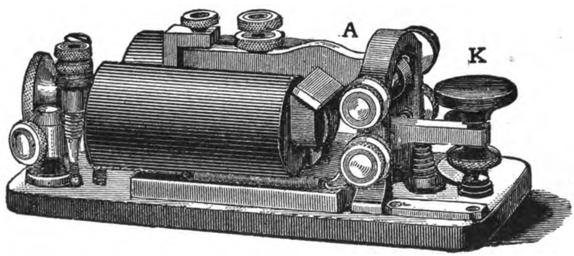


FIG. 51.—POCKET RELAY AND KEY.

repeater, an instrument which will be explained in a subsequent chapter. A local battery of say two large gravity cells is used in connection with such a set.

A compact set of sounder and key adapted for carrying in the pocket and commonly called a *pocket relay* is represented in Fig. 51. Here *K*, is the key and *A*, the armature of the sounder.

In Fig. 52, the magnets of the relay are

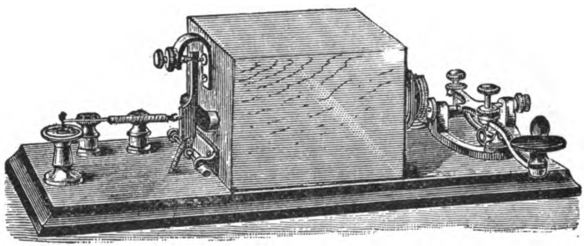


Fig. 52.—Box Sounding Relay.

enclosed in a wooden box which acts as a sounding box and intensifies the sound emitted. By this means, when necessary, the message can be read directly from the relay.

The relays we have hitherto described are known as *neutral* or *non-polarized* *relays.* In some cases, however, *polarized relays* are employed. A non-polarized relay employs soft iron in the entire magnetic circuit, and the normal condition

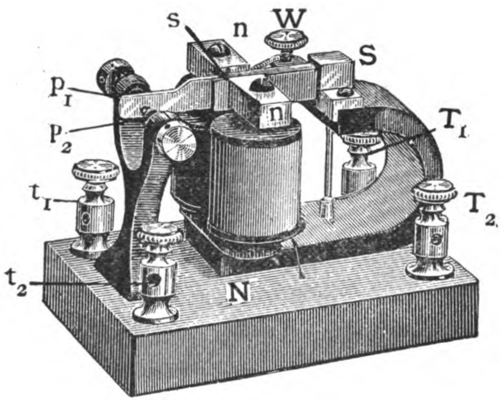


FIG. 53.—POLARIZED RELAY.

of all the iron in the relay is unmagnetized when no current flows through the coils. A polarized relay employs a permanent magnet, which gives a permanent magnetism to some portion of the magnetic circuit even when no current passes through the coils. A form of polarized relay is shown in Fig. 53. The permanent bar magnet *N S*, is bent into the form shown. Upon the end *N*, which is say the north pole, are mounted the yoke and cores of the electromagnet whose coils are connected through the terminals T_1, T_2, with the main line. The cores and pole pieces of the electromagnet, although of soft iron, will, nevertheless, acquire north magnetism from their contact with the pole *N*, or, in other words, the pole pieces of the electromagnet form virtually one pole of the hard steel permanent magnet *N S*.

To the other end *S*, of the permanent magnet, is attached a soft iron strip or armature mounted on a vertical pivot as shown, so as to be free to play between the poles n, n. To the extremity of the armature is fastened a tongue armed with

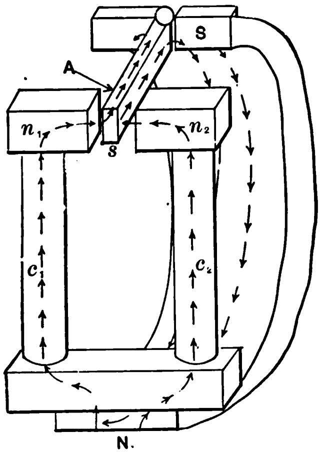


FIG. 54.—MAGNETIC CIRCUIT OF POLARIZED RELAY.

a contact which plays between the points p_1 and p_2.

The magnetic circuit of this relay is

illustrated diagrammatically in Fig. 54, Here the magnetic flux produced by the permanent magnet passes upward in two streams, one through each soft iron magnet core, and through the air gap into the armature *A*, thus completing the magnetic circuit. If the armature lies midway between the pole-pieces n_1, n_2, the magnetic flux will divide equally between the two paths and the magnetic attraction will be equal on both sides of the armature, so that the armature will lie in neutral equilibrium, and will not pull over more to one side than to the other. If, however, the armature be set nearer to one pole-piece than to the other, the air gap on the side toward which it leans will be diminished and that on the opposite side increased. The result will be that a more powerful magnetic flux will pass through the shorter air gap, and a less powerful magnetic flux through the longer air gap, thus producing a greater magnetic attraction on the side of the shorter gap. The relative intensity of the magnetic pulls on opposite sides can be adjusted by the setting of the pole-pieces and the adjustment of the contacts. In addition to this a feeble spiral spring is fastened to the armature and the tension on this spring is regulated by the screw *W*, of Fig. 53. When no current flows through the line the armature tongue will, therefore, lie over upon the stop p_1.

As soon as a current flows through the coils of the magnet the M. M. F. is increased by the action of the current in one branch of the magnetic circuit, and diminished in the other. If the current is in the right direction the increased M. M. F.

will augment the magnetic flux through the core c_2, and pole-piece n_2, of Fig. 54, and will diminish the magnetic flux through the core c_1, and the pole-piece n_1. As a consequence, the magnetic attraction between the armature and n_2, is strengthened, while it is weakened between the armature and n_1, so that the balance of forces acting upon the armature is upset, and the armature moves over until the tongue presses against its contact, thereby closing a local circuit through a sounder.

On the cessation of the magnetizing current the original distribution of magnetic flux and magnetic attraction is restored, so that the armature is once more pulled over to the dead or non-contact stop. It is evident, therefore, that in the polarized relay magnetic forces are always active upon the armature, but that these are altered in magnitude by the action of the magnetizing current; whereas, in the neutral relay no appreciable magnetizing

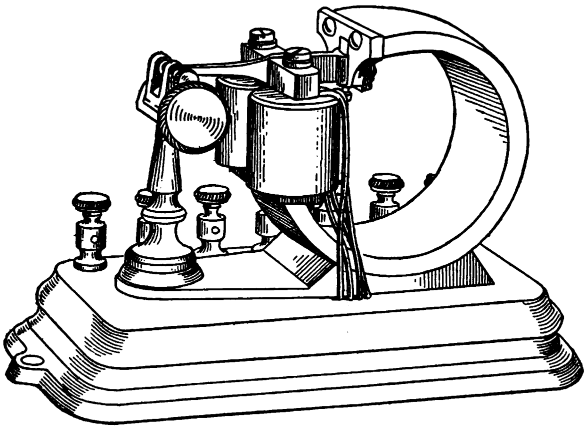


FIG. 55.—POLARIZED RELAY.

forces act when the current ceases to flow through the magnetizing coils. Moreover, by reversing the direction of current through a neutral relay the entire magnetic flux reverses its direction, so that the north pole becomes the south pole, and *vice versa*, without altering the magnetic attraction upon the armature; whereas, in the polarized relay, reversing the direction of current reverses the action of the relay and tends to move the armature in the reverse direction. Consequently, the direction of the current flowing through the line has to be taken into account in connecting a polarized relay, while it need not be considered in connection with a neutral relay.

Fig. 55, shows another form of polarized relay differing only in details of construction from that shown in Fig. 53. The permanent magnet is here bent into the shape of a G.

CHAPTER VIII.

LINE CONSTRUCTION.

Telegraph wires in the open country are always bare copper or iron conductors supported on insulators from pole cross arms. When crossing rivers, and in the streets of large cities, cables of insulated wires are frequently employed, while in crossing oceans, insulated wires are, of course, rendered necessary. Until recent times, galvanized iron wire, usually 0.165″ in diameter, was almost universally used, but lately, hard-drawn copper wire has largely replaced iron, owing to its advantage in conducting power.

In discussing line construction it will be convenient to commence with the insulator on which the wire is supported, then the pin on which the insulator rests, then the cross arms which support the pin, and finally the pole to which the cross arm is attached.

Insulators are almost invariably made of glass, a material of very high insulating properties. An insulator consists of an inverted cup upon the external surface of which runs a groove in which the wire is secured, while a thread is formed on the inside of the cup to receive the insulator pin.

Two common forms of insulator are shown in Fig. 56. They differ only in details of form, one having a deeper groove in its surface and being called a *deep-groove insulator*. The other more nearly resembles a bell in shape and is usually called the *Western Union insulator*. The thread

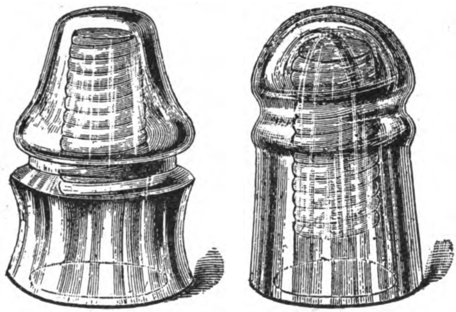


FIG. 56.—FORMS OF GLASS INSULATORS.

for the pin cast in the interior is visible through the glass.

Fig. 57, shows another form of insulator, partly in section. It will be seen that it has a *double petticoat*, the second one within the first. The object of this is to provide a longer path between the wire on the external surface and the pin in the internal thread. In all cases the leakage which occurs at an insulator from the conducting wire to the ground takes place almost entirely over the surface of the

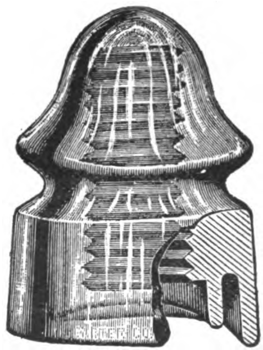


FIG. 57.—DOUBLE PETTICOAT DEEP-GROOVE INSULATOR.

insulator and not through its substance. In damp weather, a film of moisture is readily deposited on the surface of the glass. This film affords a partially conducting track over which the electric current may escape from the wire, especially if, as usually happens, the surface of the insulator is dusty, so that the film, instead of consisting of pure water which is almost an insulator, consists of muddy or sooty water which is a comparatively good conductor. The greater the length and the narrower this partially conducting film, the greater will be its resistance and hence the smaller the amount of leakage it will permit for a given voltage on the line. An additional petticoat placed within the insulator lengthens the film of surface and improves the insulation.

While the effect of moisture is to cause increased leakage over a telegraphic circuit, yet, to a certain extent, it is desirable that insulators be placed where they are freely exposed to the rain, since they are thus cleansed on their external surface from dust and dirt which otherwise would continue to accumulate upon it. For this reason, it is undesirable to place insulators under covers of any kind.

Since there are about 40 poles to the mile of ordinary telegraph line there are 40 insulators, and, consequently, 40 independent points where leakage may occur. In a line 10 miles long, there will be say 400 poles, and in a line 100 miles, 4,000; consequently, as we have already seen, the leakage increases with the length of line, so that the degree of insulation which would be fatally low upon a long line becomes a matter of indifference on a very short one.

The insulation of telegraph lines varies greatly with the weather and the locality. In fine, dry weather, the insulation may be several millions of ohms per mile, that is to say, the resistance between the wire and ground in the length of one mile may average several millions of ohms. In very wet weather the insulation may only be about one hundred thousand ohms per mile, assuming of course that the insulators are all properly set, and that the wire does not pass through trees. Where wires come in contact with the cross-arms or wet leaves, the leakage may be much greater, so that the insulation in wet weather may fall to only a few thousand ohms per mile. Near the sea, or over salt marshes, the insulators are apt to become coated with a film of salt, and in this way the leakage over them may be comparatively great. Consequently, lines running near the sea frequently have a lower insulation than those which run over dry plains in the interior

In Europe, where the climate is generally much more moist than in the interior of the United States, glass insulators are never used. Owing to the hygroscopic qualities of glass and its tendency to retain a superficial film of moisture, glazed porcelain or glazed earthenware is invariably employed and in a great variety of forms. In a few instances *oil insulators* are used, that is to say, the insulator forms a cup for the reception of oil. This prevents any continuous film of moisture being formed between the pin and the external wire, and such insulators, if periodically emptied and refilled, have a very high insulation.

A number of European insulators are illustrated in Fig. 58. Here the single and double petticoat types are represented in various forms. *A* and *B*, are oil insulators. Porcelain insulators are occasionally used on the seacoast in the United States. Although they offer a better degree of insulation for the wire they are decidedly more expensive than glass insulators.

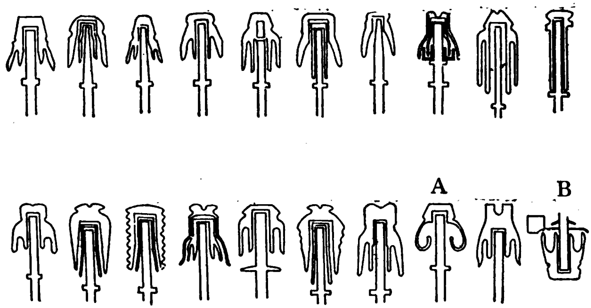


Fig. 58.—Forms of Insulators.

The insulators are screwed to pins which are either supported on a cross arm, or against a flat surface, such as the trunk of a tree or the side of a pole. Both of these forms and their mode of attachment are shown in Figs. 59 and 60. *A*, Fig. 59, is the usual pin which fits into the cross-arm, being secured in place in the latter by a transversely driven nail. *B*, is a bracket pin; *C*, is a double or duplex pin

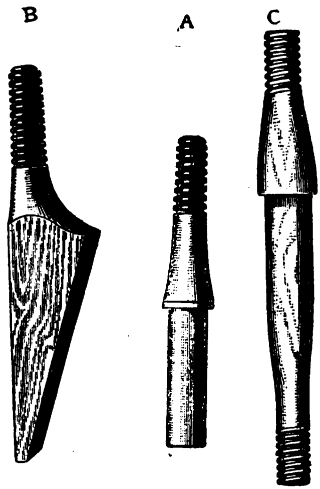


FIG 59.—INSULATOR PINS.

for supporting two insulators, one at each end. This is often employed where two wires are led off at right angles. These *duplex pins* are represented in a cross arm in Fig. 61, together with a *duplex bracket.* Pins and brackets are usually made of oak

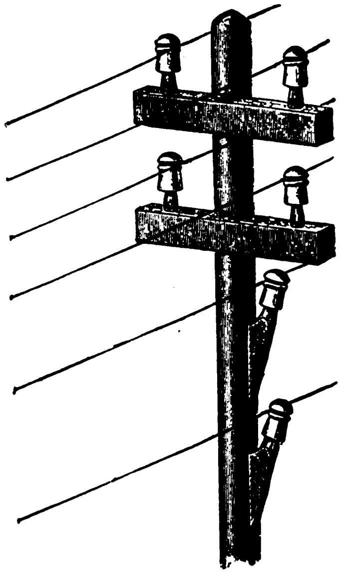


FIG. 60.—BRACKET AND PIN ATTACHMENTS.

or locust, but any tough wood will answer for the purpose.

Cross arms are made of various sizes to accommodate from two to ten insulators; *i. e.*, 1 to 5 insulators on each side of the

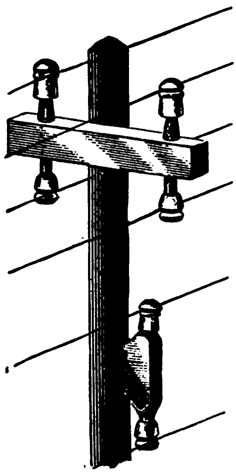


FIG. 61.—DUPLEX PINS AND BRACKET.

pole. Their size will necessarily depend upon the weight and number of wires to be supported. Two-wire cross arms are usually three feet long, and 10-wire cross arms are usually 10 feet long. The distance between wires nearest the pole is about 15″, and between other wires about 10″. The vertical height between cross arms is usually 20″. Cross arms are

FIG. 62.—FOUR-PIN CROSS ARM.

usually constructed of yellow pine and are preferably slightly rounded at the top to shed water and snow. A form of cross arm with holes drilled in it for the reception of four pins is seen in Fig. 62. Cross arms are usually secured to the pole by carriage bolts with washers, and sometimes supported by a pair of braces called cross-arm braces.

Where it is important to prevent a wire from falling off a cross arm in the event of its becoming disengaged from its insulator, a *line-wire guard arm* is employed either straight or curved. Such a guard arm is seen in Fig. 63.

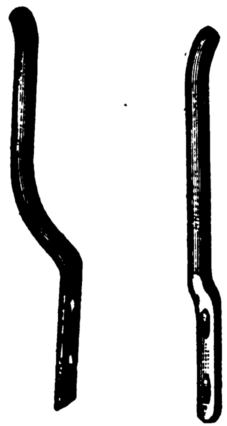


FIG. 63.—LINE-WIRE GUARD ARMS.

Poles are usually of wood and vary from 25 feet to 125 feet in length. They are set at from 25 to 40 per mile in the country and from 40 to 50 per mile in towns. Poles are cut from entire trees and should always be selected from well-seasoned lumber.

In order to avoid the decay which, as is well known, attends timber that is partly buried in the ground, it is customary to subject the poles to some preservative process, either throughout their entire length, or only in that part which is buried in the ground. In this country the processes most frequently resorted to are *creosoting* and *vulcanizing*. In creosoting, the sap of the wood is first removed by subjecting the poles to the action of a vacuum in a closed iron chamber. Steam is then admitted into the chamber and allowed to permeate the substance of the wood. Creosote, or petroleum then follows, under a pressure of about 250 pounds per square inch. This process not only serves to remove the sap and replace it by creosote, but also effectually to destroy the germs of plant or animal life which otherwise would injure the fibre of the wood.

In vulcanizing, the poles are subjected to a dry heat for several hours by which means the sap is chemically altered, and a preservative substance is produced in its place. The butt ends of poles are sometimes charred and tarred.

In addition to the above processes, the following preservative processes are sometimes adopted in Europe; namely, *burnetizing*, or introducing chloride of zinc into the pores of the wood; *kyanizing*, or similarly introducing mercuric chloride, and *boucherizing*, or similarly introducing copper sulphate.

Telegraph poles are buried from 6 to 10 feet in the ground, the depth depending on the size of the pole and the nature of the soil. In digging the hole care has to be

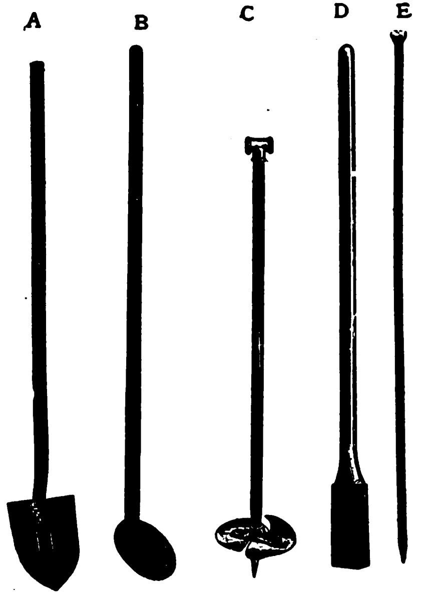


FIG. 64.—DIGGING TOOLS.

taken to disturb as little ground as possible. With this object in view special tools are employed. These are shown in Fig. 64. *A*, is a shovel with a long handle. *B*, is a spoon for removing the soil. *C*, an auger driven into the ground by a handle passed through the hole in the head. In using these tools the auger is first inserted vertically in the ground, and the loose soil which is thrown up around it, is removed by the spoon. The use of the auger is advantageous in avoiding disturbance to the ground in the vicinity. *D*, is a tamping tool which is employed for pounding or ramming the soil around the base of the pole after insertion. *E*, is a drill bar for breaking up heavy ground.

When the hole is prepared, the pole with its attached cross arms is lifted with the aid of the tools represented in Fig. 65. *A*, is a canting hook; *B*, is a "dead man" or elevating hook, and *C*, is a pike. *B* and

C, are for supporting and lifting the pole into position while *A*, is for rotating the pole about its own axis.

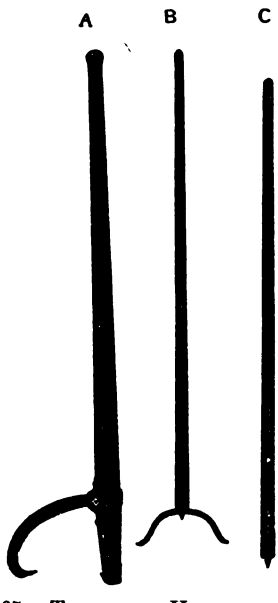


FIG. 65.—TOOLS FOR HANDLING POLES.

After the poles are in position and the earth securely tamped around them, the process of stringing the wire commences. A single wire is carried over a bracket near the top of the pole, as shown in Fig. 66; or, an insulator is mounted on the top

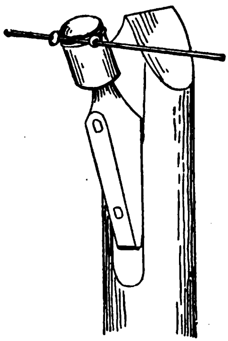


FIG. 66.—SINGLE BRACKET.

of the pole as shown in Fig. 67. The wire is laid in a roll upon a suitable frame or reel as shown in Fig. 68, and made fast to the insulators by binding wire. The wire is first laid in the insulator groove, and the binding wire is wrapped tightly around it, then around the insulator and then around the wire again on the other side. The

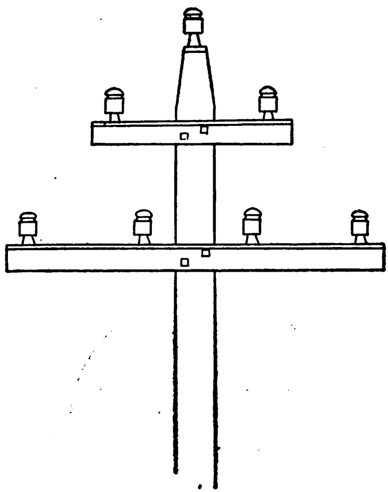


FIG. 67.—POLE AND CROSS ARM.

finished binding is represented in Fig. 69. In tying in iron wire, a smaller iron tie wire is used. In tying in copper wire a smaller copper wire is used. The wire is drawn up to the required tension by the lineman

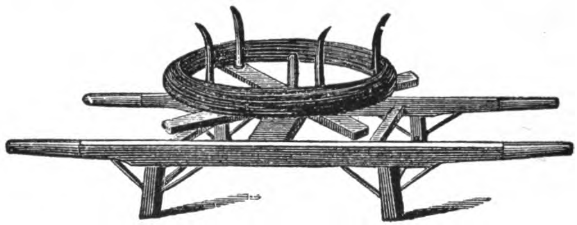


FIG. 68.—BARROW REEL.

at the next pole and then tied to the insulator on that pole in the same manner.

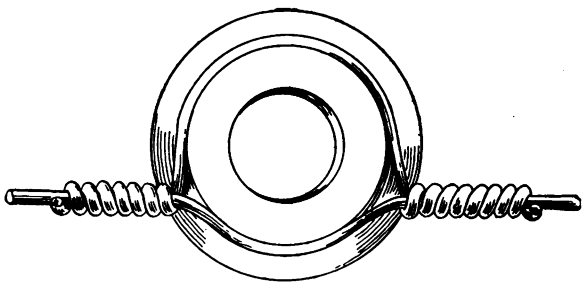


FIG. 69.—IRON WIRE "TIE."

In order to join two lengths of wire, their ends are gripped firmly side by side, and each is twisted around the other several times. The resulting joint is shown in Fig. 70. The joint so made should always be soldered so as to provide a complete metallic path from one wire to

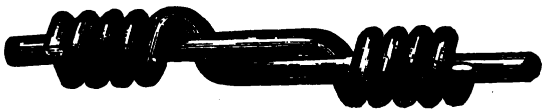


FIG. 70.—AMERICAN TELEGRAPH JOINT.

the other. If the soldering is not performed, the connection between the two wires will be made through their points of contact only, and since their surface is apt to become oxidized, and, since oxides have very great resistance in comparison with metals, the resistance of unsoldered joints may become very considerable. In Great Britain a joint is employed called the *Britannia joint.* In this joint the two ends are laid side by side for a couple of inches and wrapped together by a smaller binding wire. The entire joint is then soldered. This joint is represented in Fig. 71.

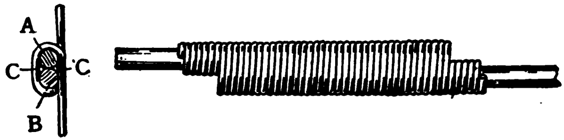


FIG. 71.—BRITANNIA TELEGRAPHIC JOINT.

When a joint has to be made between two ends which are already fastened to insulators, it is necessary to strain the wire

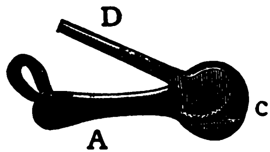


FIG. 72.—WIRE CLAMP.

up to the right tension before the joint is made. This is accomplished by clamping each end of the wire in a clamp such as that shown in Fig. 72. The steel plate *A*, carries a projection *C*, and an arm *D*, rotating upon a pin and with a serrated edge. The wire is admitted between *C*

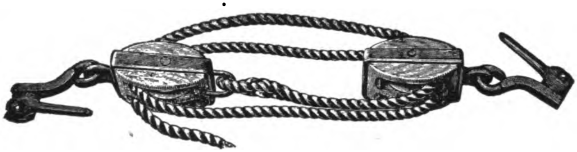


FIG. 73.—CLAMPS AND TACKLE.

and *D*, and clamped by pulling upon the arm *D*, towards *A*. A pair of these clamps are held together by the aid of a tackle as shown in Fig. 73, until the right

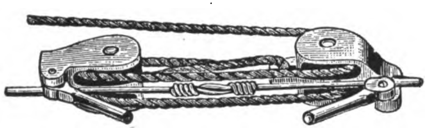


FIG. 74.—JOINT BETWEEN CLAMPS AND TACKLE.

tension is secured, when the ends are cut off at the right point and jointed together as shown in Fig. 74.

In some places iron poles are employed. These are more expensive than wooden

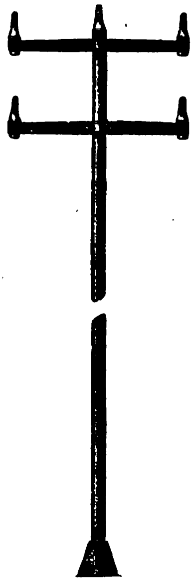


FIG. 75.—WROUGHT-IRON POLE.

poles, but are more sightly and more durable. A form of wrought-iron pole is represented in Fig. 75.

For climbing wooden poles the lineman is provided with a pair of *pole climbers* or *spurs*, which are secured on the inner side of the leg. The base of the spur goes

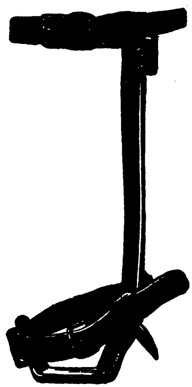


FIG. 76.—POLE CLIMBER.

under the foot while the upright is strapped to the leg. A climber is represented in Fig. 76. The frequent use of climbers is apt to disfigure a pole, since it leaves in the surface an impression at each step. To avoid this in the case of large poles in cities, or of poles which it is necessary to ascend frequently, *pole steps* are provided by screwing heavy pins in the pole on opposite sides at suitable successive elevations.

Where wires have to pass across the roofs of houses, special supports have to be employed. A flat roof support and pole suitable for carrying nine wires is shown in Fig. 77. Where a single wire has to cross a wall or flat roof, the simple structure of Fig. 78, is often found convenient, and when a single wire passes over a roof, a rigid roof support of the type shown in Fig. 79, is frequently employed.

The size of iron wire varies from 0.204″ diameter for very long lines, where low resistance is important, to 0.083″ for very

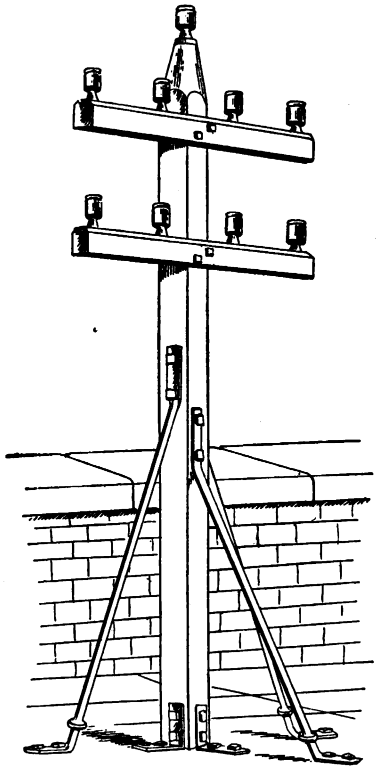


FIG. 77.—POLE AND CROSS ARM.

short wires, where the resistance per mile is of little or no consequence. In hard-drawn copper wire the usual size is 0.120″

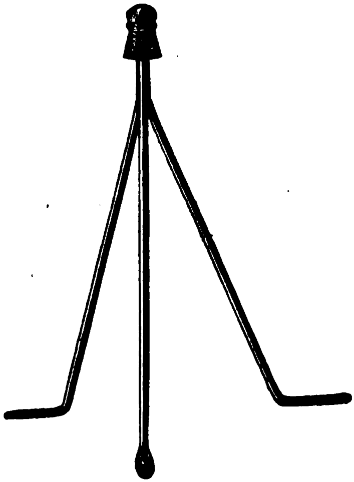


FIG. 78.—TRIPOD SUPPORT.

weighing 210 pounds per mile, and having a resistance of 4.3 ohms per mile at 68° F. The *breaking stress* of this wire is about 750 pounds weight, or, in other words, this wire should support vertically a length of 3.6 miles without breaking. Copper wire is considerably weaker than iron wire of the same diameter, but copper wire may be

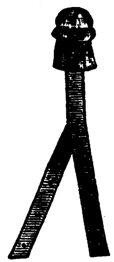


FIG. 79.—RIDGE ROOF SUPPORT.

much smaller and lighter than iron wire of the same resistance.

In large cities telegraph conductors are generally laid underground. Wires intended to be laid underground are first separately insulated and laid up into a cable which is covered externally by layers of tape or jute and sometimes of lead. These cables may contain a number of conductors not usually exceeding 50. Fig. 80, represents the appearance of one of these cables. One wire in each layer is covered in such

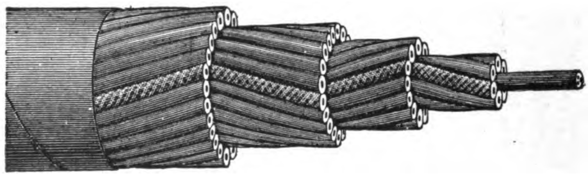


FIG. 80.—UNDERGROUND TELEGRAPHIC CABLE.

a manner as to be conspicuous or to form a marked wire in order to facilitate the numbering of the wires.

Cables are drawn into conduits which are commonly formed of iron pipes laid in cement and opening into manholes about 200 feet apart, so that 200 feet lengths of cable are drawn in and joined successively at the manholes.

CHAPTER IX.

LINE CONNECTIONS.

Having now described the construction of a telegraphic line, we will consider the connections that are made to the telegraphic line wires or conductors on entering and leaving an office. On entering the office, the line wire is connected to a *lightning arrester*. This is rendered necessary by the fact that a long line of overhead bare wire is liable to disturbance from lightning discharges. It is not necessary that a lightning flash shall actually strike the telegraph line in order to damage some of the instruments connected to it. It may happen that inductive disturbances, produced by a flash of lightning in the neighborhood, may be sufficiently severe to cause a very brief but powerful electric current to pass through the coils of wire on the different apparatus, and destroy them either by directly melting them, or by puncturing a passage through them. In the same way, the operator handling the telegraph instruments is liable to receive a severe or even dangerous shock if steps are not taken to provide against the danger.

Whether a discharge from the telegraph line is due to a direct lightning flash, or to an inductive disturbance of lightning, the line receives, momentarily, an exceedingly high voltage. This voltage is developed in the line so suddenly that a brief but appreciable interval must elapse before it can send a powerful current to the ground, or to neighboring conductors through the coils of wire wound upon the telegraphic instruments. In other words, the coils of wire offer a temporary resistance far greater than their ohmic resistance as measured with steady currents in ohms, owing to the enormous suddenness of the discharges. This apparent resistance is called the *impedance.* The impedance of the coils of wire wound on magnet cores may be hundreds of times as great as their steady current resistance. A very feeble current, therefore, passing through such a high impedance, as is temporarily developed in the magnet coils, requires a very great voltage to produce it, and this voltage may be sufficient to cause a spark to pass across a narrow air-gap.

If two metallic points, brought to face each other on insulating terminals, are separated by a very narrow air-gap, so that the points almost touch, the resistance of the film of air between them will be infinitely great so far as any measurements can be made with an ordinary voltaic battery. If, however, a sufficient voltage, say 300 volts, be connected to the two terminals, the film of air will *break down*, or will be unable to support *electrostatic stress* exerted across it, and a discharge will take place in the form of a spark. In the case of a lightning discharge, the spark will be momentary; in the case of a dynamo, the discharge may form an arc, which may be maintained by the E. M. F. of the dynamo.

A lightning arrester embodying the preceding principle is shown in Fig. 81. Here three strips of brass *A*, *B* and *C*, are supported by screws upon an insulating base in such a manner that their serrated edges are parallel and separated by

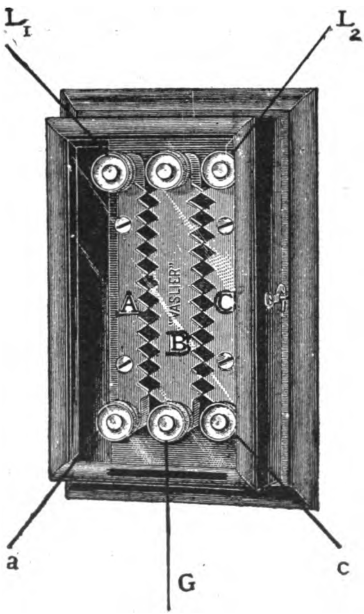


FIG. 81.—SAW-TOOTH LIGHTNING ARRESTER.

minute air spaces. *A*, is connected to one line L_1, and *C*, to another line L_2, which form the incoming and outgoing wires of the circuit. *B*, is connected to ground by the wire *G*. *a* and *c*, are wires leading from plates *A* and *C*, to the relay or other office instrument. The impedance of these instruments to a sudden lightning discharge, is so great that the voltage between the plate *B*, and the plates *A* and *C*, rises to the point at which a spark discharge will take place, so that the discharge passes almost entirely through the air-gap instead of passing through the coils of the instrument.

In some lightning arresters the lines and the ground are opposed to each other, not through a single row of points, but through a series of serrations of metallic points. An example of this form of arrester is shown in Fig. 82. Here a plate *P*, is connected to ground through the terminal *G*, while L_1 *a* and L_2 *c*, are two plates separated a slight distance beneath the plate *P*, and connected by terminals L_1 and L_2, with the incoming and outgoing line wires,

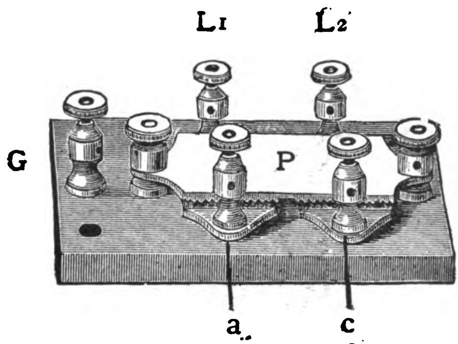


FIG. 82.—LIGHTNING ARRESTER.

while *a* and *c*, are terminals connected to the office instruments.

Instead of a thin film of air between the line plates, a thin film of other non-conductor, such as paraffined paper, is sometimes employed. A lightning arrester based on this principle is shown in Fig. 83. Two plates provided with terminals L_1, L_2, stand upon an insulating base. A brass screw clamp C, is arranged to

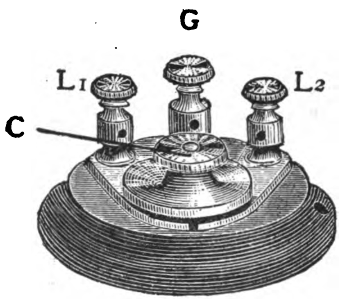


FIG. 83.—FILM LIGHTNING ARRESTER.

press a film of paraffined paper upon the surfaces of the plates L_1, L_2, while the clamp is connected through its central screw pin with a grounded terminal G. The terminals L_1 and L_2, are connected by tap wires to the two lines entering an office. Should the pressure rise momentarily to that required to pierce the film of paper on either side, the discharge will pass through the puncture and not through the instruments connected between L_1 and L_2.

In cities where telegraph lines are apt to come in contact with electric-light wires, and thereby become charged with high pressures which are sustained, and not momentary as in the case of lightning, it has been found necessary to provide some means for arresting an unduly powerful current from entering and damaging the apparatus. In some cases the line circuit is led through a *fuse wire* or *safety-fuse*; *i. e.*, a fine wire of lead or other alloy, which will melt as soon as the current strength is sufficiently increased above the normal working current to endanger the apparatus. When the wire melts, the circuit is interrupted.

As fuse wires for telegraphic lines have to be very fine and are delicate to handle, in order to melt at a sufficiently small current strength, a *magnetic protector* is often employed. A protector of this type is represented in Fig. 84. The line

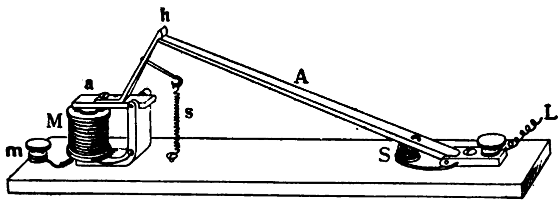


FIG. 84.—MAGNETIC PROTECTOR.

wire is connected to the terminal *L*, and passes through the metallic arm *A*, to the metallic hook *h*, and thence through the coil of the electromagnet *M*, whence it passes to the apparatus through the terminal *m*. If the current strength passing through this circuit exceeds a certain safe limiting amount, the magnet *M*, becomes sufficiently powerfully magnetized to attract its armature *a*, against the tension of the spiral spring *s*. This releases the hook *h*, and allows the arm *A*, to fly back under the action of the spiral spring *S*. The circuit is, therefore, interrupted, and the distance, to which the arm *A*, suddenly flies back, is so great that no arc can be maintained.

Before reaching the apparatus, the lines in the office are connected to a *switchboard*, except in some cases, where only a single circuit enters the office. The object of the switchboard is to facilitate connections between the lines and the instruments. A simple form of switchboard combined with lightning arrester is represented in Fig. 85. Here two brass strips are mounted upon a wooden board, which is usually fixed in a vertical position upon the office wall. The terminals L_1 and L_2, receive the incoming

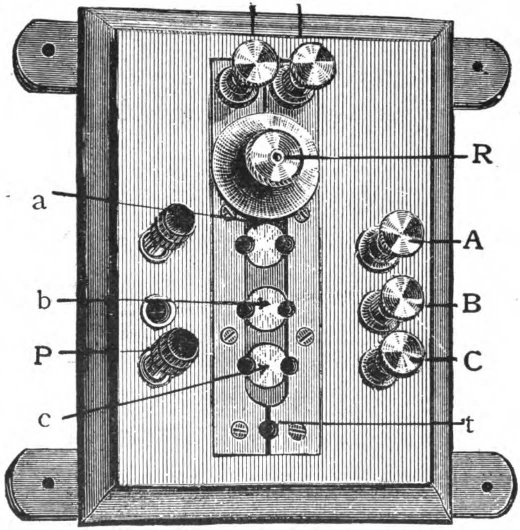


FIG. 85.—SINGLE-CIRCUIT SWITCHBOARD AND LIGHTNING ARRESTER.

and outgoing line wires. Upon the strips is mounted the *film lightning arrester* R, connected to ground through the terminal A, and in connection with the circular brass piece *a*. Terminals *B* and *C*, are connected to the small circular brass pieces, *b* and *c*, and are connected by wires to the office relay. Plugs *P*, which are kept when out of use in holes on the left hand, are inserted in the proper holes between the brass strips and the central circular pieces. If inserted in the hole *t*, the two lines L_1, L_2, are directly connected. By inserting a plug in one or other of the holes beside the piece *a*, one or other of these lines is grounded. By inserting two plugs in a diagonal pair of holes beside *b* and *c*, the relay of the office is connected between the two lines through the terminals *B* and *C*. The *pin plug* employed in such a switchboard is represented in Fig. 86. It consists of a brass pin, slotted to ensure elasticity, and with a hard rubber milled head.

The connections of a way office with a switchboard similar to the above are repre-

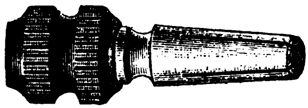


FIG. 86.—PIN PLUG.

sented in Fig. 87. Here three stations are shown *A*, *B*, and *C*. *A* and *C*, are the

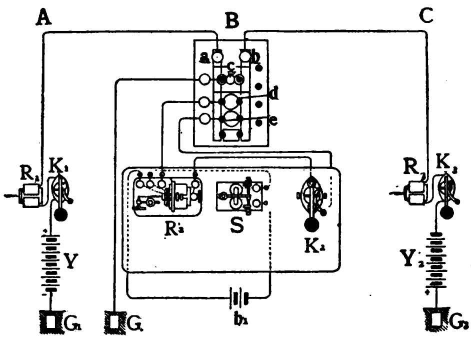


FIG. 87.—WAY OFFICE CONNECTIONS.

terminal stations, with line batteries Y_1, Y_2, keys K_1, and K_3, and relays R_1, and

R_3. B, is the *way station* with the lines entering at terminals a and b. c, is the lightning arrester connected to ground G_2. By inserting plugs in the holes d and e, the incoming current from A, passes to a, plug e, the key K_2, the coils of the relay R_2, plug d, strap b, and out to the line. The local circuit of the relay includes the local battery b_1, and the sounder S.

A simple form of *cut-out apparatus* for a way office on a single wire is shown in Fig. 88. Here the line wires are brought to the terminals L_1 and L_2. L_1, is connected with a vertical pin B, fixed in the wooden base. L_2, is connected with a metallic spring A, which carries a pin C, at its free extremity. In the position shown, the tension of the spring A, adjusted by the screw S, forces the pin C, against the fixed pin B, and thereby connects the lines L_1, L_2. The insertion of a plug, however, such as shown in Fig. 89, between the two pins, causes the

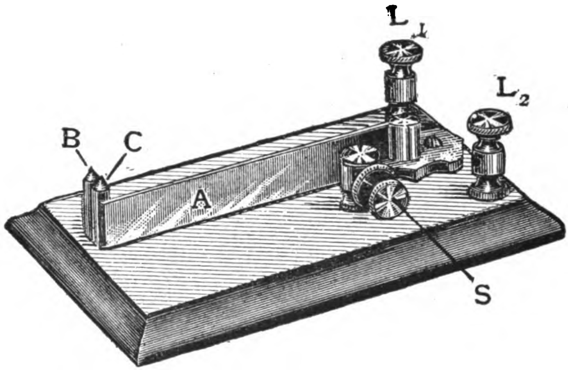


FIG. 88.—WAY OFFICE CUT-OUT.

movable pin *C*, to press against the *c*-side of the plug and the fixed pin *B*, against the *b*-side of the plug. These sides are connected with the Morse relay of the office by wires whose ends are clamped under the screws *B* and *C*. The insertion of the plug, therefore, interposes the Morse relay between the two terminals L_1 and L_2; and, consequently, in the line

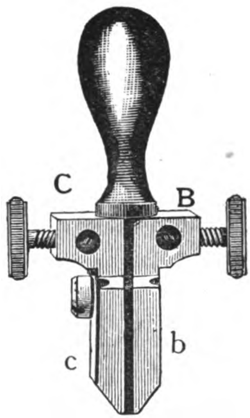


FIG. 89.—SQUARE DOUBLE PLUG.

circuit. The withdrawal of the plug removes the relay and directly connects the lines.

When a temporary station has to be set up in an emergency along a line of telegraph, the device shown in Fig. 90, is sometimes employed. The two clamps *A* and *B*, are securely fastened to the line conductor at the point selected for the station.

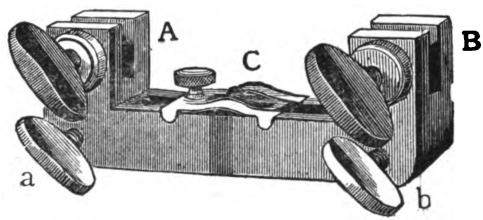


FIG. 90.—LINE TAPPING CLAMP.

The wire is then cut by a file or hand saw between the two clamps. This disconnects the line and opens the circuit, since the two clamps are insulated from each other, but the line wire is mechanically held in position. The metal bridge *C*, maintains connection between the two clamps until the Morse relay and key of the station are connected between the binding screws *a* and *b*. The bridge *C*, is then withdrawn, thereby throwing the relay into the circuit. On removing the station, the clamp is left bridged across until such time as the lineman can remove it and rejoint the wire.

A switchboard arranged for three separate lines incoming and outgoing from a way station, is represented in Fig. 91. Here the lines are connected to the terminals, *a*, *b*; *c*, *d*; *e*, *f*, connected with the strips and lightning arrester as before. All the circular pieces in one horizontal row are connected to one terminal, as at *g*, so that the terminals *l* and *m*, are connected to the lowest pair of circular pieces between each pair of strips. By this means a pair of pin plugs can be inserted in any diagonally adjacent pair of holes, so as to bring the instrument of a given pair of terminals, in connection with a given pair of lines. For example, by inserting plugs in the intersections *e* and *l*, and *f* and *m*, the instrument belonging to the

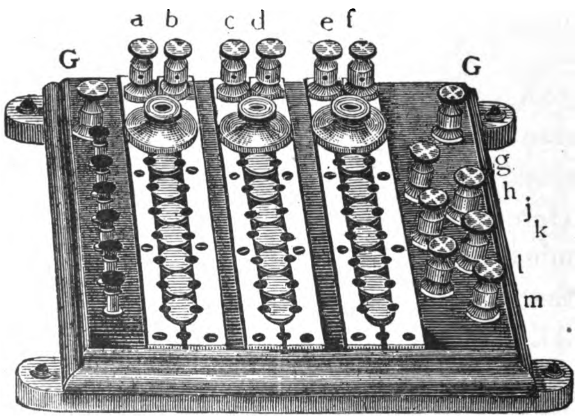


FIG. 91.—THREE-CIRCUIT WAY SWITCHBOARD.

local connection *l m*, is inserted in the line *e f*. Under ordinary conditions it is customary to have the board so wired that the plugs are normally inserted in a diagonal line across the board, thus connecting lines *a b*, to instrument *g h*, lines *c d*, to instrument *j k*, and lines *e f*, to instrument *l m*. *G*, *G*, are the ground terminals for the top circular pieces and lightning arrester pins. There are, however, several ways to connect switchboards other than that here described. For example, in terminal offices the horizontal rows may be connected with batteries so that any desired battery power may be plugged into any given line.

Fig. 92, shows a *fourteen-strap switchboard* which may be employed for 7 lines at a way station, and could be made to accommodate 14 lines by suitable connections. Here, as before, all the circular pieces are connected together in horizontal rows with a terminal on the left-hand side, so that the pin plugs may establish connection between any horizontal row and any vertical strap. In some methods of connection a double plug is inserted in one

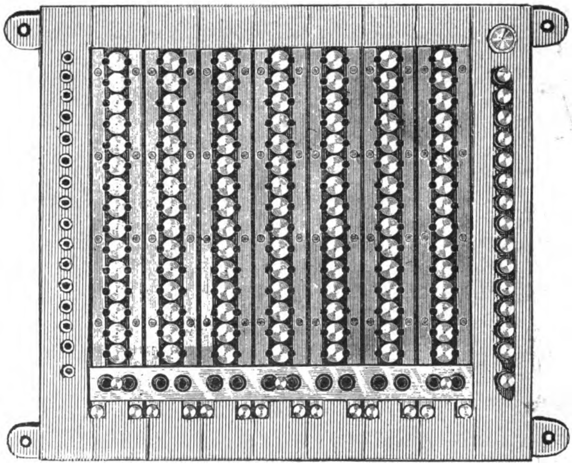


Fig. 92.—Fourteen-Strap Switchboard.

hole in a similar manner to the double plug of Fig. 89. A double plug for such purposes is represented in Fig. 93.

When a switchboard is employed at a terminal office for battery connection with the lines, a *spring-jack board* is often used in connection with it for establishing the connection of instruments with the circuits,

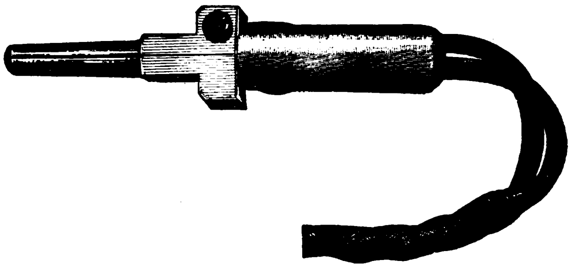


FIG. 93.—DOUBLE PLUG.

each line wire then passes from the vertical strap to one spring-jack, which differs only in details of construction from the cut-out represented in Fig. 88. A set of six spring-jacks is shown in Fig. 94. Each jack has two terminals in a line of twelve at the back. A plug of peculiar shape with a cord attached to it can be inserted in any spring-jack which is not already occupied. The act of insertion raises a spring lever, thereby breaking metallic connection between the jaws of the jack,

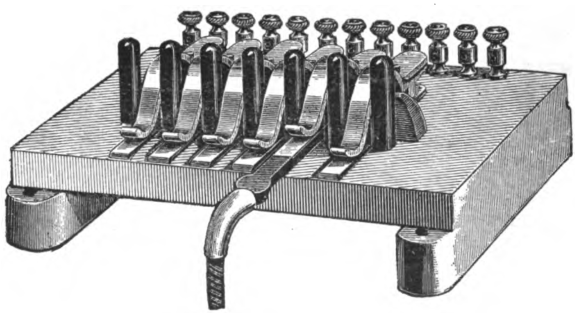


FIG. 94.—SPRING-JACK BOARD.

except through the instruments which are connected between the sides of the plug through the flexible cord. This method of connection is diagrammatically represented in Fig. 95. It will thus be seen that one relay and sounder may be connected at will in any of the six circuits connected with the board. When the plug *j b*, is withdrawn the jack *J*, rests in contact with the base *B*, under the influence of the spiral spring *P*.

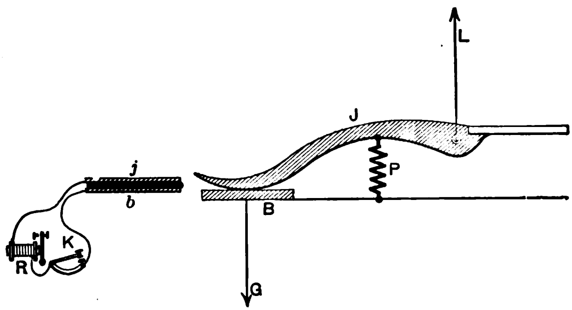


FIG. 95.—DIAGRAM OF SPRING-JACK CONNECTIONS.

Ground connections are usually effected in cities by connecting the ground wire to the water pipes. In some cases the gas pipes are employed, but there is more liability to find a faulty ground connection in a house on the gas pipes than on the water pipes, since the gas-pipe joints are often red-leaded, and may offer a comparatively high resistance path. In the absence of water pipes, a copper plate, buried in the ground, deep enough to reach permanently moist soil, is usually sufficient; or, a plate may be thrown down a well with a wire attached to it.

CHAPTER X.

REPEATERS.

THERE is no difficulty in directly operating a telegraphic line of 300 miles or less, if the line is fairly well insulated and there are not too many offices connected in the circuit. The difficulty arising from the number of offices usually settles itself, since the traffic cannot be handled without great delay when the number of offices is too great; and, consequently, it becomes necessary to employ more wires and divide the offices among them. As, however, the length of a single line increases, the difficulties with leakage and retardation increase, until the speed and certainty of signalling are largely reduced.

The greatest length of line which it is customary to operate directly in one circuit is 600 miles, and this with large and comparatively good conducting wires. When lines of considerable length have to be operated, the principle of the relay has been extended from repeating into a local circuit to repeating into a second section, or prolongation of the main-line circuit. The theoretical connections necessary for one line to repeat into another line are represented in Fig. 96. Here the signals received on the relay *R*, over the incoming line *A B*, are repeated by the tongue of the relay, into the outgoing line *B C*, through the relay *R'*. By this means a line of 800 miles in length is broken up into two sections of say 400 miles each, the signals being thereby greatly improved. Although the connections are evident and simple for repeating

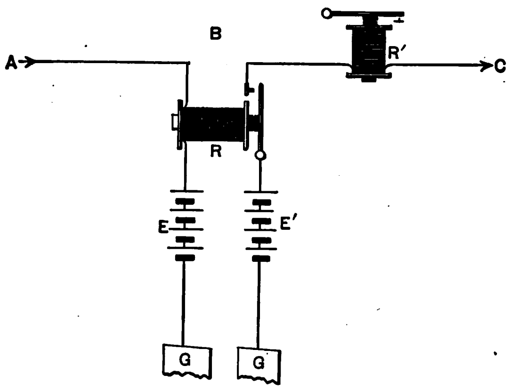


FIG. 96.—DIAGRAM OF SIMPLE REPEATER.

in one direction as shown in Fig. 96; yet when, as in practice, it is necessary to repeat in either direction, some complexity is introduced into the connections. The simplest form of repeater is called the *button repeater*, because it is operated by a button or switch at the repeating station under the manual control of an operator. The connections for a particular form of button repeater are shown in Fig. 97.

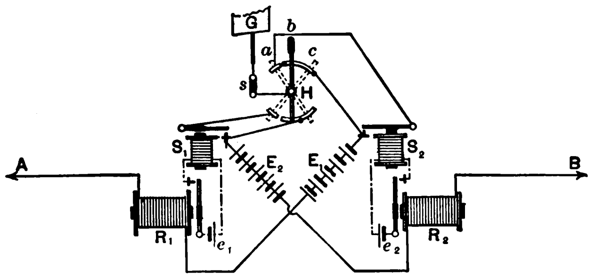


FIG. 97.—BUTTON REPEATER CONNECTIONS.

Here *A*, and *B*, are the lines leading to distant stations *A*, and *B*, respectively. In addition to the relay, sounder, and main-line battery in each circuit, the switch *H*, is added. This switch has three positions *a*, *b* and *c*. In the central position, as indicated in full lines, the two circuits are independent of each other when the small switch s, is closed. Thus the A-circuit is grounded through R_1, E_1, the strip c, the switch handle H, and the auxiliary switch s. The B-circuit is similarly grounded. When the auxiliary switch s, is opened, the lines are directly connected via R_1 E_1 c H E_2 R_2 and B. When A, desires to repeat to B, s, is closed and H, is turned to c. The A-circuit is then grounded through R_1 E_1 H and s. The movements of the armature of the relay R_1, are repeated by the armature lever of the sounder s_1, and thence into the B-circuit through R_2 E_2 H s and G. As soon as the operator hears that A, has finished sending and that B, is about to reply, he turns the handle H, to a. This grounds the B-circuit at the battery E_2, and enables the sounder S_2, to repeat B's signals into the A-circuit through R_1 E_1 a H s and G. Fig. 98, shows the repeating switch or button.

By examining the operation of the apparatus it will be found that the function of the switch is to prevent the sounder on the outgoing side from breaking the cir-

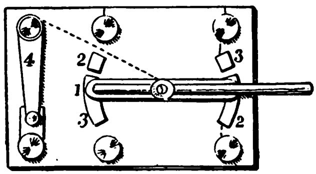


FIG. 98.—REPEATING SWITCH.

cuit on the incoming side. This is substantially the problem with which all repeaters have to deal.

In practice it would be very expensive to maintain the services of an operator listening to the transmission over a repeater merely for the purpose of turning the repeating switch when the direction of transmission changes. In order to obviate this difficulty, various forms of *automatic repeaters* have been devised. The object of these repeaters is almost invariably the same; namely, to keep the transmitting lever on the outgoing side from opening the circuit on the incoming side, but the principles which are involved and the details of construction differ considerably in different repeaters. Space will prevent our examining more than one automatic repeater which is in fairly extensive use. It is represented diagrammatically in Fig. 99.

In this repeater the relays R_1 and R_2 are provided with additional or extra magnets marked r_1 and r_2, whose levers press against the main levers in such a manner that when the working current is cut off the working winding, the spring of the extra magnet closes the local contact, against the tension of its spring, so that in order that the relay should open its local circuit at the local contact, it is necessary that the current should be cut off its main-

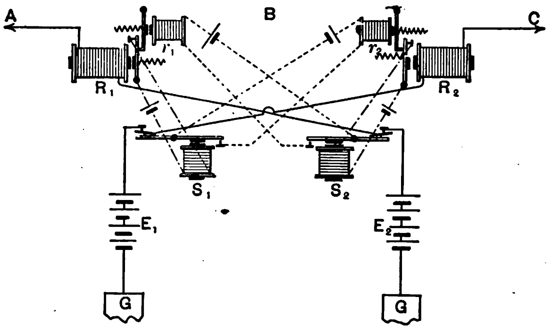


FIG. 99.—MILLIKEN'S AUTOMATIC REPEATER.

line circuit and the current should be passing through the local circuit of the extra magnet. The sounders are provided with two contacts, one, for the local circuit of the opposite extra magnet, and the other, for the closing of the opposite main-line circuit. When one of these sounders opens, its local contact is always broken very shortly before the main-line contact is broken, while in closing, the opposite takes place. If *A*, is sending a message to *C*, through the repeater at *B*, the incoming signals will be repeated by the tongue of relay R_1. This operates the sounder S_1, which in its turn repeats the signals into the *C*-circuit. The repetition of these outgoing signals in the relay R_2, would cause the circuit on the incoming side to open at its local contact, if the extra magnet r_2, were not coincidently demagnetized by the action of the repeating sounder *S*, opening the circuit. Consequently, the outgoing signals are unable to disturb the line on the incoming side.

Fig. 100, shows a Milliken repeating relay. Here *M*, are the main-line magnets, with the main retractile spring *S* and *E*,

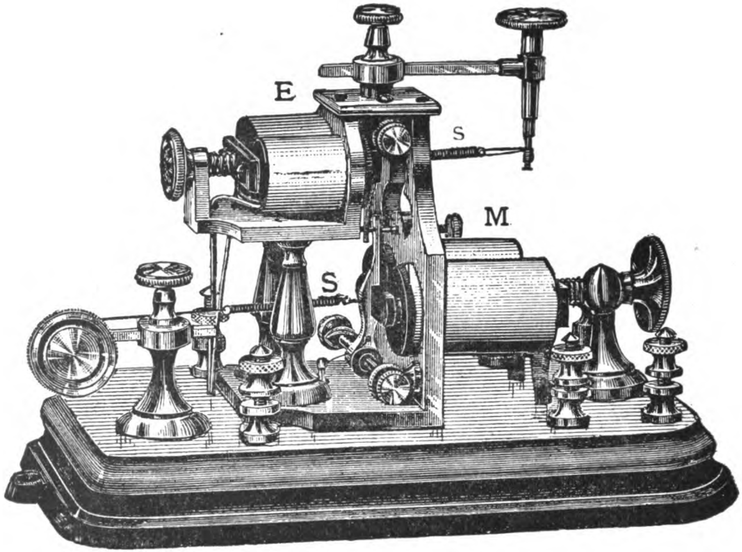


FIG. 100.—THE MILLIKEN REPEATING RELAY.

the extra or local magnets with the extra retractile spring *s*. The connection of the apparatus will be readily followed from an examination of the preceding figure.

The greatest length of circuit usually operated out of New York city, by repeaters, is to Galveston, Tex., a total length of line of 1,800 miles, through three repeaters, but it is possible to thus operate from New York to San Francisco, or even for a greater distance, as many as six repeaters being sometimes employed on one line.

CHAPTER XI.

HIGH-SPEED TELEGRAPHY.

The ordinary Morse apparatus, in which hand signalling is employed, is capable of dealing with telegraphic traffic up to a certain number of messages per hour, depending upon the speed of transmission, which, as we have seen, under practical conditions, is limited to about thirty words per minute. When the traffic between two cities exceeds what can be handled in this way on a single wire, it is necessary to adopt one of the following plans; viz., to employ more wires, equipping each with Morse apparatus; to resort to *machine transmission* instead of *hand transmission*;

or to adopt some form of multiplex transmission, whereby more than a single message can be simultaneously sent over a single line conductor.

The usual plan for transmitting a large amount of traffic in one direction over a single wire, as, for example, newspaper reports, is first to prepare the message for automatic or machine transmission. This is effected by perforating a long band of paper with a series of holes separated by spaces corresponding to the signals in dots and dashes. This work is carried out by hand, but the speed of the system is not limited to that of a single perforator, since, in a long message, several perforators may prepare different portions of the message on separate bands of paper, so that if each operator can perforate at 30 words a minute, five operators can perforate at an aggregate equivalent speed of 150 words per minute. A *perforator* for *machine*

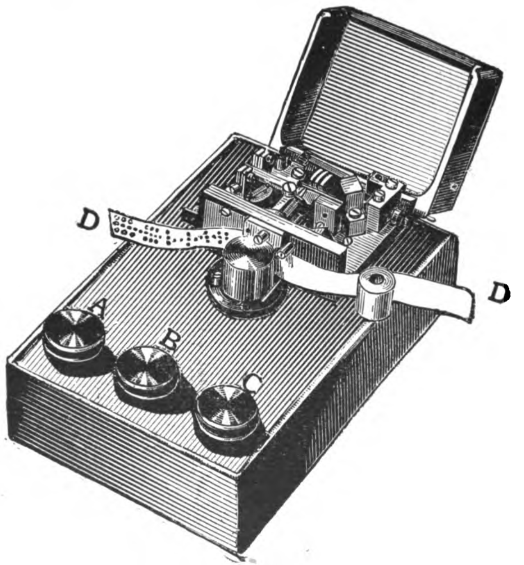


FIG. 101.—PERFORATOR FOR MACHINE TELEGRAPHY.

telegraphy is represented in Fig. 101. *A*, *B* and *C*, are three keys, *A*, marking dots; *C*, dashes, and *B*, the intervening spaces. The paper band *D D*, is driven forward from right to left during the operation of punching, and is shown in the figure as having moved to the left with three lines of holes punched through it. The middle line is a series of guide holes by which the band of paper is fed through both the perforator and the transmitting machine, while the outside lines of holes determine the signals. A dot is formed by a pair of outside holes abreast; a dash is formed by a diagonal pair of outside holes. The spaces are represented by spaces between the dots and dashes on the paper. The keys are struck by the operator with a light mallet; or, in some cases, pneumatic keys are employed, the blow being struck by pistons whose valves are controlled by the hand-operated keys.

The punched slip of paper is then taken

to the *machine transmitter* represented in Fig. 102, and is wound upon the reel *W*. The instrument is driven by clockwork,

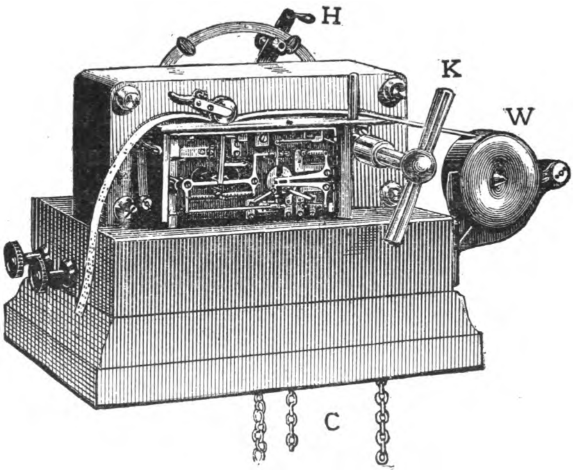


FIG. 102.—WHEATSTONE TRANSMITTER.

propelled by weights suspended on the chains *C*, and wound up by the handle *K*. The speed of the clockwork and, therefore, the speed of transmission, is regulated by the handle *H*, capable of being moved over the sector shown. The slip of paper is then passed underneath the small roller on the platform, and this roller, being caused to revolve rapidly by the clock-work, drives forward the paper at a speed which may represent 100, 200 or even 400 words per minute. As the roller revolves, a pair of needles, visible through the glass front, are kept oscillating under the platform and tend to force their way through the paper. Where a hole has been punched, the needle, rising to the surface of the platform, can pass through it, but where no hole has been punched, the needle is arrested in its upward movement by the paper band. Whenever a needle succeeds in passing up through the platform; *i. e.*, whenever a hole passes over a needle, the effect of the needle's elevation is to send an electric current to line by a contact which is effected at the full stroke of the needle. These currents are, therefore, transmitted to the line in their right order and arrangement to constitute signals, with a speed which is determined by the rate of the driving of the clockwork.

At the distant end of the line the currents are received by a form of polarized relay of great sensitiveness, adapted to extremely rapid vibration. The closing of the local circuit by the tongue of the relay actuates a magnet which causes an inked roller to be lifted against the surface of a rapidly moving band of paper. A very brief impulse to the roller makes a dot upon the moving paper, while a more prolonged elevation produces a dash. Fig. 103, shows a Wheatstone automatic receiver, which is driven by clockwork, by means of descending weights supported on chains *C*, as before, at a speed which is regulated by the handle *H*. *D D*, is the

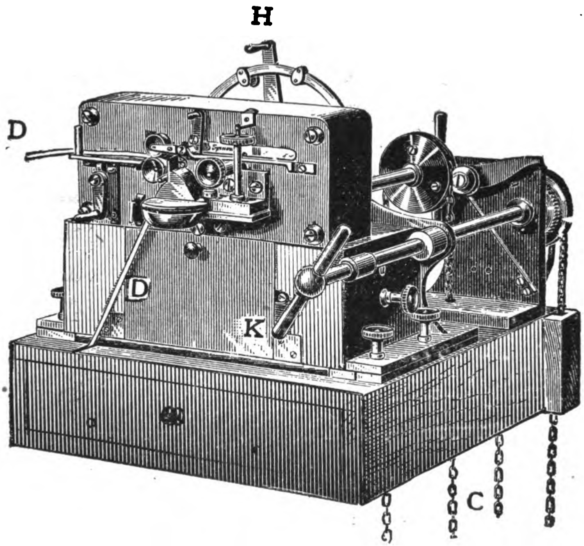


Fig. 103.—Wheatstone Receiver.

band of paper, which is coiled away in the base of the instrument, and which receives the ink markings.

The Wheatstone automatic apparatus is of great service in handling heavy traffic. Between Chicago and San Francisco a speed of about 110 words per minute is obtained, while between Chicago and New York about 190 words per minute.

Before proceeding to consider the high speed which can be attained in telegraphy on a given circuit, it will be desirable to examine into the general nature of the transmission of electric currents along a conductor, so far as these can yet be said to be understood. It is a curious fact that the popular belief concerning the transmission of an electric current through a conducting wire, a belief which has been held until recent years by the most advanced exponents of electrical knowledge, appears, in the light of recent researches, to be erroneous. According to the old idea, an electric current is something which is poured through a conducting wire like water through a pipe, and is prevented from flowing through the regions surrounding the wire, by reason of the insulator surrounding the conductor, and in truth this simile, as we have already seen, is a convenient one for many purposes; but, as a matter of fact, it would appear that when a current is said to flow through a wire, it really flows through the insulating medium surrounding the wire, and the only place where it does not flow is through the substance of the wire. In other words, it flows, in the region where it is usually considered not to flow, and does not flow, in the region where it has usually been considered to flow.

If we take an E. M. F., from a battery or dynamo, and connect it to an overhead wire, say a few feet in length, as represented by the wire *B C*, in Fig. 104, and ground the terminal *A*, of the battery,

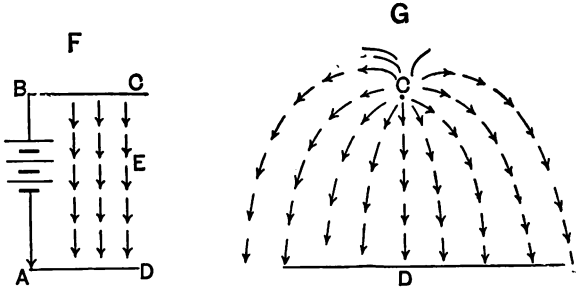


FIG. 104.—ELECTROSTATIC FLUX SURROUNDING A SHORT OPEN-CIRCUITED INSULATED WIRE.

there will be a difference of electric potential, or an E. M. F., of say 100 volts, between the wire and the ground, which for convenience may be considered as a conducting level surface, such as the surface of water. The electrification of the short wire with respect to the ground can be experimentally manifested in a variety of ways. For example, if a sufficiently delicate *electrostatic indicator* or *electrometer*, be brought underneath the wire to some point, say *E*, the indicator will show the presence of a disturbing electric force at that point. In fact, if the E. M. F. of the battery, instead of being only 100 volts, were very much greater, say 500,000 volts, a pith ball or light shred of paper, constituting a comparatively rough electrostatic voltmeter, suspended at the end of a silk string and brought to the point *E*, would be visibly attracted toward the wire. This attraction is believed to be due to the presence in the air at *E*, of an electrostatic influence, called *electrostatic flux*, emanating from the electric charge on the wire and terminating upon the conducting surface of the ground. This flux, which is invisible to the eye, invariably exists in the space surrounding an electric charge. It resides in the non-conducting materials, such as air, wood, rubber, glass, etc., in the vicinity of the charged conductor.

Excluding the distribution at the extremities of the wire, the *flux paths*, or the courses followed from point to point by the electrostatic flux, are roughly indicated by the arrows in Fig. 104, *F*, showing a side view, and *G*, a transverse view of the wire *B C*. The flux becomes feebler as we depart from the wire, especially in regions above the wire. So long as the wire remains insulated, the electrostatic flux remains fixed in the intervening space between the wire and ground. In other words, the wire is charged to a pressure of 100 volts and the electric charge endeavoring to escape from the wire to the ground under that pressure is retained in position by the insulator;

namely, the air through which the flux passes.

If we connect a long insulated wire, say 100 miles in length, to the ends of the wire at *C*, as represented in Fig. 105, the

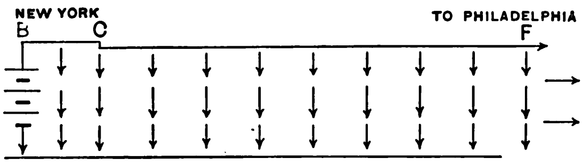


FIG. 105.—MOVEMENT OF ELECTROSTATIC FLUX.

electrostatic flux, which was impressed upon the surface of the wire *B C*, Fig. 104, as soon as the connection is made at *C*, commences to rush toward the distant end, with the velocity of light; namely, with a speed of roughly 186,000 miles per second. If the wire offered no electric resistance, the electrostatic flux would actually reach the distant end at this speed, and would only cease to move when the insulated end had attained its charge, just as at the insulated end in Fig. 104. The movement of flux, while it lasts, constitutes an electric current, and electricity; *i. e.*, electrostatic flux, will have to be supplied from the battery in order to sustain this current.

If the wire instead of being insulated at the far end were connected there to ground, either directly, or through the coils of an instrument, the charge transmitted would not be arrested at the insulated end, but the flux would continue to pour to ground through the grounded end, and would continue to pour so long as the circuit remained closed, so that there would proceed out from the battery, or source of E. M. F. at New York, a steady supply of electrostatic flux, and this would move along it so that the conductor acts as a guide over which the flux may pursue its path. Owing to the fact that the wire necessarily offers resistance, the speed with which the flux moves is very different from the speed with which it sets out on its journey, or leaves the source. A very complex condition of affairs is set up, whereby the flux is slowed down in its passage, and the speed with which it arrives at the distant end may be only a small fraction of the speed with which it starts. This speed will depend upon the size and resistance of the wire, the leakage at the various insulators along the line, and the geometrical dimensions and nature of the insulating medium.

If the wire instead of being suspended,

say 20 feet from the ground, were suspended only a few inches from the ground, the electrostatic flux would occupy a smaller volume of space, but would be very much more intense. Other things being equal, the decrease in speed toward the distant end of the line would be more marked. In other words, the *retardation* of the circuit would be increased. As it is usually expressed, the *electrostatic capacity* of the wire would be increased by suspending it closer to the ground. The same effect is produced if the wire is brought near any other conducting line, such as another wire on the same pole, or, if the wire is embedded in rubber and buried in the ground.

Whatever increases the electrostatic capacity tends as a rule to increase the retardation. The electricity given to the wire from the sending end, has to charge the entire surface before it can make its appearance and deliver a signal at the distant end, and the charge has to be withdrawn from the entire surface of the wire before the flow can be made to cease at the distant end. The *leakage* of a long line improves its speed up to a certain point, because it enables this charge to be dissipated along the line without having to make its escape at the ends. When the leakage exceeds this amount, however, the feebleness of the transmitted signals becomes more detrimental than the improvement due to reduced retardation.

It might at first sight seem that since during heavy gales telegraph lines are frequently broken, and communication interrupted, that the simplest solution of this difficulty would be to place the wires underground. There are three reasons why this plan has not been generally adopted.

First. The cost of insulating a wire all over its surface, so that it may be buried in the ground, is much greater than the cost of stringing a bare wire overhead on insulators.

Second. The increase in electrostatic capacity, due to bringing a buried conductor into such close proximity with the ground, is very great, and the speed of transmission over long circuits, would be thereby greatly reduced.

Third. The difficulty and expense of determining the position and repairing defects in a wire increase very greatly when the wire is buried. Consequently, buried wires, although secure from storms, are much more expensive to install, operate and maintain.

For a given length of line, in a given electric condition as regards capacity, leakage, conductor-resistance, etc., when a number of signals are sent in rapid succession from the sending end, the signals will become confused or merged together at the receiving end, when the speed of signalling exceeds a certain number of impulses per second.

For hand signalling, at a speed of say 30 words per minute, a circuit can, if necessary, be worked across the breadth of the United States through a sufficient number of repeaters; but, when a higher speed of signalling requires the use of machine transmission it is often found impossible to attain a high speed over an iron wire of high resistance, and repeaters become difficult to manipulate satisfactorily at machine speeds. It, therefore, becomes important on high-speed circuits to employ large conductors and, if possible, conductors of copper instead of iron. Iron wires have to be magnetized cylindrically at each current impulse throughout their length, and iron resists magnetization to a certain degree. Consequently, an iron wire not only adds its ohmic resistance to a circuit when operated at a high speed, but also adds an *apparent* or *spurious resistance* due to the rapid change in its cylindrical magnetization. Thus, while two 500 mile circuits, one of copper and the other of iron, may work equally well by hand telegraphy, at 30 words a minute, a Wheatstone high-speed transmitter may be only able to transmit 90 words a minute on an iron-wire circuit, and 130 words a minute on a copper-wire circuit. In all cases the speed of transmission may be increased by increasing the size of the conductor, so that the attainable speed of a circuit, even if 1,000 miles in length, is principally a question of the number of pounds' weight of conductor per mile.

When a speed of 400 words a minute is exceeded, there is great difficulty experienced in getting electromagnetic relays to respond with sufficient rapidity to the swiftly succeeding impulses, even assuming that the line is sufficiently short to transmit them faithfully without merging. In other words, above speeds of 400 words a minute, an electromagnetic receiver possesses too much *magnetic* and *mechanical inertia*, or becomes too sluggish. A method can, however, then be used, although it is not at the present time actually in use in the United States, for transmitting signals up to a speed of 2,000 words a minute or even more. A line to transmit such a speed would either have to be very short, if of ordinary iron wire, or of heavy copper, if say 500 miles in length. The receiving apparatus, in such cases, is operated by the electro-chemical effect of the current, which does not depend upon mechanical principles and is, therefore, devoid of mechanical inertia. If an electric current be sent from an iron needle, through a piece of paper moistened with ferrocyanide of potassium, to a plate of metal beneath the paper, the current will decompose the solution and produce a blue stain on the paper at the point where the current enters it. If the paper be moved along, beneath the iron wire, at the same time that the current is being sent, a blue line will be drawn by the point, and, if while the paper moves, dots and dashes be sent through the line, these dots and dashes will appear as blue dots and dashes upon its surface. In order to keep the resistance of the paper from becoming too high it has to be kept moist.

The speed at which signals are transmitted by Wheatstone instruments is sufficient to handle the telegraphic traffic of the present day at existing telegraphic speeds. It has been shown, however, that by the use of large copper conductors with corresponding cost for wire it is possible greatly to augment the speed of machine telegraphy over comparatively long lines. It has, therefore, been suggested that if telegraphic charges were sufficiently reduced, much of the ordinary mail matter might be transmitted by telegraph instead of by mail, the enormously increased telegraphic traffic being handled by electrochemical receivers and mechanical transmitters employing bands of perforated paper.

Fig. 106, represents a *transmitter* which has shown its capability of transmitting upward of 3,000 words per minute on lines

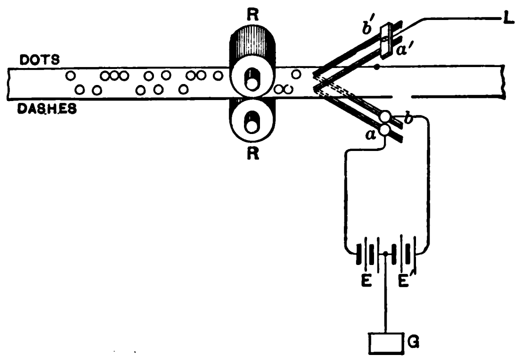


FIG. 106.—DELANY MACHINE TRANSMITTER.

below a certain length. The message is first punched in dots and dashes of the Continental Morse code, the dots being in the upper line and the dashes in the lower line. It will be seen that the signals punched in the strip of Fig. 106, are *a*, *b*, *c*, *d*, *e* and *g*, of the Continental code.

This perforated band of paper is carried rapidly through the instrument by the rollers *R*, *R*, driven by clockwork. Behind the rollers are two pairs of metallic brushes *a*, *a′*, and *b*, *b′*; *a*, *a′*, resting opposite to each other on the line of paper intended for dashes, and *b*, *b′*, opposite to each other on the line of paper intended for dots. The brushes *a* and *b*, are connected each to the E. M. F. *E E′*, of say 50 volts negative, and 50 volts positive, respectively, the middle of the battery being grounded at *G*. The brushes *a′ b′*, are connected to the line at *L*. Where a dot exists made in the paper, the *b*, *b′*, brushes come into contact through the hole, and a positive current of brief duration is sent to line. Where a dash hole exists in the paper, the *a*, *a′*, brushes come into contact and a negative current is sent to line.

The receiving instrument is diagrammatically represented in Fig. 107. Here three steel needles rest flat upon the surface of a rapidly moving band of paper, moistened with ferrocyanide of potassium. The middle needle is connected to ground;

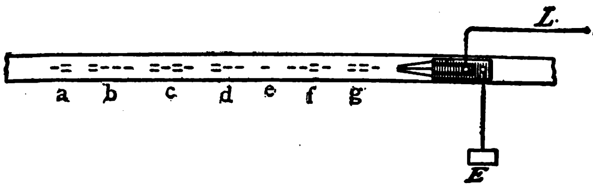


FIG. 107.—DELANY ELECTRO-CHEMICAL RECEIVER.

the two outside needles are connected to the line *L*. When a current comes from the line to ground; *i. e.*, when a positive current is received, the two outer needles will deliver jointly the current through the paper to a metallic plate beneath, and back to the middle needle and ground, so that a dot will be formed underneath each of the two outside needles. When, however, a current passes into the line from the ground; *i. e.*, when a negative current is received from the line, this current will pass through the central needle through the paper to the plate beneath, and thence in divided arc to the two outside needles. Consequently, a dot will form beneath the central needle. The central dots will, therefore, correspond to dots at the sending end, while the pairs of outside dots will correspond to dashes at the sending end. The signals received on the band of paper in Fig. 107, therefore, correspond to *a*, *b*, *c*, *d*, *e*, *f*, *g*, in the Continental code. This receiver has been shown to be capable of working at high speeds, say 1,500 words a minute, over comparatively long lines, provided such lines are constructed with sufficient copper to reduce their resistance to the right degree.

CHAPTER XII.

DUPLEX TELEGRAPHY.

We have shown, in the preceding chapter, how, when the traffic over a line exceeds a certain amount, the carrying capacity of the line can be increased by the use of machine telegraphy. There are, however, other methods by which the carrying capacity of a line can be increased. These consist essentially in combinations of apparatus whereby more than a single message can be simultaneously sent over the same wire, either in the same direction or in opposite directions. The method in commonest use is called *duplex* *telegraphy*, and consists of means whereby two messages can be simultaneously sent in opposite directions over a single circuit.

The duplex telegraphic system has proved of great importance in telegraphy, and almost all important circuits, whether overland or submarine, are operated by this system. If there are two stations *A* and *B*, connected by a single circuit, *A*, can send a message to *B*, singly as in the usual manner; or, *B*, can send a message to *A*, singly in the usual manner; or, *A* and *B*, can both send messages to each other at the same time. It is necessary, therefore, when working a line steadily by the duplex system, to employ at each end of the line one operator for sending messages and a second operator for receiving them.

In order to comprehend the operation of the duplex system, the imaginary conditions represented in Fig. 108, may first be examined. Here three stations *A*, *B* and *C*, are connected by the two overhead conduc-

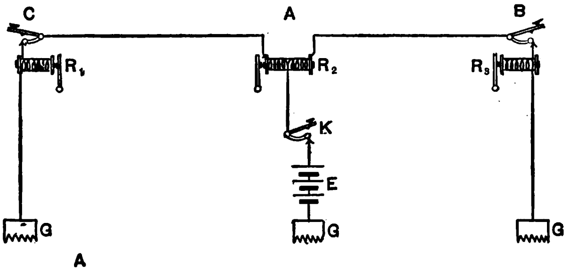


Fig. 108.—Diagram of Differential Relay Connections.

tors *A C* and *A B*. These are supposed to have equal length, resistance, and leakage, and, in fact, to be practically equal in all respects, from an electrical point of view. The E. M. F., *E*, at the station *A*, is connected to the two lines through the key *K*, and the special relay R_2. This relay has two sets of coils, so arranged that the current entering the line *A B*, from the battery *E*, produces a magnetomotive force opposite or counter to that produced by the current in the other winding entering the line *A C*. The result will be that when both currents flow, no resulting magnetomotive force, or magnetic effect, is produced in the relay R_2, so that this relay does not attract its armature, but the outgoing currents arriving at *B* and *C*, actuate the relays there in the usual way. Consequently *A's* relay will not repeat the message he sends at the key *K*, while the relays at *B* and *C*, will reproduce the signals. If, however, *A*, stops sending and closes his switch, the currents flowing steadily to *B* and *C*, pass through the relay *R*, without magnetizing it, and leave the armature unattracted, while the steady currents flowing through the relays at *B* and *C*, cause them to be steadily attracted. If now, one of the terminal stations, say *B*, opens his switch and commences sending signals with his key, those signals will not only be repeated at his own relay, in the usual manner, but will also be repeated at the relay R_2, except that the relay R_2, attracts its armature during the times when the key is open at *B*, and releases its armature when the key is closed at *B*. In other words, the relay at *A*, will operate on the backstroke; for, as soon as the current is cut off the line *A B*, by interrupting the circuit at *B*, the magnetomotive force of the current circulating steadily in the line *A C*, will magnetize the relay since its opposing or counter acting M. M. F. is now absent.

The connections for duplex working on this principle, between two stations *A* and

B, are indicated in Fig. 109. *A B*, is the line connecting the two stations. *A C*, and *B D*, are for the present to be regarded as two similar lines of equal length from an electrical standpoint. In the normal position, the keys K_1 and K_2, remain open, on their back contacts, cutting out the batteries E_1 and E_2, so that the

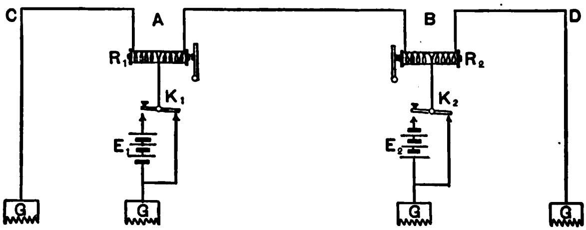


Fig. 109.—Diagram of Differential Duplex Connections.

system is an open-circuit system. If the operator at *A*, makes a dot by momentarily depressing his key K_1, his relay R_1, will not respond, since two currents will be sent, one along the line *A C*, and the other along the line *A B*, through the back contact of the key K_2, to ground. These currents will neutralize their M. M. Fs. in the relay R_1, but the current arriving at *B*, will only traverse the left-hand coil of the relay R_2, and will operate it in the usual way. Consequently, *A's* dot will reach *B*, but will not be repeated by his own relay R_1.

In the same way, when *A* stops sending and *B* sends by depressing his key K_2, on the front contact, lifting it from the back contact, his signals will be repeated by the relay R_1, at *A*, but will not actuate his own relay R_2. If, however, both operators hold their keys down, the current in the lines *A C*, and *B D*, will remain of the ordinary strength. In the line *A B*, however, the two E. M. Fs. *E* and E', will combine to produce a doubled current strength. Consequently, the current and M. M. F. in the right-hand coil of R_1, will be twice as great as the current and M. M. F. in the left-hand coil. The balance of the M. M. F. being thereby destroyed, the relay R_1, will operate differentially with the power of the ordinary current flowing through one coil, and its armature will be attracted. Similarly, at B, the current and M. M. F. in the left-hand coil of R_2, will be double that in the right-hand coil, and the relay will operate with the power of the ordinary current in one coil, thereby attracting the armature. Consequently, when both operators happen to have their keys down at the same moment both relays will respond. If then, one operator sends at a time, the message is repeated at the distant end while his own relay is silent; but if both send together, both relays will respond during the moment when the keys c :sh. During the operation of the line, it follows, therefore, that part of the signals which are reproduced at the relays are due to currents transmitted from the distant end in the usual way, and part from the joint action of both currents, but the messages are repeated faithfully at each end.

The auxiliary lines *A C* and *B D*, instead of having the actual length of the working line *A B*, have only the electrical length of this line, and are called *artificial lines.* They consist of *rheostats* or *resistance boxes; i. e.*, boxes containing spools of insulated wire offering a definite resistance. The number of separate spools inserted in the circuit corresponds to a certain number of miles of actual wire. A rheostat which occupies only a few cubic inches may, therefore, correspond electrically in its resistance to an actual line over one hundred miles in length.

In practical operation the keys *K*, are replaced by special transmitters, such as that shown in Fig. 110. The key worked by the operator closes a local circuit through the magnet coils of the transmitter, which thereupon attracts the armature and raises the opposite end of the armature lever. This brings the platinum-tipped spring *S*, into contact with the platinum-tipped screw T, thereby closing the main-line circuit, corresponding to the front contact of the key K, in Fig. 109. As the contact is made between *S* and *T*, the spring *S*, is depressed out of contact with the extremity of the armature lever,

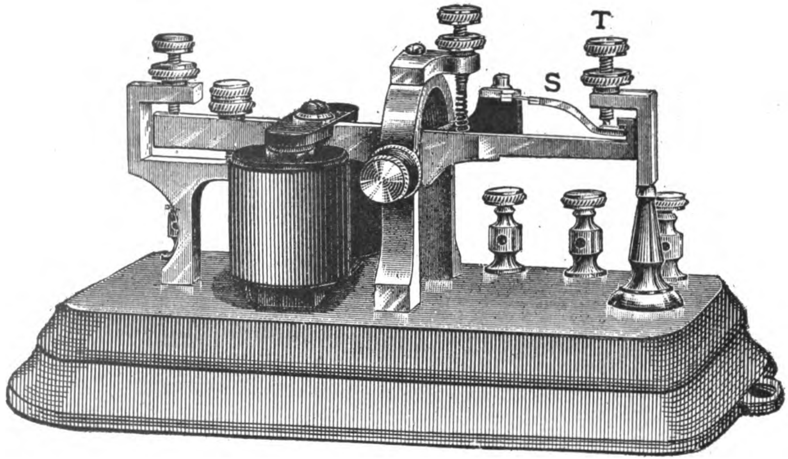


FIG. 110.—DUPLEX TRANSMITTER.

thereby breaking a contact corresponding to the back contact of the key in Fig. 109. The transmitter is, therefore, equivalent to a key with front and back contacts, mounted upon a pivot, and operated by a magnet instead of being operated by the pressure of the finger. The contacts, however, are more prolonged than would be the contacts of a hand key, owing to the fact that the spring *S*, by its elasticity remains in contact with the screw *T*, during a considerable portion of the stroke, instead of being in contact only at the end of the stroke as is the case with the ordinary hand key. In other words, the transmitter is preferable since it employs an elastic and prolonged front contact.

A modification of the *differential duplex*, called the *polar duplex*, is represented diagrammatically in Fig. 111. Here two batteries are employed at each station, one with its positive pole connected to the front contact, and the other with the nega-

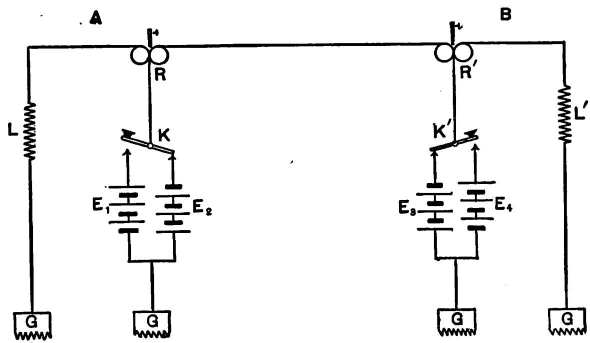


FIG. 111.—DIAGRAM OF POLAR DUPLEX CONNECTIONS.

tive pole connected to the back contact of the key. When the keys remain at rest, the currents oppose and neutralize in the line, but currents flow in the artificial lines *L* and *L'*, in the directions *G G L A R*, and *G G L' B R'*, respectfully. These currents pass through the left-hand coils of the differential relays *R* and *R′* and cause the armatures to be held over upon the dead or non-marking contact. If the operator at *A*, depresses his key, he reverses his battery. This reverses the current through the artificial line and doubles the strength of the current in the main line. Consequently, although the left-hand coil has its magnetomotive force reversed, yet the M. M. F. in the right-hand coil is changed from zero to double positive, and overcomes the marking or closing tendency of the artificial-line current thereby still keeping the armature against the dead point. The current in the line passes through the left-hand coil of the relay *B*, with double strength and in the direction to oppose the single strong current in the artificial line, thereby moving the tongue against the contact point. The *B*-relay, therefore, responds to *A's* key, while *A's* relay does not. In a similar manner when *B* alone depresses his key, *A's* relay responds but *B's* does not. When both keys are depressed, the currents in the line are once more opposed, and no current flows in the main line, neglecting that due to leakage, while the current strength through the artificial lines reversing as before, the relays are both thrown to their marking contacts closing their local circuits through their sounders. It is, therefore, evident that *A's* relay will mark whenever *B's* key is down, whether *A*, is sending or not; and *B's* relay will mark whenever *A's* key is down, whether *B*, is sending or not, but neither station repeats its own message.

The relay employed in connection with the polar duplex of Fig. 111, is called a *polarized relay*, and is shown in Fig. 55. It will be seen in that figure that four wires enter each magnet coil. This gives two wires to each coil in each magnet, which enables the magnet to be wound differentially.

Fig. 112, shows in some greater detail, the connections employed for a *polar duplex*. *E* and *E'*, are the dynamos, *E*, for the positive and *E'*, for the negative current. These supply their currents through resistance coils *r*, *r*, either of German silver wire, or of incandescent lamps. *K*, is the hand key which closes the local circuit of the pole changer transmitter *T*, represented in greater detail in Fig. 113. The position of the pole-changer lever determines which current is being sent to line through the pivot of the lever. The switch *s*, is for changing from duplex to ground connection through a rheostat r', for the purpose of enabling the distant

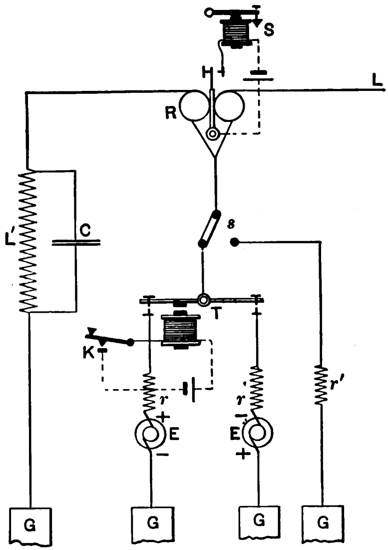


FIG. 112.—DIAGRAM OF STATION CONNECTIONS. POLAR DUPLEX.

station to obtain a balance. From the switch the current goes to the junction of the two relay coils where it divides, one half going to line L, if the line circuit be closed at the distant station, and the other half through the artificial line L', to

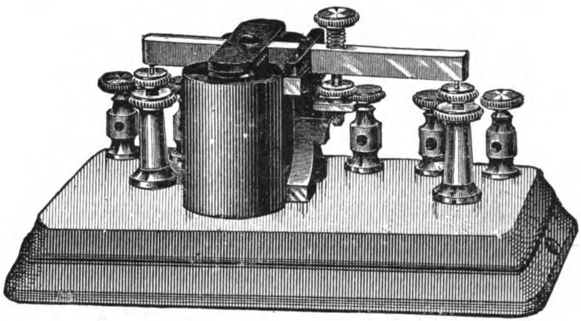


FIG. 113.—DYNAMO POLE-CHANGER.

ground. The resistance in the artificial line is made equal to the resistance of the line and relay coils at the distant station. This is adjusted, not by measurement, but by trial. The distant station turns his switch to the ground position and signals are then sent by the operator at the home station. If the balance between the artificial line and the actual line is imperfect, these signals will be repeated with greater or less power by the tongue of the relay *R*. The rheostat *L'*, is then adjusted until these signals finally disappear, and the home relay fails to respond to the home key. When this is accomplished the line is said to be *perfectly balanced*. On all but short lines a condenser *C*, is necessary, connected to the artificial line. This condenser imitates the electrostatic capacity of the line, just as the rheostat *L'*, imitates the ohmic resistance of the line. If the condenser were omitted on long lines, the sudden charges and discharges of the line would not be imitated by the simple rheostat, and kicks would be given to the tongue of the relay, interfering with the signals. *S*, is a local sounder connected with the tongue of the relay *R*.

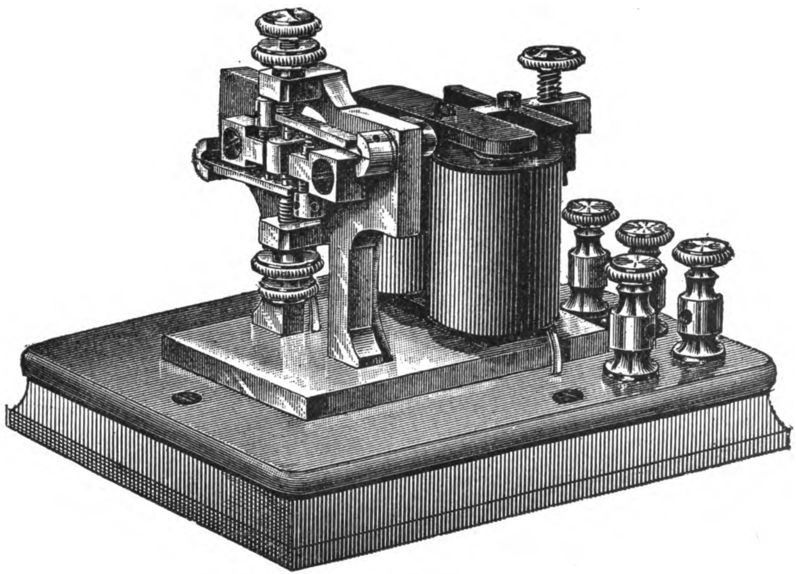


Fig. 114.—Battery Pole-Changer.

When batteries are employed as the source of E. M. F. instead of dynamos, it is sometimes important to have one battery instead of two, and to reverse this battery instead of changing contacts from one battery to another. This is accomplished by the transmitter shown in Fig. 114. Here the extremity of the armature lever moves between a pair of contact springs in such a manner that the positive pole of the battery is connected to line, when the lever is at the upper portion of its stroke and the negative pole to ground, while, when the lever is at the lower portion of its stroke, the negative pole of the battery is connected to line and the positive to ground.

CHAPTER XIII.

QUADRUPLEX TELEGRAPHY.

Quadruplex telegraphy consists of a method of sending two telegraph messages simultaneously along a single wire in one direction while two additional messages are being sent over the same wire in the opposite direction. Thus, if the line connect two stations *A* and *B*, *A*, can send two messages to *B*, at the same time that *B*, is sending two messages to *A*, so that there are two operators at the *A*-end of the line, engaged in sending, and two more engaged in receiving, while at the *B*-end of the line there are also four operators similarly engaged.

The principle upon which the quadruplex system is based is the development in the first place of a suitable *diplex telegraph*; *i. e.*, a suitable means for sending two independent messages simultaneously in the same direction. The first message is sent by changing the direction of the sending current, and the second message is sent by changing the strength of the sending current. Consequently, the first message is entirely transmitted by changes in the direction of the current without regard to strength, and the second message is transmitted by changes in the strength of the current without regard to direction, and these two principles are evidently mutually independent.

The arrangement of a diplex system between two stations *A* and *B*, is represented in Fig. 115. K_1, is a key, so arranged that when released a comparatively small E. M. F. e, say 40 volts, is connected to the circuit, but when depressed, the greater E. M. F. E, say 140 volts, is connected, of which e, is only a part. The key K_2 operates as a reverser, so that when this key is at rest, the negative pole of the battery is to ground and the positive to line; but, when depressed, the positive is to ground, and the negative to line. The key K_1, affects only the magnitude of the E. M. F. and does not reverse it, while the key K_2, has no control upon the magnitude of the E. M. F. introduced into the circuit, but takes whatever the key K_1, supplies and controls its direction to line. At the receiving end of the line B, are two relays R_1 and R_2. R_1, is an ordinary neutral or non-polarized relay, so adjusted that it will not respond to the feebler current from the feebler E. M. F. e, but will respond when the current is strengthened by increasing the E. M. F. to E, at the sending end. In other words, the relay R_1, responds to the key K_1; for, not being polarized, it will act while the current from the line is positive or negative; *i. e.*, whether the key K_2, is up or down.

The relay R_2, is a polarized relay such as is shown in Fig. 53. It will respond to a negative current and not to a positive current. It will respond to a negative current whether feeble or strong. In other words it will respond to the key K_2, whatever the position of the key K_1. Consequently, the message which is signalled at the key K_1, will be repeated at the relay R_1, while the message signalled at the key K_2, will be repeated at the relay R_2. Care has to be taken that the keys shall not interrupt the line at any time while performing their functions, and this requires that they shall be replaced by suitable transmitters, properly adjusted and operated by keys through local circuits.

If we consider the two keys at the sending end, and the two receivers at the receiving end, as a dual piece of apparatus, and then duplex the entire arrangement, we obtain the quadruplex system, or the capability of transmitting two messages simultaneously in both directions.

Where dynamos are employed as the source of the E. M. F. the diplex is usually a little differently arranged, retaining however the same principle. Two dynamos are employed with the pole changer of Fig. 113, and these are introduced and reversed under the action of the key corresponding to K_2, in Fig. 115. The current, however, is weakened or strengthened, by the insertion and removal of the resistance in the main-line circuit under

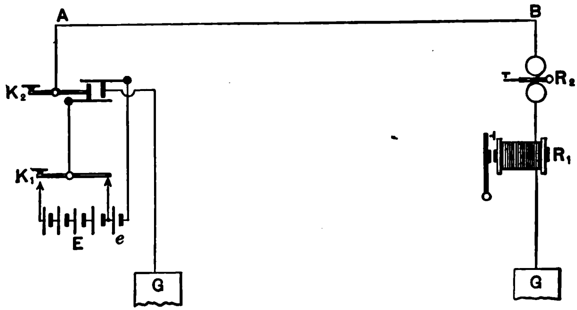


FIG. 115.—DIPLEX SYSTEM.

the control of a key similar to K_1, in Fig. 115.

The arrangement of connections for a complete quadruplex system are diagrammatically indicated in Fig. 116. Various minor details have to be introduced into the apparatus in order to operate it successfully, such as additional condensers, etc., but these do not affect the principle upon which the method is based.

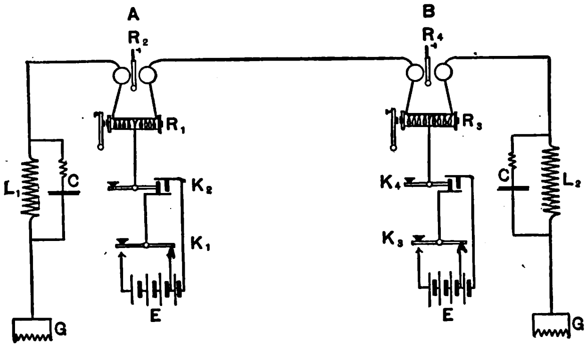


FIG. 116.—DIAGRAM OF QUADRUPLEX CONNECTIONS.

The adjustments for the quadruplex system are more complex than for the duplex system, since a balance has to be obtained as well as the successful independent operation of the two parts of the diplex. The apparatus employed in operating the polar system of the diplex is generally called the "*No.* 1 *Side of the System*," or the *polar side.* It consists of the polar key and the polar relay at either station. The apparatus employed in operating the other system of the diplex is called the "*No.* 2 *Side of the System*," or the *neutral side.* It consists of the neutral key and of the neutral relay.

Referring to Fig. 116, when none of the keys are depressed, no current flows through the line, but a comparatively feeble current flows through the artificial lines L_1 and L_2, insufficient to operate the neutral relays, and maintaining the polarized relay tongues on the dead stops. Consequently, none of the sounders respond. If now K_1, be depressed, a strong positive current is sent to line at *A*. This does not affect the relays at A, since it passes through them in opposite directions, but on arriving at *B*, it tends to keep the polarized relay tongue R_4, on the dead stop, while it has sufficient power to operate the neutral relay R_3. In the same way if K_3, alone be depressed, relay R_1, alone will respond. If K_2, alone be depressed, a feeble negative current will flow to line, in a direction which will actuate R_4, but it will not have sufficient power to actuate R_3. If K_4, alone be depressed R_2, alone will similarly only respond. By reason of the principles already explained in connection with duplex telegraphy, the depression of any key will cause its corresponding relay to close its local circuit at the distant end of the line, no matter what the condition of the keys may be at that end.

In practice the contacts are effected by transmitters like those shown in Figs. 110 and 114, operated in local circuits by hand keys.

CHAPTER XIV.

MULTIPLEX, PRINTING AND FACSIMILE TELEGRAPHY.

In addition to the diplex system described in the last chapter, several systems of *multiple telegraphy* are in existence; *i. e.*, systems for simultaneously transmitting in the same direction over a single line a number of messages greater than one. No little confusion exists as to the use of the words multiple and multiplex telegraphy. It would seem that in accordance with the definitions of duplex and quadruplex systems, the word *multiplex* should only be applied to systems of simultaneous transmission from each end of the line, so that multiplex would include duplex, quadruplex, sextaplex systems, etc.; while multiple telegraphy would only include double, triple and multiple transmissions in one and the same direction over the line simultaneously. Unfortunately, the words diplex and phonoplex have already been employed for strictly multiple transmissions.

Multiple telegraphic systems may be divided into two distinct classes; namely,

(1) Those which simultaneously employ different types of electric current upon the line, each receiver being capable of responding to its own type of electric current only.

(2) Those which synchronously apportion different circuits at the receiving and sending ends of the line to each other, so that at successive moments different re-

ceiving and sending instruments are connected together.

The first system is essentially a simultaneous multiple current system, since various types of electric current are sent on the line coincidently. The second system is essentially a single-current system synchronously controlled, the line at any moment of time being only apportioned to one set of apparatus and being successively apporportioned to each of the sets of apparatus in rapid rotation.

In the first class, there are three subtypes, two of which are in actual use in the United States, and the third of which has only had an experimental trial. This latter is called the *harmonic telegraph*. In it a number of *tuning-fork transmitters* are employed, each of which vibrates at a different definite rate. The transmitters are connected in series in such a manner that each vibration opens and closes an electric circuit. Consequently, when all the sending keys are depressed coincidently, the complete series of vibrations of electric current will be forwarded to the line, each set of electric vibrations corresponding to its own transmitter, in the number of vibrations per second. At the receiving end of the line are inserted in the circuit a corresponding number of receiving instruments with vibratory armatures, each tuned to respond to one rate only of the vibrations transmitted along the line. These receivers are, therefore, actuated independently by each rate of electric current vibration. When all the rates of vibration are simultaneously present in the electric current, all the receivers are operated. On the other hand, if only a single rate of vibration exists in the electric current received from the line, only that particular instrument will respond whose rate of vibration corresponds to this rate. In other words, each instrument will selectively respond to its own rate of vibration independently of all the rest.

The second subtype is the diplex system already described in the last chapter but is operated only in connection with the quadruplex system; that is to say, the diplex system is not employed without being duplexed.

The third subdivision of multiple systems, the *Edison phonoplex telegraph*, is to-day in use on railroad lines. The object of this system is to supply a means for conveying through messages over an ordinary Morse circuit intended for way traffic.

For example, a railroad Morse circuit may have forty or fifty relays inserted along the line at different stations; for, much of the Morse traffic on the line will necessarily consist of train orders and messages from one office to another; *i. e., way traffic.* It is frequently important, however, to secure means for transmitting a large amount of traffic directly between the terminal stations; *i. e., through traffic,* and this would necessitate the use of a duplicate wire. The phonoplex is intended to enable the terminal offices to be put in communication with each other without disturbing the ordinary way traffic, so that two sets of messages may be carried on independently over the wire. The type of electric current employed by the Morse system will be sufficiently well understood from the earlier chapters of this book.

The type of current employed for the operation of the phonoplex system is essentially distinct and consists of very brief powerful currents. The receiving instrument is a special form of telephone which responds to these brief impulses of

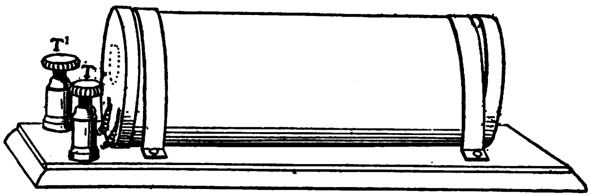


FIG. 117.—PHONOPLEX TRANSMITTER.

current but does not respond to the slower, steadier currents which operate the Morse relay. On the other hand, the Morse relay is too sluggish to respond to the brief telephonic currents. The transmitter of the phonoplex is a small induction coil which is operated by a local battery under the control of a Morse key.

At each motion of the key, the local circuit of the coil is broken, thus allowing a brief but powerful E. M. F. to be inserted in the line circuit. This causes a corresponding brief but powerful current impulse to travel along the line and operate such telephone receivers as may be connected in the circuit.

Fig. 117, shows the form of induction coil ordinarily employed. It consists of an iron core formed of a bundle of fine iron wires, wound with a helix of insulated copper wire, whose ends are brought to the two terminals *T*, *T'*. Fig. 118, shows the *phonoplex receiver*. It consists of a special form of upright telephone mounted on a wooden base. The sheet iron diaphragm of this phone is surmounted by a small weight, free to move, within limits, in a vertical direction, and retained within these limits by the small clamp screw *C*. Over the face of the instrument is a sheet brass cover to protect it from mechanical

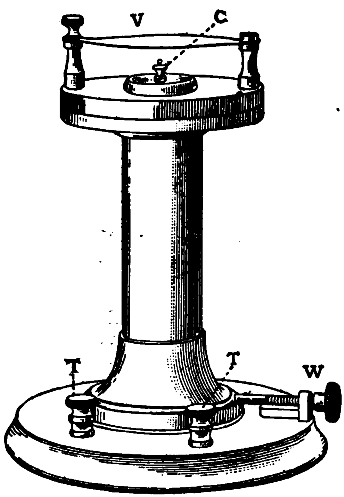


Fig. 118.—Phonoplex Receiver.

injury. *T*, *T'*, are the terminals of the telephone coils. *W*, is an adjusting screw for varying the distance between the coils and the telephone diaphragm. When a momentary current impulse passes through the coils, the telephone diaphragm is suddenly attracted. This gives a jerk to the weight supported at the centre of the diaphragm which is caused to emit a sharp click. Two such impulses in rapid succession produce upon the ear the effect of a dot, but if separated by an appropriate interval, the acoustic effect is equivalent to a dash. A special transmitter is employed, called a *phonoplex transmitter*, operated by a local circuit from the hand key.

In order that the line should not be interrupted by the phonoplex currents, by the opening of the Morse key, in signalling, a condenser is connected across the terminals of the Morse apparatus. This interposes a complete barrier to the ordinary Morse currents, but enables the phonoplex impulses to be readily conducted through the condenser.

Corresponding to the second class of multiple telegraphs the best representative is found in *Delany's synchronous multiplex telegraph.* In this system, which is used in Europe, a table of circular contacts is provided at each end of the line, with a rotating traveller or trailer. These travelling arms are maintained in strictly synchronous revolution. By means of electric correcting impulses, sent automatically over the line, any tendency of the trailers to fall out of synchronism is corrected. By this means the line is synchronously connected to successive contacts on the table leading to successive sets of Morse apparatus.

The rate of rotation of the trailers over the tables is such that each Morse apparatus is connected to the line several times during the completion of a single dot. Consequently, when any operator depresses his key he sends a current to line only for brief intervals during that time, but at these intervals the current sent is distributed automatically to the corresponding receiving instrument at the distant end, while, in the intervening intervals the other sets of apparatus are receiving their moments of interconnection. As many as 12 independent Morse transmissions can be operated simultaneously over a line in this manner, although with considerable lengths of line a smaller number may be rendered desirable.

Instead of receiving Morse signals by sound, or on a strip of paper, various *type printing telegraphs* have been devised to print the message directly, and so avoid the necessity of transcribing the message into ordinary writing. Such apparatus, moreover, has the advantage that printed messages are more legible than messages transcribed by hand. At the present time, however, printing telegraphs are very little used on ordinary telegraphic circuits in the United States, but the custom is gaining ground of typewriting by hand the messages received from the sounder, or from the Wheatstone paper slip.

In large cities, where quotations are required in brokers' offices from stock exchanges the messages are always printed automatically upon a band of paper. Such instruments are called *stock printers*. A number of these instruments have been devised, one of which is represented in Fig. 119. Here the band of paper *D D*, driven by an electromagnet in the base, is pressed forward by the action of a pulley as the message is printed.

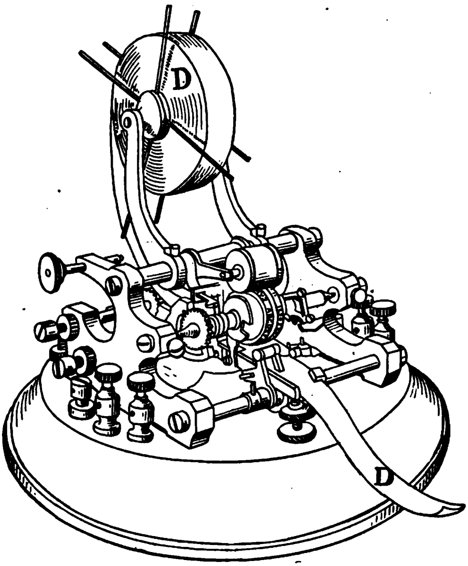


FIG. 119.—EDISON OR UNIVERSAL TICKER.

The operation of the printing telegraph is based essentially upon a principle extensively used in telegraphy called the *step-by-step principle.* An electromagnet causes a ratchet wheel to oscillate under an escapement until some particular tooth is reached. In printers of this type a *type-wheel* is revolved by a succession of electromagnetic impulses producing a step-by-step movement, until the particular letter or figure desired comes over the band of paper, when another electromagnet, called the *printing magnet*, is energized and effects the printing of the letter on the paper band. Two type-wheels are carried on the printing shaft, one for letters, and the other for figures, the transition from one wheel to the other being effected by suitable means. There are two pairs of binding posts, one on each side of the instrument, each pair being provided for connection to an independent line. In other words, two lines are employed to operate the instrument, the instruments being connected in series. Each pair of binding posts belongs to one line throughout the entire series. The apparatus can work at as high a speed as 40 words per minute.

An apparatus, which has attracted considerable attention without having yet come into commercial use, is the *writing telegraph.* In this system the movements of a pen at the transmitting end of the line, are reproduced at the receiving end, so that a message is reproduced autographically. The principle involved is a simple one, although a considerable amount of effort had to be expended in order to perfect its mechanical details. Two circuits are employed between the transmitter and receiver, one circuit being concerned with the transmission of sidewise motion on the pens, and the other circuit with the transmission of up and down motion in the pens. When a pen moves sidewise at the transmitting end, the movement is transmitted to a lever which cuts in or out a number of resistance coils, thereby either decreasing or increasing the current strength on that line. An electromagnet, at the receiving end of the line, causes the recording pen to be drawn sideways. Similarly, the up or down motion of the transmitting pen acts upon a lever in such a manner as to cut in or out resistance coils in the second line, and so vary the current in that line. This variation of the currents acts upon an electromagnet in the second line, which produces a corresponding up and down motion in the recording pen.

A form of transmitting instrument is represented in Fig. 120. Here a pen held in the hand guides the play of a vertical lever *C*, within the limits of the rec-

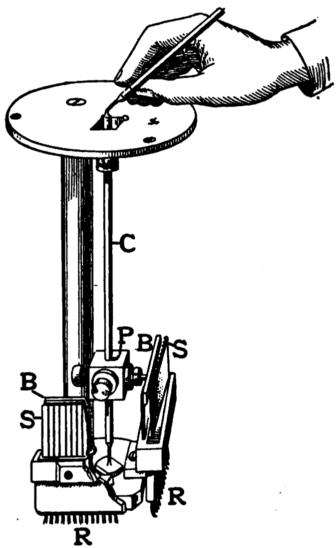


FIG. 120.—TRANSMITTER OF WRITING TELEGRAPH.

tangular aperture in the face of the instrument. Near the lower end of this lever are two sets of resistance coils R, R, which are so connected in the circuit that the movement of the upright lever cuts out or

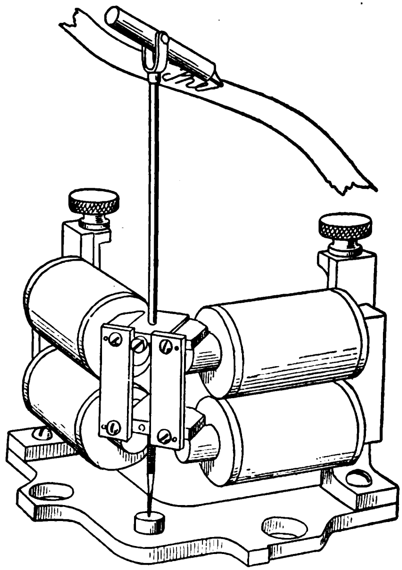


FIG. 121.—RECEIVER OF WRITING TELEGRAPH.

restores the resistance coils into their respective circuits. The receiving instrument is represented in Fig. 121. The two electromagnets are situated at right angles to each other; each is connected to one line, the movement of the armature being directly communicated to the pen over the strip of moving paper. This receiver does not lift the pen from the paper but makes a continuous mark. Writing telegraphs have, however, been employed in which the pen will dot its i's and cross its t's, and in which the line is interrupted, between words and sentences, just as the line of the writing pen is interrupted.

Instruments designed to reproduce pictures or cuts over a telegraph line are called *facsimile telegraphs.* These telegraphs are operated on two distinct principles, *viz.:* the *electrochemical,* and the *electromagnetic.* In the electromagnetic method two pens are kept in synchronous movement at the ends of the line. The *transmitting pen* moves over the drawing either in straight lines, or in a spiral. The characters of the drawing to be transmitted are made in insulating ink upon a metallic conducting sheet or surface. When the transmitting pen encounters a line, the electric current passing through the circuit is interrupted and this causes the *receiving pen* to make a mark or dot upon the paper. By covering the surface of the sheet at the transmitting end by moving the pen, in successive sweeps, the lines are reproduced by the receiving pen in a succession of dots which connect into lines and so reproduce the characters.

In the electrochemical method the transmitting pen moves over the metallic sheet as before, but the currents which are sent to line effect an electrolytic decomposition in the receiving paper through the receiving pen which moves synchronously with the transmitting pen. Fig. 122, represents a picture as received and transmitted over

Fig. 122.—Facsimile Reproduction of Photograph.

the line. It is evident from an examination of the received picture on the left hand, that the receiving pen is moved up and down in parallel lines which are vertical through the picture. The markings which are made by the receiving pen in its successive trips

FIG. 123.—FACSIMILE REPRODUCTION OF PHOTOGRAPH.

are coincident with the passages of the transmitting pen over lines of lights and shades and connect finally into a completed picture. Fig. 123, shows another picture received in this way from the prepared surface of a photograph at the transmitting end of the line. This method has not as yet come into commercial use.

CHAPTER XV.

TIME AND TRAIN TELEGRAPHY.

ELECTRICITY is extensively employed to-day for the *telegraphic distribution of time*. Its services are directed to this end in several ways.

First, by the release of an *electric time ball* for announcing the correct time to an entire neighborhood. Time balls are dropped daily at Washington noon in Boston, New York, Philadelphia, Baltimore, Washington, Newport, Wood's Holl, New Orleans, Savannah and Fortress Monroe. By observing these balls the navigating officers on board vessels can ascertain the errors of their chronometers. A large, light and conspicuous ball is electro-magnetically released, by a time current from New York as the centre of distribution. This current, lasting for one second, is sent from the New York master clock, which in turn is electrically checked and controlled by a clock in the observatory at Washington. This noon current is also forwarded to a number of cities on other main wires.

In New York, Chicago, and other cities, there are also local distributions of time which are operated or controlled from a master clock at frequent intervals. Local distribution of time in cities is accomplished either by means of clocks which are driven and controlled electrically, or by clocks which are driven in the ordinary way, but which are electrically corrected at regular intervals, usually once an hour. In the case of electrically driven clocks, an electromagnet in a clock

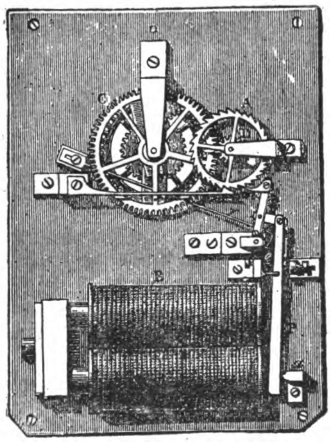


FIG. 124.—MECHANISM OF SECONDARY CLOCK.

receives an impulse each second from the master clock by a wire maintained for this purpose. Fig. 124, shows the mechanism of an electrically driven, or *secondary clock.* Here an electromagnet *B*, is inserted in the distribution line. The master clock sends a current through this line at each second. The electromagnet attracts its armature by a step-by-step movement, and communicates a movement to the dial so that the mechanism is advanced once each second.

Fig. 125, represents a form of mechanism in which an ordinary clock, driven by a spring, is corrected at each hour by a current from a master clock. The correcting mechanism is shown below the clock. The current from the line passes through the electromagnet which attracts its armature. The armature is armed at its extremity with a fork which engages with a pair of levers projecting through the clock face. These levers are drawn down by the attraction of the armature until they meet. They clutch the minute hand between them and automatically set the minute hand in a vertical position; *i. e.*, at XII, when the momentary current is

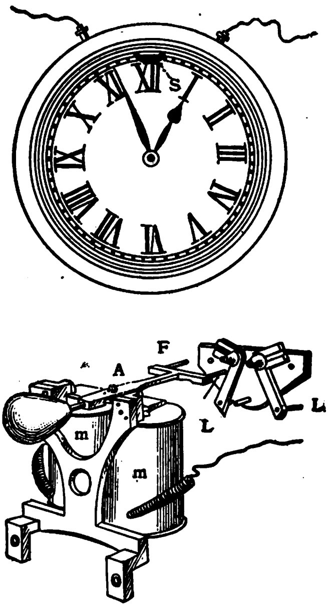


FIG. 125.—ELECTRICALLY CONTROLLED CLOCK.

received. When the current ceases, the electromagnet releases its armature and the levers release the minute hand, and retire to their position out of the way in the slot *S*. If the clock is either fast or slow no more than two minutes, the minute hand will be caught and brought to the vertical position. It is scarcely to be expected that any good clock could lose or gain more than two minutes in a single hour, so that this arrangement for correction is sufficient for all practical purposes.

Another system, called the *time telegraph service*, distributes electric currents at two-second intervals and with special signals at each minute, five-minutes, and hour interval. These signals are sent from a standard clock through relays. The signals are read from a sounder and are distributed to such persons, as jewellers and railroad timekeepers, who are in need of frequent information concerning the precise time.

In regard to telegraph messages and to the distribution of time generally, the United States is divided into zones by which local time is arbitrarily defined. These zones are each 15 degrees of longitude in breadth, the meridian representing the centre of one zone at longitude 75° west from Greenwich, serving as the standard of *Eastern time*. The Chicago meridian is taken as 90° W., and serves as the center of the zone of *Central time*. The third zone is centred on the meridian of 105° W. which serves as the centre of the zone of *Mountain time;* while the fourth zone is centred on meridian 120° W., which serves as the centre of the zone of *Pacific time*. Owing to the requirements of railroads, the exact boundaries of these zones are irregular; *i. e.*, do not conform to meridians of longitude.

A city, therefore, in accordance with the preceding system, has a *local time* depending upon its own longitude, and a *standard time*, for railroad and telegraphic purposes, depending upon the belt or zone to which it belongs. Since the earth rotates through 360° in 24 hours, 15° correspond to the rotation in one hour. Consequently, the time in each of these zones is one hour apart, and the standard time of any place is always either Eastern time, or it will be one, two or three hours less than; *i. e.*, earlier than Eastern time, and six, seven or eight hours earlier than Greenwich time. The difference between the local time, and standard time, therefore, can never be more than one hour at any one place.

A method of telegraphing to or from a moving train has been devised, which does not employ a continuous electric conductor between the receiving and transmitting instruments. In other words the message is sent to and received from the moving train without passing to it through any electrical conductor, the train being entirely disconnected from the telegraph wires which are carried alongside the track. This method is called *induction telegraphy*.

The means by which the system of induction telegraphy has been operated is shown diagrammatically in Fig. 126. *W W*, is a telegraph wire, extending alongside the railroad track, and supported on poles in the usual manner; *i. e.*, one of the ordinary railroad telegraph wires. *R*, *R*, is the metallic roof of a railroad coach which may either be at rest, or be running along the track at any speed. The roof is insulated from the ground by the wooden frame-work of the car. It is connected

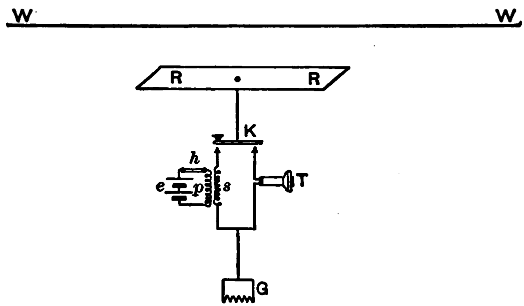


FIG. 126.—DIAGRAM OF TELEGRAPHY WITH MOVING TRAINS.

to a key *K*, the back stop of which is grounded through the truck and rails with a telephone *T*, in circuit. If the wire *W W*, be connected at the operating station with an induction coil provided with a rapid vibrator, it will be alternately charged to a high voltage, and discharged, at a correspondingly rapid rate. The electrostatic flux, which we have already described as emanating invisibly from a charged conductor, will issue from the wire to all neighboring objects such as trees, houses, car-roof and the ground generally.

The amount of electrostatic flux caught by the surface of a car will depend upon the proximity of the car to the wire, and the relative proximity of the ground or other prominent conducting objects. The telephone *T*, is so sensitive that the periodical establishment and withdrawal of this amount of electrostatic flux upon the surface of the car-roof produces a feeble electric current, of corresponding rate of vibration, which is detected by a buzzing sound in the telephone. If now, the sending station connects the induction coil with the wire *W W*, at intervals controlled by a telegraph key, buzzing dots and dashes will be detected by the listener at the telephone on board the moving car, and will enable him to read the message. If the train should get under a shelter, provided with a metallic roof, the signals will no longer be audible, since the car will not be shielded from the electrostatic influence; but, as soon as it leaves this metallic shelter, the signals will recommence.

In order to reply, the operator on board the car depresses his key and causes his own induction coil, which is operated by a local battery through a vibrator, to be connected with the car-roof in place of the telephone. This charges and discharges the car-roof to a high potential at a rapid rate, and the vibrations are caught electrically by the wire or wires in the vicinity of the car. The operator listening at his telephone in the station can hear faint buzzings in dots and dashes, in the same way that the operator on board the car can hear them when receiving from the station operator. It is curious to observe that if the wire be properly insulated it is possible to carry on ordinary Morse telegraphy over the wire at the same time without interfering with the train telegraph. The distance, however, to which the method is applicable is comparatively limited; that is to say, the sending station must be within, say fifty miles of the moving car. The system has been demonstrated as practicable, but is not in commercial use, since it requires the attention of two operators, one on board the moving car, and the other at the station, while under ordinary circumstances a telegram can always be dispatched by a passenger on a train at the next stopping place.

CHAPTER XVI.

ELECTRIC ANNUNCIATORS AND ALARMS.

Besides telegraphing messages by the use of the Morse or Continental code, in the ways we have already described, advantage is taken of the ease and rapidity with which an electromagnet acquires and loses its magnetism, to transmit telegraphically certain signals from stations connected by wires, to a central office where a class of apparatus called *annunciators* are located to receive the signals. The principle upon which such apparatus operate is the making or breaking of the line circuit at the station where the signal is sent, and the indication thereof by receiving apparatus at the central station. The receiving apparatus is generally of the electromagnetic type.

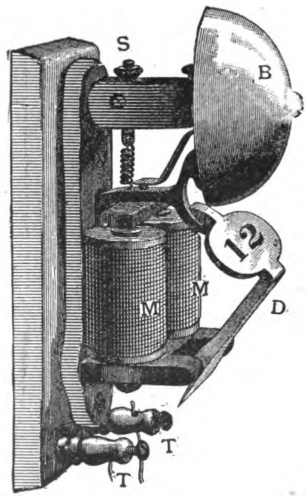


FIG. 127.—INDICATING BELL ANNUNCIATOR.

An example of this type of apparatus is seen in the annunciator shown in Fig. 127. Here an electromagnet *M M*, is connected with a circuit containing at some point a *push button*, or simple circuit-closing device. The circuit contains a voltaic battery of sufficient E. M. F. to produce

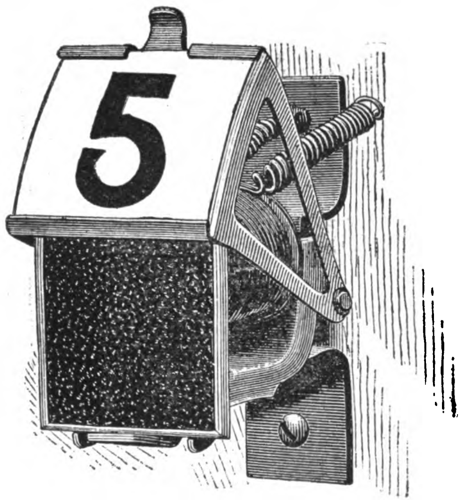


FIG. 128.—LOCK GRAVITY DROP.

an electric current, whose M. M. F. in the magnetic coils shall develop a magnetic flux through the armature, capable of attracting it against the tension of the spring *S*. When the circuit is closed at the push button, the magnet attracts the armature and causes the hammer at the

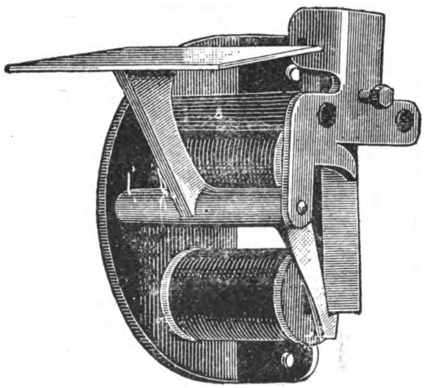


FIG. 129.—GRAVITY DROP.

end of the armature to strike the bell *B*. At the same time a hook, on the end of the armature, releases the drop shutter *D*, which falls to the horizontal position displaying the signal 12, thus indicating that this bell has been operated. The drop has to be restored by hand after attention has been called to it. Electromagnetic annunciators assume a variety of forms. The

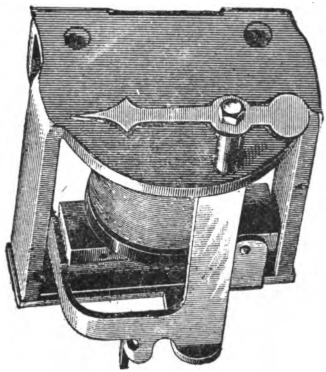


FIG. 130.—GRAVITY NEEDLE DROP.

most important of these are annunciators in houses, hotels, elevator cars and steamships.

The drops in annunciators are of various kinds, a few of which are illustrated in Figs. 128, 129, and 130. Figs. 128 and

129, show *drop shutters*, which fall in front of windows when released by their electro-

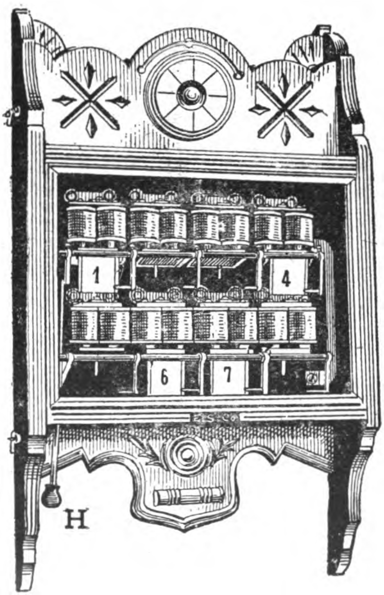


FIG. 131.—GRAVITY-DROP ANNUNCIATOR.

magnets. They have to be restored to their original position by some mechanical device controlled by hand. Fig. 130, shows a *gravity needle-drop.* Here a needle swings on a movable system which, when released electromagnetically, throws the needle to the deflected position by the action of gravity. The usual mechanism for restoring the drops is shown in Fig. 131. Here the handle *H*, when lifted, rotates two brass frames about their axis. These frames carry pins projecting under each drop shutter, and in the act of rising restore all shutters that may have fallen to a position in which they are caught by the cams under electromagnetic control. In some forms of instruments the restoring frames are lifted by pneumatic action.

Fig. 132, shows a form of house annunciator with one bell and six needle drops. Here the deflection of the needle indicating the parlor, shows that a call has come from that room. A diagram of connections for such a house annunciator is

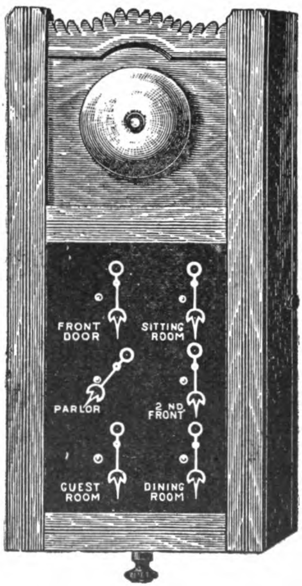


Fig. 132.—House Annunciator.

shown in Fig. 133. Here the battery *e*, supplies a current through the bell *B*, to any of the six circuits connected therewith that is closed by its push button through its respective indicator magnet. Fig. 134,

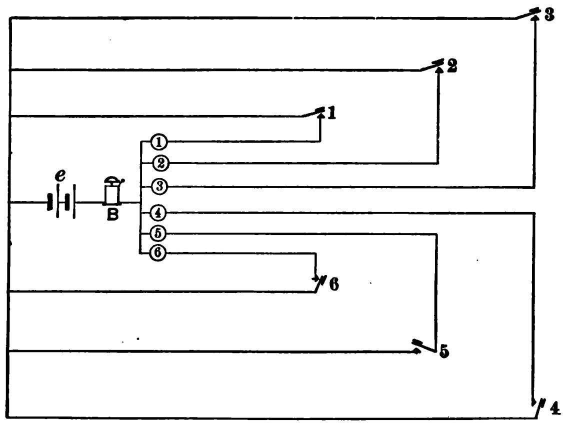


FIG. 133.—DIAGRAM OF CONNECTIONS WITH HOUSE.

represents a hotel annunciator employing needle drops arranged for 140 rooms. The connections for such an apparatus are similar to those shown in the preceding figure.

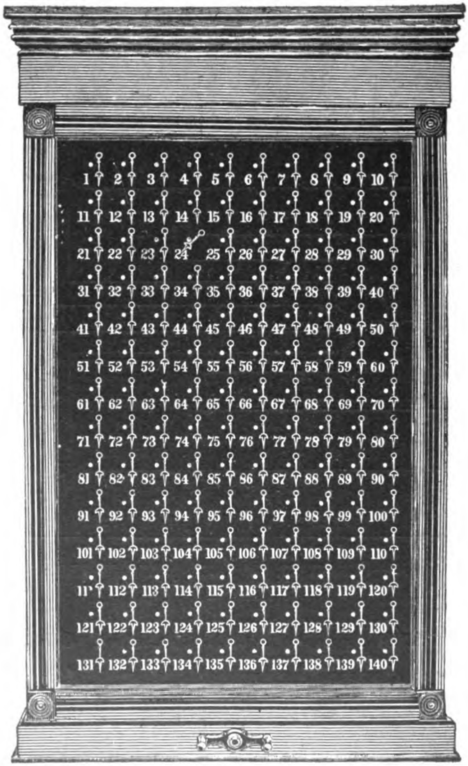


FIG. 134.—HOTEL ANNUNCIATOR.

The annunciator principle is also applied to *burglar alarms.* In a burglar-alarm system all the windows and doors of a house, through which enforced entrance may take place, are provided with contacts placed in the circuit of an annunciator situated so as to give immediate alarm. During the occupancy of the house these alarms are usually placed in a sleeping apartment, but when the house is left unoccupied, it is sometimes connected with an alarm in the nearest police station, or central call office.

There are in general two systems of operating burglar alarms, one being the *open-circuit burglar-alarm system,* in which the battery is normally out of use, but is brought into action through an electromagnetic bell by the closing of a contact in the door or window. The other system is the *closed-circuit burglar-alarm system*, in which the battery is

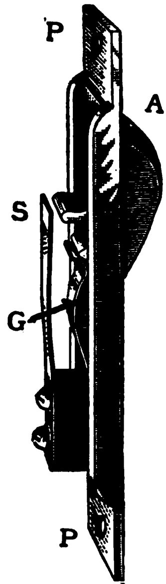


FIG. 135.—WINDOW SPRING OF BURGLAR-ALARM SYSTEM.

normally at work, causing the alarm bell to be sounded by a disconnection in the circuit or circuits at a door or window. A contact for an open-circuit system, suitable for attachment to a window, is shown in Fig. 135. The plate *P P*, is fastened into that portion of the window jamb, in which the window slides, in such a manner that the arm *A*, projects outward under the pressure of a spring *G*, at the back. When the window is raised in its frame the arm *A*, is forced back until it makes contact with the insulated contact spring *S*, thus closing the circuit and ringing the alarm bell, at the same time releasing a drop in the alarm which indicates the location of the window which has been raised.

Fig. 136, shows a similar contact apparatus intended for use in a door jamb. The brass plate *P P*, is screwed into the jamb of the door, flush with its surface.

The projecting plug *G*, is forced outward by the spring into the position shown, but, when the door is closed, it forces the plug

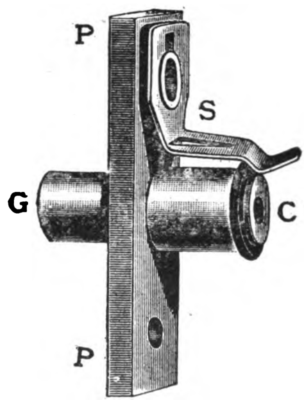


FIG. 136.—OPEN-CIRCUIT DOOR SPRING.

G, back into a position flush with the plate *P P*, and at the same time the contact piece *C*, is pushed back out of contact with the insulated spring *S*. When the door is open, the plug *G*, moves outward and effects a contact between *S* and *C*.

A form of burglar alarm suitable for a dwelling is shown in Fig. 137. It contains a clock provided for the purpose of cutting out the instrument during certain hours of the day, so that the ordinary use of the windows and doors shall not give a useless alarm. The small switches underneath the drops are provided for cutting out at will individual circuits connected to the respective contacts; that is, certain parts of the house. When the switches are connected with the upper bar the circuits will ring the bell at any time without the intervention of the clock, but when connected with the lower bar, the clock controls the circuits, so that they will ring the bell during certain hours only. In an intermediate position the switches cut out the circuits entirely. The switches are for turning off the battery or bell, and for making tests at any time concerning the

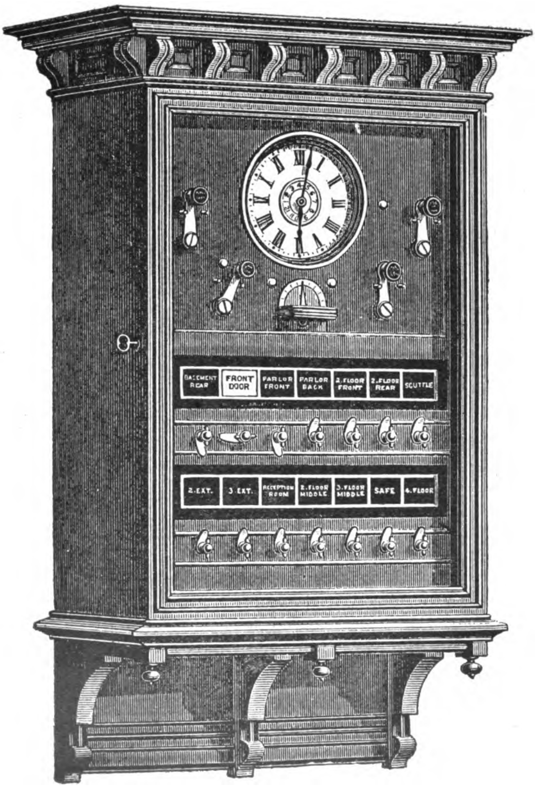
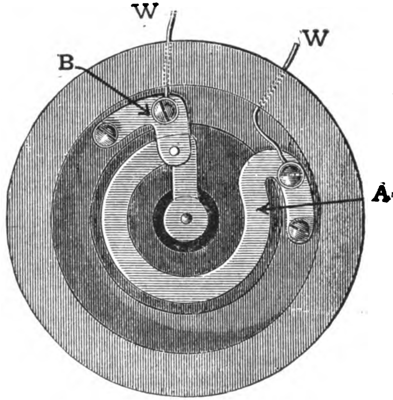


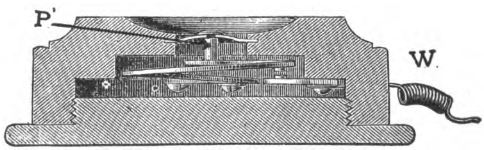
FIG. 137.—BURGLAR ALARM.

condition of the apparatus. The annunciators are so arranged that in falling, they start the bell ringing and the bell continues to ring until cut off at the annunciator by hand. In the centre of the instrument is an indicator which constantly indicates whether the battery connected with the apparatus is in good order.

Electric annunciator alarms are also used for purposes of protection from fire. *Electric fire-alarms* are either *automatic* or *hand operated.* Those employed in houses are generally automatic in character. They consist essentially of means whereby an undue increase of temperature, at any part of the house, closes or opens a circuit and thereby sounds the alarm. This may be effected either by the use of *thermostats*, or by the melting of a low-temperature alloy. An instrument of the latter class is shown in plan and in sec-



BACK VIEW OF CAP.



SECTIONAL VIEW.

FIG. 138.—FIRE ALARM CONTACT.

tion in Fig. 138. The cover has been removed in the plan view to show the interior of the instrument. Two metallic springs *A* and *B*, are insulated from each other on the wooden base, and connected by wires *W*, *W*, to the alarm circuit. They are kept out of contact against their elasticity by a plug *P*, of fusible alloy. When the temperature rises to a predetermined abnormal amount, this plug melts and a contact is effected.

In hotels, for the purpose of saving time by having the guest specify on an annunciator the service desired, special forms of *step-by-step annunciators* have been devised, whereby a needle moves over a dial on which are marked the particular services the office is ready to render. The stoppage of the needle opposite one of these, indicates the service the guest desires. A form of apparatus of this kind, shown in Fig. 139, is called a *tele-*

seme. This instrument is placed in each guest's room in the hotel. To make a call the hand of the pointer is moved until it

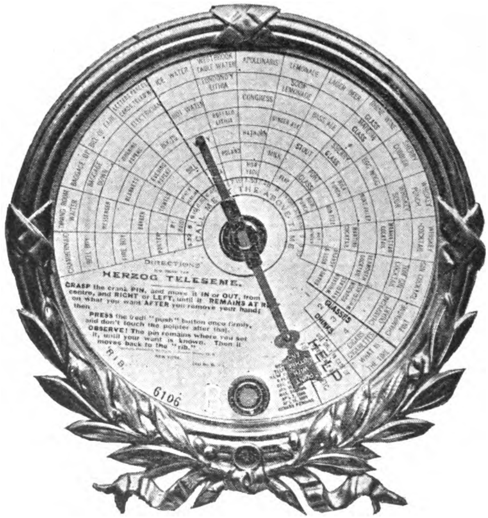


FIG. 139.—TELESEME.

rests over the particular want, of the 137 different wants which the pointer can indicate. The button *B*, is then pushed.

This closes a circuit from the room through an *electrolytic annunciator*, shown in Fig. 140, which indicates the number of the room in which the call is made. The receiving teleseme at the office is then connected with the teleseme in this room, through a second circuit and the pointer in the room released. This commences to travel around the dial in a direction opposite to that of the hands of a watch, until caught by the zigzag bronze strap. This causes the instrument at the receiving teleseme to indicate the desired service.

The electrolytic annunciator shown in Fig. 140, consists of an electrolytic cell provided with a glass front. In principle the apparatus closely resembles Sömmering's old telegraphic receiving instrument illustrated in Fig 26. At the back of the cell, and facing the observer, is a non-con-

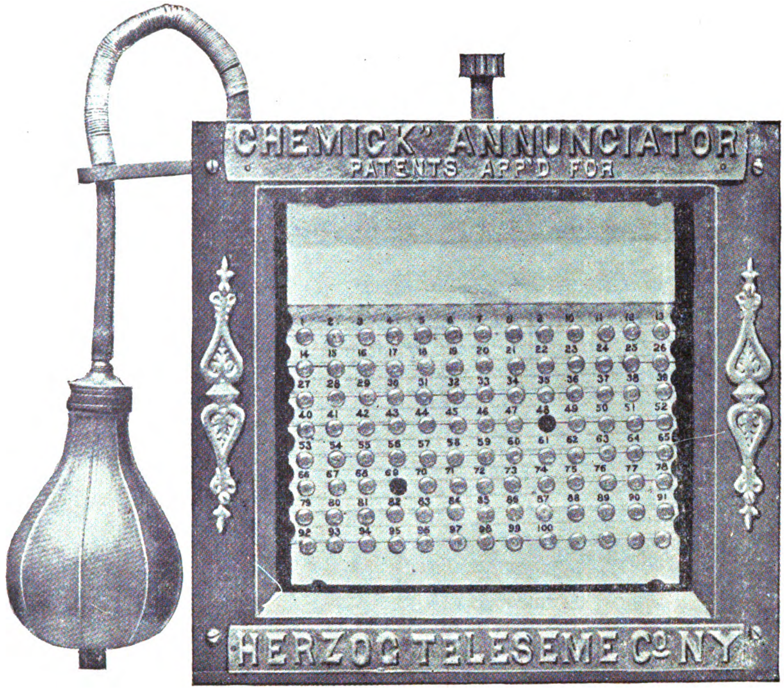


FIG. 140.—ELECTROLYTIC ANNUNCIATOR.

ducting slab containing a number of rows of metallic buttons. In the instrument shown there are 104 such buttons, each connected by a separate wire with the push button of a teleseme in the various rooms. When the push-button is depressed, the circuit of a battery is closed through the corresponding button in the electrolytic cell. The passage of the current through the liquid in the cell produces a chemical decomposition which instantly deposits a reddish brown film over the surface of the button, as indicated in the figure at Nos. 48 and 69. This serves as a visual signal to the operator, who then establishes connection between the receiving teleseme and the teleseme in the calling room by a plug switch. He then compresses the bag beside the instrument thereby forcing a stream of air through the liquid dissolving the film of deposit on the calling buttons and clearing out the indicator for further use. This instrument enables a large number of guests to be accommodated with calls within a very limited space. In other words the electrolytic annunciator has, in principle, advantages over the electromagnetic annunciator, both in compactness and in simplicity of operation.

The annunciator principle has been extended from the limits of one building to a number of buildings through the entire limits of a city. By this means different houses may be connected with one of a number of central stations, whereby a limited number of services can be rendered to each house on call. For example, a messenger, policeman, cab or a fireman may be called. Such boxes are called *district call boxes*. To operate them a lever is turned to a stop, placed over a mark indicating the particular service desired, and then released. During its return to the starting point, it effects a number of contacts within the box separated by appropriate spaces, so that there are sent over the line signals corresponding to certain movements of the Morse key. A form of call box is shown in Fig. 141. Here, in order to call, the handle is turned to the right as far as the signal indicated and then released. The connections of such a box with a central station are indicated in Fig. 142. The electromotive force *E*, supplied by a battery, maintains a constant current through the relay *r*, at the central station, the lines *l l* and *l′ l′*, and the spring contact resting upon the periphery of the contact plate *B*. When the handle *A*, is turned, it causes the wheel *B*, to make two complete revolutions during release. The first revolution makes and breaks the circuit in

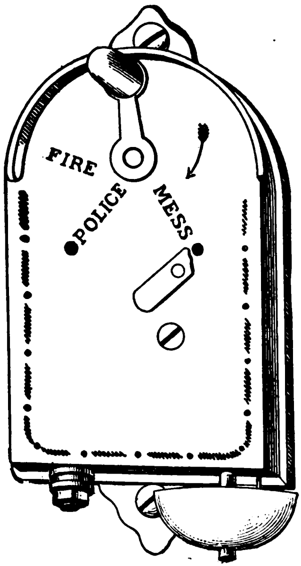


FIG. 141.—MESSENGER CALL BOX.

accordance with the serrations in the periphery of the wheel. The breaks, as they occur, cause the relay *r*, to release its armature, which closes a local circuit from the battery *e*, through the back contact,

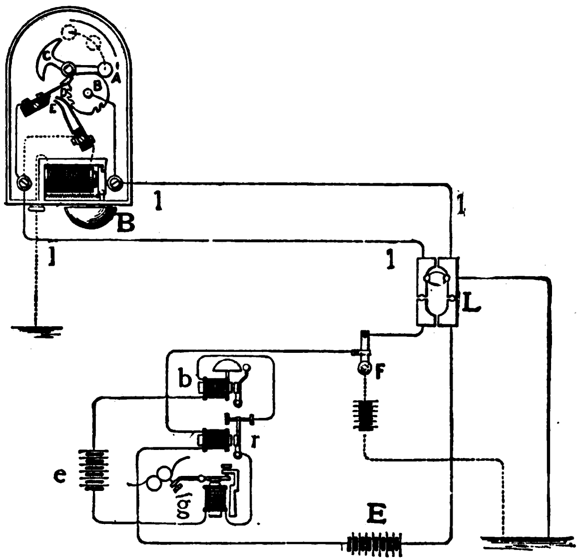


FIG. 142.—CONNECTIONS OF MESSENGER CALL BOX.

thus operating the register *g*, and bell *b*. During the second revolution of the contact wheel, the cam *C*, is caused to press the two springs *D* and *E*. This grounds the line *l'*, through the bell *B*, thus allowing a current to flow from the main battery through this bell, notifying the subscriber that his call has been received. On the second revolution, the springs *D* and *E*, are released and contact through the contact plate is restored to the main line. *L*, is a lightning arrester. A number of district call boxes are connected at the central station in series in one circuit.

In municipal systems of *fire-alarm telegraphy*, call boxes are mounted in suitable localities along the streets. These boxes are of two kinds, the *keyed* and *keyless*. The keyed boxes require to be opened by a key in the possession of a constable, or other responsible person. The keyless box may be operated by any passer-by. They are sometimes covered with glass windows which have to be broken in order to operate the mechanism. In other cases they are capable of being operated directly by turning a large handle. Keyless boxes are generally provided with a large gong so that any person opening them arouses the neighborhood by the fact. The turning of a crank, or pulling of a knob or chain, sets in action a step-by-step movement, whereby the circuit is made and broken in periods corresponding to dots and dashes. These, registered at the central station, serve to indicate the number of the box which has sent the call. A number of these boxes are connected in series in a single circuit. The signal or set of signals is generally repeated several times to make sure of successful transmission.

In the city of Philadelphia, for example,

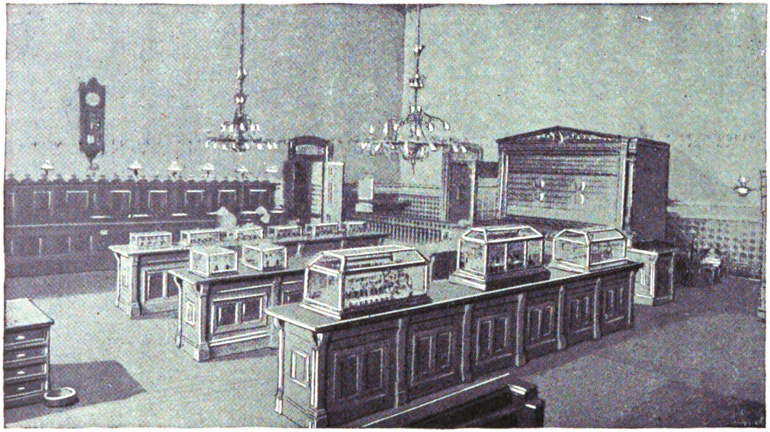


FIG. 143.—MAIN OPERATING ROOM, CITY HALL, PHILADELPHIA.

there are about 750 fire alarm boxes installed, most of them being of the key type. They are operated on the closed-circuit system, taking a current of about 1/20th of an ampere. On reception at the central office, the calls are distributed to the various fire stations, where the alarms turn out the fire engines as they may be needed. A single call at a fire alarm box may throw into action about 1,000 men in the Fire Department. The central operating room, at which the calls arrive in the City Hall, is shown in Fig. 143. Here a switchboard is shown at the back of the room, and the main receiving instruments for repeating the calls.

The electric currents for operating the system are supplied by storage batteries charged at suitable intervals by dynamos.

In many telegraph stations the operating currents are supplied from electric light mains through the intervention of either motor-dynamos or dynamotors. A motor-dynamo, as its name implies, is a dynamo mounted on the same shaft as a motor.

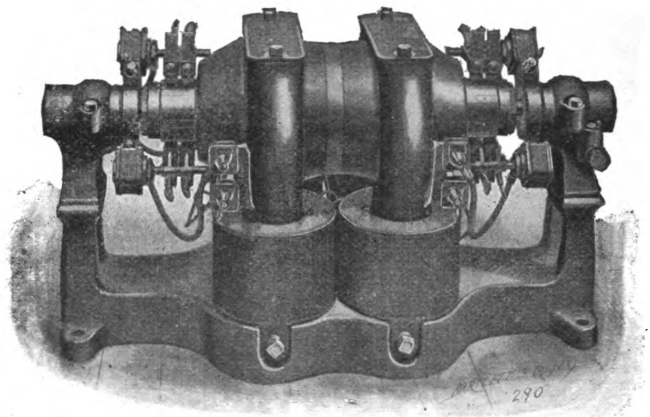


Fig. 144.

Such a machine is illustrated in Fig. 144. One half of this machine is a motor driven from electric lighting mains. The other half is a dynamo, the two armature windings being insulated from each other but mounted upon a common shaft.

In a dynamotor the two windings are insulated from each other as before, but are wound on one armature core, so that both rotate in one and the same magnetic field. The most important difference between a motor-dynamo and a dynamotor is that in the former the voltage of the dynamo can be varied by varying the excitation of the dynamo field magnet. In the latter there is no separate dynamo field magnet, and the voltage delivered at the secondary or dynamo terminals is therefore incapable of independent regulation.

CHAPTER XVII.

SUBMARINE TELEGRAPHY.

WONDERFUL as the transmission of a message across a continent by an aërial conductor admittedly is, the transmission of telegraphic messages across oceans by submarine conductors is still more wonderful. The depths to which submarine cables are laid, the difficulty which necessarily attends their repair, and the delicacy of the apparatus employed to work them, are constant sources of wonder to those who are first brought into contact with this branch of telegraphy.

The first submarine cable of any considerable length, was an experimental line laid across the straits of Dover between Calais and Cape Grinez in 1847. Owing to the fact that this cable consisted simply of a copper conductor surrounded by an insulating layer of gutta percha, it lasted only a few hours. So frail a thread could ill stand the wash of the tides and waves on the shores. It demonstrated, however, the complete possibility of submarine telegraphy, at least over comparatively short distances of oceanic waters. After 1847, submarine cables were rapidly extended. In 1858, the first Atlantic cable was laid, between Ireland and Newfoundland. This cable only lasted a few weeks. Its great length, for that date, with many small defects in its manufacture and operation, resulted in its failure by excessive leakage. In 1865, another cable was laid across the Atlantic, but broke in deep water before being completed. In 1866, a third cable was successfully laid, and the 1865 cable was recovered and repaired in deep water.

At the present time there are no less than 19 cables crossing the North and South Atlantic Oceans, with a total of about 200,000 nautical miles of submarine cable in working order over the world. Within recent years the circle of the globe has been completed by two cables across the Pacific Ocean, one from the United States to Hongkong, *via* Manila, Guam, Midway and Hawaii, the other from Canada to Australia, *via* Norfolk Island, Fiji and Fanning Islands. The cable system of the world is represented in Fig. 145. The cables girdle Africa, and extend in unbroken sequence from the United States to New Zealand and Japan.


R U S S I A
SEA OF OKHOTSK
BEHRING SEA
IRKOTSK
KIAKHTA
WERKHNE OUDINSK
NIKOLAIEVSK
KHABAROVKA
SAISAN
TOOLOOFAN
VLADIWOSTOCK
PEKIN
TIENTSIN
CHINING
SEOUL
JAPAN SEA
TOKIO
SIANGYANG
NANKING
NAGASAKI
HANKOW
SHANGHAI
SADYA
YUNNAN
AMOY
FOOCHOW
BONIN Is.
BHAMO
MANDALAY
CANTON
FORMOSA I.
MIDWAY I.
HAIPHONG
HONGKONG
PESCADORES
TO S. FRANCISCO
BANGKOK
MANILA
SAIGON
GUAM I.
YAP I.
PACIFIC OCEAN
CHINA SEA
PENANG
ACHEEN
MEDAN
SANDAKAN
MENADO
PADANG
SINGAPORE
BORNEO
PALEMBANG
BATAVIA
MACASSAR
N. GUINEA
ASTROLABE B.
PORT DARWIN
COCOS or KEELING I
FIJI Is.
ROEBUCK BAY
KIMBERLEY
CARDWELL
BUNDABERG
ROEBURNE
ROCKHAMPTON
TO VANCOUVER
AUSTRALIA
CATIONS
CHARLVILLE
BRISBANE
NORFOLK I.
GERALTON
COOLGARDIE
PERTH
ADELAIDE
SYDNEY
ALBANY
Pt. LINCOLN
D.
MELBOURNE
ZEALAND

Submarine cables consist of a conductor of stranded copper wires, an insulator, almost invariably consisting of layers of either pure gutta percha or gutta-percha mixture, a bedding of jute or hemp, and an external sheathing of iron wires covered by tape and compound. The conductor and insulator make up the cable; the hemp, bedding, and external protecting wires, the sheathing. The core varies in size according to the length of the cable and the speed at which it is to be worked. A small, long core has a slow speed of transmission. A large copper conductor, of short length, has a high rate of speed. The sheathing varies with the depth and nature of the sea bottom on which the cable has to rest. *Deep-sea cables* or sections, are lightly sheathed with slender steel wires. *Shore-end cables* or sections, which rest upon rocky bottoms, and have to resist abrasion due to storms and heavy tides, are heavily *armored.* Consequently, a *deep-sea cable*, is a small, light cable weighing about 1 1/2 tons to the mile. A shallow-water cable, or shore end, is a heavy cable weighing, perhaps, 15 tons to the mile.

Cross sections of the most recent trans-atlantic cable are shown in Fig. 146. On the right hand is shown the heavy shore end on the Irish coast; next, the shore end on the Newfoundland coast; then two intermediate sections, and finally, the deep-sea section which is the smallest of all. The core is the same throughout, consisting of a central copper wire surrounded by 12 smaller ones, the object of the strand being to avoid the probability of an accidental fracture interrupting the continuity of the conductor. The copper strand weighs 650 pounds per nautical mile, and has a resistance of nearly 1 3/4 ohms per nautical mile. The conductor is insulated by a gutta-percha envelope weighing 400 pounds per knot, or nautical

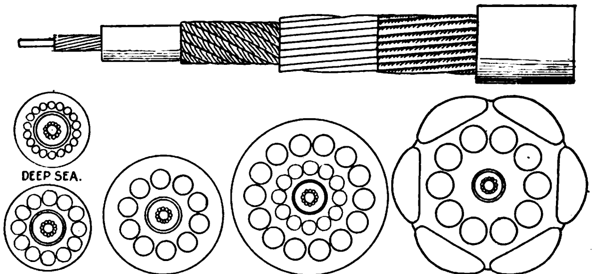


FIG. 146.—SECTIONS AND PLAN OF LATEST ATLANTIC CABLE.

mile. The length of this cable is nearly 1,850 knots, or about 2,130 statute miles. It works at a speed of about 40 words, or 200 letters, per minute. The deep-sea section weighs only 1 ton per knot in water, and its breaking stress is over 6 tons, so that the cable should support more than 6 miles of its own weight in water. This cable has a considerably heavier core and a greater working speed than any other Atlantic cable.

Some cables have been laid with cores insulated with india rubber, but the great majority have cores insulated with gutta percha. There seems to be no substance which stands pressure and submersion as completely as does this gum. Its duration under water appears to be indefinite; cables laid more than 30 years ago, still retaining the full insulating property of their gutta-percha coverings.

In manufacturing a submarine cable, the copper strand is first prepared and then passed through tanks of melted gutta percha, in such a manner that successive coatings of melted gum uniformly surround the strand, the cohesion of the different layers of gum being assisted by the interposition of an adhesive compound called *Chatterton's compound.* The core is then coiled away, in half-mile lengths, and tested under water for electrical leakage and for the resistance of conductor. The core is then jointed, or put into a continuous length, and coated with its sheathing or armor in a machine called a *closing-machine.* After completion, the cable is coiled away on board ships in large *cable tanks* provided for the purpose.

The ship which lays a submarine cable has to be specially fitted for the purpose, and, when the cable has considerable length, has also to be specially built. Such a vessel has to contain strong tanks firmly attached to her frame. These tanks are generally kept full of water after the cable

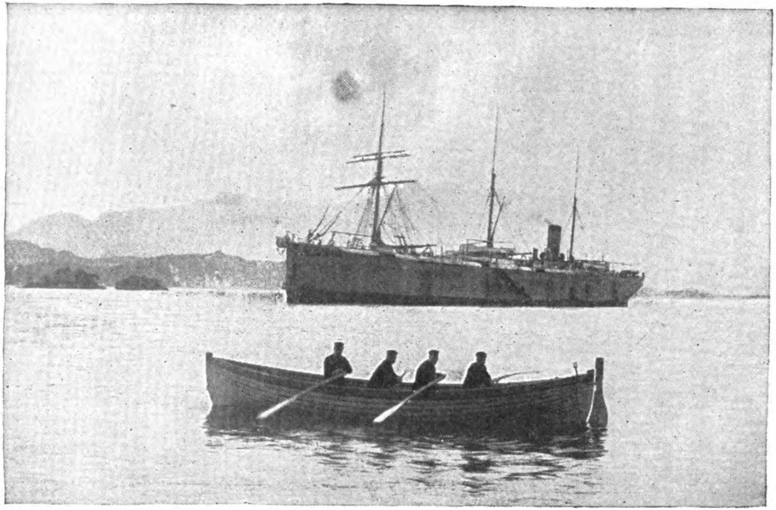


FIG. 147.—CABLE SHIP AT ANCHOR.

has been coiled in them. The largest telegraph ships can hold an entire Atlantic cable stowed away in their tanks. The ship has also to be provided with powerful machinery for paying out the cable on its ocean bed, or for picking it up when so required. Moreover, lead wheels, or guide sheaves, must be constructed between the tanks and the gear, to facilitate the passage of the cable along the decks. Finally, large sheaves have to be placed at the bow and stern of the vessel to enable the cable to be paid out, or picked up, without injury. A telegraph ship can always be recognized, even at a considerable distance, by these large bow and stern sheaves. Fig. 147, represents a cable ship in outline. A pair of bow sheaves on a bow platform, are illustrated in greater detail in Fig. 148.

A particular form of steam gear for

picking up and paying out the cable is shown in Fig. 149. Here a large steel

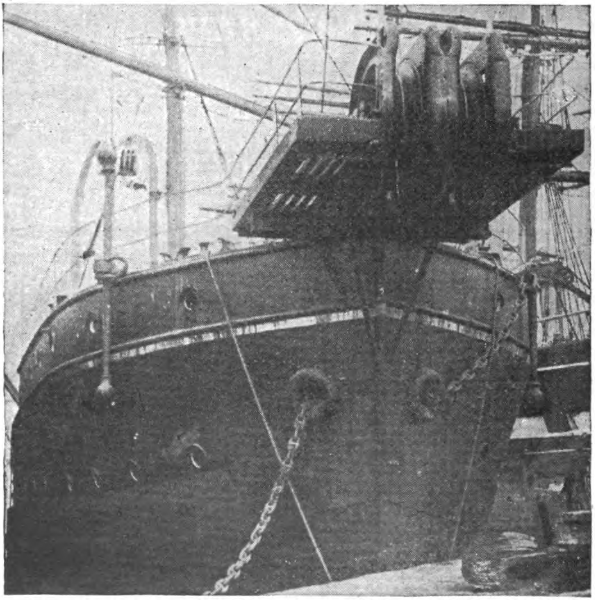


FIG. 148.—BOW SHEAVES OF CABLE SHIP.

drum *D*, is capable of being driven slowly by the steam engine, or of being freed from the engine and allowed to revolve by the tension of the cable wound over it, under the control of brakes. *j*, is a

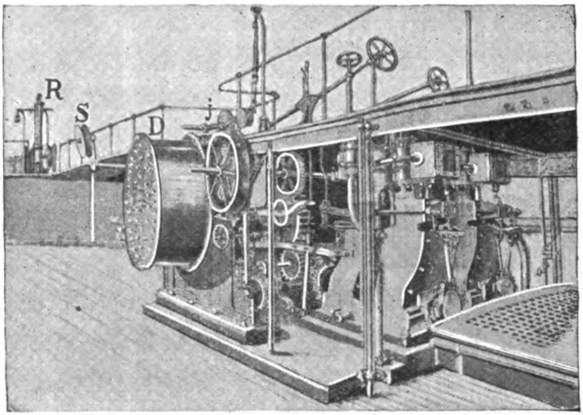


FIG. 149.—CABLE SHIP GEAR.

smaller wheel called a *jockey wheel*, from which the cable is led to the drum, around which it makes three turns. The cable passes over the guide sheave *S*, and thence under the sheave of the *dynamometer R*, which indicates the tension on the cable. After passing the dynamometer the cable is led straight over the bow sheave.

When a cable has to be laid, the shore end is first landed and its extremity secured in a *cable hut*, or small house constructed on the beach above high-water mark. There are several ways of laying a shore end. It may be coiled away in a barge, which is afterward taken in tow by a tug, so that the end can be landed on the beach, secured to the cable house, and the cable paid out by the hauling of the tug. This method is illustrated in Fig. 150, where the barge at the end of the pier is fitted with a paying-out sheave at the stern, from which the cable is seen to pass into the water. The tug ahead of the barge is ready to take it in tow, and cause

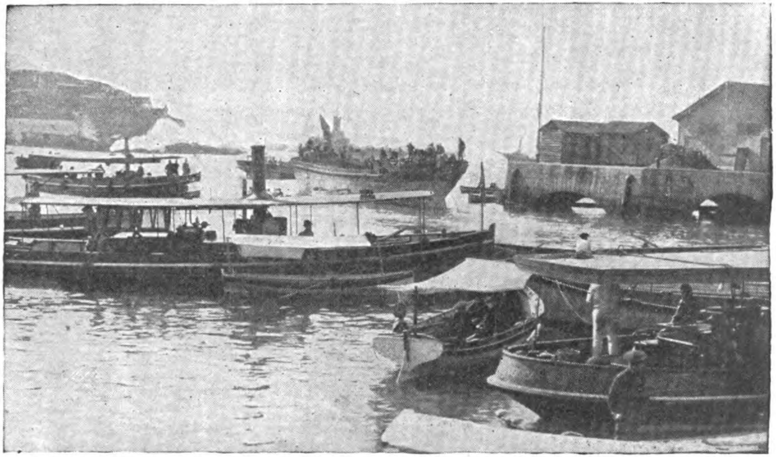


FIG. 150.—LAYING SHORE END OF CABLE.

the cable to uncoil itself from the hold of the barge and pass out over the stern.

Another method of laying the shore end of a cable is to anchor the ship securely, as near the shore as safety will permit, to then send a boat ashore with a rope, to pass the rope through a block anchored on the beach, return the end of the rope to the ship and haul upon the rope by a steam winch. When all is ready to haul, the end of the cable is lashed to the outgoing rope and the cable is floated away from the ship on a succession of buoys. This method is illustrated in Fig. 151. Here the rope is seen, which leads back to the ship, and upon which the ship is supposed to be hauling. The line of buoys indicates the line taken by the cable in its passage ashore. In the figure, the end of the cable, if not actually ashore, has nearly

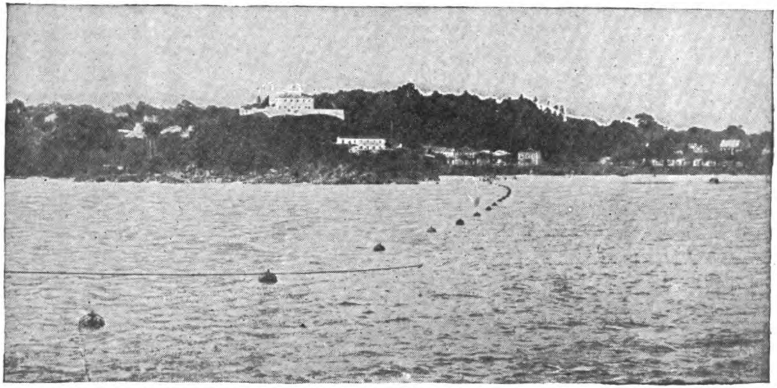


FIG. 151.—LAYING SHORE END OF CABLE.

reached the beach. When the cable is safely landed, the buoys are released from the cable, which then sinks to the bottom. The buoys are picked up and the rope hauled in, leaving the end in the cable house. Care has to be taken, when the cable is not very heavy, to anchor the end securely in the house, because the pull which is needed to haul the cable out of the tank, when the ship gets under way, is considerable, and has sometimes pulled the cable end out of the house and into the water, to the great surprise of the operator in the cable house.

After the cable is securely landed, its core, which has been sealed by the gutta percha being drawn in a viscid state over the copper, thus effecting a complete insulating envelope, is opened, the core is cleaned and dried, and the conductor is connected with the instruments. These instruments are for testing the cable and for signalling to the ship. Throughout the entire process of laying a cable, even though it lasts two weeks, the testing never ceases, watch being kept day and night upon the insulation and electrical condition of the cable, both on ship and on shore.

As soon as the shore end has been landed and connected at the cable house, and the ship is ready to start off, the anchor is weighed and the ship begins paying out the cable. The speed of the engines is so controlled that the cable shall not be pulled out of the tank too rapidly. The position of the ship is carefully watched, from time to time, and plotted on the chart, and constant observations are taken at the paying-out gear to ascertain how much cable is paid out, so that the necessary amount of *slack*, or extra cable, may be laid. The depths along the route have all been carefully determined in advance and a surplus or slack is allowed according to the depth and the weight of the cable.

It is evident, that if the ship could pay out cable at an indefinitely high speed, the cable would be laid along a flat bottom, perfectly stretched, or without any slack. In other words, the length of the cable would be exactly equal to the length of the bottom on which it rested. Such a cable could not, however, be lifted from the bottom in any depth, without breaking, since its elasticity would not be sufficient to permit it to rise in a loop to the surface when desired. It is, therefore, necessary to pay out a certain percentage of slack not only to enable the cable to be lifted to the surface at any future time, but also to permit the cable to accommodate itself to the contour of the ocean's bed. The slack so paid out may be from 3 per cent. in shallow water, to 15 per cent. in deep water. The speed at which the cable is paid out may vary from 4 to 8 1/2 knots per hour, according to the weather, the type of cable, and the condition of the coiling.

In fine weather, with a smooth sea, the tension upon the cable may vary from one to three tons according to the type of cable, and the depth of water, as well as the speed of the ship. In rough weather, the tension will periodically vary with the pitch of the ship and the mean tension only can be regulated. If the tension is too great the slack expended will be excessive and the cable will be wasted.

The drum of the paying-out gear will, therefore, have to be tightened in the brakes to retard the cable. On the other hand, if the cable is too taut there will be an insufficient amount of slack and the brakes on the paying-out drum will have to be released.

A cable uncoils in a tank from the exterior turns, that is from the turn in contact with the wall, counter clockwise, until the interior turn at the eye of the tank is reached, when the cable then runs to the wall of the tank on the next flake, and uncoils again toward the eye as before. In this way one horizontal *flake* or layer of the cable is uncoiled at a time. The men in the tank assist the cable by lifting up the turn next in advance, so as to make sure that there shall be no adhesion between one flake, and the next beneath, Should two flakes adhere, a foul flake is produced, and a terrible tangle ensues which usually breaks the cable and leads to much expenditure of time, cable, and work. The cable is always whitewashed, before being coiled in a tank, so as to keep the pressure of the superincumbent layers from cementing adjacent flakes. Great care has to be taken, when uncoiling near the eye, that no foul flake shall occur, since the angular rate of uncoiling is, of course, considerably greater at the eye than at the outside turn.

When a tank is nearly emptied of its cable, the operation of changing tanks is necessitated, that is to say the paying out has to change from one tank to another. For this purpose the speed of the vessel is slowed down shortly before the last flake is paid out, and the rate of paying out is reduced to such as can be readily controlled, the bight or loop of the cable is then handled carefully as it leaves the tank and changes position, so that no kink or twist may occur, since such a kink would probably lead to the fracture of the cable, while passing through the machinery, and, as soon as the paying out commences in the next tank the speed of the vessel is increased as before.

When the cable in two tanks has to be spliced together, or two lengths in the same tank, a joint and splice have to be effected. A *joint*, is the connection of the cores, and a *splice* is the connection of the sheathings. Both of these require considerable skill, since, otherwise, a fault, electrical or mechanical, may occur. When a joint is made, the two ends of the core are carefully prepared, cleansed and fixed in a vise. They are then soldered together in a scarf or diagonal joint. After cleansing the soldered connection, the gutta percha at each side is drawn down, after heating it with a spirit lamp, until, with the aid of a heated iron tool, the two coatings are united. Fresh layers of gutta percha are then added, interspersed with Chatterton's compound, by the use of sheet gutta percha cut off to the right size. This stock is carefully preserved in air-tight boxes, since gutta percha although absolutely preserved in water undergoes oxidation and decay in air, particularly under the influence of light.

After the joint is completed and smoothed off, it is cooled by immersion in a bath of some suitable cooling mixture. It is then tested for insulation, and, after cooling, the splice is commenced. The jute is first connected around the core, tied in position, and the iron wires, which are stripped in advance from one end of the cable, are laid up with the wires in the other end in nautical fashion. The splice is then served down with yarn with the aid of a tool called a *serving tool*, the object being to press the wires tightly so as to make them thoroughly coherent. A well-made splice is as strong, mechanically, as any other part of the cable, but never looks so symmetrical as the cable itself, and can always be detected in its passage over the deck or paying-out drum. The positions of the splices, as they pass out, are always carefully noted and marked on the chart so as to aid in determining the positions and lengths, should the cable be subsequently raised for repairs. From two to three hours is usually needed to effect a careful joint and splice according to the skill of the workmen and the type of the cable.

The cable is always connected on board ship to the testing room, where, by the aid of a voltaic battery and testing instruments, its electrical condition is constantly observed and recorded. For communicating with the shore through short lengths, the ordinary Morse apparatus is employed, but with considerable lengths of cable the speed of the Morse instrument becomes so slow, owing to retardation, that an instrument called the *mirror galvanometer* has to be employed. This apparatus is illustrated in Fig. 152. It consists of three parts:

(1) A *mirror galvanometer*, which is a delicate receiving instrument for showing the presence of a feeble electric current.

(2) A lamp and shade for throwing a

beam of light on to the mirror of the galvanometer; and

(3) A scale for receiving the beam of reflected light from the mirror.

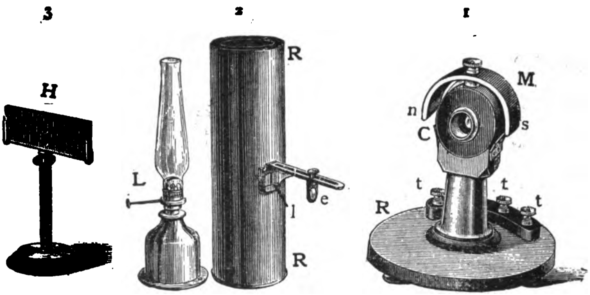


FIG. 152.—MIRROR SPEAKING INSTRUMENT.

The galvanometer consists of a coil *C*, of fine insulated copper wire, mounted upon a base *R*, and connected to the cable by the binding posts *t*, *t*, *t*, different binding posts being connected to different portions of the coil. *M*, is a permanent magnet with its poles at *n* and *s*. In the centre of the coil *C*, and, therefore, in a line joining the poles *n* and *s*, a small permanent magnet, formed of a piece of watch spring, about a quarter of an inch long, is suspended on a vertical fibre. This magnetic needle tends to remain in a horizontal position between the poles *n* and *s*. When, however, an electric current passes through the convolutions of the coil, the coil becomes magnetized, magnetic flux passing through the coil in the direction of its axis, threading the coil either toward the observer or from the observer, according to the direction of the current. Under these circumstances the resulting magnetic flux at the centre of the coil is due to two components; first, the flux from the permanent magnet across the coil, and second the temporary magnetic flux due to the M. M. F. of the coil, in a direction along the axis of the coil. The needle, therefore, tends to turn around the fibre and point in a direction along the axis; *i. e.*, it will turn from a position across the coil to a position slightly inclined towards the axis, either to the left or to the right, according to the direction of the current in the coil. These movements may be very powerful, if the current strength of the coil is great, so that with a powerful current the needle may tend to set itself almost along the axis, but with a very weak current through the coil, the disturbance of its position may be very small, or the deflection of the needle due to the current may be scarcely perceptible to the eye. A little mirror, however, is fastened to the front surface of the needle and a beam of light from the lamp *L*, is transmitted back to the sheet of white paper placed in the holder *H*, at a suitable distance from the instrument. So long as the needle is quiescent, the reflected beam of light will form a bright motionless spot upon the paper in the holder, but, as soon as any electric current passes through the coil, the deflection of the mirror through a very small angle will cause the spot of light to be deflected either to the right or to the left. The beam of light in fact constitutes a weightless pointer, or index of the position occupied by the suspended magnet.

The signals are so sent that a negative current, for example, causes the needle and spot of light to deflect to the left, while a positive current, will, on the contrary, cause the needle and spot to deflect toward the right. A dot will then correspond to an impulse of negative current, and a dash to an impulse of positive current. Consequently, when a dot is sent, the receiving operator observes the spot of light to give a jump to the left and then return to its original position. By watching the movements of the spot of

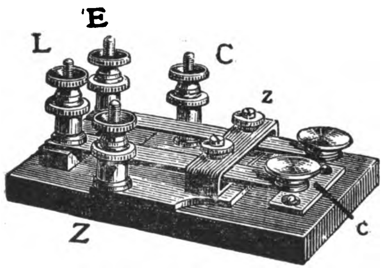


FIG. 153.—CABLE SENDING KEYS.

light the message can be spelled out, at a speed which may be as great as 25 or even 30 words per minute.

The sending instrument employed for mirror signals is shown in Fig. 153, in its simplest form. It consists of a pair of finger keys, one of which is operated by the index finger, and the other by the second finger of the right hand. Two brass strips are connected with the terminals *L* and *E*. The former, being connected say to the cable, and the latter to the earth or ground; or, on board ship, to the steel hull of the vessel. These strips rest by their elasticity against two back contacts in the strip *z*, connected with the terminal *Z*. By depressing one of these keys it is lowered out of contact with the strip *Z*, and placed in contact with the strip *c*, connected to the terminal *C*.

The signal battery is connected with, say its copper or positive pole to the terminal *C*, and its negative or zinc pole to the terminal *Z*. The effect of leaving both keys up is to allow the line to remain grounded through the two back contacts. The depression of the left-hand key breaks the circuit and inserts the battery with the copper pole to line and the zinc pole to ground, corresponding to a dot signal, while the depression of the right-hand key reverses this connection and puts the copper pole to ground and the zinc pole to line, thus corresponding to a dash signal. The rate of hand signalling by these keys is from 20 to as high as 30 words per minute. The maximum speed of the Morse key is not attainable, since the impulses employed are only those of the finger and wrist instead of the finger, wrist and arm as in the case of the Morse key.

The connections of these instruments with the cable are indicated in Fig. 154, where K, K', are the keys, M, M', the mirror instruments, L L', the cable conductor, S, S', switches, and G, ground;

e, *e'*, are signal batteries. At *A*, the switch is turned to send, and at *B*, it is turned to receive, so that *A*, is supposed to be sending a message to *B*.

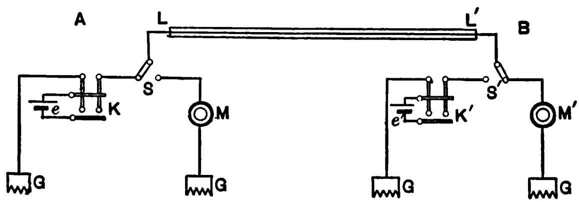


FIG. 154.—DIAGRAM OF CABLE SIGNALLING CONNECTIONS.

The sensibility of the mirror instrument is so great that a single cell, such as might be formed of a copper percussion cap with a zinc wire in it, or of an orange with a steel knife and silver fork thrust in it, will serve to signal across the Atlantic cable with some little adjustment. Usually, however, a battery of 10 or 20 cells is employed and the greater the E. M. F. the sharper and swifter the signalling up to a certain limit.

If fine weather continues the ship can continue to lay a cable until either the whole distance is covered, or until her stock of cable is exhausted. Should the weather become boisterous, it becomes necessary to cut the cable and buoy the end of it. As soon as the cable is cut, the core is sealed water-tight, after giving the shore final notice, and instructing the keeping of a watch for the call of the ship when the end is raised. The end of the cable is then carefully secured to a length of chain with an anchor attached to it, called a *mushroom anchor*, such as illustrated in Fig. 155. This anchor is intended to moor the end of the cable without allowing the anchor to fasten itself inextricably among rocks. The end

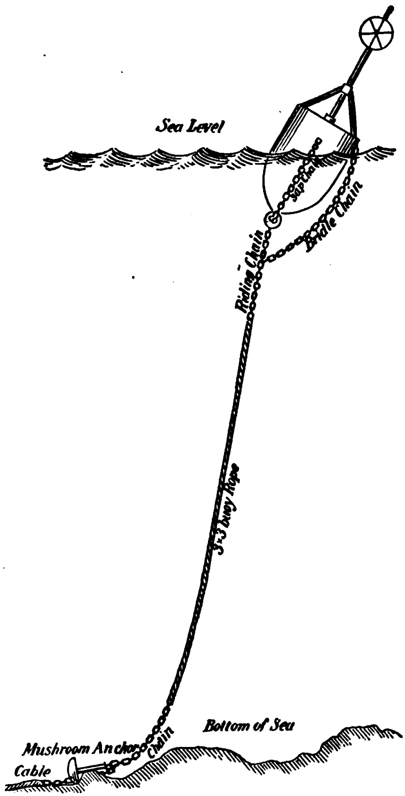


FIG. 155.—BUOY MOORING WITH MUSHROOM ANCHOR.

of the cable is then lowered away from the ship with a rope of steel and hemp fastened to it until the end is safe on the bottom of the sea, when a buoy of the shape shown is slipped upon it. This buoy is made of sheet steel in different sizes according to the weight which it has to support. An ocean buoy is about 8 feet high, independently of the flag-staff and beacon. At sea these buoys are kept in the rigging of the ship and are often so large that their presence is apt to have a local disturbing effect upon the ship's compasses.

When the ship reaches her destination, the shore end of the cable has to be laid at that point. This is usually laid in advance of the ship's arrival, and its end buoyed. The ship pays out the cable until she reaches this buoy, when she takes it up at the bows, steadily hauls on board the rope fastened to the cable, brings the buoyed shore-end up, and then proceeds to make a final splice between this shore end and the cable which has been paying out. For that purpose the cable is cut on board, and passed forward to the bows, so that the two ends may be spliced together. As soon as all is ready the splice is dropped and the cable is then electrically completed from end to end.

CHAPTER XVIII.

OPERATION AND MAINTENANCE OF CABLES.

We have already seen that while a short submarine cable may be operated like an overhead land line, by the usual Morse or Wheatstone apparatus, long cables require special, delicate instruments if they are to be worked at any speed, for, having a given type of core with determined electrical constants, the speed of signalling is always found to be inversely as the square of a cable's length, so that if 320 words per minute can be just reached on a cable 300 miles long, with the aid of a Wheatstone instrument, only 80 words per minute can be just reached on a cable 600 miles long, and 20 words a minute on a cable 1,200 miles long.

The *mirror receiving instrument* was the first commercial apparatus for the operation of long submarine cables. In fact without this instrument long submarine cables would scarcely have become commercially successful. The disadvantage of the mirror instrument lay in the fact that it required two men to operate it; one for reading the signals aloud, or spelling out the letters from the movements of a spot of light which is flashed to-and-fro on a sheet of paper, and the other to write the letters down and put them into words and sentences. Moreover, no record was kept of the signals beyond the recording of their interpretation by the reading operator.

The first difficulty has been overcome by allowing the spot of light to fall upon the sheet of paper on which the operator writes, so that by practice he is enabled not only to follow with his eye all the motions of the beam of light, and so decipher these into letters and words, but also to write the words down, with his pencil. The latter difficulty of non-recording has never been overcome with the mirror instrument. A recording apparatus has, however, been introduced, which while not quite so delicate as the mirror instrument, yet enables long submarine cables to be operated at practically the same speed.

This instrument, called the *siphon recorder*, is represented diagramatically in Fig. 156. Here a coil of insulated copper wire *h h'*, is suspended by threads between the poles of the large and powerful magnet *N S.* When no current passes through this coil, the suspension causes it

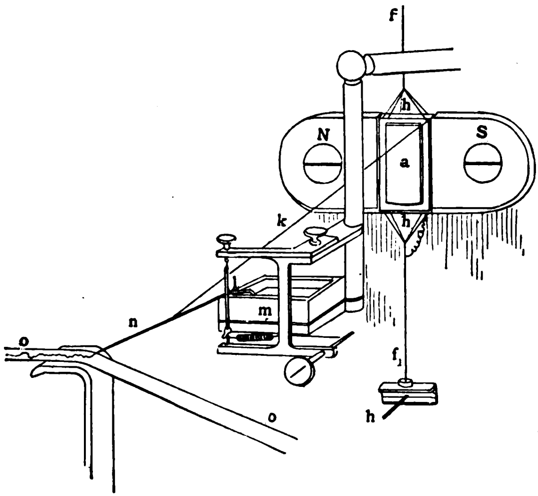


FIG. 156.—SIPHON RECORDER.

to hang in the plane of the poles. If, however, a current passes through the coil, it develops a M. M. F. and a magnetic flux which cause the coil to deflect to one side or the other about its vertical axis of suspension. These movements, which may be very feeble, are magnified by attaching a thread from one corner of the coil to a delicate glass siphon with a fine capillary bore whose extremity rests just over a band of moving paper without actually touching it. Consequently, when no current passes through the recorder coil, the ink, which is caused to squirt through the siphon from the ink well, forms a fine line along the centre of the moving paper band; but, when the coil moves to the right or left, it causes the siphon to be similarly deflected and to make a corresponding deflection in the ink line. The Continental Morse alphabet, as it appears upon recorder slip with a cable of moderate length, is shown in Fig. 157. The Morse alphabet is not used on long cables, principally because the spaced letters would be difficult to detect, and would, therefore, be liable to give rise to errors in transmission.

On short cables the recorder signals stand out with each dot and dash clear

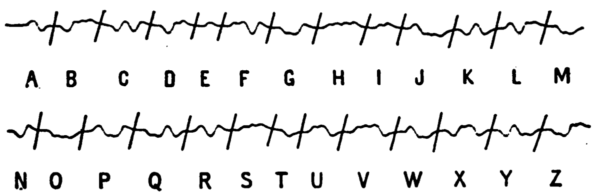


FIG. 157.—CABLE ALPHABET.

and sharp, but, as the speed is increased, or, as the length of cable increases with a given speed, the signals tend to merge and run into each other, so that it takes a trained eye to read the signals. Thus, while the separate dots and dashes are fairly distinguishable in Fig. 157, yet they are much less clearly discerned in the specimen of Fig. 158, which shows a portion of an actual message received, on an Atlantic cable, from Lord Kelvin, the inventor of the speaking mirror galva-

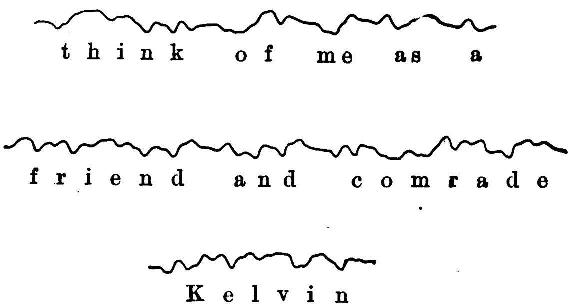


FIG. 158.—END OF LORD KELVIN'S MESSAGE TO AMERICAN ELECTRICIANS IN NEW YORK ON THE OCCASION OF HIS JUBILEE.

nometer and siphon recorder, upon the occasion of his jubilee at Glasgow University in 1896.

Figs. 159 and 160, show two forms of siphon recorder. In Fig. 159, the coil is suspended between the poles of a large vertical horseshoe permanent magnet

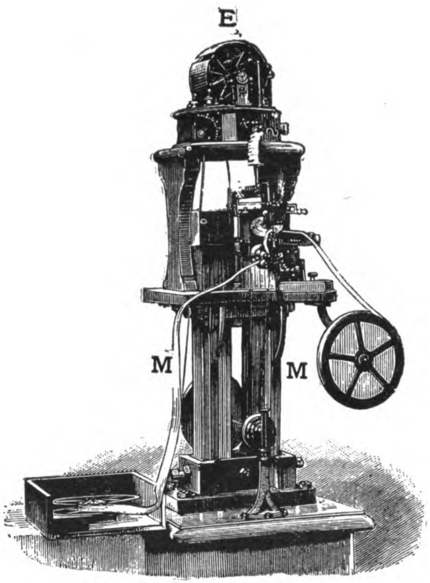


FIG. 159.—SIPHON RECORDER.

M M. The ink is forced through the siphon in this instrument by electrification, that is to say the ink well, into which the siphon dips, is insulated and charged to a high voltage by an electrical influence

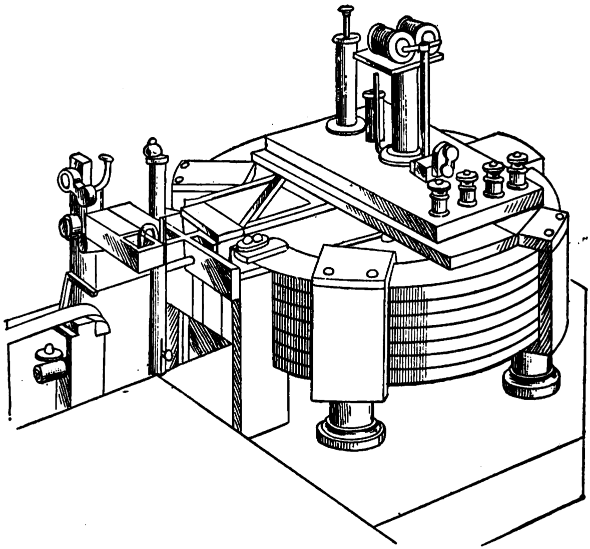


FIG. 160.—SIPHON RECORDER.

machine, so that the ink being powerfully repelled, is urged from the siphon point on to the moving paper. The electrification is obtained from the influence machine *E*, which is driven by a small electric motor operated by a battery. In Fig. 160, the ink is not electrified, but the siphon is kept in vibration, in a vertical plane, by a trembling electromagnetic attraction, so that the ink is shaken out of the siphon on to the paper slip, capillary attraction filling the siphon as fast as it is emptied.

All important long cables are duplexed so as to permit the simultaneous sending of messages in opposite directions. The balance in such cases is always more difficult to obtain than with the ordinary Morse system on land lines; owing to the greater sensitiveness of the apparatus. Special condensers have to be employed to form the artificial line, which is, consequently, a comparatively heavy and costly apparatus. The principle of operation is, however, the same as that which we have already described in connection with land lines. In duplex working there is no switch employed, the receiving instrument being always in circuit. In simplex working a switch is employed.

There are no means yet known for either diplexing or quadruplexing a long submarine cable. In the same way, no means have yet been devised for automatically repeating a message from one long submarine cable to another. Short cables can, of course, be operated by Morse repeaters in the usual way, but the signals on a long cable are not only so faint that the receiving mechanism has not the power to make repeating contacts with sufficient firmness, but the distortion of the signals, already alluded to, would prevent such contacts from being properly timed and spaced. When a message is sent from New York to Bombay, it may be sent first from New York to a cable station in Nova Scotia; then from Nova Scotia to Ireland; from Ireland to London; from London to Marseilles; from Marseilles to Malta; from Malta to Alexandria, Egypt; from Alexandria to Suez; from Suez to Aden, and from Aden to Bombay. Consequently, the message by this route would have to be repeated eight times before its final reception at Bombay. Taking the total distance as roughly 10,000 miles, this represents an average of about 1,100 miles at each transmission. There are therefore, in this particular transmission, nine times, at which it is possible to introduce an error or errors into the message.

It was formerly the invariable practice

to write down a message as it was received at each intermediate station and retransmit the message from this written record. A plan has, however, been generally introduced wherever possible, to retransmit messages from the recorder slip without first writing it out. Consequently, the repeating of a message in such a case is performed through the agency of the operator, instead of by automatic mechanism. In other words, the message is received, say at Aden from Suez, on the recorder slip, and is retransmitted by the operator on the next circuit, or to Bombay, as fast as it is received at Aden. At the end of the message, the operator at Aden reverses the connections between the sending and receiving cables, so that he is now able to act as a manual repeater in the opposite direction, or from Bombay to Suez.

With lines operated by duplex both circuits may be continually operated by manual repeater, so that at Aden, one operator is always repeating messages from the Suez cable to the Bombay cable, and another operator is always sending messages from the Bombay cable, on to the Suez cable. Such a system is only applicable to through traffic, since way traffic necessitates its interruption. Whereas, on land lines using automatic repeaters, several repeaters may be included in one long circuit, when long cables employ manual repeaters it is not found advantageous to employ more than one manual repeater in any one combination circuit.

Apart from the fixed charges upon the capital investment, the frequent repetition which is rendered necessary for cable messages over great distances, adds materially to the cost of operation and transmission. It is necessary that the operators should be skilled in transmission and should make as few errors as possible, since in many retransmissions a message might be mutilated beyond hope of deciphering. Particularly is this the case with messages in foreign languages, and with code messages, which, owing to their economy in the number of words transmitted, are so much in vogue.

It is customary, in a large cable system to employ a *clearing house* whereby every message sent over the system is returned to the head office, and a comparison effected between the original message as received for transmission, and the final message as delivered to the addressee. In case of any errors appearing in this comparison the records of the intermediate offices are examined and the error traced to the delinquent operator, who is fined for the same, perhaps three months after its occurrence. So accurate do operators become, under training of this character, that it is not a rare occurrence for a skilled operator to work steadily eight hours a day sending and receiving messages, and yet not to have a single error recorded against him in a whole month's work.

The exigencies of cable traffic require that at certain hours of the day, the streams of messages shall be in one direction, and at other hours, in the opposite direction. The usual custom is to refer all messages to Greenwich time as a standard of comparison, so that each message in transmission carries with it the Greenwich time of its reception, thus eliminating all calculations involving local time in determining the period of transit. Where an extensive cable system is operated, it is customary to give precedence to messages which have to be sent long distances between important telegraphic centres, over messages which only have to be sent short distances to less important commercial centres. In other words, *through traffic* usually takes precedence over *way traffic*, unless the latter has become heavily delayed. By this means the average time of transmission is greatly reduced.

When special swiftness is desired, a message can be sent from New York to Japan around the Western Hemisphere in a few minutes, but under ordinary conditions, the time required for the transmission of such message might average several hours. This time is required for changing from circuit to circuit, since, of course, each signal only occupies a small fraction of a second in passing from the sending to the receiving end of any one circuit. When a transmitting key is depressed on an Atlantic cable in America, the signal commences to make its appearance in Europe in about the one-seventh of a second; and, all through the transmission, the signals, as repeated by the siphon recorder on the moving paper slip, are a fraction of a second behind the keys of the operator at the sending end. The speed of transmission on a transatlantic cable, operated by hand, is from twenty to twenty-five words a minute, and this means that the message is being forwarded across the ocean at this speed, but each signal arrives a fraction of a second later than it is sent.

The interior of a cable office is repre-

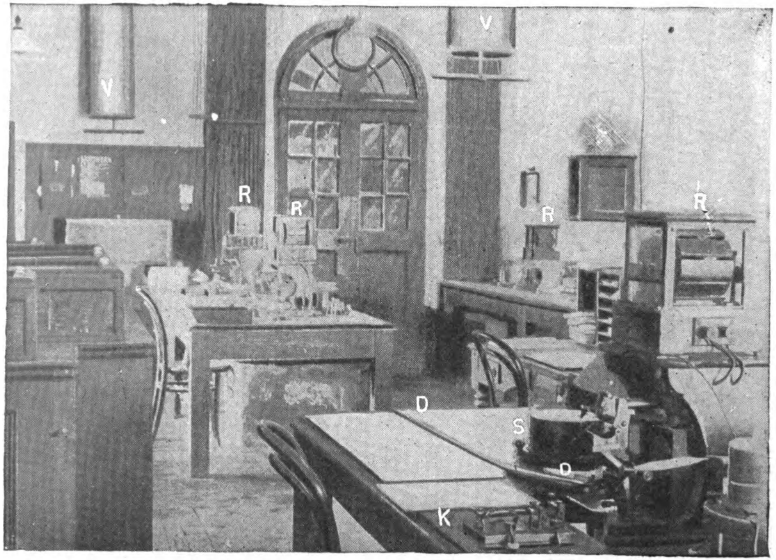


FIG. 161.—INTERIOR OF CABLE OFFICE.

sented in Fig. 161. There are four recorders *R*, *R*, *R*, *R*. The moving band of paper is represented in the foreground, at *D D*; the signalling key *K*, and a switch *S*, constitute the equipment for simplex working. *V*, *V*, are ventilators.

When submarine ocean cables were first laid it was a matter of speculation as to how long they would last, and as to whether they could ever be repaired. It was supposed by some that in shallow waters there would be no great difficulty in repairing a broken cable, but that in deep water the difficulties would be overwhelming. The repair of the Atlantic cable of 1865, in mid-Atlantic, in more than two miles of depth of water, settled the question of deep-water repairs beyond dispute. It has been found that wherever a cable rests upon a rocky bed it is practically sure, sooner or later, to be injured by abrasion, especially in shallow water where waves or currents are present. A cable which rests upon a rocky shore is, therefore, destined to give much trouble in repairs. In some parts of the world, where cables are landed upon a rocky shore, it is not unusual for a heavy gale upon the coast to produce an interruption of the cable. Consequently, a cable system requires the existence of duplicate or triplicate lines, to prevent total interruption of the traffic by accidental cable fractures, and, therefore, the maintenance of specially equipped repairing telegraph steamships.

The *faults* which occur in submarine cables are of two kinds; viz., first the *total fracture* of the cable; or, as it is called, the *parting* of a cable on its rocky bed, usually due to suspension across a submarine chasm; and second, a heavy electric leakage, due to some imperfection in the gutta-percha envelope. This may be due either to some imperfection in the manufacture of the core, to the presence of an imperfect joint, to the ravages of the teredo or boring worm, which penetrates the gutta-percha envelope, to chemical decomposition due to the action of some salt, on the bottom of the sea, exercising a local corrosive influence; or, finally, to partial abrasion. A fracture completely interrupts all telegraphic communication.

A partial fault may vary in its consequences according to the magnitude and position of the leak, from a slight impairment in the rate of signalling, to a complete suspension of signals.

As soon as the signals are found to

suffer from the presence of a fault, it becomes necessary to determine its position with a view to repairing the damage. We will suppose that an Atlantic cable suddenly breaks without warning, perhaps, in the middle of a message. It is necessary to determine where the break has occurred. This is done by measuring the electric resistance of the conductor from each end. If the cable had normally a resistance of 8,000 ohms in its copper conductor, and when broken, the resistance from each end was found to be precisely 4,000 ohms, then it would be obvious that the fracture had occurred exactly midway in the electric resistance of the line. The electric resistance as measured from each end, after due corrections have been made for the resistance offered by the exposed conductor at the fracture, gives the electrical distance of the fracture from each end of the line. By reference to the records which have been kept of the conductor during its manufacture, laying, and subsequent testing, the corresponding distance in miles of cable from each end to the point where the fracture exists is readily computed. With these data the position of the fracture on the chart is next determined by the aid of the records made during the laying of the cable.

The accuracy of the determination of the exact location of a fault depends upon the accuracy of the data in each step of the process. An electrical determination, though very accurate as regards the number of ohms between the shore and the fault, may, nevertheless, be miles in error owing to imperfect mechanical or nautical data. On the other hand, the mechanical and laying records may be very accurate, and yet, owing to imperfect electrical measurements, the position may also be largely in error. The electrical position of a fault can almost always be determined within 25 miles. When a fault is so large as to require repair, it can, in many cases, be determined to a mile, and, in rare cases, to a few yards.

The repairing ship proceeds to the point on the chart, indicated by the measurements and computations, and, having reached this position, lowers a buoy with a mushroom anchor. This is called a *mark buoy*, and serves to preserve the position in case wind or current should cause the vessel to drift. A sounding has first to be made, in order to ascertain the depth of water, and an additional length of rope must be allowed to make sure that the mushroom anchor has a fair hold on the bottom. In rare instances cables have been repaired in three miles of depth of water. The surface of the ocean's bed, when composed of sand, mud or ooze, is usually fairly smooth and uniform, so that, when once a cable is laid on such a bottom, with a sufficient amount of slack, there is no reason why it should ever break, the galvanized steel wires used as sheathing often appearing in perfectly good condition after many years' submersion. On rocky bottoms, however, submarine precipices are by no means uncommon. In very rare cases a difference of depth of half a mile has been found between soundings taken at the bow and stern of a ship.

As soon as the weather permits, grappling begins for one end of the broken cable, within view of the mark buoy. If the cable lies east and west, the ship puts down a grapnel on one side of the line, with a sufficient extra allowance of rope, and pulls the grapnel slowly over the bottom in a north and south direction. The grapnel, in its simplest form, is a heavy six-pronged iron hook, as shown in Fig. 162. It lies on its side on the bottom, burying two of the hooks in the mud. The ship pulls the grapnel along at a steady rate of about half a mile an hour, the strain on the grapnel rope being carefully watched. When the cable is hooked, the strain slightly rises with a steady elastic tension, while if rocks are engaged the strain rises more rapidly and with sudden jerks. In some cases the vessel moves so slowly, and with so little steerage way, that in deep water the man at the wheel is the first to ascertain that the grapnel has hooked, owing to the ship no longer responding to her rudder.

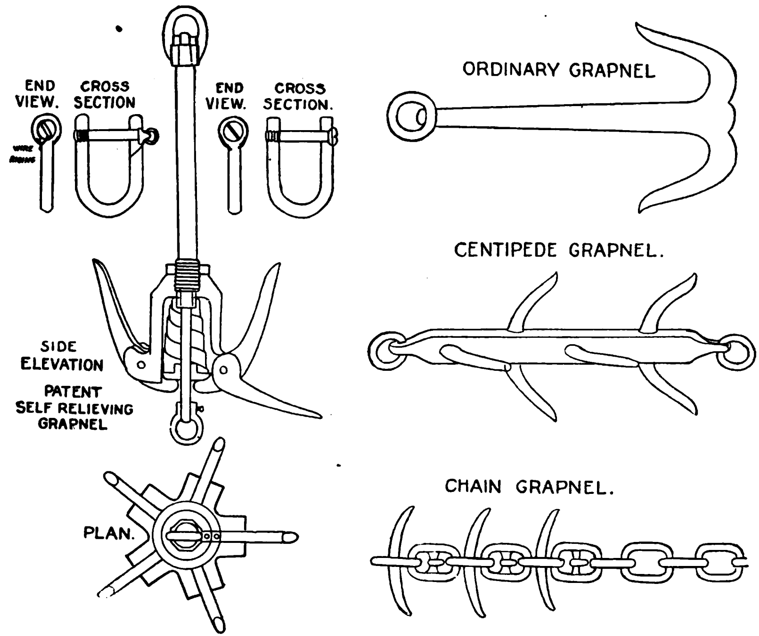


FIG. 162.—GRAPNELS.

The length of the *sweeps* which are made to-and-fro across the line of cable, depend upon the accuracy with which the line of cable is laid down on the chart, and the accuracy with which the position of the ship has been determined at the mark buoy. In the vicinity of land, where angles and bearings have been obtained in both operations, the sweeps are short; but, far out of sight of land, where the errors in longitude may amount to several miles, the sweeps may be ten miles long.

Rocky bottoms cause great annoyance and delay, not only because the vessel has to stop grappling and commence lifting as soon as the strain indicates a hook, but also because, from the suddenness with which the strain increases at a rock, the prongs of the grapnel are apt to be torn off. In shallow water, on a rocky bottom, many grapnels may be disabled from this cause in a single day. A form of *centipede grapnel*, which is especially adapted to rocky bottoms, is shown in Fig. 162. This form of grapnel is also more easily repaired on board ship by the blacksmith. A form of *chain grapnel* is also shown. The same figure shows a form of grapnel which automatically releases its prongs when thus engaged with a rock, but which cannot release a cable when once hooked. The prongs of this grapnel abut upon a powerful spring in the base, which, at a certain tension, allows the prongs to fly back and release a rock. When a cable is hooked, however, it falls on two fixed prongs at the base of the movable prongs. Consequently, the spring is powerless to release it.

When the cable has been hooked, the

ship is stopped, and the grapnel rope is slowly hauled in. If the end is not too far away, the bight of the cable will lift easily, dragging the short end along the ground as it does so. But if the cable is intact for a considerable distance on each side, and if the ship is in deep water, *the strain on the cable* will, probably, increase until the cable breaks at some point, in which case the lost end must be grappled for afresh. On raising the bight of the cable to the bows, it is secured by chains and the grapnel is then removed. The bight is then cut at the bows, between the fastenings, so that each end is finally secured to the vessel by a chain.

The apparatus in the testing room is now connected by an insulated wire to each end of the cable core, and by tests it is soon determined which end of the cable is intact, and which faulty. The ship then calls the shore station, say America, by a signal, using a mirror galvanometer as the receiving instrument, unless the cable is short, when a Morse instrument is used. The American station, which has been keeping a lookout day and night for the call of the ship, answers, and tests and messages are rapidly exchanged. The ship then notifies the shore that it is about to seal and buoy the end, and to keep a lookout for calls until further notice, after which the end of the core is sealed, thus preserving the insulation of the cable to America. The end, secured by a mushroom anchor and buoy, is then dropped to the bottom of the sea. This buoy is called a *cable buoy*, in contradistinction to a mark buoy. The ship then proceeds to pick up the short faulty end, following the cable line as she does so, and coiling the picked-up cable away in a tank. In this way the cable will either break, or the faulty end will come up. A gap of some length, perhaps several miles, is therefore left in the line of cable. The ship then proceeds to grapple for the European end, beyond the fracture, proceeding in the same manner as before. When the cable is again hooked, the bight is raised to the surface as before and the European end is brought into communication with the ship's testing room. After ascertaining that this end is in good electrical condition, and exchanging messages with the European station, the ship commences a joint and splice between this European end and her own cable. The short end of the break on the western side, is then either hauled in, or abandoned by letting it go.

When the splice is finished and has been found to test satisfactorily, the ship commences paying out toward the American buoyed end. On reaching this, she slows down and sends away a boat to prepare the buoy for picking up. A rope is then thrown to the boat from the bows, and made fast to the chain leading from the buoy to the American end. At a signal from the ship, the boat releases the buoy, which is then picked up at the vessel's side, and hauling in commences on the moorings leading to the submerged end. All going well, the American end comes up safely with the mushroom anchor. The testing room is put into communication with it and messages exchanged. When all has been found in good order, the ship's cable, which has ceased to be paid out, is cut, and both American and European ends hang together from the bows. They are brought together for the final joint and splice, after the completion of which the final splice is let go.

A cable repair may last any length of time, from a few days to several months, depending entirely upon the nature of the cable, the depth of water, the skill of those engaged on board the ship, the nature of the bottom, and a variety of other circumstances. It is evident, however, that all such operations entail great expense. A number of cable repairing steamships are employed in different parts of the world.

Although cables have been repaired at three miles depth of water, the average depth of cable lifting is, however, less than half a mile, since fractures and abrasions most frequently occur in shallow water. The bottom of the ocean in deep water is generally found to be formed of sand, mud and ooze, and very little organic life is discovered at great depths. In shallow water, however, rocks are more common, and, in the tropics, corals abound, so that a cable, when picked up from a coral bottom, often comes up covered with quite a garden of many-colored corals in great variety of form. It is very rarely that a cable is found to sink in mud in the course of a few years. Only a few instances have been known in which special grapnels with extra long prongs have been necessary to pick up a cable that has become covered by, or sunk in, soft mud.

CHAPTER XIX.

SIGNALLING WITHOUT WIRES.

We have heretofore described methods, whereby, for the purpose of carrying on telegraphic communication, either aërial, subterranean, or submarine conductors are employed. In addition to these methods, there are means whereby telegraphic communication can be established without wires. These methods may be divided into two distinct classes; viz., the non-electric and the electric. Of the former there are two distinct systems; the *heliographic*, and the *semaphoric systems.* The latter class is akin to *induction telegraphy* already alluded to in connection with telegraphy to moving trains.

Heliographic transmission is based on sending flashes of sunlight, reflected from a mirror, to a distant station, the flashes being caused to follow one another in a manner corresponding to dots and dashes of the Morse code. Fig. 163, shows a form of *heliograph*. *M*, is a mirror mounted on a tripod *T*. A small area at the centre of the mirror is left unsilvered. The arm *A*, is employed as a *sighting stick*, directed toward the station with which communication is to be held. The operator places the sighting stick in line with the centre of the mirror, by observing through the hole in the back of *M*. The beam of sunlight is then thrown upon the distant station by illumining the sighting stick with the beam. Signals are sent, either by intercepting the beam with an opaque object, such as a cap, at intervals corresponding with the spaces in the Morse code, or the mirror is manipulated so as to throw the beam on and off the sighting

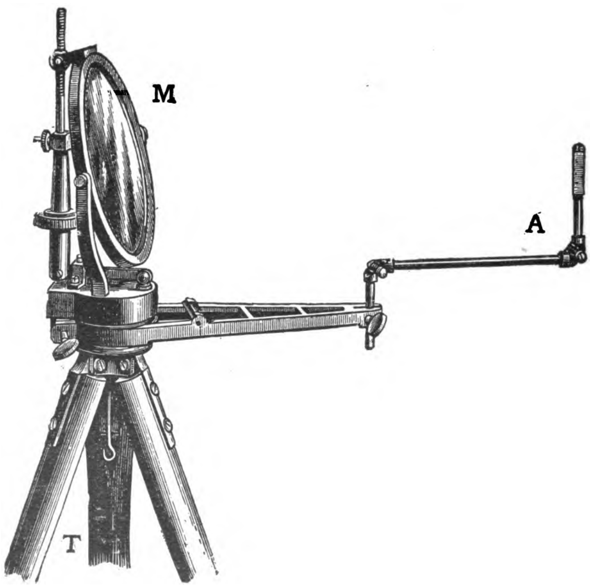


FIG. 163.—HELIOGRAPH.

stick, and thus remove and restore the flash at the distant station. In tropical countries, where sunshine is available for most of the days of the year, this apparatus is often a very economical telegraph, as many miles may be covered at a single stretch.

At night, similar signals may be sent by the aid of lanterns, or electric arc-light projectors. In all heliographic and lantern transmissions, care has to be taken to make the dashes of full or extra length, and the dots comparatively short, since the retention of light by the retina of the receiving observer, would, otherwise, tend to obscure the signals. Whistles on locomotives and steamers, have been employed in a similar manner by the use of the Morse code.

Flag signalling is extensively used by the signal corps of armies. A light flag, held in the hand, is waved to the left for dots, and to the right for dashes, as observed by the receiving operator; or, the swing is a short one for a dot, and a longer one for a dash.

During the last ten years great developments have been made in the science and art of wireless electric telegraphy, employing the invisible electromagnetic waves that were theoretically predicted by Maxwell about fifty years ago, and experimentally demonstrated by Hertz in 1888.

If we throw a pebble into a pond, a series of events is produced which are readily observed and with which everyone is familiar. There is first the splash at the spot where the pebble falls into the water, and immediately afterwards a wave consisting of an elevation or crest, followed by a depression or trough. This wave progresses at a substantially uniform slow speed over the surface of the water, radiating equally in all directions from the splash. At any instant the wave front forms a circle having the splash, or orgin of disturbance, as center. This is represented in Fig. 164, where *O* is the origin of disturbance at which the splash has occurred. At successive intervals of time, say one second apart, the wave will occupy the circular positions *A*, *B*, *C*, *D*, and so on. As the wave advances it loses intensity, partly by friction in the water and air, and partly by its constantly expanded area. If there were no loss of wave energy by frictions, the area of pond-surface involved in the wave at *A* would be doubled on reaching *B*, and would again be doubled on reaching *D*. Or expressed in another way, if the circumference of the inner circle *OA* be, say 3 feet, the same energy of wave which at *A* exists in 3 feet of wave

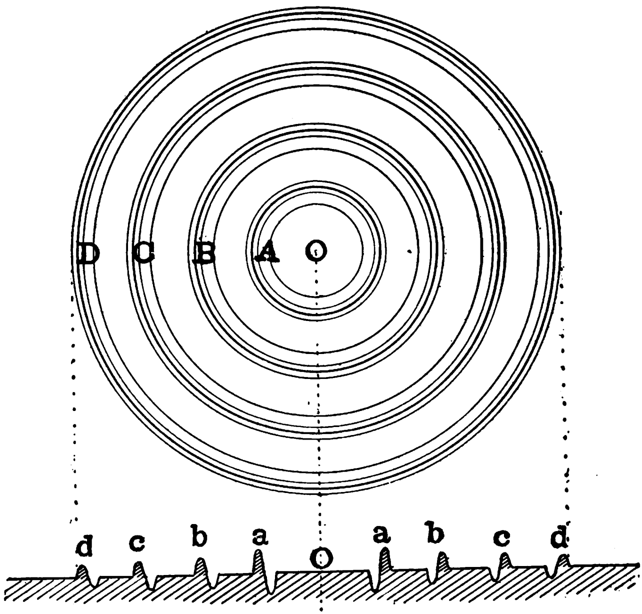


FIG. 164.

front, is spread over 6 feet of wave front when the wave reaches *B*, over 9 feet when it reaches *C*, and over 12 feet when it reaches *D*.

Since the height of the wave is a measure of its energy per foot of wave front, the height of the wave will speedily diminish, as indicated at the profiles at *a*, *b*, *c*, and *d*. After the wave has advanced many feet from the origin of disturbance it ceases to be visible to the eye.

If an apparatus were constructed to produce a succession of splashes or disturbances at the point *O*, Fig. 164, in periodic sequence corresponding to dots and dashes of the Morse alphabet, each disturbance would run out over the pond as a wave equally in all directions, and might possibly affect a suitable receiving instrument, such as an electric relay contact closed by a floating cork, at any suitable position on the pond surface. A telegraph sounder connected to such a floating cork relay might click out the dots and dashes which had been splashed out at the point of disturbance. There would be a certain time-lag or delay between the emission of any particular dot or dash signal at the sending point and its reception on the sounder at the receiving point, during the interval of transition of the waves. Moreover, it is evident that there might be many receivers at different distances from the origin or sending station, and in different directions, since the same wave spreads out to all parts of the pond. The more remote the receiving station, however, the more delicate would have to be the adjustment of the cork relay.

The surface of the globe is, in the main, electrically conducting and over this con ducting surface electric waves can flow. Any sudden electric disturbance, like an electric splash, at any point on the surface of the earth is able to send out an invisible wave through the atmosphere, or more nearly correctly, through the space occupied by the atmosphere. This wave runs out over the surface of the earth in all directions like the pond wave, but with enormously greater speed. It runs with the speed of light, which, in air, is about 186,000 miles per second. If it persisted, the wave would be able to make 7 1–2 journeys around the earth in a single second of time. Just as the pond wave becomes enfeebled as it advances over the pond and soon becomes inappreciable, so the electric wave becomes enfeebled as it advances over the globe and becomes inappreciable after it has extended a certain distance. This distance depends:

(1) On the violence of the electric splash or disturbance.

(2) On the perfection of the conditions for launching the waves from the disturbance upon the surface of the earth.

(3) On the sensitiveness of the wave-detecting instrument or receiver.

Ordinarily the electric waves become indistinguishable at a radius of a few miles or tens of miles from the source of disturbance, or sending station; in some cases they can be appreciated at a radius of hundreds of miles, and in rare instances they have been recognized at a radius of several thousand miles. It would not seem unlikely that they should be ultimately rendered capable of detection at any distance over the earth's surface.

In the case of the water wave on the pond, we see its height diminishing steadily as the wave gets further from the source of disturbance. In the case of the electric wave, however, the height of the waves is believed to increase as they advance from the origin. It is supposed that after leaving the source, the waves become hemispherical in form, and radiate upwards as well as outwards from the origin; so that the expansion is like that of a soap-bubble, or the upper half of an ordinary soap bubble. If this is correct, the energy in the wave front per square foot of surface must dwindle inversely as the square of the distance from the source, like light, assuming no frictional losses, whereas a wave restricted to a surface, like a water wave, would only dwindle in energy inversely as the distance. Few published measurements are yet available as to the actual rate of diminution of the electric wave energy with the distance.

The electric waves do not follow straight lines like beams of light in free space, but are guided by the conducting surface of the earth, bending over its globular surface. This is diagrammatically indicated in Fig. 165, which represents a source of electric waves or a sending station at the point *n* in North America. The dotted circle represents the line of the wave front after about 1/80th of a second has elapsed. The wave will then be reaching the coast of England and will have also encircled Iceland and parts of Spain, Greenland, Canada, and the Southern States. If the wave had followed a strictly rectilinear path, it would have pursued the straight line which would have taken it to a distance *ef*, 680 miles above the surface of the globe at this radius.

The apparatus for producing the electric

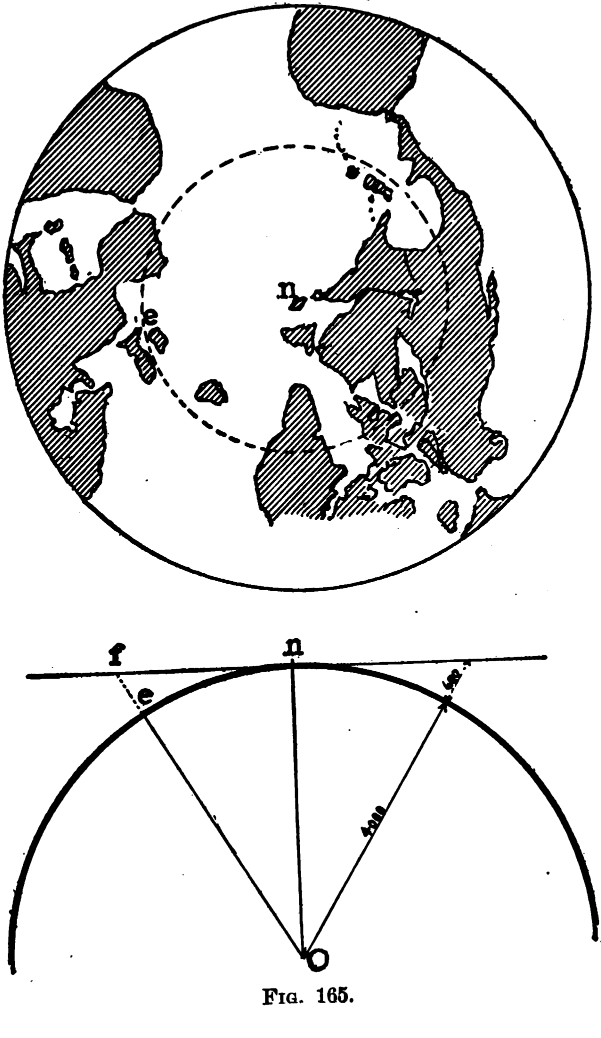


Fig. 165.

splash or disturbance at the sending station is indicated in Fig. 166. A mast is erected to hold a vertical wire *I P*, insulated above at the insulator *I*. The wire is grounded at the ground-plate *P*. The continuity of the wire is interrupted at the air-gap *g* between the discharge balls of a high-tension induction coil. On closing the primary circuit of the induction coil through the exciting battery *B* and the key *k*, the *vertical wire*, *aerial*, *air-wire*, or *antenna gI*, as it is variously called, is raised to a high electric potential and then suddenly discharged across the air-gap *g*. The rapidity of the discharge will depend upon the electric inductance and capacity of the insulated system. Under favorable conditions, the discharge, instead of taking place in a single electric flow, takes the form of a series of electric oscillations gradually dwindling in strength. That is to say, an

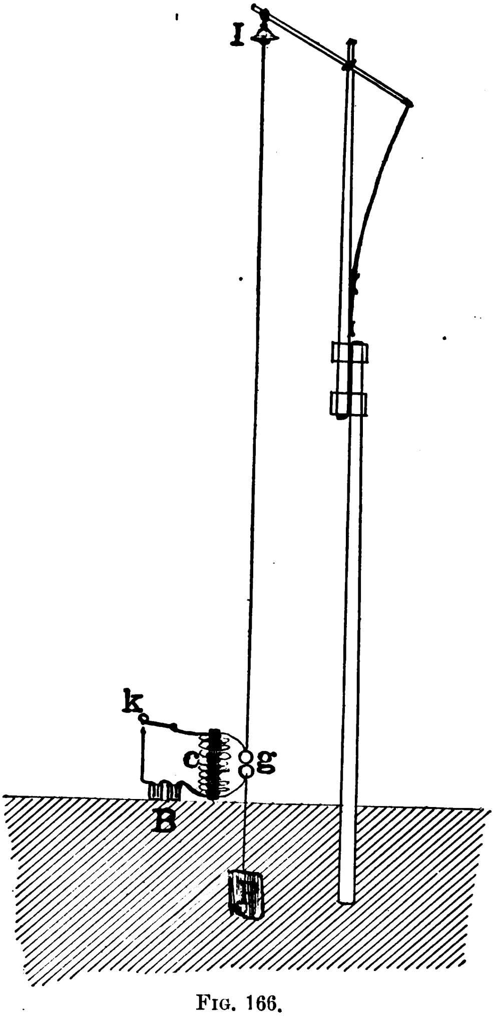


FIG. 166.

alternating current of diminishing strength and short duration will flow through the antenna. During its existence, the voltage of the oscillating current may be thousands of volts and the current strength hundreds of amperes. The frequency of alternation may be hundreds of thousands or millions of cycles per second. The greater the inductance and the capacity of the system the lower will be the frequency of the series of dwindling oscillations in each discharge. In an antenna of one vertical wire, free from any additional coils or condensers, the frequency will diminish as the length of the antenna increases.

It is usual to include a vibrating contact or vibrator in the primary circuit of the induction coil *c* in order that a single dot formed at the key *k* may set up a number of discharging impulses or sets of electric oscillations in the antenna.

The lengths of the waves emitted from a sending station depend entirely upon the frequency or frequencies of the oscillations set up in the air-wire, since the speed of transmission is accepted as the speed of light. Taking the latter as about 186,000 miles per second, if the frequency of oscillation be 186,000, there would be this number of complete waves in the distance they would cover in a second, or each wave would be one mile long. With twice as high a frequency, the wave-length would be half a mile, and so on. A continuous series of oscillations maintained at the sending station would cause a continuous series of electric waves to be radiated out, which would be essentially similar to waves of light, except for the lower frequency

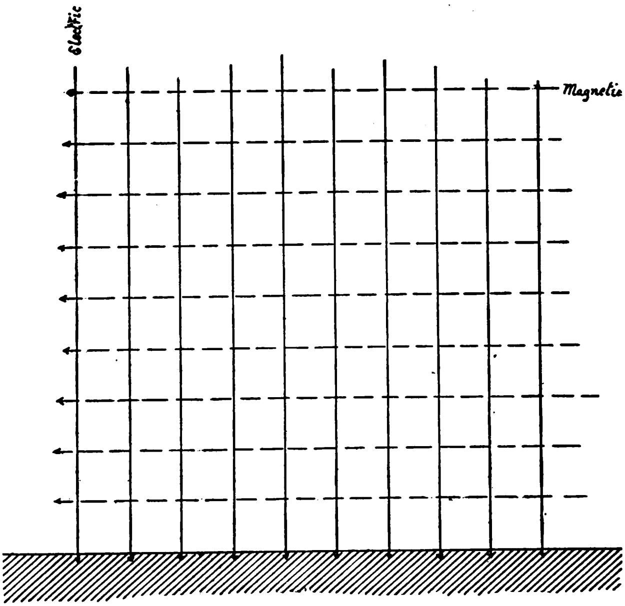


Fig. 167.

and corresponding greater wave-length. The eye is unable to perceive these long waves, being only sensitive to waves so short that one inch will contain roughly from 30,000 to 60,000 of them. In wireless telegraphy, the waves vary from say 100 feet to a few miles in length.

In the waves of wireless telegraphy, there exist both electric and magnetic forces. Near the surface of the earth the electric force is vertical and the magnetic force horizontal. The distribution of these forces is indicated diagrammatically in Fig. 167, where the wave front is supposed to be receding from the observer, over the surface of the ground. The broken lines pointing to the left-hand side represent the direction of the magnetic force; while the unbroken lines terminating in the earth represent the electric force. If such a wave, instead of rushing away at light-speed, could be arrested at a given spot, the horizontal magnetic force would be expected to exert a slight deflecting action on a horizontally suspended magnetic compass needle, tending to make it point along the horizontal arrows; while a positively electrified pith ball would also be feebly acted upon downwards in the direction of gravitation.

If the earth conducted perfectly from an electrical point of view, the electric lines of force would terminate at its surface, *i. e.*, they would not penetrate below the surface of the earth. The more imperfect the earth's conductivity, the more deeply the electric force can reach. Such penetration of the electric force into the earth entails expenditure of electric energy within the substance of the earth, at the expense of the energy in the wave. The waves penetrate more deeply into the dry surface of the earth than into the surface of the ocean, the salt-water ocean being a better electric conductor. Moreover, the waves are but little affected by passing through brick walls, or other obstacles of insulating material. On the contrary, where the waves encounter obstacles of electrically conducting substance, such as steel buildings, or even trees, rents or gaps are torn in the wave at the encounter. After passing such obstacles, however, the wave is able to spread out laterally and mend itself, although at the expense of energy in the neighboring parts of the wave, which are correspondingly weakened in intensity. For both of these reasons the waves suffer much more loss by sinking into the surface and by absorption into conducting obstacles when running over the land than when running over the sea; so that the distance to which wireless telegraph messages can be sent and received at sea is considerably greater than over land, with the same apparatus.

In order to render evident the passage of these invisible electric waves, a tall vertical insulated wire is suspended from a mast or other suitable structure as seen in Fig. 168. When the wave strikes this wire, the wire becomes momentarily embedded in the wave front. The wire may be considered either as bridging the voltage contained in the height of electric force to which the mast rises, this voltage being proportional to the height; or the wire may be considered as being cut by the horizontal magnetic force in the wave, at the speed of light. From either standpoint an electric impulse must be generated, either up or down the vertical wire. If there be a train of waves passing the wire, a train of electric oscillations will be set up therein, of the same frequency as was emitted by the sending antenna. These high-frequency oscillations in the

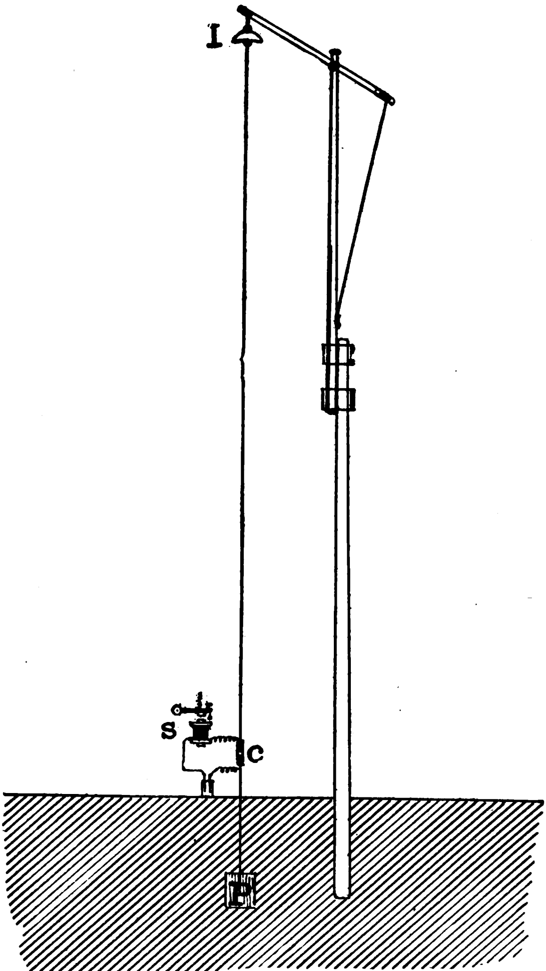


FIG. 168.

receiving antenna are capable of actuating various types of receiving instruments. Such receiving instruments are sometimes called kumascopes.

One of the earliest forms of kumascope was the coherer of Fig. 169. A glass tube *AB*, sealed at each end, and partly exhausted of air, contains two metal plugs *p p*, with

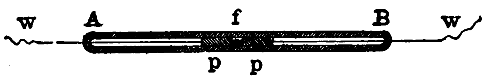


Fig. 169.

which external connection is secured by platinum leading-in wires *w w*. Between the plugs there is a small gap. This gap is partly filled with metallic filings *f*, loosely aggregated. The electric resistance of this mass of filings to a battery current, supplied through the wires *w w*, is normally very high. That is to say, the metal filings lie in imperfect mutual contact. If, however, the coherer be inserted in the circuit of the receiving mast wire as in Fig. 168, the effect of the electric impulses, or oscillations, set up by the passage of an electric wave, or wave-train, is greatly to improve the contact between the filings; or, as it were, partially to weld them together into a conducting mass. Consequently, after the electric wave has passed the air-wire, the local voltaic cell *v*, Fig. 168, is able to send a current through the coherer and to operate either a sounder *s* directly, or a relay working a sounder in its turn. In this manner the passage of the wireless telegraph signal may be detected. In order to restore the coherer to its initial non-conducting state, it is usually necessary to agitate it, as by a tap upon the glass coherer-tube, which shakes up the filings, and prepares them for the reception of the next succeeding signal. The armature lever of the sounder *s* may be made to deliver automatically the required tap to the coherer.

Another type of receiver is seen in Fig. 170. It consists of a small quantity of liquid *a*, usually an aqueous solution of

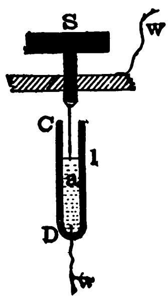


FIG. 170.

nitric acid, contained in a vessel *CD*. The wire *w* is electrically connected with this liquid. Into the liquid *a* dips the extremity of an extremely fine platinum wire (about 1/20,000 inch in diameter), which may be fed downwards by turning the milled-head screw *S*. In order to manipulate so fine a platinum wire, a composite wire is employed about 1/300 inch in diameter, composed of silver with the minute platinum wire as a core. When the end of this composite wire is brought into contact with the surface of the nitric-acid solution, the silver dissolves away, leaving the central platinum filament intact. This instrument being connected in a path between the receiving mast wire and ground, the electric impulses produced by the passing wave or waves pass into the liquid through the tip of the fine platinum filament. The liquid layers surrounding the tip being necessarily very constricted in area, a relatively high resistance is there produced. The passage of the electric impulses through these layers of liquid serves definitely to reduce the resistance of the apparatus, and thus enables a local voltaic battery to send momentarily a stronger current through the same, and through a telephone inserted in the local circuit. Each electric wave or train of waves, therefore, produces a sound or signal in the telephone. Dots and dashes thus received can be interpreted into the language of a message by a skilled operator at the telephone.

Another form of receiver employing the telephone as the operated instrument is the magnetic detector of Fig. 171, shown both in front and in side elevations. This consists of a small induction coil. The primary coil *b* is wound upon a horizontal tube *g*, and is connected between the air-wire *A* and the ground *G*. External to the primary coil is the secondary coil *c*, which is directly connected to the receiving telephone *T.* The iron core of the induction coil is not a fixed bundle of wires; but consists of a strip or band of iron wires *a*, moved over the pulleys *e e* by a small mechanical driving motor not shown in the illustration. Under these

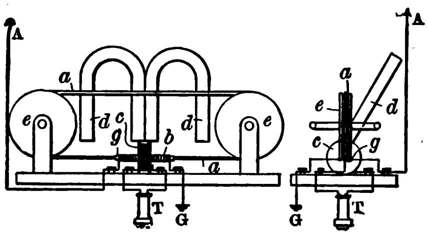


FIG. 171.

conditions the flexible iron-wire core moves at a low speed through the primary and secondary coils, in proximity to the poles of the fixed permanent magnets *d d.* These magnets are so placed and adjusted that they cause the magnetization of the iron-wire core to become magnetically unstable in the part which is entering the primary coil. Consequently, very feeble oscillations of current received from the air-wire through the primary coil will be enabled to shake the magnetism out of the core in this critically unstable magnetic condition. In the absence of such oscillatory currents, however, the magnetic condition would remain unchanged in the core until after it had passed through the coil and come before the pole of the magnet *d* beyond, when the magnetism would be removed and reversed. The continuous movement of the iron core over the pulleys provides a continual renewal of magnetic instability in the core, which is thus always ready to be demagnetized by the action of currents from the receiving mast wire. The change in magnetization effected in this way by the primary current induces much larger secondary impulses in the secondary circuit through the telephone than would be possible if the iron core were not in the critical magnetic condition of remanent magnetization. Like the liquid receiver, this magnetic receiver is self-restoring; whereas the coherer of Fig. 169 is not self-restoring, but needs mechanical agitation.

The telephone-operated types of receiving instruments have the advantage of great sensitiveness and speed of operation. The coherer type has, however, the advantage of permitting an automatically printed record to be made of the messages in dots and dashes.

It is evident that one and the same mast and antenna will serve both for sending and for receiving signals. Fig. 172 indicates such an arrangement. Here

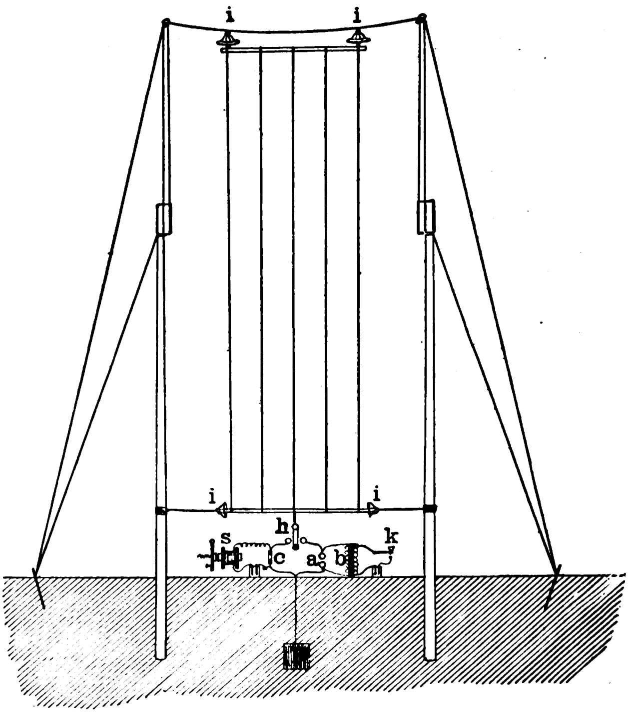


FIG. 172.

a pair of masts supports a harp of several similar wires, all connected electrically. Such a plurality of wires is nearly equivalent electrically to a solid sheet of metal, and offers far less wind-surface than a metallic sheet. The harp offers a larger surface of electric radiation and is thus preferable to a single wire for launching the electric waves. Four insulators *i* serve to insulate the suspended electric oscillator. The insulation must be sufficient to keep the electric leakage negligible, under all conditions of weather, at a pressure of many thousands of volts, generated by the induction coil. When the switch *h* is turned to the right, the apparatus is connected for sending messages at the key *k*. When the switch is turned to the left, the antenna is connected to the receiver *c*, here shown as a coherer.

It is evident that the range of possible transmission of wireless messages will depend, first upon the energy of the waves created at the sending station, or, in mechanical analogy, upon the violence of the electric splashes; and second, upon the sensitiveness of the receiving apparatus, as well as the extent of surface of the wave which can be caught and forced to deliver up its electric energy to the receiver. A tall mast, and a large expanse of antenna, assists not only to create a large splash, when sufficient electric power is available at the sending station, but also offers a large catchment area to receive the energy of passing waves at the receiving station. Consequently, the longest ranges of transmission have been secured with powerful electric generators, tall and ample sending and receiving antennæ, and very delicate receiving instruments.

Since any single sending station sends out waves in all directions, its emitted waves tend to influence all receiving air-wires, especially those in the immediate neighborhood. It has not been found possible to direct such waves in a straight beam from the sender to the receiver. With ordinary light such parallel beams are produced with the aid of a reflector behind the light-source. But the reflector must have dimensions that are large with reference to the wave-length. This condition is easily complied with in the case of the electromagnetic waves of visible light; but cannot readily be complied with in the case of wireless telegraph waves, considering that their wave-length is many yards and that adequate reflectors of sheet metal or wires would need to be many times as great in linear dimensions.

The fact that a receiving antenna is open to the reception of waves from any number of sending stations simultaneously opens the possibility of interference between messages, to the confusion of all parties. Various devices have, however, been either applied or suggested for effecting selective signalling, whereby any one receiving station would only receive the signals intended for its reception. The principal method employed depends upon the tuning of the receiving mast wire or mast circuits to one, and only one, frequency or length of wave, whereby waves of that frequency and length only may be capable of operating the receiving instrument. This plan has met with a considerable measure of success. There are always difficulties, however, in the way of exact tuning.

The great value of wireless telegraphy is found over the oceans between fixed stations, or floating stations, or both. It can be carried on between vessels that are hidden from each other, either by sea, land, distance, or fog, during day or night, and in fair or cloudy weather.

INDEX.

A

B

C

D

E

F

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

Z