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Modern practice of the electric telegraph

Franklin Leonard Pope

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MODERN PRACTICE

OF THE

ELECTRIC TELEGRAPH.

A HANDBOOK

FOR

ELECTRICIANS AND OPERATORS.

By FRANK L. POPE.

CLINTON HALL
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PREFACE.

During the quarter of a century which has elapsed since the introduction of the Electric Telegraph in the United States, those engaged in its service have been almost entirely dependent upon verbal instruction, and long practical experience, for a thorough technical knowledge of their profession. The works heretofore accessible to the American Telegraphist have been of a popular, rather than a scientific character, or else of so elementary a nature as to be of little service except to the most inexperienced students.

The present work has been prepared with a view of supplying, in some measure, an acknowledged deficiency in telegraphic literature—a treatise for the practical electrician and operator, written in a concise but clear manner, avoiding as far as possible all scientific and technical expressions, and embracing all the recent discoveries and improvements which have stood the test of actual experience.

The author is aware that several excellent foreign works have appeared within the past few years, but aside from the fact that the systems of telegraphy to which they refer differ in many respects from our own, the difficulty and expense of obtaining them has prevented their general circulation among the class for whom this treatise is more especially designed.

It is hoped that a work of this kind will not only be serviceable to the student, as well as to the more advanced electrician, but also tend to arouse an interest in the subject among many who have hitherto been content to employ the services of electricity in their daily business, without caring to acquaint themselves with the laws which govern its operation.

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The system of testing telegraph lines by actual measurement, which has been employed for some years in Europe with the most excellent results, and which is beginning to attract much attention in this country, has been fully treated upon and explained, in a manner which, it is hoped, will give the reader a complete and satisfactory knowledge of the subject.

The principles laid down for the guidance of the student in the formation of the telegraphic alphabet, and the subsequent progressive exercises, intended for practice with the key, differ but slightly from those employed by the author, while teaching a class of students for the American Telegraph Company, in the city of New York, during the year 1864. This system was believed at that time to be original, but as a plan embodying substantially the same principles was devised and subsequently published by Prof. J. E. Smith, in his valuable little manual, with modifications and improvements—some of which have been adopted in the present treatise—it seems proper to make this explanation of the circumstances. The author would recommend Prof. Smith's work to the student desirous of becoming acquainted with the business forms, abbreviations, etc., employed in transmitting railway and commercial business by telegraph.

In conclusion, the author would also acknowledge his obligation to the excellent works of Culley and Sabine on the Telegraph, and the recent treatise of Latimer Clark on Resistance Measurement, as well as to the researches of Messrs. C. F. Varley, David Brooks, M. G. Farmer, and other Electricians. Much valuable material has also been obtained from the columns of *The Telegrapher*.

The illustrations of apparatus contained in this volume have, for the most part, been engraved expressly for its pages, the drawings having been made by the author from instruments kindly loaned him for the purpose by the manufacturers.

ELIZABETH, N. J., *March*, 1869.

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MODERN PRACTICE

OF THE

ELECTRIC TELEGRAPH.

CHAPTER I.

ORIGIN OF THE ELECTRIC CURRENT.—GALVANIC BATTERIES.

1. Simple Galvanic Circuit.—If two plates of different metals, such as copper and zinc for example, are immersed in a vessel of water to which a small portion of sulphuric acid has been added, and the upper ends of the two plates are brought in contact, or connected together with a metallic wire as in fig. 1, a continuous

Fig. 1.

current of electricity will pass from the copper to the zinc through the connecting wire, and from the zinc to the copper through the liquid, as indicated by the arrows in the figure. If the metallic communication be interrupted, or the *circuit*, as it is termed, broken, the current at once ceases, but is instantly renewed whenever the connection is again formed. Electricity produced by this means is usually termed Galvanic or Voltaic electricity, from the names of its discoverers, and is the effect of chemical action by the acidulated water

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2. The plate (usually of zinc), upon the surface of which the electricity is generated by chemical action, is called the *negative pole*, and the opposite plate, generally of copper, platina or carbon, is called the *positive pole*. They are also frequently designated by the signs — (minus) and + (plus).

3. If both metals in this arrangement were equally acted upon by the solution, no electricity would be produced, as this effect arises in all cases from the difference in the chemical action upon the two plates. For this reason the positive plate is made of some metal or other substance upon which the liquid has little or no effect.

4. The apparatus for producing voltaic electricity, which has been described in its simplest form, is called a *battery*. As electricity is produced under any circumstances in which the above conditions have been complied with, there are various methods of constructing a battery. The forms used in the practical operation of the telegraph will hereafter be described in detail.

5. Conductors and Non-Conductors.—Some substances, such as metals, possess the property of allowing electricity to diffuse itself freely throughout their whole substance, and are therefore termed *conductors*. Others, such as glass, hard rubber, and dry wood, offer great resistance or opposition to this diffusion, and are called *non-conductors* or *insulators*.

6. This division however is relative and not absolute. Few if any bodies are perfect insulators, and even metals, the most perfect of all conductors, offer *some* resistance to the passage of electricity, or in other words insulate slightly. A good insulator, therefore, is simply a bad conductor, and *vice versa*.

7. In the following list each substance named conducts better than that which precedes it, the first being the best insulator and the last the best conductor:

Dry Air,
Paraffine,
Hard Rubber,
Shellac,
Dry Paper,
Porcelain,
Dry Wood,
Dry Ice,
Lead,
Tin,
Iron,
Platinum,

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India Rubber,	Water,	Zinc,
Gutta Percha,	Saline Solutions.	Gold,
Sulphur	Acids,	Copper,
Glass,	Charcoal or coke,	Silver.
Silk,	Mercury,	

8. Electrical Tension.—If two or more simple batteries. or *elements* as they are called, are connected together in such a manner that the positive plate of the first is united by a metallic conductor with the negative plate of the second, and so on, as shown in fig. 2 the

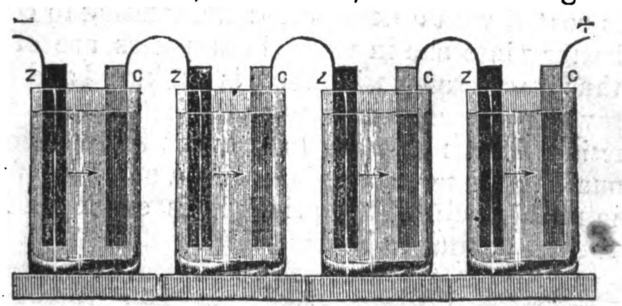

Fig. 2.

electrical *tension*, or power of overcoming resistance, is increased in direct proportion to the number of elements. Four elements will therefore possess four times the tension of one element, and the current generated by their combined action will be capable of overcoming four times the resistance of that from a single element.

9. Electrical Quantity.—It is important, however, to observe, that although the *tension* increases with each element added to the series, no greater *quantity* is produced by a great number of elements than by a single one—the action in each cell serving only, as it were, to *urge forward* a quantity equal to that arising from chemical decomposition in the first cell. If, on the contrary, we connect together the four zincs and the four coppers, forming in effect a single element, with plates equivalent to four times the original surface, there will be four times the original quantity of electricity generated; but its tension, or power of overcoming resistance, will be no greater than that of a single pair of plates. This distinction is of great importance,

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and should be thoroughly understood and carefully remembered.

10. In the simple form of battery previously described (8), if the poles are united by a conductor for a considerable length of time, bubbles of hydrogen, arising from the decomposition of the water, cover the positive plate, and in a great measure prevent the liquid from coming in contact with it, and the surface of the plate also becomes coated with a deposit of zinc, tending to convert the battery into one in which both plates are of zinc, and thus its electro-motive force is weakened and finally destroyed. In order to render the battery *constant* in its action, it is necessary to prevent these effects by surrounding the negative plate with a solution of a salt of the metal itself. This principle is employed in the arrangement about to be described.

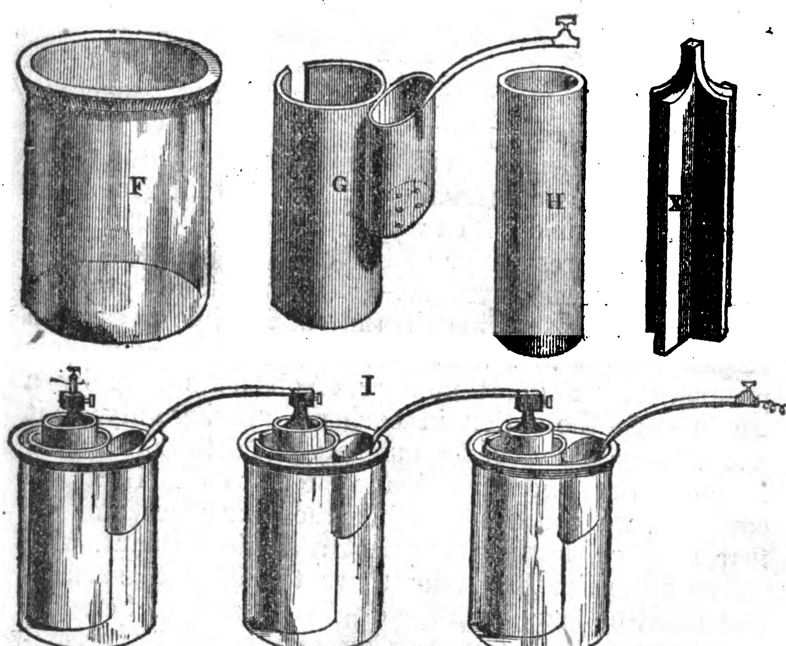

FIG. 3.

11. THE DANIELL BATTERY.—This combination consists of a jar of glass or earthenware, F (fig. 3), about six

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inches in diameter and eight or nine inches high. A plate of copper, G, is bent into a cylindrical form, so as to fit within it, and is provided with a perforated chamber, to contain a supply of sulphate of copper in crystals, and a strap of the same metal with a clamp for connecting it to the zinc of the next element. H is a *porous cup*, as it is technically termed, made of unglazed earthenware, six or seven inches high and two inches in diameter, within which is placed the zinc, X. This is usually of the shape shown in the figure, which is called the "star zinc," but it is often made in the form of a hollow cylinder, the latter giving greater power, but being somewhat more difficult to clean.

The outer cell is filled with a saturated solution of sulphate of copper (blue vitriol), and the porous cell with a solution of sulphate of zinc. A series of three elements connected together, as usually employed on American lines for a *local battery*, is shown at I.

12. Effect of Continued Action.—By continued action sulphate of zinc is formed in the porous cup, and the sulphate of copper in the outer cell consumed, the zinc being constantly dissolved away while the copper plate is at the same time increased. When all the sulphate of copper has been decomposed, and the water in the zinc compartment saturated with sulphate of zinc, the action of the battery ceases. Some of the sulphate of zinc in this case usually passes into the copper cell, and appears upon the copper plate in the form of a black powder; it is therefore necessary to maintain a constant supply of pulverized vitriol in the perforated chamber attached to the copper cylinder.

13. When the solution in the porous cup becomes saturated with sulphate of zinc it crystallizes upon the zinc plate, interfering with the action of the battery. Part of this solution should therefore be removed occasionally and replaced with water.

In setting up the battery pure water may be used in the porous cell, and the battery allowed to stand a few hours with a closed circuit, when it will be found

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ready for use. The addition of a little sulphate of zinc will greatly hasten its action.

14. THE DEPOSIT OF COPPER UPON THE POROUS CUP.—This cannot be entirely prevented, but may be greatly lessened by suspending the zinc so that it will not touch the porous cup below the surface of the liquid, and by saturating the bottom of the cell to the height of half an inch with melted paraffine.

15. When constructed as above described and used in a local circuit, the Daniell battery will continue in action about ten or fifteen days without attention, the time depending upon the size of the wire in the magnet and the amount of daily service. The sulphate of copper solution should be kept of good strength, otherwise the upper portion becomes weak and an extra current is set up within the battery, which tends to eat away and destroy the copper plate without any useful effect.

16. RENEWAL OF THE BATTERY.—In renewing this battery the zincs should be scraped and well cleaned with a stiff brush, the porous cups thoroughly washed, and the old solution contained in them thrown out, with the exception of about one third of the clear portion, which should be returned, otherwise the battery will require some hours to recover its full strength. The copper deposit upon the zincs is valuable, and should be preserved.

Every two or three months the coppers ought to be taken out and the deposit upon their surface removed, which may be done two or three times. When they become too much encrusted to afford room for the porous cups they must be replaced by new ones.

Porous cups ought to be renewed whenever they become too much encrusted with copper. If cracked they should be changed at once, otherwise a great waste of material will ensue.

17. The crystals which form around the edge of the outer jar require to be occasionally wiped off with a damp cloth, or they will eventually run down the outside and form a connection between the jars, giving rise

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to a great consumption of material without corresponding benefit.

18. In order that the current may act with its full force, it is necessary to keep the clamps and connections of the battery clean and bright, and free from rust or dirt. As chemical action is promoted by heat, the battery will act more vigorously if kept in a warm place.

19. Application of the Daniell Battery to Main Circuits.—This battery is sometimes used for main circuits, but in that case it is preferable to arrange it differently by placing the zincs outside and the copper within the porous cell, as in fig. 4, in which Z shows the

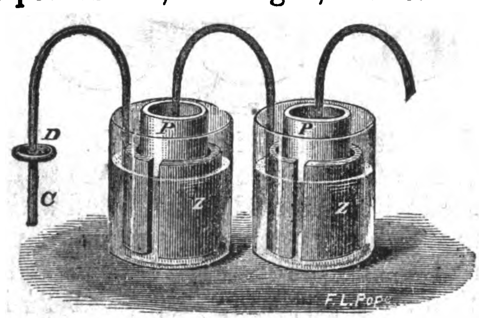

Fig. 4.

zinc and P the porous cell. The copper, C, is provided with a perforated shelf, D, upon which the vitriol is placed.

Other forms have been devised which dispense entirely with the porous cup, the two solutions being separated by the difference in their respective specific gravities. Some of these bid fair to come into extensive use.

20. The Grove Battery.—The most intense and powerful voltaic combination that has yet been discovered is that of Grove. For many years it was exclusively used for telegraphic purposes in this country, and is still employed in that capacity to a considerable extent. Its component parts are shown in fig. 5, in which A represents a glass jar or tumbler, about 3

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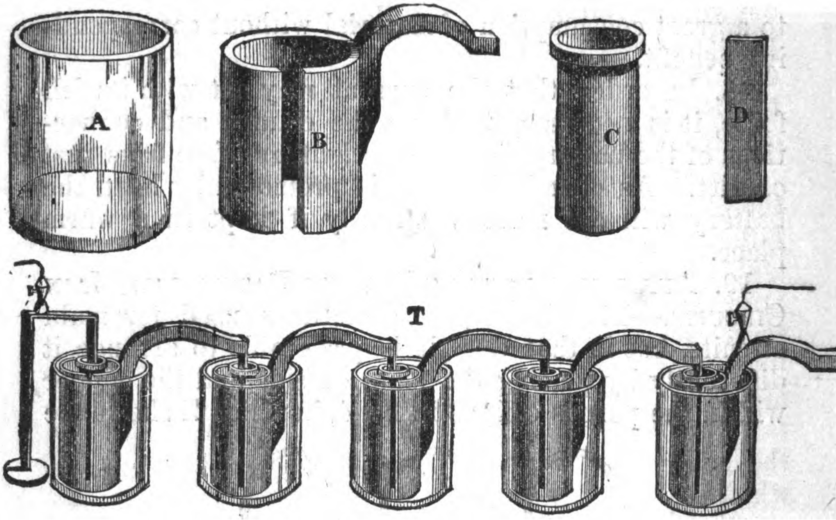

FIG. 6.

inches in diameter and 4½ inches high. A thick cylinder of zinc, B, of a size nearly sufficient to fill the tumbler, is placed within it, and is furnished with a projecting arm, to which is attached the positive plate of the next element. The porous cup, C, is placed within the zinc. A thin strip of platina, D, about 2½ inches long and half an inch in width, is soldered to the end of the zinc arm projecting from the adjacent cell, and reaches nearly to the bottom of the porous cup.

21. SETTING UP A GROVE BATTERY.—It is necessary that the zinc should first be thoroughly *amalgamated*. The ordinary zinc of commerce contains particles of lead, iron, and other impurities, which, when the plate is immersed in dilute acid, form as it were small batteries upon the surface, which eat away numerous cavities in the zinc without producing any useful effect. This is termed *local action*, and may be, in a great measure, prevented by the above process of amalgamation, which is usually performed by immersing the zincs in a vessel containing dilute muriatic or sulphuric acid, and then plunging them in a bath of metallic mercury. After remaining in this for a minute or two they are taken

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out and placed in a vat of clean water, where the superfluous mercury is allowed to drain off. The mercury dissolves a little of the zinc, which flows over and covers the impurities, and prevents the acid solution from coming in contact with them.

22. In putting the Grove battery together, first place the glass tumblers in position and fill them about half full of a solution composed of one part of sulphuric acid and twenty to thirty parts water, by measure, thoroughly mixed. Then place the amalgamated zincs in the tumblers, with the arms turned at right angles to the line of cells. Fill the porous cups nearly full of strong nitric acid and place them within the zincs, then turn the zincs around so as to immerse the platina strips in the nitric acid of the adjoining cell, throughout the whole series, as shown at T, in fig. 5.

23. The strength of the dilute sulphuric acid solution in this battery should be varied in proportion to the number of wires worked from it. The less the number of the latter the weaker the solution may be made.

24. When in continuous service a Grove battery ought to be taken apart every night, and the nitric acid from the porous cups emptied into a vessel and kept closed until morning. The zincs should be removed and placed inverted in a trough of water, acidulated with sulphuric acid, and in the morning rubbed with a brush, and the mercury diffused evenly over their surfaces. To every ten parts of the nitric acid taken from the battery add one part of fresh acid every morning. By this means a steady and uniform current will be maintained when the battery is in action. The dilute sulphuric acid requires renewal about twice a week. In handling this battery great care is required not to injure the connection between the zinc and the platina. A set of Grove zincs, in continuous service, will require renewal about once in three months.

25. THE CARBON BATTERY.—This is a modification of the Grove battery, and is sometimes called the Electropoion battery. It is extensively employed on the Ame-

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rican lines for main circuits. In its general construction and arrangement it differs but little from the battery last described. The different parts of which it is composed are shown in fig. 6, consisting of a glass tumbler, zinc and porous cup. In place of the platina of the Grove battery, a plate of carbon or coke is employed for the positive element, as shown in the figure.

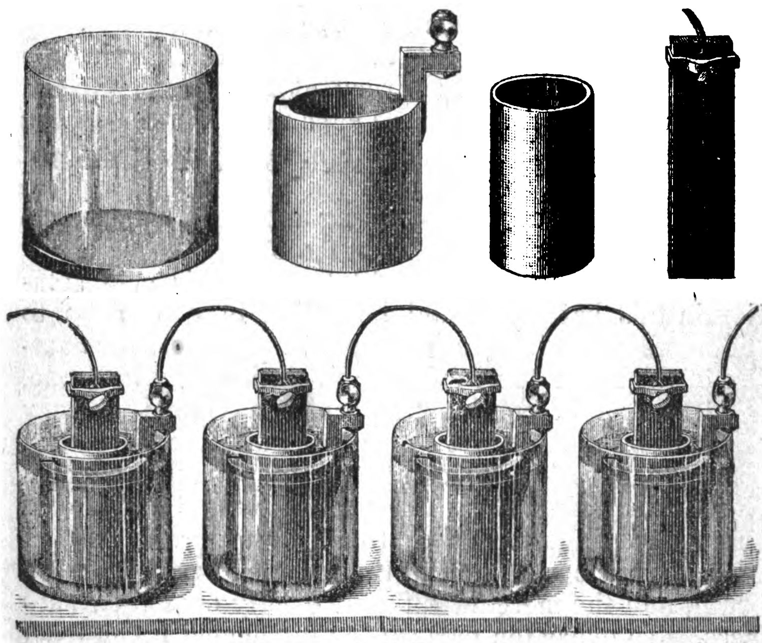

FIG. 6.

A clamp is arranged so as to press a platina button firmly against the carbon, this button being permanently attached to a wire leading to a binding screw on the zinc arm of the next element. The parts are usually made of about the same size as in the Grove battery.

The carbon connection is sometimes made by means of a platinized copper wire inserted into its upper end, and surrounded with lead, to prevent the action of the acids upon the copper.

26. In setting up this battery the different parts

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should be put together in the position they are to occupy, as shown in fig. 6, and care taken that all the connections are firmly screwed up. The zincs must be thoroughly amalgamated, and the dilute sulphuric acid solution mixed as directed for the Grove battery. A sufficient quantity of this solution is poured into the tumblers to cover the cylindrical portion of the zincs. The porous cups are then filled with a solution of bi-chromate of potash,* care being taken not to pour it upon the connections or clamps.

27. When the battery is in service, one third of the bi-chromate solution in the porous cups should be removed every morning by means of a large rubber syringe, and replaced with fresh. A new set of zincs will require to be amalgamated a second time after having been in use three or four days; after which once in two to four weeks will be often enough—depending somewhat upon the amount of work required from the battery. The battery ought to be taken apart every two weeks, the zincs brushed, the dilute sulphuric acid solution renewed, and the carbons thoroughly soaked in clean water. It is better, if possible, to have a spare set of cells complete, so that one may be renewed while the other is in use.

28. Power of the Carbon Battery.—This is quite equal to that of the Grove, as far as the intensity of its action is concerned. The latter however will work nearly twice as many wires at the same time as the former. The expense of the carbon battery for materials and attendance is less than one third that of the Grove. A set of zincs, if properly cared for, will last from fourteen to sixteen months on an ordinary telegraph line. It is a good plan to coat the zincs with asphaltum varnish at the junction of the projecting arm, as these are frequently eaten off while the rest of the zinc remains in good condition.

* This solution is made as follows: Mix one gallon of sulphuric acid and three gallons of water. Then, in a separate vessel, dissolve five lbs. bi-chromate of potash in two gallons of boiling water and add to the above, mixing the whole thoroughly together. The proportion of bi-chromate is sometimes made one fifth greater than the amount given.

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29. INSULATION OF BATTERIES.—The cells of a battery should always be thoroughly insulated from each other. This is especially important in the case of the Grove battery. A convenient and effective mode of insulation is shown in fig. 7, in which the battery tumblers, AA, are set upon hollow cylinders of wood, BB, saturated with asphaltum or paraffine, and insulated from the upright wooden pins, DD, by the glass sockets, CC. The pins are inserted into a horizontal scantling, E, which forms the top of the battery stand.

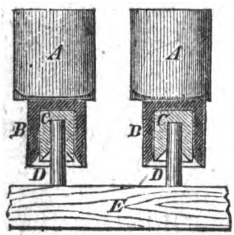

FIG. 7.

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CHAPTER II.

ELECTRO-MAGNETISM.

30. Whenever the poles of a battery are connected by a conductor, or series of conductors, so as to form a *circuit*, a *current* of electricity is assumed to flow from the negative to the positive pole, through the battery itself, and from the positive to the negative pole through the conductor.

31. If the conducting wire is covered with an insulator (5), such as silk or cotton; so as to compel the current to traverse its entire length, and is wound into a spiral or coil, surrounding a magnetic needle, the needle will be deflected from its natural position, and will tend to take up a position at right angles to the direction of the current. If the current be passed in the opposite direction through the wire, the deflection of the needle will also take place in the opposite direction. The *Galvanometer*, an extremely useful instrument for the purpose of indicating the presence, direction, and strength of a voltaic current, is constructed upon this principle.

32. If the conducting wire, covered as above, be wound upon a bar of soft iron, the iron becomes *magnetic* as long as the current continues to flow, and possesses the property of attracting other pieces of iron in its vicinity. This arrangement is called an *electro-magnet*.

33. If the iron is very soft and pure it loses its magnetism instantly upon the cessation of the current, but if impure, or if hardened by hammering or turning, it retains a certain amount of *residuary magnetism*, especially after it has been acted upon by a powerful current. It is, therefore, necessary that the iron *cores*, as they are termed, of electro-magnets, should be annealed with great care.

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34. Electro-Magnets are generally made in a U form, two bobbins or spools, *a a* (fig. 8), being filled with covered copper wire, and the soft iron cores, *c c*, passing through them, fixed upon a connecting bar, *b*, also of soft iron, as shown in the figure. The two spools, *a* and *a*, are virtually continuations of one spool, the direction being apparently reversed by the bend of the U. The ends of the cores, *c c*, opposite to the connecting bar, are called the *poles* of the magnet, the magnetic force being accumulated at these points. The bar of soft iron, *d*, upon which the magnet exerts its force, is called the *armature*.

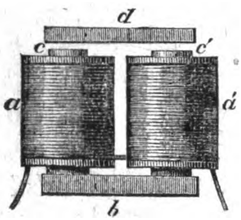

Fig. 8.

35. In electro-magnets and galvanometers the magnetic effect of the current is multiplied by the number of convolutions of the wire in the coil, but it is diminished in proportion to the distance of the wire from the core, each layer of wire acting with less power than the one beneath it.

36. Every addition to the length of the conducting wire enfeebles the current, because of the increased resistance (5, 6,) it offers to its passage. In a very long circuit, such as a telegraph line, the action of the current will necessarily be feeble, and the coil is, therefore, made of *fine* wire, which occupies little space, and allows many layers to be wound on without too greatly increasing the distance from the cores, while its resistance is too small in proportion to the rest of the circuit to reduce the strength of the current materially.

37. When, however, the circuit is very short, coarser wire is employed in the coil. A fine wire would add to the resistance of the circuit more than would be made up by the effect of an increased number of turns, for even a very few layers would double the resistance of the circuit.

The former is frequently called an *intensity*, and the latter a *quantity magnet.*

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38. Iron does not acquire its full magnetism instantaneously, and the act of demagnetization also requires time, but is effected more rapidly than magnetization. The greater the tension of the battery the more rapidly the iron acquires its magnetism; therefore, if very rapid action is required, even on a short circuit, a number of cells of battery must be used.

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CHAPTER III.

TELEGRAPHIC CIRCUITS.

39. A Telegraphic Circuit consists of one or more batteries, the line wire, the instruments and the earth. When the circuit is very short a return wire is frequently used instead of the earth.

40. Owing to the immense rapidity with which the electric force is propagated throughout a circuit, any effect which can be produced at hand can be produced in any other part of a circuit, however distant, at the same instant of time, subject to a diminution of force, arising from causes which diminish the quantity of electricity, or the force of the current before its arrival at the distant end, thus weakening its effect. The principal causes of this diminution are the resistance of the circuit and defective insulation, in consequence of which a portion of the current escapes from the line to the earth, and returns without traversing the distant portion of the circuit.

41. The *effective force* of the current leaving the battery depends upon two things—the *tension* of the battery, which sets the current in circulation, and the *resistance* the current encounters in traversing the circuit.

42. Resistance of the Circuit.—This depends upon the length and size of the conductor, and the material of which it is composed. In an ordinary telegraphic line wire the resistance is in direct proportion to its length, and also in inverse proportion to its weight per mile. Thus, 150 miles of No. 8 wire will conduct as well as 100 miles of No. 10 wire, and as great an effect can be produced at its remote end with a battery of equal tension. There is, therefore, a great advantage

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in using the larger sizes of wire in the construction of lines intended to be worked in long circuits.

43. ELECTRICAL MEASUREMENT.—In order to institute a comparison between the resistances of different circuits, etc., a standard has been fixed upon by the British Association, called the *Ohm*, which is equivalent to about $\frac{1}{16}$ of a mile of galvanized No. 9 iron wire, such as is usually employed in the construction of telegraph lines. This standard unit of resistance is now made use of in all electrical measurement.

44. RESISTANCE COILS.—As no battery is constant in its power, and no magnet uniform in its strength, neither of these can be made use of as an accurate basis of comparison. *Resistance coils*, composed of wire of certain alloys of metals, carefully prepared, have been found not to vary $\frac{1}{1,000,000}$ in eight years. The only variation is that due to difference in temperature, which may be readily calculated and allowed for when necessary.

It will, therefore, be understood that the ohm is a unit of resistance in the same manner that an inch is a unit of length, or a pound a unit of weight.

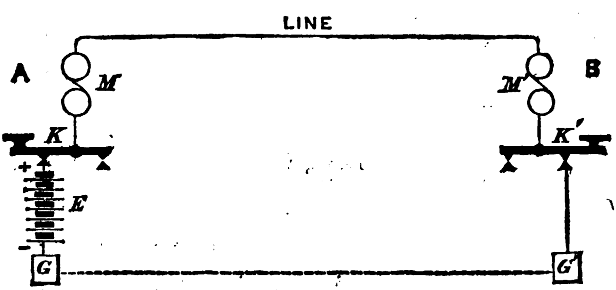

FIG. 9.

45. A TELEGRAPHIC CIRCUIT, in its simplest form, is shown in fig. 9. A and B represent two stations. The circuit may be traced as follows: From the + pole of the battery E to the key K (52) and electro-magnet M, thence through the line L to the other station, electro-magnet M′ and key K′ to the earth at G′, and thence through the earth, as represented by the dotted line, to the − pole of the battery E. A continuous current will

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therefore flow through the circuit as long as it remains uninterrupted, and the armatures of the electro-magnets M and M′ will be attracted by the cores, but if the circuit be broken by means of one of the keys, K or K′, both electro-magnets will be demagnetized. Thus, the breaking of the circuit at either station affects the electro-magnets of both, as they are in the same circuit.

46. The Earth Circuit.—In thus using the earth as part of the circuit, it is found that it offers, practically, no resistance to the passage of the current. Although comparatively a poor conductor, it is an infinitely large one in proportion to the wire, and, therefore, its resistance is not appreciable (42).

47. Arrangement of Batteries.—In practice it is usual to divide the battery E into two parts, placing half at each end of the line, for reasons which will hereafter appear. It is important, however, when this is done, that the positive pole of one battery should be connected with the negative pole of the other, otherwise they would neutralize each other, and no effect would be obtained. In such a case the batteries are said to be *reversed.*

48. Intermediate Stations.—It is evident that intermediate stations may be introduced at any point upon the line shown in the above figure, each being provided with an electro-magnet and key, forming part of the circuit, and that the breaking and closing of the circuit at any of these points will affect all the electro-magnets through which it passes, in the same manner and at the same instant of time.

Any desired number of intermediate stations may be placed upon a line until the combined resistance of their electro-magnets reduces the strength of the current below that required for the convenient working of the circuit.

49. The Morse System.—The principle of the Morse system of telegraphy consists in conveying arbitrary signals by means of the magnetization and demagnetization of an electro-magnet, by the alternate breaking

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and closing of a voltaic circuit in the manner above explained. The conventional alphabet used in America for this purpose is given in another part of this work.

50. OTHER TELEGRAPHIC SYSTEMS.—The type printing telegraph, employing the "Combination" instrument of Phelps, is the only system other than the Morse now in use upon the public lines in the United States. The limited extent to which it is employed renders it unnecessary to give a detailed description of its construction and mode of operation in a work of this kind. The electro-chemical telegraph of Bain, and the beautiful type-printing instruments of House and Hughes, were formerly extensively employed in this country. The former has now given place to the Morse, while the two latter have been superseded by the equally rapid and more simple and effective instrument of Phelps.

In addition to these, the magneto-electric dial instrument of Edmands & Hamblet, and the electro-magnetic alphabetical instrument of Chester are finding extensive employment upon private lines, where extreme rapidity of transmission is not required, thus rendering the employment of skilled operators in such cases unnecessary.

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CHAPTER IV.

THE MORSE, OR AMERICAN TELEGRAPHIC SYSTEM.

51. THE Morse Telegraphic Apparatus consists of a signal key for breaking and closing the circuit, and an electro-magnet, the armature of which is attached to a lever carrying a steel point or style, which embosses a mark upon a narrow strip of paper, moved uniformly along by clock-work. As long as a current continues to flow through the coils of the electro-magnet the armature is attracted, and a mark is made upon the moving paper. As soon as the circuit is broken the armature ceases to be attracted, and is withdrawn from contact with the paper by means of a spring. The duration of the current, and consequently the length of the mark, depends upon the duration of the contact made by the key.

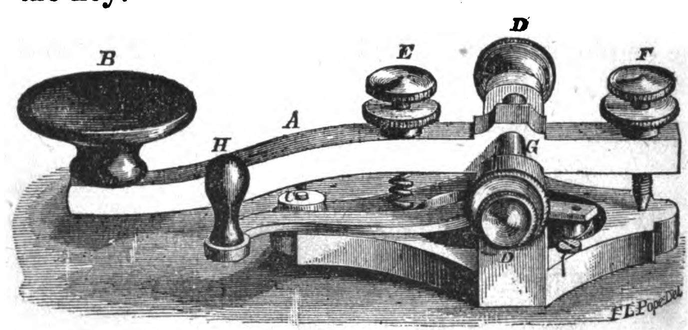

FIG. 10.

52. THE MORSE SIGNAL KEY is shown in fig. 10.* It consists of a brass lever, A, four or five inches in length, which is hung upon a steel arbor, G, between adjustable set screws, D D, in such a manner as to allow it to move freely in a vertical direction. This movement, however, is limited in one direction by the *anvil* C, and in the other by the adjustable set-screw, F.

* The drawings of the signal key, register and relay (figs. 10, 11 and 12), are from instruments manufactured by Bradley.

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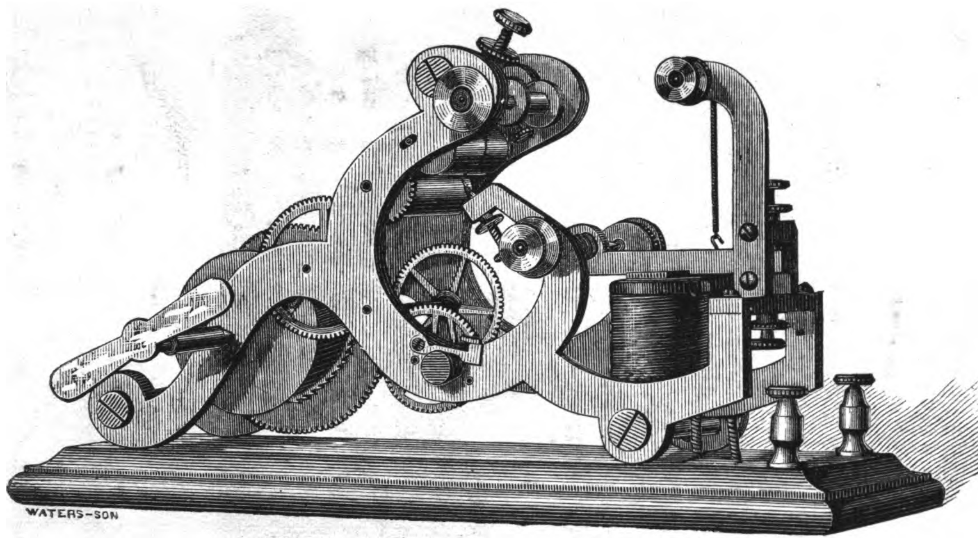

MORSE REGISTER.

Manufactured by L. G. Tillotson & Co., New York.

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One wire of the main circuit is connected to the metallic frame of the key, and the other to the anvil, C, which is insulated from the frame. These connections are made by screws passing up through the table from beneath. The lever is provided with a knob of vulcanite, B, by means of which it may be pressed down by the finger of the operator, bringing the lever in contact with the anvil, and thus closing the circuit, precisely as if the wires themselves had been brought together. The points of contact between the lever and the anvil are made of platina, as ordinary metals would be fused by the passage of the electric spark when the circuit is broken. A spring beneath the lever restores it to its original position when the pressure of the operator's finger is withdrawn. When the key is not in use the circuit is completed by bringing the lever of the *circuit closer*, H, into contact with the anvil, C.

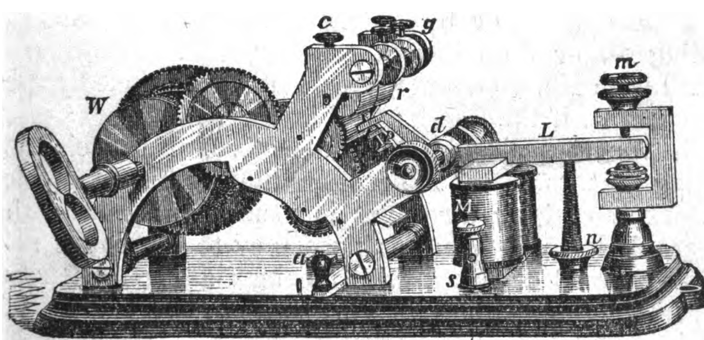

Fig. 11.

53. The Morse Register.—Fig. 11 represents the recording apparatus, usually termed a *register*, which is made in several different forms, all involving the same principles. M is the electro-magnet, the two ends of the wire forming the coils being carried to the terminal binding screws on the base, one of which is shown at *s*, to which the conducting wires are attached. Above the electro-magnet is seen the armature attached to the lever L, which moves upon an arbor at *d*. The opposite extremity of the lever carries a steel point, *p*.

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The strip of paper passes through the guide *g* and between the grooved rollers *r r*, which are moved by a train of wheels driven by a weight attached by a cord to the drum, W.

When the armature is attracted by the magnet the style *p* is brought forcibly in contact with the paper, moving above it upon the grooved roller, and a raised line is embossed upon it corresponding in length to the time the armature remains attracted. A spring adjusted by the nut *n* withdraws the lever when the attraction ceases. The movement of the lever is limited by the adjustable screw, *m*. The screw *c* regulates the pressure of the rollers upon the paper. and the clock-work is started and stopped by the brake *a*. The weight is wound up occasionally, as required, by the operator.

54. The Morse instrument is worked either by the *main line* current or by *relay*. For a distance not exceeding 20 or 30 miles, a register, whose coils are wound with No. 30 copper wire, may be worked by the line current, if the line be well insulated (57).

55. When the insulation is defective, or the circuit so long that its resistance renders the current too weak to work a register direct, as is usually the case with telegraph lines, it becomes necessary to employ a *receiving magnet* or *relay*, which brings a local battery (11) into action at the receiving station, the current of which operates the register.

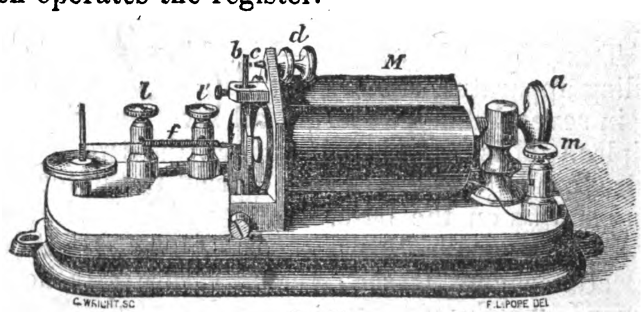

FIG. 12.

56. THE RELAY MAGNET.—The construction of the relay is shown in fig. 12. M is the electro-magnet,

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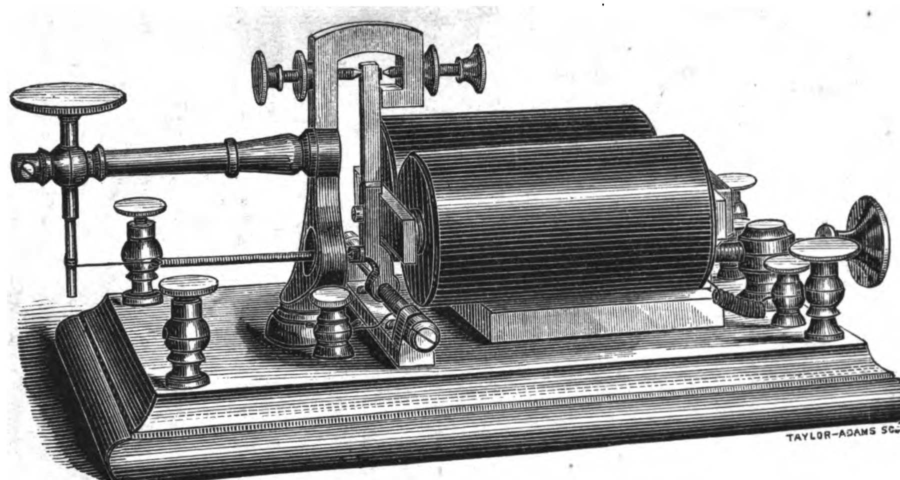

RELAY MAGNET.

Manufactured by Charles Williams, Jr., Boston, Mass.

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which is placed in a horizontal position, and is movable by means of the screw *a*. The coils of the magnet are of fine wire, usually from No. 30 to No. 36 in size, of great length and closely wound.* The ends are connected to the line circuit by the binding screws, *m m'*. The armature lever *b* is connected with the binding screw *l* by a wire carried underneath the base of the instrument. A platina point, *c*, on the armature lever, is brought in contact with a similar point on the end of the screw *d* whenever the armature is attracted by the magnet, the screw being in metallic connection with the binding screw *l'*, by means of the frame of the apparatus and a wire beneath the base. One of the screws, *l l'*, is connected to one pole of the local battery (11), and the other to the other pole, embracing the register magnet in its circuit. Therefore, whenever the armature is attracted by the force of the main current acting upon the relay magnet, the circuit of the local battery is completed through the register. As the relay is constructed with great delicacy, a feeble line current is enabled to actuate a register powerfully through the intervention of a local battery.

The movement of the armature is regulated to correspond with the varying strength of the line current by means of the adjustable spiral spring *f*. The magnet may be also set at any required distance from the armature by means of the screw *a*, which is cut with a right and left hand thread, passing through the soft iron bar connecting the two cores, and also through the supporting post in the rear of the coils. The latter slide through openings in the upright metallic plate which supports the adjustable platina pointed screw *d*.

* In the instruments manufactured by Dr. Bradley the helices or coils of the electro-magnets, instead of being composed of silk insulated copper wire, as described in § 34, are made of naked wire, ingeniously wound by accurate machinery in such a manner that the convolutions are separated from each other by a space of 1–600 to 1–800 of an inch, the several layers being insulated from each other by thin paper. It is claimed that, by this method of winding, a coil of a given length and gauge of wire, and, consequently, of a given resistance, can be made of much less diameter than is possible with silk insulated wire, while, at the same time, the number of convolutions will be increased as well as the power of the electro-magnet.

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Fig. 13 represents a *Pocket Relay*, as it is usually termed, although it is properly a main line sounder (57).

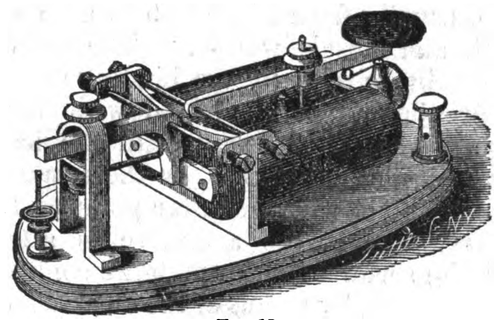

FIG. 13.

This is provided with a key, as shown in the figure, the whole being conveniently and compactly arranged to fit into an oval case four or five inches long, which may be carried in the pocket. It is an extremely convenient apparatus for line repairers. The cut shows the arrangement manufactured by the Messrs. Chester.

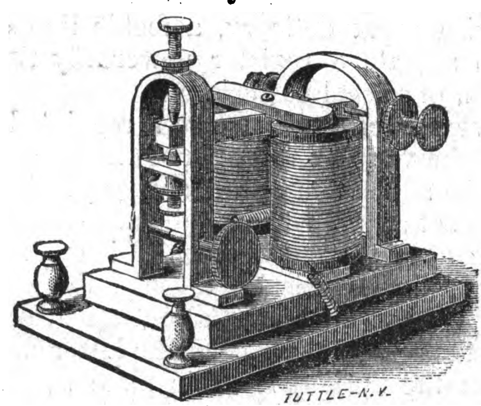

FIG. 14.

57. THE SOUNDER.—In many of the larger telegraph offices the recording apparatus is dispensed with, and the communications read by the sound of the armature lever. In that case the *Sounder* (fig. 14) is employed in the place of the register, the connections of the wires being arranged in precisely the same manner. The Sounder consists simply of the electro-magnet, arma-

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ture and lever, fixed upon a base.* The coils are usually wound with No. 23 wire.

Main Line Sounders are used in some offices, which enables the operator to dispense with the local battery. The coils are wound with fine wire, usually No. 30, and are frequently made somewhat larger than those of the relay. A common form of this instrument is known as the "Box Sounder." The lever, striking upon a hollow wooden box containing the magnet, gives a sound that may easily be distinguished by the operator under ordinary circumstances.

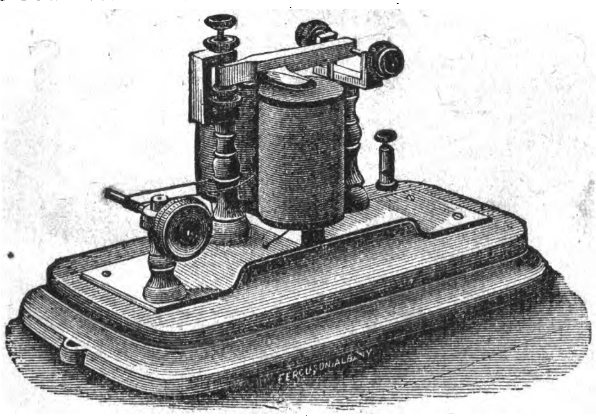

FIG. 15.

Fig. 15 (*S. F. Day & Co.*) shows an excellent form of Main Line Sounder. The parts of the instrument are mounted upon a metallic plate, the centre of which is raised slightly above the base, so as to form a bridge, as shown in the cut. The armature lever is of steel, and the whole arrangement is well adapted to increase the sound of the lever as much as possible—a feature of great value in working with weak currents or on badly insulated lines. These instruments are also made in several other forms, and various devices for increasing the sound of the lever are made use of. On many lines they are found to answer as well as the usual arrangement, employing a relay and local battery.

* The instrument shown in the figure is from the manufactory of C. T. & J. N. Chester.

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For circuits of moderate length a *Main Line Register* (fig 16), manufactured by Day & Co., has been employed with excellent results.

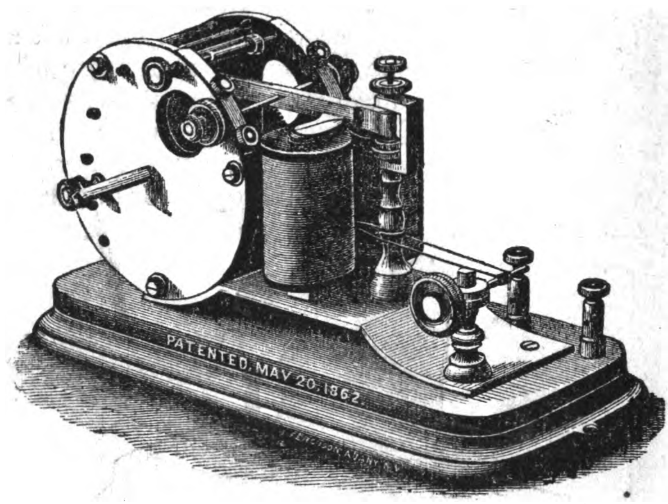

FIG. 16.

58. ARRANGEMENT OF A TERMINAL STATION.—Fig. 17 is a diagram showing the arrangement of wires, batteries,

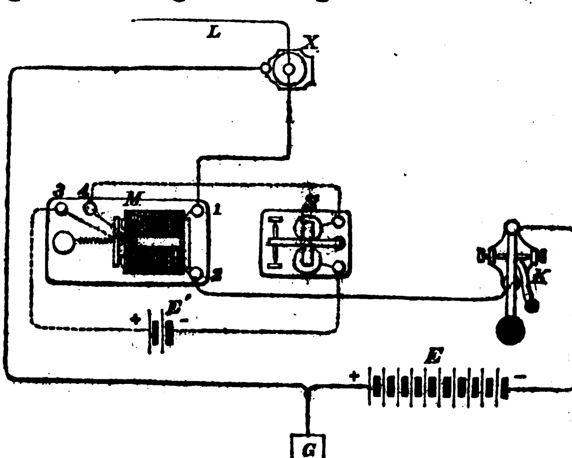

FIG. 17.

and instruments for one of the terminal stations of a line. The line wire L first enters the lightning arrester X, and passes thence through the coils of the relay M by the binding screws, 1, 2, and thence to the key K, main battery E, and finally to the ground at G. The local circuit commences at the + pole of the local battery E′ and through the platina points of the relay by the binding screws, 3, 4, thence through the register or sounder coils, S, and back to the other pole of the battery.

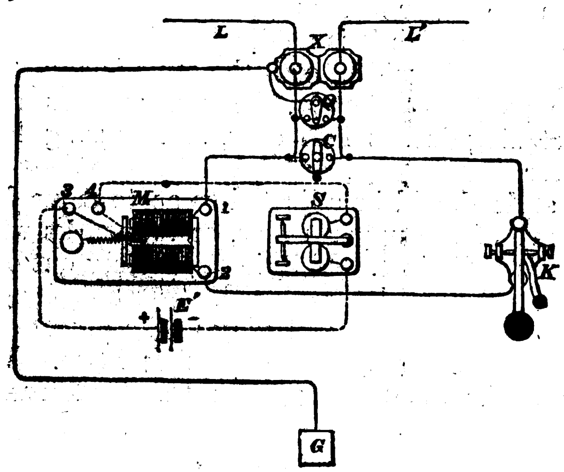

FIG. 18.

59. ARRANGEMENT OF A WAY STATION.—Fig. 18 shows a plan of the instruments and connections at a way station. The line enters at L, passes through the lightning arrester X (70), and thence through the relay M, key K, and back to the lightning arrester, and thence to the next station by the line L′. The arrangement of the local circuit is the same as in the last figure. The button C, arranged as shown in the figure, is called a "*cut-out*" (62). When turned so as to connect the two wires leading into the office, it allows the line current to pass across from one to the other without going through the instruments. The instruments should always be cut out by means of this apparatus when leaving the office temporarily, or for the night, and

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also during a thunder storm, to avoid damage to the apparatus.

The *Ground Switch*, Q (63), is used to connect the line with the earth on either side of the instruments at pleasure. It is only used in case of accidents or interruptions on the lines, as will be hereafter explained.

60. Adjustment of the Apparatus.—The principal difficulties which the operator is liable to meet with in working the Morse apparatus are as follows:

1. When the paper in the register does not run freely from the reel on which it is held, or sticks in the guides from irregularity in width, or if the style is adjusted to indent the paper too deeply, the paper moves irregularly, shortening dashes into dots, and causing dots to run together.

2. The style should be adjusted so as to move freely in the groove of the upper roller, or the marks will be more or less indistinct. If it is completely out of the groove, no marks will be produced. These faults generally arise from too much end play in the pivots of the lever, or from the pivot screws working loose. When the lever works too loosely in its bearings, irregular dashes, too deep at their commencement, and tapering off to nothing, will be produced.

Residuary magnetism sometimes causes the armature of the electro-magnet to *stick*. This will always happen if the armature is allowed to touch the poles of the magnet. The screw stop should therefore be adjusted so as to prevent the armature from approaching too closely to the poles of the magnet. The upper screw stop, which regulates the play of the lever, should be adjusted so that the movement is just sufficient to withdraw the style from contact with the paper.

3. If the paper runs between the rollers "crooked," the pressure of the upper roller upon the paper is greater at one end than the other. This pressure is regulated by two springs, one on each side of the instrument, and they should be made as nearly equal in pressure as possible.

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4. When the signs are confused the relay requires adjustment to suit the strength of the current.

5. If the relay moves by the action of the line current, and the register or sounder does not act, the fault is somewhere in the local circuit. If the register does not work when the relay is moved by the finger, the local circuit is certainly at fault, either from weakness of the local battery, a loose connection, a broken wire, or dirt between the platina points of the relay. The latter should, when too much corroded, be cleaned carefully with a very fine file, taking care to remove as little of the platina as possible.

6. The *sticking* of the key, which sometimes occurs, is caused either by the platina points becoming oxidized and dirty, or by small particles of metal and dirt collecting behind the circuit closer and about the anvil, causing a partial connection when the key is open.

7. *It is very important that all the connections about an office should be firmly screwed up.* Neglect of this precaution is a *very prolific* cause of trouble upon a telegraph line.

8. In rainy weather, or when the insulation of the line is defective from any cause, the cores of the relay must be withdrawn to a greater distance from the armature, to avoid the influence of the residual magnetism, caused by the escape of the "current" from the line. This is called "adjusting" the instrument, and is one of the most important of an operator's duties, requiring great judgment and skill during unfavorable weather and on poorly insulated lines. The key should never be opened without carefully adjusting the relay, to be *sure* that no other offices are using the line.

SWITCHES OR COMMUTATORS.

61. These are employed for the purpose of connecting one circuit with another, for dividing a circuit into two parts, or in short, for any purpose where it is necessary to alter the connections of a line or circuit.

62. Fig. 19 shows the simple *Button* or *Circuit Closer,*

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which is usually employed as a "cut out" (58). The base A is of wood or hard rubber. The brass lever, B, when in the position shown in the figure, forms an electrical connection between the metallic studs C C, which

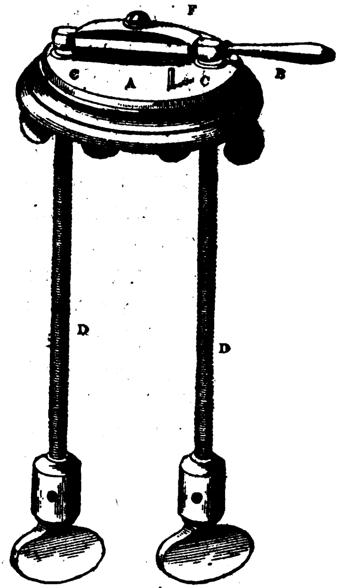

FIG. 19.

are continuous with the screws, D D, passing through the table and terminating in binding screws, to which the wires are attached. The spring F, pressing against the lever, insures a firm contact with the studs. This circuit closer is sometimes, for special purposes, made with four connections instead of two.

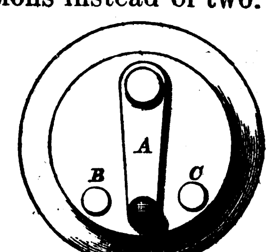

FIG. 20.

63. Fig. 20 represents a *Ground Switch* (58). The lever

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A is attached to a wire leading to the earth, and the two studs, B, C, are connected to the line wire on each side of the instruments.

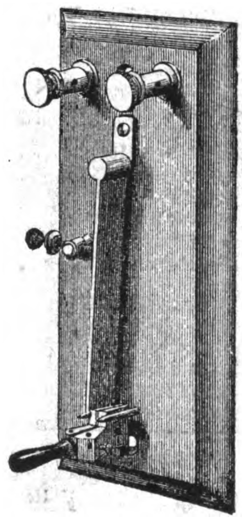

FIG. 21.

64. THE PLUG SWITCH is shown in fig. 21. This arrangement consists of a brass spring, brought very firmly against a stationary pin. A wedge or plug made of two pieces of brass, separated by an insulating material, is made in the form shown, to admit of insertion between the spring and the pin. The wires leading to the instrument are attached to this wedge by flexible conductors. When the wedge is inserted, the line current is diverted through the instrument, but is not interrupted. The instrument may readily be withdrawn from the line by taking out the wedge, the spring instantaneously closing the main circuit. This arrangement is found extremely useful in connecting batteries as well as instruments. At a way station it is preferable to a simple cut-out, for the reason that the apparatus is entirely disconnected from the circuit when the wedge is withdrawn (59).

65. THE UNIVERSAL SWITCH, for the use of offices having a considerable number of wires, is constructed

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in several different forms, although the principle involved is nearly the same in each. Fig. 22* represents

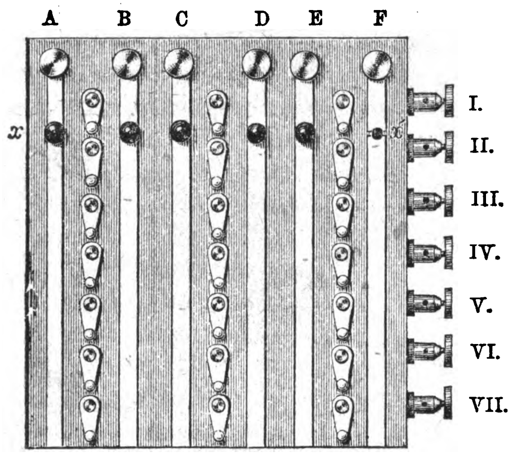

FIG. 22.

the arrangement most generally used, which is known as the Culgan Switch, from the name of its inventor. The upright straps of brass, A, B, C, D, E, F, are fixed upon a slab of hard wood, or other non-conducting material, and provided with binding screws at their upper extremities, for the reception of the line wires. The binding screws, I, II, III, IV, V, VI, are in electrical connection with the horizontal rows of buttons, by wires underneath the board, not shown in the figure. Thus, any wire attached to one set of binding screws may readily be connected with any wire attached to the other set, by simply turning the appropriate button. A row of metallic pegs, *x x'*, are so arranged that either of the upright straps may be separated into two parts by the withdrawal of the peg belonging to it, as shown at *x'*. The object of this device will be explained hereafter.

This switch may be made of any size and with any number of connections, depending upon the number of lines it is designed to accommodate. The wires may be attached to it in a number of different ways, the parti-

* L. G. Tillotson & Co., New York.

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cular arrangement adopted in each case depending upon the nature of the changes required to be made.

66. Arrangement of the Connections.—The switch shown in the figure, placed at a *way station*, could be arranged to accommodate three through wires, and an equal number of instruments, providing for all the necessary changes. The arrangements in this case would be as follows: Connect line wires Nos. 1, 2 and 3, *east*, with A, B and C; 1, 2 and 3, *west*, with D, E and F. Instrument No. 1 to I and II, No. 2 to III and IV, No. 3 to V and VI. Turn the buttons so as to connect A with I and D with II. The circuit of No. 1 wire will then enter at A, go to instrument No. 1 *via* I, returning to II, and thence going out at D. The other instruments may be connected at pleasure in the same manner. If it is desired to connect a circuit *through*, for instance No. 1, leaving the instrument out of circuit, it is done by turning the buttons so as to connect both A and D to the *same* horizontal wire, either I or II. By a little study it will be seen that any wire east may be connected with any other wire west, with or without any desired instrument, at pleasure. The ground wire is attached at VII, and may be connected with any line wire east or west at pleasure.

67. The same switch, placed at a *terminal station*, would provide for six wires, by connecting them as before to the screws A, B, C, D, E, F, and the instruments to I, II, III, IV, V, VI. The wires of a *loop* (87) may be connected to I and II in place of the instrument, and may be put in circuit with any wire by turning the buttons connected with I and II both on to the corresponding strap, which is then divided by withdrawing the peg, forcing the current to pass through the loop. Extra sets of buttons for loops are usually provided when the switch is intended for a terminal station, which can be used without diminishing the capacity of the switch for other purposes.

68. Jones' Lock Switch is employed for the same purposes, and connected in the same manner as the one

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last described, but the connection between the vertical and horizontal wires is made by a metallic peg, provided with a spring, as shown in fig. 23 (*Chester*). This arrangement entirely obviates the danger of imperfect connections, from the loosening of buttons, etc., which is sometimes a source of trouble in the Culgan Switch.

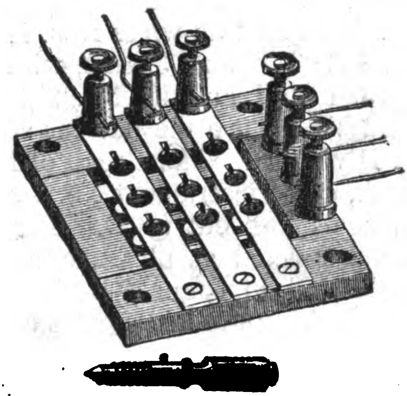

Fig. 23.

It is also cheaper and much more compact; a matter of some importance in arranging for the accommodation of a large number of wires.

69. There are other forms of switches designed for special purposes, which it is unnecessary to describe in a work of this kind. Those already referred to are all that are generally required in fitting up a telegraph station.

LIGHTNING ARRESTERS.

70. The danger of injury to the instruments and operators at a telegraph station, by atmospheric electricity, is usually guarded against by the use of an apparatus termed the *Lightning Arrester*, which is constructed in accordance with the well established fact that this kind of electricity, being possessed of enormous intensity, prefers a short route through a poor conductor to a longer one through a good conductor, while the comparatively low intensity of the voltaic

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current, used for telegraphic purposes, confines it to the conducting wires.

71. THE PLATE ARRESTER.—The arrester most usually employed upon the telegraph lines in this country consists of a flat plate of brass, about five or six inches in length, which is attached to the "ground wire." Other plates of brass rest upon this, being separated from it by a thin sheet of insulating material. These last mentioned plates are provided with binding screws, for the attachment of the line wires. Any surplus charge of atmospheric electricity, entering by the line wires, forces its way through the insulating material into the ground plate, and is thus carried off to the ground without injuring the apparatus. The form of arrester supplied by the Messrs. Chester is shown in fig. 24.

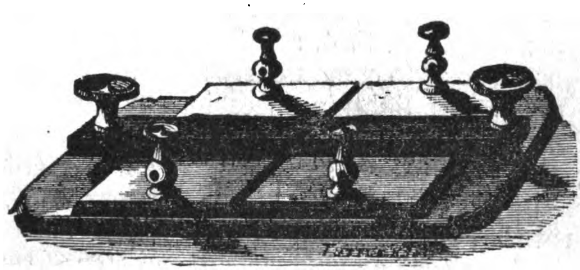

FIG. 24.

The plates in connection with the line wires are firmly held in their places by a wooden cross piece, secured by screws at each end, as shown in the cut. A thin sheet of gutta percha, or paper, is used to separate the plates. When paper is used it should be saturated with paraffine. Mica is, perhaps, better than either, as it is not carbonized by the passage of the spark, as paper sometimes is, so as to form a ground connection. The manner in which the arrester is connected with the wires leading into an office will be seen by reference to fig. 18, where the two line wires, L and L′, are attached to the two upper plates of the arrester, X, while a wire leading to the ground at G is attached to the lower plate.

72. BRADLEY'S ARRESTER.—Another form of arrester,

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designed by Dr. Bradley, is shown in fig. 25, and has recently been quite extensively employed, with excellent results.

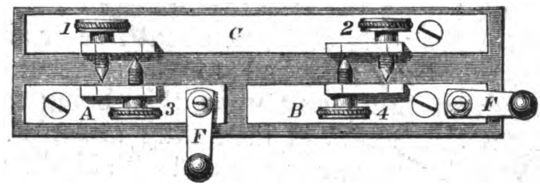

FIG. 25.

It depends for its action upon the well ascertained fact that lightning always passes from a point to a plate with great facility. The line wires leading into the office are attached to the metallic plates A and B by means of binding screws beneath, the ground wire being attached in the same manner to the plate C. Platina tipped screws, 1, 2, 3, 4, are fixed to each plate, and are adjusted so as to come nearly in contact with the opposite plate. As lightning occasionally passes from the earth to the clouds, as well as from the clouds to the earth, this arrester is so arranged as to facilitate its passage in either direction. The buttons, F F, are so arranged that the apparatus serves for a "cut-out" and a "ground switch" as well as an arrester. Its application to these purposes will be at once understood by an inspection of the cut. This form of arrester is peculiarly well adapted for the protection of cables, or any situation where it is exposed to accidental dampness, as it is much less apt to interfere with the working of the line in such cases than the plate arrester previously described.

73. Lightning arresters must always be kept free from dampness and dirt, as far as practicable. Much annoyance often arises from neglect of this precaution, as moisture between the plates will often cause a serious escape, greatly interfering with the working of the line. This difficulty is especially liable to occur where the arresters are used for the protection of submarine cables. A flash of atmospheric electricity also fre-

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quently carbonizes the paper between the plates, or fuses the metal, so as to permanently connect the ground and the line. Consequently, the lightning arresters should be frequently taken apart and examined. *This should invariably be done after a thunder storm.*

REPEATERS.

74. When the length of a telegraphic circuit exceeds a certain limit, depending upon the insulation, the size of the conductor, the number of instruments in circuit, etc., the line current becomes so enfeebled, even when large batteries are employed, that satisfactory signals cannot be transmitted. In such cases it was formerly customary to re-write the messages at some intermediate station, but this duty is now usually performed by an apparatus called a *repeater*. The principle of this arrangement consists in causing the sounder or register connected with one circuit to open and close the circuit of another line by an action similar to that of a relay (56). Repeaters are also often used for connecting one or more branch lines with a main line, for the purpose of transmitting press news, etc., simultaneously to different places. This enables all the stations in connection to write to each other as readily as if they were situated upon the same circuit.

Since the general introduction of repeaters it has become quite practicable to telegraph direct between places situated at very great distances from each other. It is not uncommon, at the present day, to work direct through four or five thousand miles of continuous line by the aid of these instruments with almost as much facility as if it were one continuous circuit. On one or two occasions the stations at Heart's Content, Newfoundland, and San Francisco, California, have been placed in direct communication with each other, the operators at these widely separated points conversing with each other across the entire breadth of the continent without the slightest difficulty.

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75. Wood's Button Repeater.—This is the simplest arrangement of this kind now in use. Fig. 26 shows

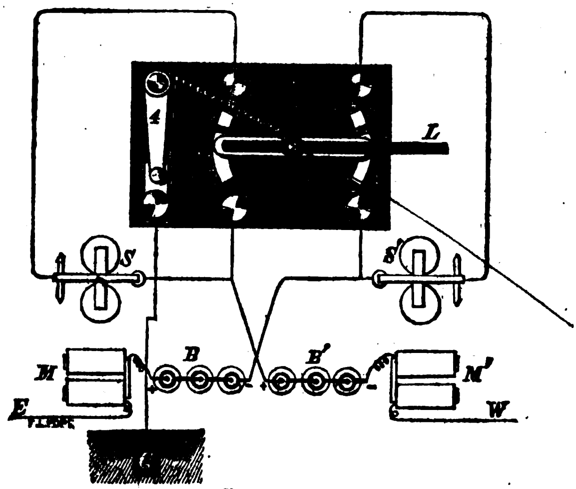

Fig. 26.

the most convenient and serviceable form in which the button or switch, and its connections, can be arranged for the purpose of changing the circuits. The instruments, batteries, &c., are shown in outline, for convenience of explanation. M and M′ are the eastern and western relays, S and S′ the eastern and western sounders. The local connections are not shown, but are run as usual. The eastern and western main batteries are shown at B and B′, and are placed with *opposite* poles to the ground, at the repeating station, so that when the line is put "through" the two batteries will coincide.

By means of this arrangement the following result may be obtained:

I. *Two distinct and independent circuits.* The lever L remaining in the position shown in the drawing (marked 1), and the button at 4, *closed.*

II. A *through circuit.* The lever L remains as before, but the button at 4 is *opened*, throwing off the ground connection between the two batteries, B and B′.

III. *Two distinct circuits arranged for repeating.* The button at 4 is closed. If the lever L be placed in the position indicated by the figures 2, 2, the eastern sounder repeats into the western circuit. If the lever is changed to 3, 3, the western sounder repeats into the eastern circuit. The operator in charge of a button repeater will find his duty very simple if he governs himself by the following

RULE.—When either sounder fails to work coincident with the other, *turn the button instantly*.

In connecting up this apparatus, the arrangement of the poles of the main batteries above specified should be carefully borne in mind. It is also of the utmost importance that these batteries should be *perfectly insulated* from the ground, as the point at which the circuit is open and closed is between the battery and the ground. Therefore, an escape occurring from the battery to the ground will cause a residual current upon the main line, when the circuit is open at the repeating points of the sounder, and thus interfere with its working.

In cases where it is not required to work the two lines through in one circuit, the connections are arranged differently from the plan shown in fig. 26, the main battery being placed in the circuit between the lever L and the ground G, instead of at B and B′, as shown. In this case the switch 4 may be dispensed with altogether.

76. The lever of the sounder moves through a certain space before closing the circuit of the second line, so that the duration of the current sent forward is shorter than that received from the transmitting station. A second repeater shortens it still more, so that the dots cease to be repeated, and are frequently lost altogether. The sending operator must therefore transmit the signals more *firmly*, as it is termed; that is, increase the length of the key contact, especially when sending dots. For the same reason, the sounder levers in a repeating apparatus should be adjusted to have as little motion as possible.

77. HICKS' AUTOMATIC REPEATER.—This arrangement

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dispenses with the attendance of an operator for the purpose of changing the circuits while working, the only attention required being to keep the relays properly adjusted. The principle of the apparatus is shown in fig. 27.

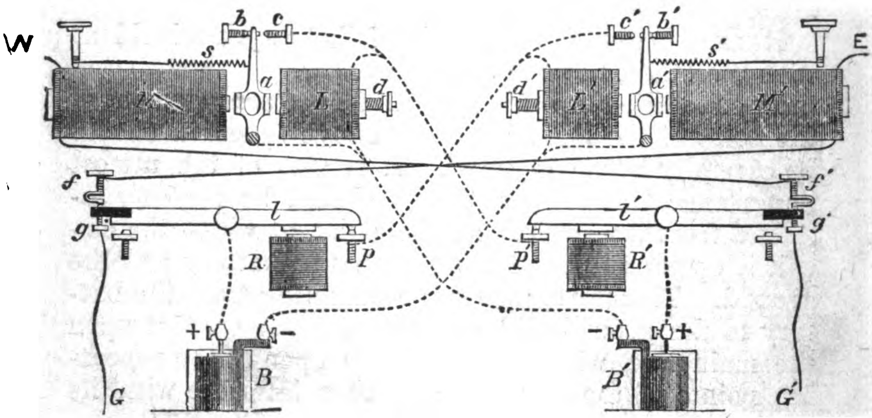

FIG. 27.

The main circuits pass through the relay magnets M and M′, thence to the repeating points *f g* and *f′ g′*, attached to the opposite sounder levers respectively, and thence to the main battery and ground at G and G′. The platina points of the screws *f* and *f′* are placed upon U shaped springs, which, in a great measure, prevents the shortening of the signals referred to in the last paragraph. The local circuits are run through the relay points *b* and *b′* and the sounders R and R′, on each side of the apparatus, in the ordinary manner, but to prevent confusion of lines, are omitted in the drawing. The "extra local" magnets, L and L′ act upon armatures placed upon the relay levers *a* and *a′*, opposite to the regular armature. (See figure.) These extra local magnets are movable by means of the screws *d d′*, and the adjustment of the relays M M′ is performed by means of these extra local magnets, the springs *s s′* not being used for this purpose.

In the figure the repeater is shown in its normal position, with both circuits closed. The circuits of the

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extra local batteries B B′ (shown by dotted lines) pass through the sounder levers *l l′*, the screws *p p′*, and thence respectively to the extra local magnets on the opposite side of the apparatus. These magnets must be so adjusted that their attraction is not sufficient to draw the armatures away from M M′ unless the main circuit is broken.

It will also be seen, by referring to the drawing, that when the main circuit is broken and the armature falls back on the point *c*, that the extra local magnet L is *cut out*. But the instant this happens the spring *s* draws the armature away again. As soon as the contact is broken at *c* there is a circuit through L, and the armature is again drawn back to *c*. The tension of the spring *s* being but just sufficient to draw the armature away from *c*, the armature *vibrates* on the point *c* through such a small space, and with such rapidity, that the motion is invisible to the eye. On account of the extreme rapidity of these vibrations, it is impossible to close the main circuit at a time when the extra local magnet L is *not cut out*, and the armature will consequently obey the slightest impulse caused by the attraction of the relay magnet.

The working of the apparatus requires but little further explanation. If the western main circuit be broken, for instance, the armature lever *a* falls back and vibrates on the point *c*, as above described. The sounder lever *l* first breaks the circuit of the eastern extra local magnet L′; then that of the eastern main line, which passes through the relay M. The circuit through both L′ and M′ being thus broken, the slight tension of the spring s′ will hold the armature in its place, and prevent the local circuit through R, and consequently the western main circuit, from being broken. When the western circuit is again closed the reverse of these operations takes place.

78. In using this repeater the springs *s s′* should be adjusted with the smallest possible amount of tension, just sufficient to hold the armature in place. *When once*

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adjusted they should be let alone. Care must be taken that none of the wires under or about the magnets touch any part of the brass. The extra local magnets, for example, may be cut out entirely in this way. The screws that adjust the extra local magnets should be oiled with fine oil to prevent wear and make their adjustment easy. The extra local batteries must be kept of a uniform strength; if they are allowed to become weak the instrument will be thrown out of adjustment.

79. MILLIKEN'S REPEATER.—In the general arrangement of its connections this repeater somewhat resembles that of Hicks', but is more simple in principle. Fig. 28 is a plan of its connections. The main line

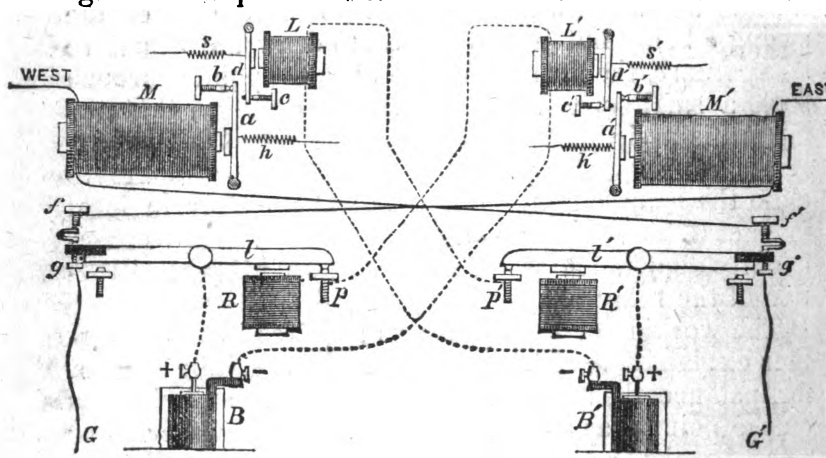

FIG. 28.

wire from the west passes through the relay magnet M and the repeating points f' g' of the opposite sounder, and thence to the battery and ground at G'. The eastern line passes through M', f and g to G, in a similar manner.

The extra local magnets L and L' are arranged, as shown in the figure, so that when either of their armatures is released it is drawn back by the spring attached to its lever, bringing the latter firmly in contact with the armature lever of the corresponding relay. The extra local batteries are shown at B and B' the circuit

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of each being indicated by dotted lines. The ordinary local circuit through the relay and sounder is omitted, to avoid confusion in the diagram.

If the main circuit be broken in the western wire, the relay M breaks the local circuit of the sounder R at *b*. The movement of the lever *l* of the sounder first breaks the extra local circuit at *p*, causing the magnet L′ to release the armature *d*′, which is drawn back by the spring *s*′ against the top of the lever *a*′, and, secondly, the eastern main circuit is also broken at *f*. *g*. The lever *a*′ is prevented from falling back when the circuit of M′ is broken by the tension of the spring *s*′, which is so adjusted as to be greater than that of the spring *k*′. The apparatus on the right hand side of the repeater, therefore, remains quiet while the west is working, and *vice versa*, the current through M′ being always restored before that through L′ is broken, which is effected by the U shaped spring on the screw *f*.

One of the principal advantages in the construction of Milliken's repeater consists in the fact, that any slight variation in the strength of the extra local circuit, from weakness of the battery or other causes, does not affect the adjustment of the relay magnets, as in the case with Hicks' repeater. The adjustment and action of the two magnets are entirely independent of each other, as will be seen by reference to the diagram. The relay levers also move more freely, being unencumbered with extra armatures or other appliances.

In this, as in the Hicks repeater, buttons are provided, by means of which each line may be worked separately without interfering with the other, if desired. These are omitted in the drawing, to prevent confusion, but are arranged so that, when closed, one button forms a permanent connection between *f* and *g*, thus preventing the movement of the lever *l* from breaking the eastern main circuit, and another connects *p* and *l*, thus keeping the extra local circuit constantly closed, and the armature lever *d*′ withdrawn from interference with *a*′.

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The same thing may be accomplished by causing the button to break the extra local circuit entirely, when the instruments are to be worked separately, and "turning down" the adjusting spring *s'* of the lever *d'*. It will, of course, be understood that the other side of the repeater is arranged in precisely the same manner.

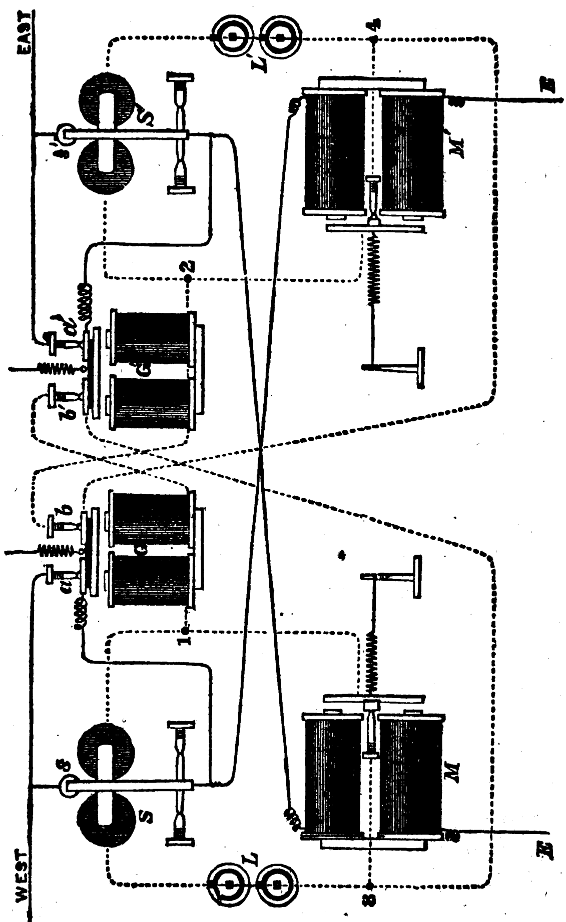

Fig. 29.

80. Bunnell's Repeater.—The arrangement of the main circuits in this repeater is exactly the same as in

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with extra armatures and other appliances. The adjustments required are the same as in a simple relay and sounder.

82. Various other repeaters have been contrived, and to some extent adopted in this country, but as those we have described are much more extensively used than any others, it has not been deemed necessary to describe the others in a work of this kind.

83. COMBINATION LOCALS.—In offices containing a number of instruments, a single local battery is frequently employed to operate all the sounders in the office. Such an arrangement is called a combination local. The best way of making the connections is shown in fig. 30, in which the instruments are represented at

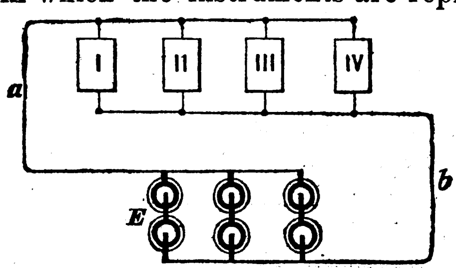

FIG. 30.

I, II, III and IV. The local battery is shown at E. The common conductors, *a* and *b*, should be of large copper wire, say No. 12 or 14. If the ordinary Daniell's battery is used for this purpose, the cells should be connected for *quantity*, as shown in the diagram, and not in a single series. Every sounder in the combination should have the same size and amount of wire in its coils, as nearly as possible, in order to secure the best results.

84. Another plan is to use separate locals, a wire being run from one pole of each local to its corresponding instrument, the opposite poles of the batteries, and the instrument wires being all connected to a common return wire.

85. These combination locals are very objectionable, however, and their use should be avoided wherever

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possible. The iron cores in two different relays may happen to be in connection with the silk covered wire with which they are wound, a circumstance which frequently occurs. In such a case, if the two armatures chance to touch the poles of their respective relays, a metallic connection, technically called a *cross*, is made between the two main lines. Again, if these two relays are at a terminal station, and in connection with two main batteries, with opposite poles to the ground, the combined force of both batteries is thrown on short circuit, through the local return wire, burning the relays, exhausting the batteries, and interfering with the operation of every wire connected with them. The cause of these troubles being somewhat obscure, it might, for a considerable time, escape detection.

86. Local Circuit Changer.—In offices containing two sets of instruments on different circuits, it is often desirable to change them. A simple arrangement for this purpose it shown in fig. 31, in which the relays are

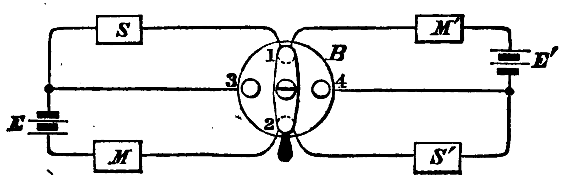

Fig. 31.

represented at M and M′; S and S′ are the sounders or registers, E and E′ are the local batteries. B is a simple button or circuit closer (62), having four connecting points, 1, 2, 3, 4. When the button is in the position 1, 2, as shown in the figure, the relay M works the sounder S, and the relay M′ the Sounder S′. By changing the position of the button to 3, 4, S is worked by M′ and S′ by M. This simple arrangement is often very convenient in railway stations, where a sounder may be placed on one circuit and a register on the other, so that an operator who is unable to read by sound can instantly shift the register upon either line at pleasure.

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TECHNICAL TERMS USED IN THE TELEGRAPH SERVICE.

87. *Line.*—The wire or wires connecting one station with another.

Circuit.—The wires, instruments, &c., through which the current passes from one pole of the battery to the other.

Metallic Circuit.—A circuit in which a return wire is used in place of the earth.

Local Circuit.—One which includes only the apparatus in an office, and is closed by a relay.

Local.—The battery of a local circuit.

Loop.—A wire going out and returning to the same point, as to a branch office, and forming part of a main circuit.

Binding Screws or Terminals.—Screws attached to instruments for holding the connecting wires.

To Cross-connect Wires.—To interchange them at an intermediate station, as in § 117.

To put Wires straight.—To restore the usual arrangement of wires and instruments.

To Ground a Wire, or put on Ground.—To make a connection between the line wire and the earth.

To Open a Wire.—To disconnect it so that no current can pass.

Reversed Batteries.—Two batteries in the same circuit with like poles towards each other.

To Reverse a Battery.—To place its opposite pole to the line; or, in other words, interchange the ground and line wires at the poles of the battery.

Escape.—The leakage of current from the line to the ground, caused by defective insulation and contact with partial conductors.

Cross.—A metallic connection between two wires, arising from their coming in contact with each other, or from other causes.

Weather Cross.—The leakage of current from one wire to another during rainy weather, owing to defective insulation.

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CHAPTER V.

INSULATION.

88. A telegraph wire suspended on poles is attached to *insulators*, to prevent the escape of the current to the earth at the points of support. Insulators should be regarded in the light of *conductors*, whose value depends upon their resistance to the passage of the current.

89. The insulation of a line is never perfect, even in the dryest weather. There is a leakage at every support, which is greatly increased when the surfaces of the insulators are damp, especially if covered with smoke or dirt. Experiments show that soot will destroy the surface insulation of even the best insulators, unless exposed to the cleansing action of the rain. This evil is confined, however, principally to cities, and does not manifest itself to nearly so great an extent in the open country.

90. Insulators, considered as conductors, follow the same law as other conductors. The less the diameter and the greater the length, the more resistance is opposed to the escape of the current. As in this case the resistance is almost entirely a question of surface, the best insulator is that having the smallest diameter and the greatest length between the wire and the support. The latter is accomplished by making the insulator of a cup form, or still better, of two cups, one placed within the other.

91. The material of which the insulator is composed should be a poor conductor of electricity and heat, a non-absorbent of moisture, with a surface repellant of water, and free from pores or cracks. It should also remain unaffected by exposure to the weather, and the effects of heat and cold. Nearly all of the materials

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ordinarily employed are, however, liable to some of these objections.

Insulators of glass and porcelain being conductors of heat, a change of temperature from cold to warm causes a condensation of moisture upon their surfaces, including the portion protected from the direct action of rain, and from this arises the principal objection to the use of these substances in the construction of an insulator.

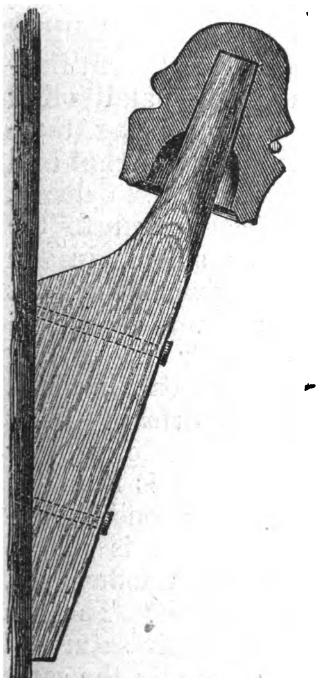

FIG. 32.

Hard rubber is in itself a better insulator than glass; but its surface, from exposure to atmospheric influences, soon loses its property of repelling moisture, and becomes rough and porous.

A surface which repels watery accumulations will cause them to flow disconnectedly in drops, instead of forming a continuous conducting film. This property is therefore one of great value for the purposes under consideration.

92. THE GLASS INSULATOR.—The insulator most commonly employed in this country is the glass. This is generally made in the form represented by Fig. 32, which is a sectional view of the insulator fixed upon a wooden bracket, the latter being securely spiked to the side of the pole. The line wire passes alongside the groove surrounding the insulator, and is fastened with a *tie-wire* encircling the insulator, both ends of which are wrapped around the line wire. The concavity of the under side of the glass keeps it dry during a rain, and prevents the current from escaping to the wet

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bracket and pole through the medium of a continuous stream of water.

93. The Wade Insulator.—This is largely used in the Western States. Its construction is shown in Fig. 33.

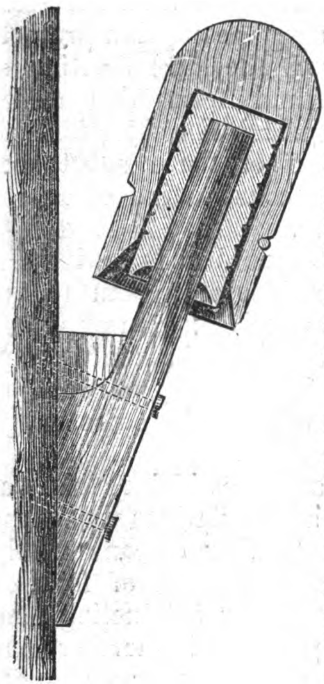

Fig. 33.

A glass insulator, somewhat similar in shape to that last described, is covered with a wooden shield, to prevent fracture from stones and other causes, the wood being thoroughly saturated with hot coal tar, to preserve it from decay. The line wire is tied to the outside of the shield, in the same manner as when the glass insulator is used.

This insulator is usually mounted upon an oak bracket, as in Fig. 33, secured by spikes to the side of the pole or other support. When it is intended to be mounted upon a horizontal cross-arm it is placed upon a straight wooden pin, instead of a bracket. The pin or bracket is usually saturated with hot coal tar, in the same manner as the insulator shield.

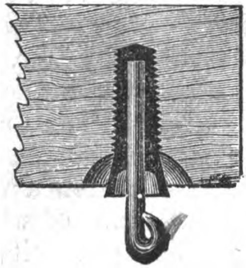

Fig. 34.

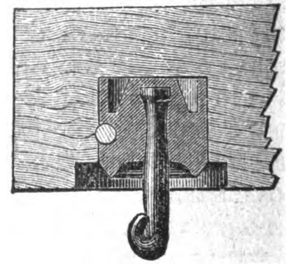

Fig. 35.

94. The Hard Rubber Insulator.—This insulator is shown in Fig. 34. It is a good insulator when new,

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but by exposure to the weather its surface becomes rough and spongy, and retentive of moisture. It is screwed to the under side of the cross-arm or wooden block, which is secured to the pole. The best form is that which is made with a drip or shed, as shown in the figure. If exposed to the direct action of rain it ought always to be placed in a perpendicular position. It will be noticed that this insulator holds the line wire by suspension.

95. The Lefferts Insulator.—This is composed of a suspension hook fixed in a socket of glass, of the form represented in Fig. 35. This is inserted into a hole bored in the under side of a block or cross-arm, and fastened with a wooden pin. In painting the arm or blocks the paint must not be allowed to get on the surface of the glass.

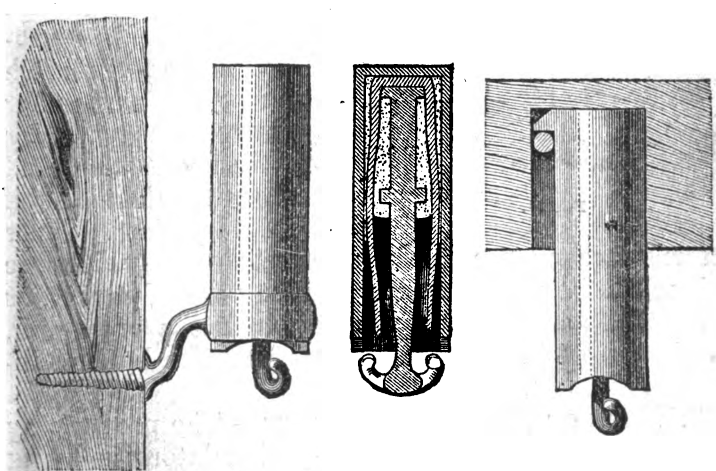

Fig. 36. Fig. 37. Fig. 38

96. The Brooks Insulator.—Figs. 36 and 37 show the construction of this insulator, which consists of a suspension hook cemented into an inverted blown glass bottle, which is again cemented into a cast iron shell, provided with an arm which screws into the pole, as in Fig. 36. Another form is made, designed for attachment

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to a cross-arm, as in Fig. 38. The remarkable insulating properties of this arrangement are mostly due to the use of paraffine, with which the cementing material (sulphur) is saturated. It has also been discovered that blown glass possesses extraordinary properties of repelling moisture. Additional advantage of this fact has been taken in the construction of this insulator, as may be seen by reference to the cut.

97. Brooks' Stone-ware Insulator.—This arrangement is made in the form shown in Fig. 39, the body of the insulator being completely saturated with paraffine. Numerous severe tests, to which this insulator has been subjected during the past year, in comparison with others, show that its insulating qualities are much greater than any other known arrangement, being more than one thousand times greater than that of the ordinary glass. Other patterns are now manufactured, some of which are designed to be placed upon a wooden pin or bracket, as in Fig. 33, and others for insertion into a cross-arm, being secured in the same manner as the Lefferts insulator (Fig. 35).

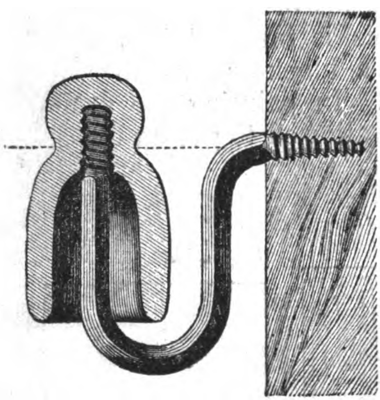

Fig. 39.

98. Mode of Testing Insulators.—The proper way to test the comparative value of insulators is to fix them upon frames or standards, in sets of ten or more, and place them where they will be fully exposed to the weather. The tests should be made when the weather is very wet, by means of a wire attached to all of them in the usual manner, and leading to the testing instrument, battery and ground. By this means the relative resistances of either of the insulators above described, and their consequent value in the construction of a line, may be readily ascertained.

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99. ESCAPE.—When the insulation is defective, or the wire comes in contact with the branches of trees, a wet wall, or other partial conductor, a portion of the current passes to the ground, forming what is technically known as an *escape*.

100. WEATHER CROSS.—The escape of the current from one wire to another one upon the same poles, owing to defective insulation, is sometimes wrongly called "induction," or "sympathetic currents." Weather cross is a much more appropriate term.

As electric currents always move in the direction of the least resistance, their tendency is to escape from a long circuit to a shorter one. This mixing of the currents from different wires is a much more serious evil than a simple escape to ground, for the latter may in most cases be overcome by increased battery power; but when cross connection exists between different wires upon the same poles, an increase of battery upon one wire gives it an advantage over the others, but necessarily at their expense.

The effects of weather crosses usually manifest themselves upon the occurrence of a shower sooner than the escape to ground, because the horizontal arms become wet sooner than the vertical pole.

On the English lines this difficulty is obviated by means of an earth wire attached to each pole, and wrapped around the center of the arms, thus cutting off the currents passing from wire to wire, and conveying them to the ground. The battery can then be increased at will on one wire, without interference with the others. This practice might be adopted in this country, with great advantage to the working of the lines.

101. EFFECT OF ESCAPES AND GROUNDS UPON THE CIRCUIT.—If the wire touches a conductor communicating with the earth, or the earth itself, in a moist or wet place, so that the point of contact offers little or no resistance compared with the wire beyond, the fault is called a *ground*. The effect of a ground or escape is to increase the strength of the current going out to the

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line, and to exhaust the batteries more rapidly. Therefore, in working with a continuous current, as is the case on American lines, the line current *increases* in strength in wet weather, but the *variation* or difference in the current at one station, when the line is opened and closed at another, *decreases*, and the effective signals are therefore weakened.

102. THE LAWS OF THE ELECTRIC CURRENT.—The laws which govern the propagation and distribution of electric currents are so simple, and at the same time so important, that every telegrapher should be familiar with them. By their aid the phenomena above referred to may be readily comprehended. The most important of these laws was first enunciated by Ohm, in 1827, and is known as *Ohm's law*. It may be briefly stated as follows:

Call the sum of the electro-motive forces...E
" " internal resistance of the battery..R
" " resistance of line and instruments..L
" " the effective strength of current...C

$$\text{Then } C = \frac{E}{R + L}$$

That is: *The effective strength of the electric current in any given circuit is equal to the sum of the electro-motive forces divided by the sum of the resistances* (174).

103. PRACTICAL APPLICATION OF OHM'S LAW.—FIRST CASE.—To illustrate the application of this law to circumstances occurring in practical telegraphy, take the

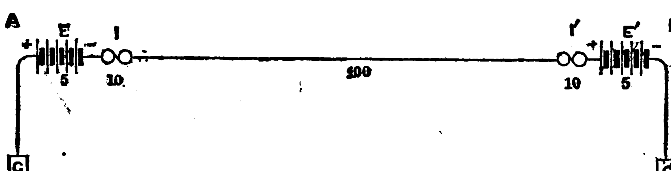

FIG. 40.

case of an ordinary telegraph line (Fig. 40), extending from A to B, and perfectly insulated, having a resistance of 100 Ohms. Let the main batteries, E and E' have each an electro-motive force of 1,000, and a resistance of 5 ohms, and let the resistance of the instruments I and I′ be equal to 10 ohms each. The total resistance of such a circuit will be :

$$\left.\begin{array}{lll} 100 & \text{ohms, line,} & \\ 20 & \text{“ instruments,} & \end{array}\right\} = L$$
$$\begin{array}{lll} 10 & \text{“ batteries,} & = R \\ \hline 130 & \text{“} = R + L & \end{array}$$

The line being perfectly insulated, the whole current from the batteries will necessarily act upon both instruments.

As the effective strength of the current in any circuit is, by Ohm's law, equal to $\frac{E}{R+L}$ in this case it will be

$\frac{2000}{130}$	= 15.4
With key open at A or B..............	= 00.0
Difference, or effective working strength.	= 15.4

If, on the above line, an escape occurs between the stations A and B, offering a resistance of 50 ohms, the effect will be the same as if a wire having a resistance of 50 ohms were connected from the centre of the line to the ground. The current from each battery has a tendency to divide at the fault between the two routes open to it, in proportion to their relative conductivity; or, what is the same thing, in inverse ratio to their respective resistances. But in this case the electromotive forces and the resistances are exactly the same on each side of the fault; and the positive current from one battery, and the negative from the other, have an equal tendency to escape to ground at the fault. These opposite tendencies consequently neutralize each other, and no effect whatever is produced upon the circuit by the fault as long as the line remains closed both at A and B.

If, however, A is sending to B, his key is alternately open and closed. When open, the circuit of the bat-

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tery E (Fig. 41) is entirely broken. There will still, however, be a circuit from the battery E′, through I′ and the line to the fault F, and thence to the ground.

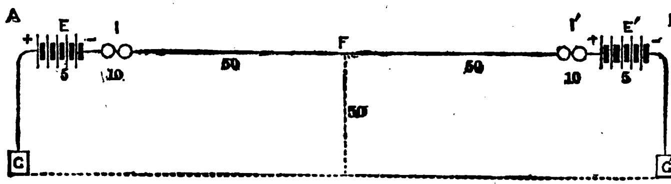

FIG. 41.

By Ohm's law we find the strength of this current to be as follows:

5	ohms resistance of battery, . .	= R
10	" " " instrument,	= L
50	" " " ½ line,	
50	" " " fault,	
115 = R + L.		

$$C = \frac{E}{R + L} = \frac{1000}{115} = 8.7$$

With the key *closed* at A, the strength of the current in the instrument at B was found to be

	15.4
With key open at A, as above........	8.7
Difference, or effective working force...	6.7

In this case the latter will obviously be the same, whether A sends to B or B to A.

104. SECOND CASE.—Suppose the same fault to be located near A (see Fig. 42).

The current from the battery E will divide at F, part going to the ground through the fault, and the remain-

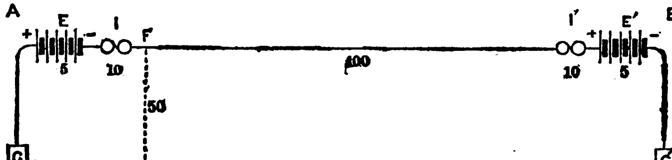

FIG. 42.

der over the line to B, and through the instrument and battery to ground. The current from E′ will divide in

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the same manner between the fault and the route through I and E. Taking the battery E alone, and considering the other battery E′ simply as a conductor, the two circuits beyond the fault give the following resistance:

1. By the line instrument and battery at B.. 115 ohms.
2. " fault F.......................... 50 "

Their joint resistance will be* ..... $\frac{115 \times 50}{115 + 50} = 34.8$ ohms.

Add resistance of battery itself, 5 ohms, and instrument, I, 10 ohms .... 15 "

The total resistance will be.......................... 49.8

And the current leaving the battery, E, $= \frac{1000}{49.8} = 20$

This current will divide at the fault between the two circuits, whose resistances are respectively 115 and 50, or in the proportion of 23 to 10. Therefore 23 parts of the current will go to the ground at F, and 10 parts, $= \frac{20 \times 10}{33} = 6.1$, will go over the line to B.

The current from the other battery, E′, in like manner divides at F, between the fault and the circuit through the instrument and battery at A. The joint resistance of the two circuits is

$$\frac{15 \times 50}{15 + 50} = 11.5$$

Add the resistance of the battery E, 5 ohms, instrument I, 10 ohms, and line, 100 ohms 115.0

Total resistance 126.5

The current leaving the battery E will therefore be $\frac{1000}{126.5} = 7.9$

The resistance of the two circuits beyond the fault being 15 and 50, or as 3 to 10, 3 parts will go to ground and 10 parts, or $\frac{7.9 \times 10}{13} = 6.1$, through I.

* The *joint resistance* of any two circuits is found by *dividing the product of the two resistances by their sum.* When there are three circuits, first find the joint resistance of two circuits as above, and treat it as a single circuit, again applying the same rule. In the same manner the joint resistance of any number of circuits may be calculated (175).

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When A sends to B, the current in the instrument at B will be:

Key closed at A.		
From battery E′........................	7.9	
" " E........................	6.1	
Total strength in I′.....................		14.0
Key open at A.		
From battery E′................ $\frac{1000}{165}$ =	6.1	
" " E........................	0.0	6.1
Difference, or available working current at B,		7.9

Now let B send to A. The current at A will be:

Key closed at B.		
From battery E........................	20.0	
" " E′........................	6.1	
Total strength in I.....................		26.1
Key open at B.		
From battery E............... $\frac{1000}{65}$ =	15.4	
" " E′........................	0.0	
Total strength in I....................		15.4
Difference, or available working current at A,		10.7

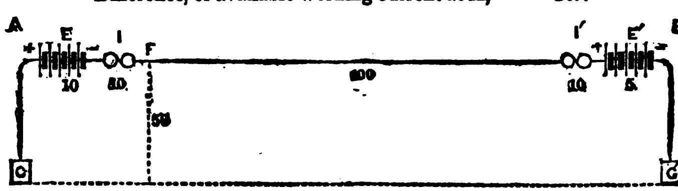

FIG. 43.

105. THIRD CASE.—Let the battery at A be doubled, the fault remaining as in the last case. The electromotive force and internal resistance of E are both doubled, as in Fig. 43. The current from E will now be:

$$\frac{2000}{20 + \frac{50 \times 115}{50 + 115}} = 36.5$$

which will divide at the fault in the same proportion as before, the part going to B being $\frac{36.5 \times 10}{33} = 11.0$.

The current from E′ will be $\frac{1000}{115 + \frac{20 \times 50}{20 + 50}} = 7.7$, and the portion reaching A $\frac{7.7 \times 5}{7} = 5.5$.

When A sends to B the signals will be as follows:

Key closed at A.
Current at B $= 7.7 + 11.0 = 18.7$

Key open at A.
Current at B...... $= \frac{1000}{165} = 6.1$

Effective strength at B......... 12.6

Now let B send to A:

Key closed at B.
Current at A $= 36.5 + 5.5 = 42.0$

Key open at B.
Current at A....... $= \frac{2000}{70} = 28.6$

Effective strength at A......... 13.4

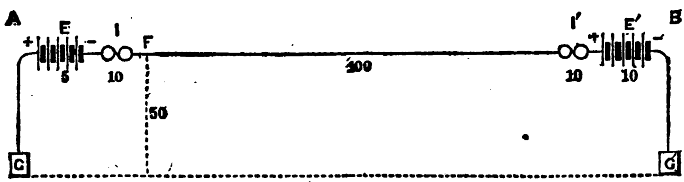

FIG. 44.

106. FOURTH CASE.—Double the battery at B, the fault remaining unchanged. See Fig. 44.

$$\text{Current from E} = \frac{1000}{15 + \frac{50 \times 120}{50 + 120}} = 19.9$$

$$\text{Portion going to B...} = \frac{19.9 \times 5}{17} = 5.8$$

$$\text{Current from E}' = \frac{2000}{120 + \frac{50 \times 15}{50 + 15}} = 15.2$$

$$\text{Portion going to A..} = \frac{15.2 \times 10}{13} = 11.7$$

A sending to B:

Key closed at A.
Current at B $= 15.2 + 5.8 = 21.0$

Key open at A.
Current at B........ $= \frac{2000}{170} = 11.8$

Effective strength at B.......... 9.2

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B sending to A:

Key closed at B.

Current at A $= 19.9 + 11.7 = 31.6$

Key open at B.

Current at A........ $= \frac{1000}{65} = 15.4$

Effective strength at A........... 16.2

107. Thus we find that on a circuit consisting of

Line wire resistance	100	ohms.
2 batteries "	10	"
2 instruments "	10	"

each battery having an electro-motive force of 1000, the signals received will be as follows:

	Signals at A.	Signals at B.
When the line is perfect	15.4	15.4
With escape 50 ohms in centre	6.7	6.7
Same fault at A	10.7	7.9
Same fault at A, with battery doubled at A	13.4	12.6
Same fault at A, with battery doubled at B	16.2	9.2

108. The results of this investigation may be summed up as follows:

When the batteries and instruments are equal at each end of a line, a given fault will interfere most with the working of the circuit when in the centre.

When the fault is near one end of the line, the station farthest from it will receive the weakest signals, and the station nearest it the strongest signals.

In increasing the battery power for working over an escape, the addition should be made to the battery nearest the fault.

109. Distribution of Battery Power.—If the insulation of a line was perfect at all times, the position of the battery in the circuit would be a matter of indifference. As all lines, however, are subject to more or less leakage or escape throughout their entire length, the whole battery should not be located at one end of a long line, for in this case signals would be received much better at one end of the line than the other. The usual arrangement is to place half the battery at each

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end of the line, although if the escape be uniform throughout the entire length of the line, the effect upon its working will be the same, whether all the battery is placed in the centre of the line or a portion of it in the centre and the remainder divided equally between the two ends.

If a certain portion of the line is especially defective in its insulation, the distribution of battery power may sometimes be varied in accordance with the principles laid down, with manifest advantage.

The insulation of the batteries themselves is a matter of great importance, and should never be neglected. (29.)

110. Working several Lines from One Battery.—It has been for many years the practice in this country to work a considerable number of lines at the same time from a single battery. The number of wires that can be worked in this manner without interference depends entirely upon the proportion between the internal resistance of the battery employed and the joint resistance of all the circuits connected with it. If the resistance of the battery itself is inappreciably small in comparison with that of the lines connected with it, the current on any given circuit will vary but little, whether the others be open or closed. With the Grove battery of, say, 50 cups, it is possible to work as many as 40 or 50 well insulated lines, of 300 miles or more in length, without appreciable interference. The great objection to this system is that, in wet weather, the resistance of the lines is enormously diminished, and the interference of one circuit with another, as a necessary consequence, greatly increased.

It is a common practice when this occurs to increase the *number* of cups in the battery, which in most cases has a tendency to aggravate the very evil it is sought to remedy; for with every such addition the resistance of the battery becomes greater in proportion to that of the lines, and the currents more unsteady and fluctuating. No small part of the trouble experienced in

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working lines in wet weather arises from this cause, although usually attributed entirely to defective insulation. It is true, however, that the latter indirectly causes the difficulty, by lessening the resistance of the wires.

111. Experiments made on a very wet day, upon a number of circuits of nearly the same length (100 miles), leading out of New York city, proved that when one such wire was attached to a carbon battery of 60 cups the addition of three other similar wires reduced the current on the first one 12 per cent. It is a common practice to attach as many as eight wires to such a battery, which in the above case would have reduced the current about 25 per cent.

112. It is the opinion of many scientific experts in practical telegraphy that increased efficiency, as well as economy, would result from working telegraph lines with a single series of Daniell's battery, in its most approved form, upon each circuit. The objection urged against this battery is the increased amount of room it takes up, as well as its somewhat greater original cost.

113. As long as the present system remains in vogue, care ought to be taken that the different circuits leading from the same battery are as nearly as possible equal in resistance; and it must not be forgotten that the interference caused by attaching too many wires to a battery *cannot be remedied by the addition of more cups for intensity.* The electro-motive force of a carbon battery is exhausted with a rapidity nearly in proportion to the number of circuits supplied from it. In the case of the Grove battery this effect is not so apparent.

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CHAPTER VI.

TESTING TELEGRAPH LINES.

114. Interruption and interferences from various causes are constantly occurring upon telegraph lines, and one of the most important of an operator's duties is to be able to discover promptly the nature and location of a fault, that measures may immediately be taken for its removal. This is done by an investigation called *testing*. The apparatus and methods now in general use in this country are of a somewhat primitive nature, but the improved modes of testing which have long been employed in Europe are gradually becoming appreciated here, and as these are based on sound scientific principles, it is to be hoped that they will soon supersede the imperfect ones heretofore employed.

115. The principal interruptions to which a telegraphic circuit are liable may be summed up as follows:

DISCONNECTION.—The continuity of the circuit is broken, so that no current passes over the line.

PARTIAL DISCONNECTION.—This is usually caused by rusty and unsoldered joints in the line, or by loose screw connections in offices or about switches, which offer great *resistance* to the passage of the current.

ESCAPE or leakage of current from the line to the ground, caused by defective insulation, or contact with trees, &c. When an escape is sufficient to entirely prevent the working of the line it is called a "*ground.*"

CROSS.—When two wires are in contact, so that one cannot be worked without interfering with the other.

WEATHER CROSS.—When a portion of the current from one wire leaks into others upon the same poles, through defective insulation. The effect is similar to that of a cross, but much less strongly marked. This is often improperly called *sympathy*, or *induction*.

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DEFECTIVE GROUND CONNECTION.—It sometimes happens that the ground wire, or ground plate, at a terminal station, is defective. The effect of this is to make the wires connected with it appear as if in contact, or *crossed*. This difficulty is often caused by the removal of a meter in offices where a gas pipe is used as a ground connection for several lines.

116. TESTING FOR DISCONNECTION.—If the circuit is broken at any point the relays will all remain open. The operator at each way station should immediately proceed to test the wire by connecting his ground wire, first on one side of the instruments and then on the other. If either connection closes the line circuit, the interruption is on that side, as the circuit of the opposite main battery is completed through the ground, in place of the broken wire. If the ground wire gives no circuit either way, it is probable that the interruption is in the office, or that the ground connection is defective. Each operator should always first make sure that the fault is not in or about his own office. Having ascertained the direction in which the difficulty lies, he should at once report the state of the case to the terminal station at the opposite end.

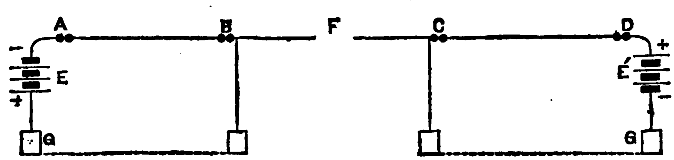

FIG. 45.

Fig. 45 represents a line with four stations, A, B, C and D. Suppose the wire broken at F. By connecting the ground wires at B and C, as shown, two distinct circuits are formed. A can work with B, and C with D, showing that the fault is between B and C.

Disconnection is usually caused by the breaking of the line wire, or by a key carelessly left open. Some other causes are wires loose in their binding screws, or defective switches, or the fine wire in or about the re-

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lay may be broken. The latter is sometimes burned in two by atmospheric electricity.

117. PARTIAL DISCONNECTION.—It is rather difficult to discover this fault by the ordinary relay tests. It is frequently of an intermittent character, and requires to be very carefully tested for. In the latter case, the best plan is to cross connect, or interchange the defective wire with a good one at the terminal, and also one other station, as in Fig. 46. Suppose the fault is at F, on No. 2 wire; by cross connecting at A and B, as shown,

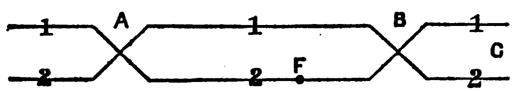

FIG. 46.

the fault will shift to No. 1 circuit, showing that it is between those points. If it were beyond B, it would remain on No. 2 circuit. In this case, let the wires be put straight at B, and cross connected at C, and so on, station by station. When the fault is passed it shifts to the other circuit, and will therefore be found between the two last stations.

118. TO TEST FOR AN ESCAPE.—Call the stations up in rotation, beginning with the one farthest off, and have them open key for a minute or two. When a station beyond the escape is open, more or less current will still pass out to the line through the relay, returning through the ground from the fault.

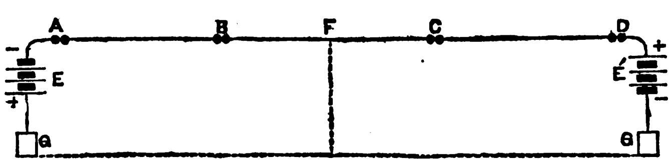

FIG. 47.

Suppose A (Fig. 47) is testing. When the circuit is open at C or D a current will pass from E through the fault, F, which will be interrupted when B opens, showing the fault is between B and C.

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119. TESTING FOR GROUNDS.—A ground is tested for in a similar manner. The operator at a way station can ascertain which side of him the ground is situated, from the fact that it cuts off or greatly weakens the main battery current from that direction, when tested with a ground wire by means of the finger or tongue.

Telegraph lines are very liable to be grounded by the action of atmospheric electricity upon the lightning arresters. These should be carefully looked after at frequent intervals, especially where exposed to dampness, as in cable boxes.

120. TESTING FOR CROSSES.—In case a cross is suspected between two wires, say Nos. 1 and 2, instruct the most distant station to open one wire, preferably the through wire, or No. 1, and "send dots" upon the other. Open No. 2 at your own station, and if the dots sent on No. 2 at the distant station are received on No. 1, the wires are crossed. Care must, of course, be taken not to be deceived by the leakage from one wire to another, caused by defective insulation. If the wires are in actual contact, the signals received upon No. 1 wire will be nearly or quite as strong as if received upon No. 2.

Next, instruct the distant station to leave No. 1 open, and open it also at your own station. No. 2 will now be free from interference, and the stations upon it may be signalled without difficulty. Call them in regular succession, commencing at the farthest end of the line, and instruct each one in turn to send dots on No. 2. If the dots are received on both wires the cross is between you and the station sending; but if upon No. 2 only, it is beyond that station. It is better that each operator, while sending dots, should open the other wire, if practicable.

The principle of this test will be understood by reference to Figs. 48 and 49, which represent a two wire line, with four stations, A, B, C and D, the wires being "crossed" between B and C. The operator testing for

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the cross is supposed to be at A. In Fig. 48 station C has No. 1 open, and station A has No. 2 open. If C sends dots on No. 2 the circuit will shift to No. 1, at the cross, as shown by the arrows, and the dots will

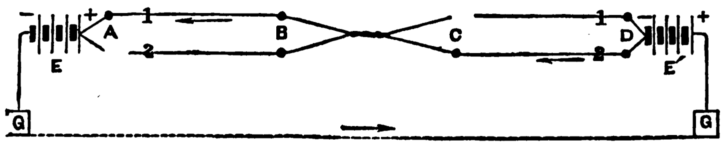

FIG. 48.

come on No. 1 instrument at A, showing that the cross is between A and C. In case C were unable to open No. 1 the effect would evidently be the same, provided it remains open at D.

Now let C close both wires, and B open No. 1, and write dots on 2 (Fig. 49). If No. 2 be open at A, B will be unable to work in this case, as both wires are open, one at A and the other at B. With both wires

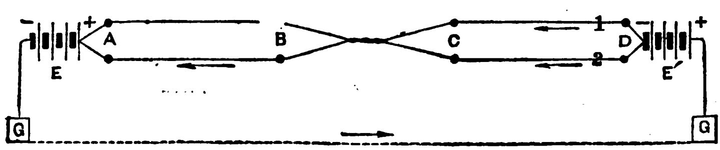

FIG. 49.

closed at A, B's dots will come on No. 2, the current from F passing over both wires to the cross, and from thence on No. 2, No. 1 being open, as shown in the figure. Thus the fault is located between B and C.

In large offices, where there are a considerable number of wires, it will often be found a much more convenient and expeditious method of testing for crosses for the operator to station himself at the switch with a single instrument, which can be placed at pleasure on any wire, for the purpose of communicating with different stations. When any station is "sending dots" the testing operator can feel them by placing a finger upon the ground wire, and another upon the proper line wire

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at the switch. The principle involved is of course the same as in the method first described. In wet weather, however, testing by the sense of feeling is attended with much uncertainty, as it is impossible to distinguish between the effect of a metallic cross, or actual contact, and the leakage arising from bad insulation.

121. It would be difficult to specify all the minor interruptions that are liable to occur in and about telegraph offices, or on the lines; the operator will therefore, in many cases, be obliged to depend upon his own ingenuity for the best method of testing applicable to each particular case. By carefully studying, however, the principles heretofore explained, the intelligent telegrapher will usually be able to cope with any difficulty that may chance to arise in the ordinary service of the lines.

122. Testing with the Galvanometer and Resistance Coils.—In the more accurate and scientific modes of testing, which have been for some years em-

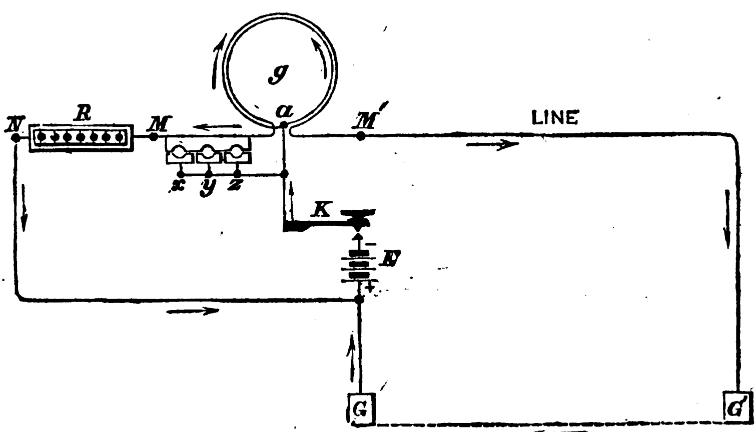

Fig. 50.

ployed upon the European lines, the instruments used are the *differential galvanometer* and a set of standard *resistance coils* (44).

The arrangement of the connections will be understood by reference to Fig. 50.

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The galvanometer coils are wound with two wires of the same length and resistance, insulated from each other with the utmost care. The needle is, therefore, surrounded by an equal number of convolutions of each wire, which are also equi-distant from it.

The inner end of one coil surrounding the galvanometer, g, is joined to the outer end of the other at a, and a key, K, attached to this junction, when depressed, forms the connection with the testing battery, E. The other ends of the coils run to binding screws, M M′, for the convenient attachment of lines to be tested. The principle upon which the action of the instrument depends is the following:

When the battery is connected by depressing the key the current divides into two equal portions at a, one flowing from a to M, tending to deflect the needle to the left, and the other from a to M′, tending to deflect it to the right; but as long as the two currents are of the same strength they balance each other, and the needle remains at rest. Suppose that the terminal M′ is connected to a telegraph line whose remote end is to ground, and the terminal M is connected through the resistance coils, R, to the ground likewise, as shown in Fig. 50. We have already seen (102) that the strength of an electric current is in all cases equal to the electromotive force divided by the resistance. Therefore, if in this case we let

E = electro-motive force of battery,
l = resistance of line wire,
g = resistance of galvanometer coil,
r = resistance coils in circuit,

the current in the two circuits surrounding the needle will be

$$\frac{E}{g + l} \text{ and } \frac{E}{g + r}$$

If, therefore, the resistance coils in circuit be varied until R = l, the needle will remain unaffected. As the earth offers no appreciable resistance to the passage of the current, the resistance of the line l will be accu-

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rately represented by the amount of resistance interposed at r, in order to bring the needle to zero. The value of the above equation will obviously not be affected by any change in the value of E.

123. The resistance coils, R, accompanying the galvanometer, are so arranged as to be adjustable to any required resistance, from 1 ohm up to 10,000. For the measurement of still higher resistances one coil of the galvanometer is provided with three "shunts," or branch circuits, x, y, z, having resistances respectively equal to $\frac{g}{9}$, $\frac{g}{99}$, and $\frac{g}{999}$; therefore, if x be connected, $\frac{1}{10}$ of the current will pass through g, and $\frac{9}{10}$ through the shunt. In the same manner y and z respectively allow but $\frac{1}{100}$ and $\frac{1}{1000}$ of the current to pass through one wire of the galvanometer, when connected, and by this means the instrument may be made to measure any resistance, from 0.001 up to 10,000,000 ohms.

124. Testing for the Distance of Faults.—The principle upon which the methods of *distance testing* are founded is that of finding the resistance of the line wire between the testing station and the fault by means of the apparatus described. When the line is broken at any point one of the following four cases generally occurs:

1. Line wire broken, giving full, or nearly full, ground connection.
2. Line wire unbroken, but gives nearly enough escape to ground to make signals imperceptible.
3. Line wire broken, without making contact with earth.
4. A cross between two wires, so that signals sent on one are communicated to both.

125. It is very essential that the resistance of each circuit should be frequently measured and recorded, so that when a fault occurs the actual resistance per mile of the line may be known. If the broken line gives a full ground, its resistance divided by the resistance per mile at once gives the distance of the break from the testing station; and if the distant station obtains a

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corresponding result, the confirmation is complete. Thus, in a line of 100 miles in length, if the tests from the two extremities indicate distances of 45 and 55 miles, respectively, the locality of the interruption is clearly indicated. As the fault, however, usually gives a very considerable resistance at the point where the line is in contact with the earth, and the sum of the two resistances, measured from stations at the opposite ends of the line, greatly exceeds the resistance of the line itself when perfect, it is usual in such cases to estimate the fault midway between the two points indicated. Thus, when the respective resistances indicate 86 and 26 miles, the sum of these exceeds 100 miles by 12, and therefore half this excess, or 6, is deducted from each of the measures.

126. When the line is unbroken, but shows a heavy escape or partial ground, sufficient to weaken signals, two or three different methods are available for determining its locality. The first plan is that of direct measurement, alternately from each end, the distant end at the same time being insulated, or, in other words, left open, in the manner explained in the last paragraph. In this case the resistance of the fault is measured twice over, and is roughly allowed for by the method of calculation above given.

127. THE LOOP TEST.—A second and more accurate method, which gives a measure entirely independent of the resistance of the fault itself, is known as the loop test. It is only available, however, in cases where there are two or more parallel wires on the same route. In order to make this test, let the operator proceed as follows:

Make the length to be tested as short as possible, and have all the instruments in circuit taken out. Select a good wire, similar, if possible, to the one it is required to test. Both these wires must then be connected together in a loop, at the nearest available station beyond the fault, *without* ground connection. The resistance of the faulty wire, when perfect, must be

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ascertained. This may be taken from previous records, or it may be found thus:

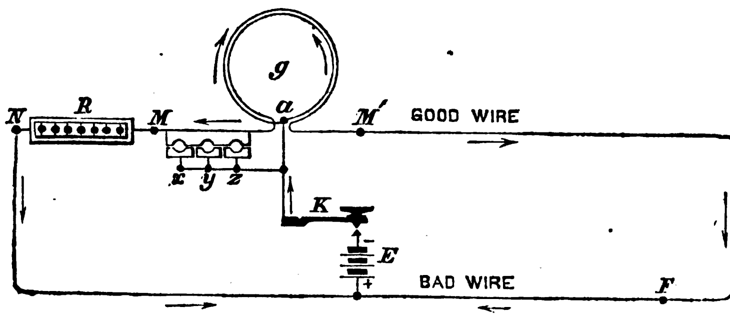

FIG. 51.

Connect one end of the loop to the + pole of the battery E, and the other to one of the galvanometer wires at M'. Connect also the + pole of the battery with the resistance coils, R, at N, and the − pole of the battery to the key, K, and common terminal, *a*, of the galvanometer. Connect the remaining galvanometer wire with the resistance coils at M (Fig. 51).

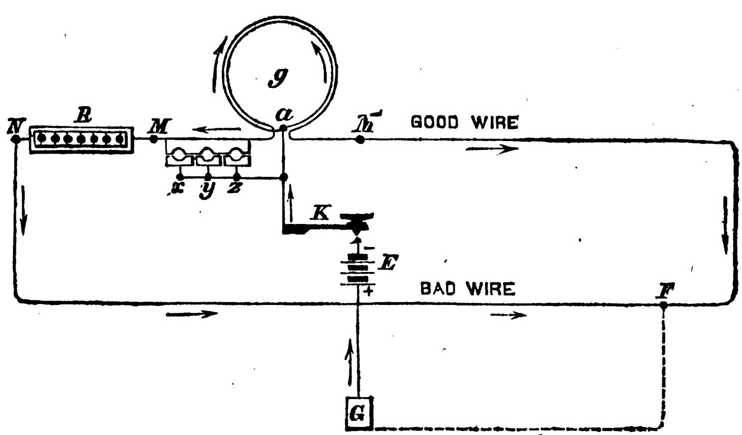

FIG. 52.

Having ascertained the resistance of the loop, arrange the connections as shown in Fig. 52.

Upon depressing the key, K, the battery current will

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flow through M and R, and also through the loop. The resistance required at R to balance the needle will be equal to the sum of the resistance of the two lines. Although there is a partial ground at F it will not affect the measurement, as there is no other ground in circuit.

Connect the + pole of the battery E to ground, and connect the — pole to the key K. Connect the perfect wire of the loop to one of the galvanometer wires at M′, and the faulty wire to the other galvanometer wire at M, interposing the resistance coils R. When the key K is depressed the current from the battery E flows into both lines simultaneously, passing to the ground through the fault at F. By adding resistance at R, so as to bring the needle to zero, the resistance *a* N F will be made equal to *a* M′ F.

The resistance thus added, deducted from the total resistance of the loop, previously ascertained, and divided by two, is the resistance of the line between N and F.

Thus, if the resistance of the loop be 1,000 ohms, and 100 ohms have been added to the defective wire to balance the needle—

Then $\frac{1000 - 100}{2} = 450$ ohms, the resistance of the wire between the resistance coils R and the fault.

Let $M' F = x$, $N F = y$.
Then $x + y = L$, the resistance of the loop.
As $R + y = x$, or $R + N F = M' F$.

Therefore, $y = \frac{L - R}{2}$

Suppose that the loop of 1,000 ohms measures 120 miles, then, by proportion,

If 1,000 ohms = 120 miles, 450 ohms = 54 miles.

When an instrument or section of small wire is included in the circuit, allowance must be made for their resistance. It is a great assistance in these tests to know from previous records the exact resistance of every section of the line.

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128. **Blavier's Formula for Locating an Escape.**— Where there is but one wire the following method may be employed. Three tests have to be taken for the operation, viz:

Let R = resistance of the line before it was defective. This must be obtained from previous records.
" S = resistance of the line when grounded at the distant end.
" T = resistance of the line when disconnected at the distant end.

Multiply S by S and T by R, and add the products together; subtract from this amount T times S, and also R times S. Subtract the square root of the remainder from S; the remainder will give the resistance, x, or the distance of the fault from the testing station.

This process appears complicated, but is in reality very simple. For example, suppose the line 100 units long, and the fault 68 units distant, and the resistance of the fault 96 units, as shown in Fig. 53

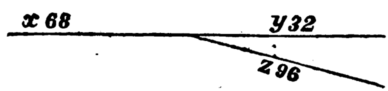

Fig. 53.

$$\text{Then } R = x + y = 68 + 32 = 100$$

$$*S = x + \frac{y \times z}{y + z} = 68 + \frac{32 \times 96}{32 + 96} = 92$$

$$T = x + z = 68 + 96 = 164$$

We shall, however, have obtained these resistances by measurement. and not by calculation. We therefore have:

$$\left.\begin{array}{l} S \times S = 92 \times 92 = 8464 \\ T \times R = 164 \times 100 = 16400 \end{array}\right\} 24864$$

$$\left.\begin{array}{l} T \times S = 164 \times 92 = 15088 \\ R \times S = 100 \times 92 = 9200 \end{array}\right\} \begin{array}{r} 24288 \\ \hline 576 \end{array}$$

And the square root of 576 is 24; which deducted, S = 92, gives 68 as the resistance of x, or the distance of the fault from the testing station.

The distance, x, being known, the others are obtained with ease; for R — 68 gives y, the distance from the opposite end; and T — 68 gives z, or the resistance of the fault itself. This test should be taken from both

* See note, § 104.

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ends of the line, if possible. In the above calculation the resistance of the fault is supposed to remain constant during the measurements; but as this is not often the case in practice, the average of several measurements should be taken.

129. To Find the Distance of a Cross.—The two wires in contact form a *loop*, provided they are clean, and are twisted together, so that the contact offers no appreciable resistance. In such a case open both wires at the nearest station beyond, and test the resistance of the loop. Half this resistance will be the resistance of the wire between the galvanometer and the fault, and from this the distance can be calculated, as before explained (127). All relays in circuit must be taken out, or the proper allowance made for their resistance.

As it is difficult to tell with certainty whether the cross offers resistance or not, it is a better plan to test it as a ground. Test each wire in turn by the loop method (127), grounding the wire at both ends. The wire tested will then make a ground through the other wire at the point of contact, and the location of the latter may be readily ascertained.

*Second Method.**—Suppose two wires, A and B, touch one another at the point F. Connect A to the zinc of the testing battery, leaving it open at the remote end; it will then serve as a battery wire between the battery and the fault (F). Ground B at the distant end, and connect it to one coil of the differential galvanometer at the testing station Put the other wire of the galvanometer to ground. The current of the battery will pass along the wire A and divide at F, one portion going to ground at the distant end of B, and reaching the galvanometer through the wire connected with the ground, the other portion returning to the galvanometer through the nearer portion of B. If the cross is exactly in the centre of B the needle will not move, as the two currents will balance each other. If one section of B is longer than the other, the resist-

* Culley's Handbook, 3d edition, page 279.

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ance added to the shorter section to balance the needle will show the difference in the resistance of the two sections.

Let L = the total resistance of B.
" x = resistance of the shorter portion.
" $L - x$ = " " longer "
" R = resistance added to shorter portion.

$$\text{Then } x = \frac{L - R}{2}$$

130. Advantages of Testing by Measurement.—The testing of lines by actual measurement lies at the very foundation of all efforts to improve the working of our telegraphic system. The insulation resistance of each of the principal circuits should be measured every morning, and a record of the results kept for reference. In England the standard of insulation is 1,000,000 ohms per mile in the worst of weather. Therefore, a line of 200 miles should not give less than $\frac{1,000,000}{200} = 5,000$ ohms. If it gives less than this the low resistance is due to defective insulation. The line should, in that case, be tested in many separate sections, either from the terminal office or by a visit to each section. If the resistance per mile is the same for each section, the fault is probably owing to the nature of the insulation; but if, as is usually the case, some sections are very much worse than others, the trouble will be found in contact with trees, broken insulators, and the like. A visit to the faulty locality will disclose the cause of the evil.

131. In comparing the insulation of line wires of different lengths, the insulation *per mile* must be ascertained, otherwise the longest wire will appear the worst; therefore, multiply the insulation test in ohms by the length of the wire in miles. If the insulation is uniformly good throughout the circuit tested, the leakage will increase in direct proportion to the length of the wire, irrespective of its thickness or conducting power, for the resistance of the wire is very small in comparison with the insulators, and need not be taken into account.

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The following example from Culley's work will illustrate this. The figures given are the results of an actual test:

The wire A had a leakage equal to	29
" B " " "	30
" C " " "	50
Total leakage	109

The three wires, when connected together at the testing end and left open at the distant end, gave a combined leakage of 110.

When connected so as to form a continuous wire, open at the distant end, the leakage was still 110. The experiment was repeated, and extended to other wires, with the same result. In this case the resistance of the insulators was very great compared with that of the wire—as much as two million ohms per mile. But on a wet day three similar wires, whose respective leakages were 196, 185 and 141, making a total of 552, when looped in a continuous line, as in the second case above, gave a test of only 476, the distant portion of the wire being in reality tested by a current weakened by the leakage in the nearer portions.

132. Testing for Conductivity Resistance.—The metallic resistance of the line wires should be occasionally tested in sections, in the finest weather. The resistance should be uniformly in proportion to the length of the wire. If any section discloses an unusually high resistance per mile, it is very probable that there are rusty, unsoldered joints in the line, or that the ground connections are defective. It is difficult for those who have not tried it to believe the vast improvement that may be made in any line in a few days by actual measurement, and an inspection of the sections which give indications of being defective.

It is not an uncommon occurrence to find that a single unsoldered joint in galvanized iron wire, which appears perfectly firm and sound, will give a resistance, when tested by the galvanometer, equal to many miles of line. A line containing many bad joints will frequently

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work better in wet than in dry weather, as the moisture increases the conductivity of the oxide between the wires at the joints.

In testing for conductivity, with the distant end of the wire to ground, as in Fig. 54, the result is sometimes interfered with by *earth currents*. It is therefore better, when practicable, to use the loop method, by connecting the wire to be measured in a loop with another wire of known resistance. Unless this test is made in fine weather, however, the leakage from one wire to the other will decrease the resistance of the loop. The battery must also be insulated from the

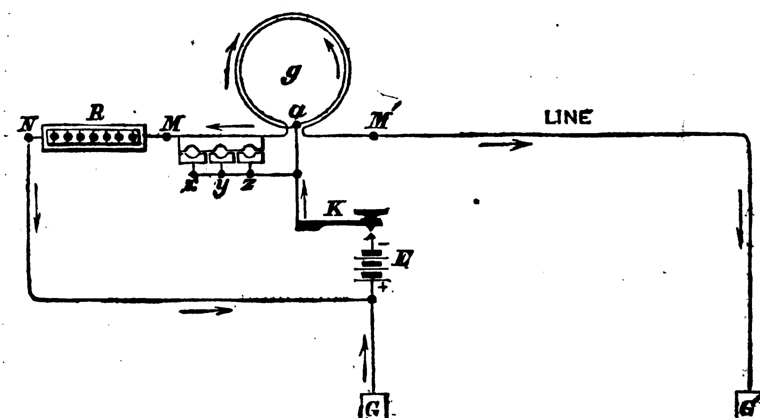

FIG. 54.

earth, otherwise the leakage at each insulator will decrease the apparent resistance, especially if the insulation is defective. For instance, two wires on the same poles, disconnected and looped at the distant end, had a resistance of 6,475 ohms when the battery was entirely disconnected from the earth. Upon putting the zinc pole of the battery and the line attached to it to earth, the apparent resistance fell to 5,250 ohms. The insulation resistance, with one wire disconnected, was 9,250 ohms, the weather being damp.

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CHAPTER VII.

NOTES ON TELEGRAPHIC CONSTRUCTION.

133. In order to maintain uninterrupted telegraphic communication between any two points, it is of the first importance that the line should be well constructed and properly insulated throughout. There are numerous minor details in the construction and repairing of telegraph lines which merit much more attention than they generally receive. The bad working of our lines is in a great measure owing to the neglect of these apparently trifling details, through ignorance or carelessness.

134. Poles.—The poles intended for an ordinary line should never be less than five inches in diameter at the top, their length depending upon the number of wires to be provided for, and in some measure upon the location of the line. They should be set in the ground to the depth of five feet, wherever practicable.

In setting poles around the curve of a railway, they should be made to lean back against the strain of the curve.

135. Wire.—For ordinary lines, galvanized iron wire, of No. 8 or 9, Birmingham gauge, is generally employed. For short lines, No. 10 or 11 will answer very well. The "American Compound Wire," a recent invention, is composed of a combination of a steel core with a sheathing of copper. It has come into extensive use within the short time which has elapsed since its introduction, and has, thus far, been found to answer admirably. A wire of this kind, having a conductivity equal to a No. 8 iron wire, weighs only 80 pounds per mile.

136. The less the size, and consequently the conductivity of the line wire, the more care is required in its

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insulation, for an increased resistance virtually adds to the length of the circuit. Increased conductivity thus admits of a reduction in battery power, with a consequent decrease in the escape of electricity, and long circuits may be thus worked with much greater facility; a fact which has been most unaccountably ignored in the construction of the greater portion of the lines in this country.

137. GALVANIZED OR ZINC COATED WIRE must always be used for permanent work, for rust reduces the conducting power of wires very rapidly. This is especially the case with the smaller sizes, such as No. 11 or 12. In smoky places it is a good plan to paint the wire before it is put up, for the gas arising from the combustion of coal destroys the zinc coating in a short time, as may be observed in many of our larger cities.

138. ARRANGEMENT OF WIRES UPON THE POLE.—Wires arranged vertically upon the poles, or one above another, are more liable to get into contact with each other than when arranged horizontally upon cross-arms. When placed one above another, each alternate wire should be fastened upon opposite sides of the poles.

It is better not to place wires of different sizes upon the same poles or cross-arms if it can be avoided, as they are much more likely to get "crossed" than wires of the same size would be, as they do not keep time with each other when swung to and fro by the wind.

139. JOINTS OR SPLICES.—In the construction of a line nothing is of greater importance than the perfect continuity of the circuit, and this depends, in a great measure, upon the perfection of the joints. The importance of this has been very generally overlooked by the telegraphers of this country, and much trouble in working lines has been experienced in consequence, the cause of which has remained unsuspected. A single rusty unsoldered joint will often cause more resistance than fifty miles of line.

No joint or splice, however clean and firm, can be depended upon if made by mere contact or twisting.

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Sooner or later the metals will certainly rust, and this tendency is increased by the passage of the current. When copper and iron wires are joined together the joint is especially liable to become defective from this cause. It is a common error to suppose that joints made in galvanized wire do not require soldering.

140. In making a joint each wire should be twisted round the other, in the manner represented in Fig. 55, the turns passing as close, and as nearly at right angles as possible to the wire which they surround. A wire must *never* be spliced by being bent back and twisted around itself.

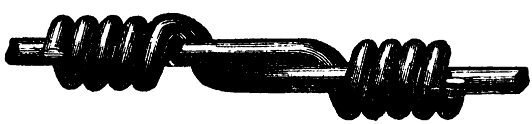

FIG. 55.

141. The best solution for soldering is chloride of zinc, with a little muriatic acid added, for the purpose of cleansing the wire. In connecting copper and iron wire together, it is well to wash off the chloride of zinc, and then coat the joint with paint or rosin, or else to solder with the rosin alone. This will prevent local galvanic action between the metals.

142. FIXING THE INSULATORS.—In attaching insulators to the poles they should be arranged in such a manner as to prevent, as far as possible, the lodgment of snow about them, so as to form an escape between the wire and its support. The glass insulator is usually cemented to the bracket by means of white lead or asphaltum. *The edge of the insulator must never be permitted to touch the shoulder of the bracket;* for in this case, during a shower, a continuous stream of water flows directly from the wire to the pole, entirely destroying the usefulness of the insulator. For the same reason an insulator ought never to be fastened down to a bracket by means of a spike driven over it, as is often done where there is an upward strain upon the wire. The proper way, in such cases, is to use some form of

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hook, or suspension insulator, and fasten the line into it with a tie-wire.

In turning a sharp angle it is better to put on two insulators and brackets at the corner pole, or the wire will be liable to come in contact with it.

When the Lefferts or Brooks insulator is used, there is danger of fracturing the glass while stringing wire, by violently wrenching the wire into the hooks. By a little precaution this result may be avoided.

143. Insulators and brackets are sometimes attached to a cross-arm, or other support, in a horizontal position. This ought never to be allowed, for a driving rain will wet the whole inner surface of the insulator, causing a great leakage of the current at every support. The same thing often occurs with improperly shaped brackets, which cause the spray from falling rain-drops to be dashed against the inside of the insulator. The shoulder of the bracket ought to be rounded or sloped off, so as to prevent this from happening.

Unless the insulator is securely fastened to the pin or bracket which supports it, it is liable to be lifted off by the wind, causing an interruption.

144. Leading Wires into Offices.—The wires leading into offices are fruitful sources of escapes and other interruptions, as the work is often very unskilfully or carelessly done. Gutta-percha covered wires, unless well protected, become entirely useless in a year or two, if exposed to the air and light. The method employed in England to protect this kind of wire might be adopted with great advantage in this country. The gutta-percha wire is first covered with tape, and then saturated with a preservative mixture.*

The best way to lead wires through the side of a building is to enclose them in hard rubber tubes, with

* This mixture is made and applied as follows: Take equal portions of wood tar, gas tar and slacked lime. Boil these together, stirring them well while boiling, until the moisture is entirely driven out, which may be known by the subsidence of the frothing. When cool apply to the taped wire, and then cover the latter with dry sand. Hang the wire up to dry in the air, and in three or four days it will be ready for use. This coating resists sun and moisture, and effectually protects the gutta-percha.

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the outer ends inclined downwards, to prevent moisture from entering. In arranging these wires, it should be borne in mind that the current will follow moisture and dampness along the outer surface of covered wire, unless it is so placed that the line of leakage is broken at some point.

145. Fitting up Offices.—In running wires inside an office, it is better never to allow two wires to touch each other, even when covered with an insulating coating, as this may be burned by lightning or otherwise rendered imperfect causing a cross-connection. The proper mode of arranging the office connections and running the wires to the instruments is shown in Figs. 17 and 18, pages 34 and 35. Splices in the office wires should be avoided as far as possible, but when required, they should be made by turning each wire eight or ten times around the other. A less number of turns answers for the line wire, because the strain tends to keep the joint pressed together. Great care must be observed in making the joint between the iron and copper wire, which must in *all cases* be soldered.

146. Ground Connections.—It is of the utmost importance that the ground plate at each end of the line should make a perfect connection with the earth. The plate must be large, and buried deep in wet soil below the reach of frost. A water or gas pipe makes an excellent ground connection. The ground wire should be attached outside the metre, as the latter is liable to be occasionally disconnected for repairs. It is advisable, whenever practicable, to form a connection both with the gas and water pipes. The connection should be carefully made and always well soldered.

147. Cables.—The shore ends of cables should be bedded well out to low water mark. Dig the trench to a good depth, and cover the cable with a piece of heavy plank or joist, and secure it well with heavy stones, laid at short intervals. If the covering be merely of sand it will soon wash away and leave the cable uncovered. *Never allow any portion of a cable to*

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be exposed to sun or air, but cover it all the way from the box where the connection is made with the air line.

Cable boxes always ought to be made double (one box within another), in order to prevent wet from entering. The unskilful manner in which these are often arranged is a fruitful source of trouble in working lines.

Lightning arresters should be kept attached to cables *all the year round*. It is not uncommon for heavy lightning to occur in midwinter in this country.

148. MAKING JOINTS IN CABLES.—In splicing cables, or other gutta-percha wire, the following is the method recommended by the Bishop Gutta-Percha Company, who have manufactured the greater portion of the submarine cables in use in this country:

"Use gutta-percha one sixteenth of an inch thick, cut in pieces to suit the joint. Soften it in hot water, and keep it flat. Wipe the surface with a cloth. Heat the surface by holding it near a flat file or other iron, about as hot as a laundress's iron; if the iron causes the gutta-percha to smoke, it is too hot. When dry and a *little sticky*, wind two or three coatings of gutta-percha around the joint, taking care that each coating is perfect and each layer is dry; then smooth off and lap the joint well over on the gutta-percha on each side of the joining. *Use no spirit lamp, nor anything with a blaze.* When gutta-percha is burned it cannot be restored. Hot water joints are worthless. They will not stand, and will open when dried out.

"In making joints it is *absolutely necessary* that the hands of the operator should be clean, and that no water, grease, dirt, or anything of the sort must be allowed to touch the gutta-percha."

149. Another method is given in *Culley's Handbook of Practical Telegraphy*, as follows:

"Prior to making the joint the gutta-percha is removed from the ends of the wires for about one and a half inches, and the copper wires are carefully cleaned by scraping; the wires are twisted together for one inch, the sharp ends being closely trimmed off. The

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joint is then soldered with *rosin* and good soft solder, containing a sufficiency of tin.

"After this the gutta-percha is scraped, or very carefully pared back for about two inches, to remove its outer surface, which is oxidized, and will not join properly; the wire joint is covered with Chatterton's compound* and the gutta-percha, heated on both sides, and tapered down over the joint till that from each side meets. The junction is completed by means of a warm joining tool, care being taken to mix the gutta-percha well without burning. As soon as this has cooled another coating of Chatterton's compound is spread over the gutta-percha, taking care not to burn the compound.

"A new and clean sheet of gutta-percha is then heated by means of a spirit lamp, and while so heated carefully stretched so as slightly to thin it. Then, while it and the Chatterton coated joint are still hot, it is laid on the joint, and pinched tightly round it with the finger and thumb, after which it is trimmed off close with scissors. The seam is again pinched and carefully finished off with a warm tool, so as to mix the gutta-percha of the two sides, and the coating of the wire itself, well together.

"The joint, when cool, is again covered with Chatterton's compound, and a longer and larger sheet of gutta-percha is laid over it, pinched, cut, and tooled off as before.

"When the joint is complete, another coating of Chatterton's compound is applied over the whole, well tooled over the joint, and when cool, rubbed with the hand, well moistened, till the surface is smooth.

"The mixing of the old and the new gutta-percha is most important, and joints generally fail from this having been imperfectly done, or from the percha being overheated. Cleanliness is essential to success. The fingers should be used as little as possible, and must be kept very clean."

* The ingredients of this are by weight, as follows: one part of Stockholm tar; one part of rosin, and three parts of gutta-percha.

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CHAPTER VIII.

HINTS TO LEARNERS.

150. **Formation of the Morse Alphabet.**—The characters of the American Morse Alphabet are formed of three simple elementary signals, called the *dot*, the *short dash* and the *long dash*, separated by variable intervals or *spaces*. There are four spaces employed in this alphabet, viz., the space ordinarily used to separate the elements of a letter; the space employed in what are termed the "spaced letters," which will be hereafter referred to; the space separating the letters of a word; and lastly, that separating the words themselves.

The value of these spaces should be carefully impressed upon the mind of the learner. Beginners are apt to conceive that the Morse alphabet consists solely of dots and dashes, and this misconception has a tendency to greatly increase the time required to become good "senders." Uniformity and accuracy in spacing is of no less importance than in the formation of the letters themselves. The foundation of perfect Morse sending lies in the accurate division of time into multiples of some arbitrary unit.

151. The duration of a dot is the unit of length in this alphabet.

1. The short dash is equal to *three dots*.
2. The long dash is equal to *six dots*.
3. The ordinary space between the elements of a letter is equal to *one dot*.
4. The space employed in the "spaced letters" is equal to *two dots*.
5. The space between the letters of a word is equal to *three dots*.
6. The space between two words is equal to *six dots*.

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The dot is an unfortunate appellation for this sign, because it conveys the idea of a point, or to speak electrically, a current of infinitely short duration. Electro-magnets, however, require time in magnetization (38). Currents involve time in transmitting signals. Clock-work requires time to run. Currents must be of sensible duration. The dot, therefore, involves *time*, but this time is variable, according to circumstances. The length of the dot should increase with the length of the circuit. In long submarine lines the dot has to be made longer than the dash itself on short open air lines, and the same thing occurs in working through repeaters (76). In commencing, therefore, the habit should be acquired of making short, firm *dashes*, instead of light, quick *dots*. After the student has once learned to send *well*, it is very easy to learn to send *fast*, but after once getting in the habit of sending short and rapid dots, or "clipping," it is almost impossible to get in the way of sending firmly and steadily. Beginners should rather take pride in the accuracy with which they space out the elements of the telegraphic music than in the number of words they can stumble through in a minute.

152. In the excellent little Manual of Prof. Smith* six elementary principles are laid down as the basis for practicing the alphabet, viz:

First principle. Dots close together.

I	S	H	P	6
··	···	····	·····	······

Second principle. Dashes close together.

M	5	¶
— —	— — —	— — — —

Third principle. Lone dots.

E
·

Fourth principle. Lone dashes.

T	L or cipher
—	——

* Published by L. G. Tillotson & Co., New York

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Fifth principle. A dot followed by a dash.

A

▪▬

Sixth principle. A dash followed by a dot.

N

▬▪

153. Correctness in sending depends in a great measure upon the manner in which the key itself is handled. Place the first two fingers upon the top of the button of the key, with the thumb partly beneath it, the wrist being entirely free from the table. The motion should be made by the hand and wrist, the thumb and fingers being employed merely to grasp the key. The motion, both up and down, must be free but firm. *Tapping* upon the key must be strenuously avoided.

154. The downward movement of the key produces *dots* and *dashes;* the upward movement *spaces.* It is first necessary to acquire the habit of making dots with regularity and precision, then dashes, and finally combinations of dots and dashes. It is the best plan for the student to practice upon a register in a local circuit with his key, as he will the more readily be able to observe and correct the faults in his manipulation.

155. The student may now proceed to practice upon the elementary principles.

1. Practice making *dots* at regular intervals, until they are produced with the regularity of clock-work, and of definite and uniform dimensions. The regular tick of a watch or of a short pendulum is a valuable auxiliary in acquiring this habit.

2. Next proceed to make dashes, first at the rate of about one per second of time, which may afterwards be slowly increased to three. The space between the dashes must be made as short as possible. If the upward motion of the hand, in forming the space, be made *full,* it cannot be made too quick.

3. The third principle occurs but once in the alphabet, and forms the letter E. It is made by a quick but firm downward movement of the key. In practicing

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upon this or any other character, it should not be repeated too rapidly, nor should the thumb and fingers be taken from the key in the intervals between the successive repetitions of the letter.

4. The fourth principle is somewhat difficult. The usual tendency is to make T too long and L too short. It will be observed that the same character is used for L and the cipher or 0. Occurring by itself or among letters it is always translated as L, but when found among figures becomes 0. This would at first seem liable to cause confusion, but in practice it is found not to be the case. It was formerly the custom to make the cipher equal to three short dashes.

5. The fifth principle, which forms the letter A, may be timed by the pronunciation of the word *again*, strongly accenting the second syllable. The tendency of beginners is usually to make the dot too long and the dash too short, and more especially to separate them too much.

6. The final principle, the dash followed by a dot, usually presents some difficulties. The universal tendency of the student is to separate the dot from the dash by too great a space. Time the movement by pronouncing the word *ninety*, with the first syllable somewhat longer than usual.

156. Having become thoroughly conversant with the six elementary principles, the following exercises may be taken up in order.

(1.)	E	I	S	H	P	6
	.	..	...	....	.....	......

These should be practiced separately, until the right number of dots can be made invariably, the last dot in each being neither shorter nor longer than the preceding ones.

(2.)	T	M	5	¶	L or cipher.
	—	— —	— — —	— — — —	——

In practicing this exercise, care must be taken not to separate the dashes too much, and to make the final one in each letter exactly equal to the preceding ones.

Observe not to make the L too short. There is a general tendency in beginners to shorten the final dash, where two or more occur together.

(3.)	A	U	V	4
	·—	··—	···—	····—

The usual tendency to make too much space between the dot and dash, in the above letters, may be avoided by making them as if by prolonging the final dot in I, S, H and P.

(4.)	I	A	S	U
	··	·—	···	··—
	H	V	P	4
	····	···—	·····	····—

These are to be practiced in couples, as represented, the object being to impress upon the student the difference in the characters thus coupled together.

(5.)	N	D	B	8
	—·	—··	—···	—····

The student having thoroughly mastered the sixth elementary principle, he will have no difficulty in forming the above characters.

(6.)	A	F	X	Parenthesis
	·—	·—·	·—··	·—··—
	Comma	Semicolon	W	1
	·—·—	·—·—·	·——	·——·

The only caution necessary in this exercise is to form the letters compactly, with the dashes of equal length. (See Exercise 2.) Observe, that the Parenthesis may be formed by running A U together, and the Semicolon by A F, etc.

(7.)	U	Q	2	Period	3
	··—	··—·	··——··	··——··	···—·

These differ but little from exercises previously practiced, and require no particular directions.

(8.)	K	J	9	Interrogation
	—·—	—·—·	—··—	—··—·
	G	7	Exclamation	
	——·	——··	———·	

J and K are generally considered the most difficult letters in the alphabet. Do not separate J into double

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N, and be careful that the dashes correspond in length. (See Exercise 2.) The figures 7 and 9 require care in spacing correctly.

(9.) O	R	&	C	Z	Y
. .	. ..	. ...	.. .	... .	.. ..

These are termed the "spaced letters," and require great care in order to make them correctly. The "space" should be just double that ordinarily used between the elements of a letter. The usual tendency is to make it too great. It should be just sufficient to distinguish these characters from I, S and H.

157. The construction and manipulation of the alphabet having been thoroughly mastered by the practice of the foregoing exercises, it is now presented in its complete and consecutive form.

I. Alphabet.

A	.-	O	. .
B	-...	P	.....
C	.. .	Q	..-.
D	-..	R	. ..
E	.	S	...
F	.-.	T	-
G	--.	U	..-
H	....	V	...-
I	..	W	.--
J	-.-.	X	.-..
K	-.-	Y	.. ..
L	—	Z	... .
M	--	&	. ...
N	-.		

II. Numerals.

1	.--.	6	......
2	..-..	7	--..
3	...-.	8	-....
4	....-	9	-..-
5	---	0	——

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III. PUNCTUATION, ETC.

*Period	··——··	Exclamation	———·
Comma	·—·—	†Parenthesis	·—··—
Semicolon	·—·—·	Italics	—···—
Interrogation	—··—·	‡Paragraph	————

Numbers are always sent twice over, to avoid error; once written out in full, and then in figures. In fractions one dot is used to represent the line between the numerator and denominator.

158. It is necessary to again caution the student against falling into the common error—from which most books on the telegraph are not exempt—that is entertained respecting the elementary signs of the Morse alphabet. It is said to consist of two characters, the dot and the dash. The importance of the *space* is utterly ignored. The difference between good and bad sending is almost entirely a matter of *spacing*. A common fault of young operators is to run their words too closely together.

If the principles laid down in this work be firmly adhered to, the learner will be surprised, not only at the rapidity with which he masters what appears to be a very difficult lesson, but at the extreme accuracy with which he manipulates his instrument. He must also carefully bear in mind that one of the most universal faults, among those attempting to learn the telegraphic art, is that of going over a great deal and learning nothing well.

159. READING BY SOUND.—This can only be attained by constant and persevering practice, keeping in mind the principles above given. The lever of the Morse apparatus makes a sound at each movement, the down-

* The Semicolon, Parenthesis and Italics are seldom used in this country. It is customary among operators to emphasize particular words by separating the letters more widely than ordinarily.

† Preceding and following the words to which they refer.

‡ When this occurs the copyist makes a new paragraph, by commencing the next word upon another line.

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ward motion producing the heavier one, or that representing dots and dashes; or, more properly, the heavy stroke indicates the commencement of a dot or dash and the lighter one its cessation. A dot makes as much noise as a dash, the only difference being in the length of time between the two sounds. Thus, if the recoil or lighter stroke be dispensed with, it would be impossible to distinguish E, T and L from each other.

In learning to read by sound it is best for two persons to practice together, taking turns at reading or writing, and each correcting the faults of the other. The characters must first be learned separately, and then short words chosen and written very distinctly and well spaced, the speed of manipulation being gradually increased as the student becomes more proficient in reading. After becoming sufficiently well versed in the art to read at the rate of twenty-five or thirty words per minute, the best practice will be found in copying with a pen and ink from an instrument connected with a line employed in transmitting regular commercial messages, in order that the student may familiarize himself with the usages of the lines and the minute details of actual telegraphic business.

In conclusion, the student is warned against falling into the common error of expecting great results from little labor. To become an expert operator requires much time and patience, and the most unwearied application. Remember, that whatever is worth doing at all is worth doing well. The time will seldom or never be found when a thoroughly competent operator cannot obtain immediate and remunerative employment, however overcrowded the lower walks of the profession may have become.

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CHAPTER IX.

APPENDIX AND NOTES.

160. **Double Transmission.**—One of the most interesting problems in practical telegraphy is that of double transmission, or working in opposite directions at the same time over a single wire. This apparently paradoxical result may be accomplished in several different ways, the principles involved being very simple and easily understood. The method shown in the accompanying diagram is that of Siemens & Halske, of Berlin, Prussia; the apparatus now used in this country differing slightly from it in some of its minor details.

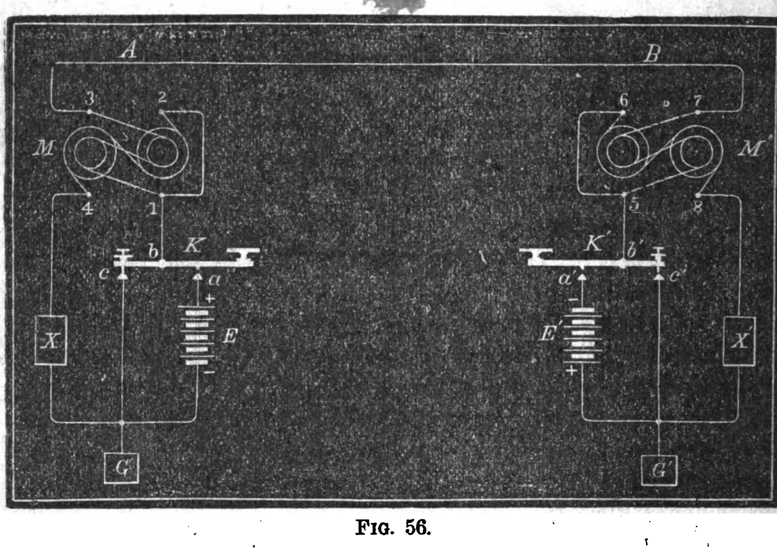

Fig. 56.

A and B (Fig. 56), are the two terminal stations of the line. The main battery E, at station A, is placed with its +, and the battery E′ at station B with its —

pole to the line, as represented. M and M′ are the receiving magnets or relays, which are wound throughout with two similar wires of equal length, as shown in the figure, whose connections will hereafter be explained. The rheostat or resistance, X, must be adjusted so as to be exactly equal to that of the line A, B, added to that of the relay wire 7, 5, at the other station. Similarly X′ is also made equal to the line including the relay wire 3, 1.

If, now, the key K at station A be depressed, the current from the battery E will divide at the point 1, one portion going through the relay coils to 3, over the line A, B to 7, and thence through the relay M′ to 5, key lever 6′, and contact C′ to the earth at G′, and the other portion in an opposite direction through the relay coils from 2 to 4, and thence through the resistance X to the negative pole of the battery. These two currents will be equal to each other, the resistance being the same by each of the two routes, as before explained, but as they pass in opposite directions through the two wires surrounding the relay M, they produce no magnetic effect upon it. The relay at B, however, will be affected by the current coming from A through the wire 7, 5, and will give signals corresponding to the movements of the key at that station.

If, now, the key at B be also depressed, the same action takes place; one half the current passes over the line, combining with the current from A, and the other half returns to the battery through the other wire of the relay and the rheostat.

The relay wires 1, 3 and 7, 5 are now traversed by the double current, equal to $\frac{A}{2}+\frac{B}{2}$, but the wires 2, 4 and 6, 8 are traversed only by the current of a single battery, having at A the force of $\frac{A}{2}$ and at B the force of $\frac{B}{2}$. The latter current being in the opposite direction to the former, the relays at both stations are affected by the difference in the forces of these currents, the relay at A by $(\frac{A}{2}+\frac{B}{2}) - \frac{A}{2}$, and the relay at B by $(\frac{A}{2}+\frac{B}{2}) - \frac{B}{2}$.

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Thus each station receives its signal through the action of the distant battery only.

In the arrangement shown in figure 56 a third position occurs, where one of the keys, at B for instance, is in the act of changing from the front contact A′ to the rear contact C′, or *vice versa*, in which case the current from A is interrupted at B′, and therefore passes through the second wire of the relay 6, 8, but this time in the same direction, and thence through the rheostat X′ to the ground. The current arriving at B is considerably weakened in consequence of the additional resistance encountered at X′, but this is compensated for by its passing through *both* wires of the relay M in the same direction, and its action upon the relay, therefore, remains about the same as before.

One slight difficulty, however, arises in this connection. It will be seen that when the current at the receiving station is thus momentarily thrown through both relay wires and the rheostat, it must necessarily cause an unequal division of the current between the two opposing relay wires at the sending station, as the resistance of the long circuit becomes about double that of the short one. This effect is avoided in the American system by a modification of the transmitting apparatus, which is operated by the lever of a sounder placed in a local circuit in connection with the key. When the local circuit is closed the downward movement of the sounder lever makes the battery connection upon a flat spring, and the movements thus imparted to the spring breaks the earth contact. The spring being attached to the line wire the connection is necessarily always complete, either direct or through the battery, and it is not obliged to pass through the rheostat when the transmitter is changing from the battery to the earth contact, or *vice versa*. The disadvantage in this case arises from the fact that the main battery is thrown on short circuit at each movement of the transmitter, rendering it necessary to interpose a considerable additional resistance between the back contact and the bat-

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tery, to prevent the rapid consumption of the latter which would otherwise ensue. These improvements were devised by Mr. J. B. Stearns.

In working this system, it is necessary to keep the rheostat so adjusted that its resistance will correspond exactly with that of the line, as above shown. If the relay works too feebly the counter current must be weakened by increasing the resistance of the rheostat. If the magnetism is too strong the resistance should be diminished. A careful study of the diagram will show that this system operates equally well, whether similar or opposite poles of the two batteries are placed towards the line. With like poles the action will be as follows:

If the key at A be depressed, the current on the line will be $\frac{A}{2}$ and through the rheostat $\frac{A}{2}$, neutralizing each other upon the relay of A, but giving a current of $\frac{A}{2}$ in the relay at B. Now, if the key at B be also depressed, a current equal to $\frac{B}{2}$ is thrown through each wire of his relay, but the current $\frac{A}{2}$ being equal and opposite to $\frac{B}{2}$ the current of the main line will $= 0$.

The current through the second wire of the relays being still unaffected, each relay will give a signal corresponding to the time the key at the other station is depressed.

161. Edison's Button Repeater.—This is a very simple and ingenious arrangement of connections for a button repeater, which has been found to work well in practice. It will often be found very convenient in cases where it is required to fit up a repeater in an emergency, with the ordinary instruments used in every office. Fig. 57 is a plan of the apparatus.

M is the western and M′ the eastern relay. E is the main battery, which, with its ground connection G, is common to both lines. E′ is the local battery, and L the sounder. S is a common "ground switch," turning on two points, 2 and 3. In the diagram the switch is turned to 2, and the eastern relay, therefore, repeats into the western circuit. while the western relay ope-

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rates the sounder, the circuit between 1 and 2 through the sounder and local battery being common to both the main and local currents. If the western operator breaks the relay M opens, and consequently the sounder, L, ceases to work. The operator in charge then turns the switch to 3, and the reverse operation takes place; the western relay repeats into the eastern circuit, and the eastern relay operates the sounder. The sounder being of coarse wire, offers but a slight resistance to the passage of the main current.

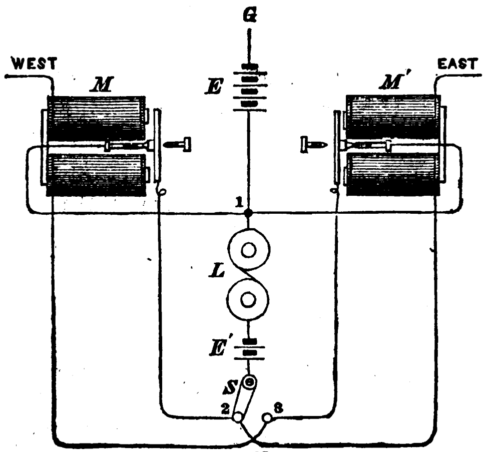

FIG. 57.

162. BRADLEY'S TANGENT GALVANOMETER.—The common galvanometer used for the measurement of electric currents consists of a magnetized steel needle, suspended in the centre of a hollow frame covered with insulated copper wire. The degree of deflection of this needle from its normal position in the magnetic meridian, when a current is passing, indicates the strength of the current. In the ordinary galvanometer, however, the angle through which the needle is moved, or in other words, the number of degrees over which it passes, is not an accurate measure of the strength of the current when the deflection exceeds 15°, for the further the needle moves from a position parallel to the wires of the coil the more nearly does it approach a right angle, in which position the effect is null, so that the action of the current upon it becomes less and less powerful as the deviation increases. Several arrangements have been tried in order to obviate this objection, the most common being that of a ring having a groove on its edge

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filled with wire. The needle is hung precisely in the centre of the ring, and must not be longer than one sixth of its diameter—a half inch needle requiring a three inch ring. The needle is then deflected with a force varying as the *tangent* of the number of degrees through which the needle moves. Owing to the great distance of the coil from the needle, this arrangement has very little sensitiveness compared with the common galvanometer.

In Bradley's Galvanometer a compound needle is employed, composed of several needles of thin, flat steel, fixed horizontally upon a light flat ring of metal, forming a complete circular disc of needles, having an agate cup in the centre, to rest upon the pivot upon which it moves. At each extremity of the meridian light points project, to indicate the degrees of deflection. This compound needle, after having been magnetized, is placed within or over a coil whose breadth is exactly equal to the diameter of the disc. This compound circular needle, being under the influence of the same number of convolutions of the coil in all its deflections, fulfils the required conditions for a true tangent galvanometer.

The theorem, "*The intensity of currents, as measured by the tangent galvanometer, is proportional to the tangents of the angles of deflection,*" may be verified in the following manner:

Call the terrestrial magnetism, whose tendency is to direct the galvanometer needle to the magnetic meridian, the unit of directive force, and let this unit be represented geometrically by the line A M (Fig. 58), which is the radius of the circle M B M—the line M A M representing the meridian. When there is no other force acting on the needle its direction is with the meridian. Now let an electric current be sent through the galvanometer coil, whose directive force is precisely equal to the terrestrial force, and whose tendency is to direct the needle in a line perpendicular to the meridian, and let this force be represented by the line A B.

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If the terrestrial force could now, for a moment, be suspended, the needle would point due east and west; but the combined action of the two equal forces will direct the needle toward the point of intersection of the line drawn perpendicularly from M, and that drawn horizontally from B, at 1, which direction cuts the quadrant at 45°, the line M 1 being the tangent of 45°, which is 1.

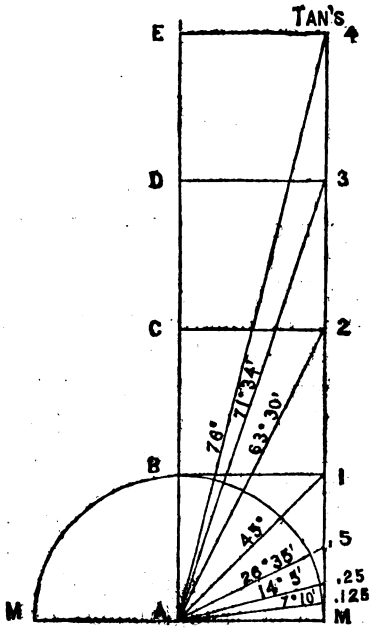

FIG. 58.

Now, if we augment the intensity of the current through the coil to twice its present force, which will be 2, and will be represented by the line A C, the combined forces A M and A C will direct the needle toward the point 2. If we now lay a protractor on the circle, we find that the line A 2 cuts it about 63° 30', of which the tangent is 2.

We may increase the parallelogram erected upon A M at pleasure, and the two forces combined will always so balance the needle between them as to make it point from A, diagonally, across the parallelogram to its opposite angle, the height of which is the tangent of the angle of deflection.

By inspection of the diagram it is seen that the law holds good in the subdivisions of the force A B, as at .5 .25 and .125, a truth admitted by all experimenters, as to the relations, up to 14°.

163. THOMPSON'S REFLECTING GALVANOMETER.—This is the most delicate apparatus of this kind which has yet been devised, and is for this reason employed in operating the Atlantic Cables.

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The special feature which distinguishes this galvanometer from an ordinary one, is the extreme lightness of the magnet or needle, and the delicacy with which it is suspended in a horizontal position. Instead of an index needle, to render the motions of the magnet visible to the eye, a reflected ray of light is made use of, which, of course, can be made of any required length. This arrangement is of great practical value in measuring faint electrical currents, too feeble to be indicated by any other apparatus. It is especially valuable in submarine telegraphing, because it permits the use of such extremely low battery power.

When the insulation of a cable is in the slightest degree defective at any point, a current of intensity has a tendency to aggravate the fault, and to corrode and eat away the conductor by chemical decomposition, at the point where the escape occurs, finally destroying the communication altogether.

Fig. 59 is a side elevation of this instrument, showing a section through the galvanometer coils and the outer case containing them. Fig. 60 is a cross section through the coils, showing the magnet, technically termed the needle. Similar letters refer to like parts in both figures. The magnet A is a small bar of steel, one half inch in length and one tenth of an inch square, cemented to the back of a very thin circular glass mirror, *a*. The mirror is suspended in a brass frame, B (Fig. 61), by an exceedingly delicate silk fibre, and is adjusted in height by the screw *b*. This frame slides into a vertical groove left in the centre of the coil, dividing it into two parts. The coil and mirror are enclosed in the brass case D, this case having pieces of glass let in wherever necessary, to permit the passage of light. The object of this arrangement is to prevent the mirror and its attached needle from being disturbed by currents of air.

A narrow pencil of luminous rays from the lamp, E, passes through the opening, F, which is capable of adjustment by the slide G. This pencil of light, passing through the lens, is reflected by the mirror back through the lens upon an ivory scale at I, as shown by the dotted lines. The scale is horizontal, extending to the

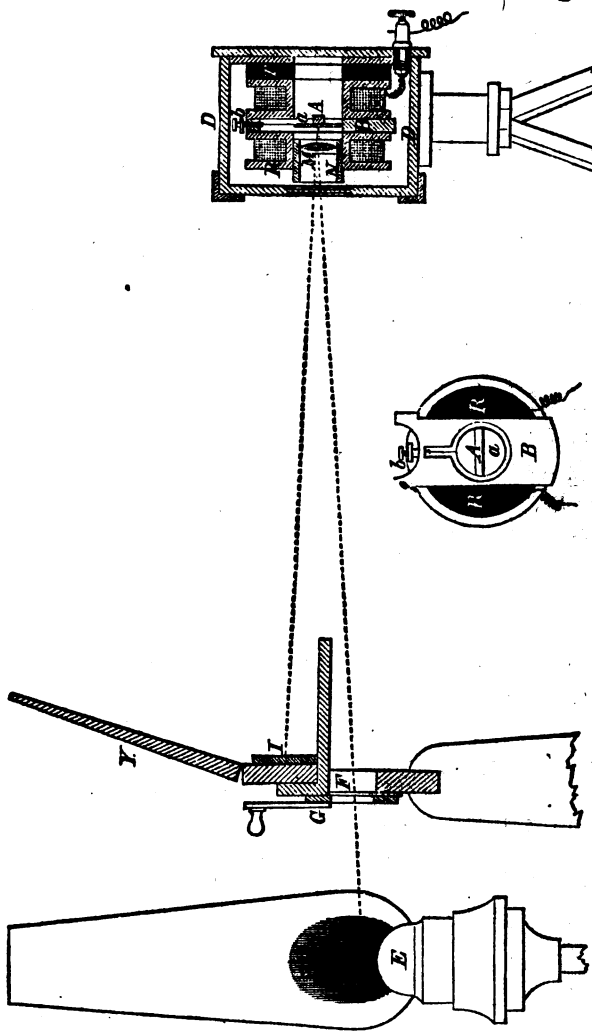

Fig. 60.

Fig. 59.

right and left of the centre of the instrument, the zero point being exactly opposite the lens. The luminous pencil is brought to a sharp focus upon the scale by a sliding adjustment of the lens M, in the tube N. When the needle is at rest in its normal position, and no current is passing, the spot of light which serves as an index will remain at zero on the scale.

The operator reads the signals from a point just in the rear of the magnet and coils, the light of the lamp being cut off by the screen Y, so that he only sees the small luminous slit through which the light enters the instrument, and a brilliantly defined image of the slit upon the white ivory scale just above, which is kept in deep shadow by the screen Y. A very minute displacement of the magnet gives a very large movement of the ray of light on the scale I, the angular displacement of the ray of light being double that of the needle.

It is obvious that the ray of light from the needle will be reflected to the right or left of zero on the scale, according as the deflection is produced by a positive or negative current. The Morse alphabet is used for signaling through the Atlantic cable, deflections on one side of zero indicating dots, and on the other side dashes.

It will be observed that the end, and not the broad part of the flame of the lamp, is presented to the slit F, which is also arranged to receive the brighest part of the vertical section of the flame.

The galvanometer coils, R, consist of many thousand convolutions of fine insulated copper wire, and they are insulated from the case, D, by a disc of hard rubber, T, to which they are fastened.

The instrument is usually provided with a directing magnet, by which its sensitiveness may be varied to a great extent. This magnet is in the form of a bar, slightly curved, and is of considerable power. It is placed upon a vertical rod passing through its centre, which is fixed above the coil immediately over the needle, in such a manner that it can be turned horizontally so as to follow the movements of the needle, or be removed nearer to or further from it vertically. If

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it is placed with its south pole over the north pole of the needle, it will add its directive force to that of the earth, and by holding the needle more powerfully in its position, will lessen its sensitiveness. The nearer the magnet approaches the needle the greater will be its power over it, and it can be arranged so as to hold the needle in any desired position. If it is placed in a reverse direction, so as to repel the needle instead of attracting it, it will lessen the attractive force of the earth so as to increase its sensitiveness, and in a certain position will render the galvanometer astatic. When the magnet is too near the needle it repels to the full extent of the scale. If it is raised upon the supporting rod the repelling effect will decrease, until, at a certain distance from the magnet, the spot of light on the scale can be held at zero. The greatest sensibility is obtained at the point at which the slightest lowering of the magnet upon the rod will again repel the needle to the full extent of its swing.

An improvement in this instrument, made by Mr. C. F. Varley, consists in giving the mirror a concave form, silvered upon the back, and thus dispensing with the use of the lens above described.

164. Mode of Working the Atlantic Cables.—Very little has been made public in regard to the precise method employed in signaling through the Atlantic cables. As before remarked, the reflecting galvanometer is employed as a receiving instrument, and by employing deflections on one side of zero to represent dashes, and those on the other side dots, the Morse alphabet is found to answer the purpose admirably. It is said that the two cables have been looped in a metallic circuit without ground connection, and that they have also been worked separately with and without condensers. The latter method is made use of in order to avoid the disturbances generated by what are known as "earth currents."

Different parts of the earth and sea are found to be at different electric potentials. One part is electro-

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positive or electro-negative to another. That is to say, there is the same difference between the two parts of the earth that exists between the two poles of a battery. If, therefore, these two points are joined by a wire, a current will flow through that wire as if from a battery, and this current is termed an earth current, to distinguish it from the current generated by an ordinary voltaic battery. This difference of potential between two given points, such as Newfoundland and Valencia, is not constant but continually varies, causing a corresponding variation in the current it produces. This current and its fluctuations interfere with the signaling current, disturbing the distinctness of the signals. When very rapid changes take place in the electric condition of the earth, it is known as a magnetic storm, and this occasionally interferes with the working of all telegraph lines.

By the method of working with condensers the disturbances from this cause are avoided. The condenser is constructed of alternate layers of tin foil and thin plates of mica, gutta-percha or paper, saturated with paraffine, arranged like the leaves of an interleaved book. Each *alternate* metal plate is connected so as to form two distinct series, insulated from each other, one of which is connected with the line and the other with the earth. By an inductive action, similar to that of the well known Leyden jar, a quantity of electricity, in proportion to the amount of surface exposed, may be accummulated or stored up upon the metallic plates. If, therefore, one series of plates be charged with positive electricity the other series will become negative by induction, and by means of this induction a much larger quantity of electricity may be accumulated than would otherwise be the case.

The manner in which the condenser is made use of in working a cable is as follows:

The sending apparatus consists of a battery, B (Fig. 61), which is permanently connected with the cable through the back contact of a Morse key, K, and the

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cable is therefore kept constantly charged from this battery. When the key is depressed the cable is placed in connection with the earth at E. The receiving apparatus consists of the reflecting galvanometer G (163), one terminal of which is attached to the cable and the other to one series of plates in the condenser C—the other series being connected with the earth, as shown in the figure. R is a very high resistance, inserted in a wire leading from the point O, between the cable and the galvanometer, so as to allow a very slight but constant leakage from the cable to the earth. The cable is, therefore, charged to the tension of the battery B, and the condenser to a tension equal to that of the point O—but owing to the high resistance at R the tensions are nearly the same. Upon charging the cable with the battery at K a charge of electricity enters the cable, and a quantity sufficient to charge the condenser passes through the galvanometer, deflecting the mirror until the condenser is charged equal to the tension of the point O—when the mirror will return to zero. By putting the cable to earth at K a portion of the charge will be withdrawn, and the tension of the point O lowered below that of the condenser. A portion of the charge of the latter, therefore, flows into the cable, deflecting the galvanometer in the opposite direction. The right and left hand deflections necessary for signaling are therefore produced without reversing the currents, or rendering it necessary to entirely discharge the cable after each signal. This mode of signaling possesses many important advantages over the old method, in point of rapidity of action and freedom from interference by earth currents. The rate of working through the cable by expert operators

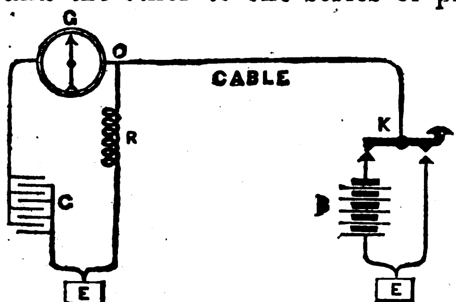

FIG. 61.

is said to average from fifteen to twenty words per minute.

165. VELOCITY OF ELECTRIC SIGNALS.—For many years the velocity of electric signals in passing through a conductor was supposed to be infinitely great, or at least so great as to be incapable of measurement. In 1849, Professor Sears C. Walker, of the United States Coast Survey service, while engaged in measuring longitude by means of the electric telegraph, discovered a perceptible retardation. Experiments between Washington and St. Louis indicated a velocity not far from 16,000 miles per second. Some of the measurements were as low as 11,000 miles per second. On the evening of the 28th of February, 1868, a number of experiments were made by the officers of the Coast Survey, for the purpose of determining accurately the difference in longitude between Cambridge, Mass., and San Francisco, Cal. A wire was connected from Cambridge to San Francisco and back, embracing thirteen repeaters—the whole distance thus traversed by the signals being about 7,000 miles.

The following table shows the time, in hundredths of a second, occupied by a signal in passing from Cambridge to each of the repeating stations and back. The number of repeaters in circuit is also given:

TIME OF TRANSMISSION FROM CAMBRIDGE.

	Seconds.	
To Buffalo and Return	0.10	1 Repeater.
" Chicago "	0.20	3 "
" Omaha "	0.33	5 "
" Salt Lake "	0.54	9 "
" Virginia City "	0.70	11 "
" San Francisco "	0.74	13 "

The actual time of transmission from Cambridge to San Francisco and back was estimated not to exceed three tenths of a second, the "armature times" of the thirteen repeaters probably amounting to four or five tenths of a second.

In submarine cables the velocity of signals is considerably less than upon air lines. Prof. Gould, in his

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experiments upon the Atlantic Cable, found it to be between 7,000 and 8,000 miles per second—being greater when the circuit was composed of the two cables, and less when the earth formed a part of the circuit. His experiments seemed to show that, instead of travelling around the entire circuit in one direction, the electric wave, or polar influence, travelled both ways from the battery, and the signal was received when the two influences met. Experiments made on air lines indicate that an instrument placed at the central point of resistance between the two poles of the battery will record the signal sooner than when placed in any other part of the circuit, it being understood that the two terminal batteries of a telegraph line are in effect but one, being connected by the earth, which is a conductor of infinitely small resistance.

166. SPEED OF TRANSMISSION.—The average rate of transmission, by the most skilful operators upon the Morse apparatus, is about 1,800 words per hour. This has been considerably exceeded, however, by many operators within the past two or three years. On the evening of January 28th, 1868, 2,520 words of Press news were sent from New York to Philadelphia in one hour, and legibly copied by the receiving operator, without a stop or break—the average rate being forty-two, and the maximum rate forty-six words per minute. On the 7th of February following 2,630 words of Press news were sent from Milwaukee, Wis., to St. Paul, Minn., in one hour, the distance being about 400 miles. On the 19th of the same month 1,352 words of Press news were sent from New York to Philadelphia in thirty minutes, the average rate being over forty-five words per minute.

This is believed to be the quickest time on record which has been made in the transmission of regular business by the Morse system. The receiving operator, in all the above cases, copied entirely from the sound of the instrument.

The speed of the printing instrument exceeds that

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of the Morse under favorable circumstances. On the 24th of September, 1867, the Combination instrument transmitted from Albany to New York 1,453 words of Press news in thirty-three minutes. It is claimed that, on some occasions, as many as 2,900 words per hour have been transmitted by the House instrument.

167. COMPARISON OF WIRE GAUGES.—The different sizes of wire employed for telegraphic and other purposes are designated by a series of arbitrary numbers. The system known as the Birmingham gauge is the one in most general use at the present time, but is objectionable, both on account of the irregularity of its gradations and the absence of any authorized standard—wire of the same number from different makers often varying considerably in its size. The American gauge is formed upon a geometrical progression, and it is to be hoped will eventually supersede the old gauge: it is already employed to a considerable extent.* The following table gives the diameter, in thousandths of an inch, of each number in the American and Birmingham gauges:

TABLE OF DIAMETERS OF WIRES.

Number.	American Gauge.	Birmingham Gauge.	Number.	American Gauge.	Birmingham Gauge.
0000	.460	.454	19	.03589	.042
000	.40964	.425	20	.03196	.035
00	.36480	.380	21	.02846	.032
0	.32495	.340	22	.02535	.028
1	.28930	.300	23	.02257	.025
2	.25763	.284	24	.0201	.022
3	.22942	.259	25	.0179	.020
4	.20431	.238	26	.01594	.018
5	.18194	.220	27	.01419	.016
6	.16202	.203	28	.01264	.014
7	.14428	.180	29	.01126	.013
8	.12849	.165	30	.01002	.012
9	.11443	.148	31	.00893	.010
10	.10189	.134	32	.00795	.009
11	.09074	.120	33	.00708	.008
12	.08081	.109	34	.0063	.007
13	.07196	.095	35	.00561	.005
14	.06408	.083	36	.005	.004
15	.05707	.072	37	.00445	....
16	.05082	.065	38	.00396	....
17	.04526	.058	39	.00353	....
18	.0403	.049	40	.00314	....

* This gauge is manufactured by Darling, Brown & Sharpe, of Providence, R. I.

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168. USEFUL FORMULÆ FOR WEIGHT AND RESISTANCE OF WIRES.—The following formulæ, from Clark's tables, will be found convenient in telegraphic work:

The *weight* of any iron wire, per statute mile of 5280 feet, is $\frac{d^2}{72.15}$ lbs.; d^2 denoting the square of the diameter of the wire

The *conductivity* of ordinary galvanized iron wire, compared with pure copper 100, averages about 14, or about one seventh that of pure copper.

The *resistance* per statute mile of a galvanized iron wire is about $\frac{360000}{d^2}$ ohms at 60° Fahr.

The resistance of iron wire increases about .35 per cent. for each degree, Fahr.

The *weight* per statute mile of 5280 feet, of any copper wire, is $\frac{d^2}{63.13}$ lbs. A mile of No. 16 wire weighs in practice from 63 to 66 lbs.

The resistance per statute mile of any *pure* copper wire is $\frac{54892}{d^2}$ ohms at 60° Fahr. No. 16 copper wire of good quality has a resistance of about 19 ohms.

The resistance of any pure copper wire l inches in length, weighing n grains, $= \frac{.001516 \times l^2}{n}$ ohms.

The resistance of copper increases as the temperature rises, .21 per cent. for each degree, Fahr.

The conductivity of any copper wire is obtained by multiplying its calculated resistance by 100, and dividing the product by its actual resistance. Pure copper is taken as 100.

169. CONDUCTING POWERS OF MATERIALS.—According to the experiments of Mr. M. G. Farmer, made some years since, the relative electrical resistance of different metals and fluids at ordinary temperatures is as follows, pure copper being taken as 100:

Copper Wire	1.00	Tin wire	6.80
Silver "	.98	Zinc "	3.70
Gold "	1.13	Brass "	3.88
Iron "	5.63	German Silver Wire	11.30
Lead "	10.76	Nickel "	7.70
Mercury "	50.00	Cadmium "	2.61
Palladium Wire	5.50	Aluminum "	1.75
Platinum "	6.78		

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His experiments with fluids gave the following results :

Pure Rain Water	40,653,723,00
Water, 12 parts; Sulphuric Acid, 1 part	1,305,467,00
Sulphate Copper, 1 pound per gallon	18,450,000,00
Saturated solution of common salt	3,173,000,00
" " of sulphate of zinc	17,330,000,00
Nitric Acid, 30 B	1,606,000,00

The following table gives the specific resistance in ohms of various metals and alloys, at 32° Fahr., according to the most recent determinations of Dr. Matthiessen :

NAME OF METALS.	Resistance of wire 1 foot long, weighing 1 grain.	Resistance of wire 1 foot long, 1-1000th inch in diameter.	Approximate per cent. variation in resistance per degree temperature at 20 degrees.
Silver annealed	0.2214	9.936	0.377
" hard drawn	0.2421	9.151	....
Copper annealed	0.2064	9.718	0.388
" hard drawn	0 2106	9.940	....
Gold annealed	0.5849	12.52	0.365
" hard drawn	0.5950	12.74	....
Aluminum annealed	0.06822	17.72	....
Zinc pressed	0.5710	32.22	0.365
Platinum annealed	3.536	55.09	....
Iron annealed	1.2425	59.10	....
Nickel annealed	1.0785	75.78	....
Tin pressed	1.317	80.36	0.365
Lead pressed	3.236	119.39	0.387
Mercury liquid	18.746	600.00	0.072
Platinum silver alloy, hard or annealed, used for standard resistance coils	4.243	148.35	0.031
German silver, hard or annealed, commonly used for resistance coils	2.652	127.32	0.044
Gold silver alloy, 2 parts gold, 1 part silver, hard or annealed	2.391	66.10	0.065

The use of this table is as follows : Suppose it is required to find the resistance at 32° Fahr. of a conductor of pure hard copper, weighing 400 lbs. per knot. This is equivalent to 460 grains per foot. The resistance of a wire weighing one grain is found by the table to be 0.2106, therefore the resistance of a foot of wire weighing 460 grains will be $\frac{0.2106}{460}$, but the resistance of

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one knot will be 6087 times that of one foot, therefore the resistance required will be $\frac{6087 \times 0.2106}{460} = 2.79$ ohms. If the diameter of the wire be given instead of its weight per knot, the constant is taken from the second column. Thus the resistance at 32° Fahr. of a knot of pure hard drawn copper wire 0.1 inch in diameter would be $\frac{6087 \times 9.94}{10000} = 6.05$. The resistance of wires is materially altered by annealing them, and a rise in temperature increases the resistance of all metals. Dr. Matthiessen found that for all pure metals the increase of resistance between 32° and 212° Fahr. is sensibly the same. The resistance of alloys is much greater than the mean of the metals composing them. They are very useful in the construction of resistance coils.

The highest value which has probably been found for the conducting power of pure copper is sixty times that of pure mercury, according to Sabine. Commercial copper may be considered of good quality when its conducting power is over fifty. Different samples of copper vary greatly in their specific conductivity, as may be seen by the following table, which gives the result of careful determinations by Dr. Matthiessen, the conducting power of pure copper at 59.9° Fahr. being taken as 100.

Lake Superior, native, not fused	98.8 at 59.9°
" " fused (commercial)	92.6 at 59.0°
Burra Burra	88.7 at 57.2°
Best selected	81.3 at 57.5°
Bright copper wire	72.2 at 60.2°
Tough copper	71.0 at 63.1°
Demidoff	59.3 at 54.8°
Rio Tinto	14.2 at 58.6°

Thus Rio Tinto copper possesses no better conducting power than iron. This shows the great importance of testing the conductivity of the wire used in the manufacture of electro-magnets, cables, etc.

170. Internal Resistance of Batteries.—This may be measured by the sine or tangent galvanometer. Place the battery to be measured in circuit with a sine galvanometer giving a certain deflection. Insert resistance till the sine of the deflection becomes half what

it originally was. The total resistance of the circuit is now doubled, and the resistance added is, therefore, equal to the original resistance. Deduct the resistance of the galvanometer and connections from the resistance added, and the remainder is the resistance of the battery.

*Second Method.**—Let D = the deflection obtained with the battery in circuit with a galvanometer whose deflections are proportional, and some resistance *r*; and *d* the deflection with some larger resistance R (the resistance of the galvanometer being included in R and *r*), and let *x* = the resistance of the battery.

$$\text{Then } D : d :: R + x : r + x$$

$$\text{and } x = \frac{(d \times r) - (D \times r)}{D - d}$$

In using this method any other resistance *y* may be included with *x*, and the formulæ becomes—

$$x + y = \frac{(d \times R) - (D \times r)}{D - d}$$

and by deducting *x* we get the value of *y*, or if *y* be large in comparison with *x*, the latter may be neglected. By this method one resistance *r* may be compared with another.

The approximate resistance of the batteries in common use is as follows, according to Mr. Farmer:

Grove..	0.41 ohms
Carbon..	0.63 "
Daniell..	1.70 "

171. ELECTRO-MOTIVE FORCE OF DIFFERENT BATTERIES.—The following table gives approximately the electro-motive force of various batteries, being the mean of numerous observations taken on a sine galvanometer by Mr. Latimer Clark.† The electro-motive force of batteries is within certain limits very variable, depending on a variety of undetermined causes. It is not much affected by temperature.

---

* Clark, *Resistance Measurement*, p. 100. † *Resistance Measurement*, p. 108.

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Grove's	100
Carbon with bi-chromate solution	107
Daniell's	56
Smee's (when not in action)	57
" (when in action) about	25
Copper and zinc in acid (Wollaston)	46
Sulphate mercury and graphite (Marié Davy)	76
Chloride silver	62
Chloride lead	30

When connected on short circuit, the electro-motive force of several of the batteries, especially Smee's and Wollaston's, will fall off 50 per cent. or more, owing to the formation of hydrogen on the negative plate. Grove's and Daniell's do not so fall off, because the hydrogen is reduced by the nitric acid in one case and by the oxygen in the other.

172. Measurement of Electro-motive Force.*—When a number of cells are joined up in circuit with, but in opposition to, a number of other cells with a galvanometer inserted, by adjusting the number of cells so that no current passes, the relative electro-motive force of the two batteries may be determined.

Second Method.—Call the electro-motive forces of the two batteries E and E′; join them up successively in circuit with the same galvanometer, and by varying the resistance, cause them both to give the same deflection; their forces will then be in direct proportion to the *total* resistances in circuit in each case, or

$$E' = E \times \frac{R'}{R}$$

where R represents the resistance with E (including that of battery, galvanometer, and the adjustable resistance) and R′ with E′.

173. Forces of Electro-magnets.—The laws which govern the forces of electro-magnets have been investigated by Lenz, Jacobi and Müller.

Let M = the magnetic force of the electro-magnet.
n = the number of convolutions of wire.
d = the diameter of the soft iron core.
Q = the quantity of electricity in circulation.
and c a constant multiplier.

Then $M = c\, n\, Q \sqrt{d}$.

* Clark, *Resistance Measurement*, p. 103.

This law only holds good for bars of iron whose length is considerably greater than their diameter, for feeble currents of electricity, and under the supposition that the number of convolutions of wire is not so great as materially to diminish the influence exerted by the outer coils upon the bar of iron. These conditions are fulfilled in the electro-magnets used for telegraphic purposes.

It will be noticed, in the above formulæ, that M increases directly as Q and as n, but Q decreases as n increases, supposing the electric force to remain constant. Hence it is evident that a certain proportion between the resistance of the wire and that of the remaining portions of the circuit must be preserved to obtain the maximum magnetic force. This relation is found to be the following:

*When the resistance of the coils of the electro-magnet is equal to the resistance of the rest of the circuit, i. e., the conducting wire and battery, the magnetic force is a maximum.**

The application of this law to a telegraphic circuit would be to make the sum of the resistances of all the magnet coils in circuit equal to the resistance of the line and batteries, but as in practice the resistance of a telegraphic circuit varies, being considerably reduced by defective insulation, the total resistance of the instruments should be less than that of the line when in good condition, to attain the best results during unfavorable weather.

ELECTRICAL FORMULÆ.

174. OHM'S LAW.—Let C = the quantity, or strength, or force, or intensity of the current, as it is variously called.

Let n = the number of cells.
" E = the electro-motive force in each cell.
" R = the internal resistance of each cell.
" r = the resistances exterior to the battery.

Then $$C = \frac{n\,E}{n\,R + r}.$$

* Noad's Students' Text-book of Electricity, p. 277.

175. PARALLEL OR DERIVED CIRCUITS.—1. The joint resistance of any two parallel or derived circuits, whose resistances = a and b, is equal to their product divided by their sum, or

$$R = \frac{a\,b}{a + b}$$

2. The joint resistance of any three circuits, a, b and c, is

$$R = \frac{a\,b\,c}{a\,b + b\,c + a\,c}$$

3. The joint resistance of any number of circuits is obtained by adding their reciprocals together, thus:

$$R = \frac{1}{\frac{1}{a} + \frac{1}{b} + \frac{1}{c}}$$

176. GALVANOMETERS AND SHUNTS.—1. The joint resistance of a galvanometer and shunt is as follows:

Let g = resistance of galvanometer.
s = resistance of shunt.

Then $R = \frac{g\,s}{g + s}$

2. The multiplying power of any shunt is equal to

$$\frac{g + s}{s}, \text{ or } \frac{g}{s} + 1$$

3. To prepare a shunt having some definite multiplying power, for example 10 100 or 1,000,

Let n = the multiplying power required,

Then $s = \frac{g}{n - 1}$

177. FORMULA FOR THE LOOP TEST (127).—Let x = resistance of shortest part of the loop.

y = resistance of longest part.
L = total resistance of both.
R = resistance added to shortest part, to make it equal to the longer.

Then $x + y = L.$
$y = x + R.$
and $X = \frac{L - R}{2}$

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178. **Blavier's Formula for Locating a Fault** (128).—Let R = resistance of line when in good order, S = resistance of defective line when distant end is to ground, and T the resistance when it is disconnected or open at distant end.

The distance (x) of the fault from the testing station will be

$$x = S - \sqrt{S^2 + TR - TS - RS},$$
$$\text{or } x = S - \sqrt{(R - S) \times (T - S)},$$

and the resistance of the fault (z) will be

$$z = T - S + \sqrt{S^2 + TR - TS - RS}$$
$$\text{or } z = T - S + \sqrt{(R - S) \times (T - S)}$$

179. **Measures of Resistance.**—1.0456 Siemen's units = 1 ohm. To convert Siemen's units into ohms. multiply by .9564.

1 Varley's unit = 25 ohms.
1 Megohm = 1,000,000 ohms.
1 Microhm = $\frac{1}{1,000,000}$ ohms.

Strain of Suspended Wires.*—The ordinary dip of line wires, for a span of 80 yards, is about 18 inches in mild weather; this gives with No. 8 wire a strain of 420 lbs., its breaking weight being about 1,300 lbs.—(*Culley.*)

The strain varies directly as the weight of the wire, and inversely as the dip or versine; it increases as the square of the span if the dip be constant; but to preserve a given strain the dip or versine must increase as the square of the span, or,

$$L^2 : l^2 :: V : v.$$

The strain is greater at the point of suspension than at the lowest point of the span, by a quantity (equal to the weight of a length of wire of the same height as the versine) which may be neglected in practice. Calling l the length of the span in feet, w the weight in

* Clark. *Resistance Measurement* p. 154.

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cwts. of one statute mile, v the versine in inches, and s the strain in lbs.,

$$\text{Strain} = \frac{l^2 \times w}{31.43 \times v} \text{ lbs. approximately.}$$

$$\text{and dip} = \frac{l^2 \times w}{31.43 \times s} \text{ inches.}$$

When both supports are of the same height the lowest point in the curve will be in the centre of the span; but if one support be higher than the other the lowest point will be near the lower support, so that the greater portion of the weight is borne by the higher pole. In calculating the strain the wire should be considered as if prolonged beyond the lower end to a point equal in height to the upper one, and the strain will be proportional to the length thus increased, or to twice the distance from the top to the bottom of the dip.

The weight of a wire increases with its strength, the quality being the same. The advantage of using thin wire for long spans is only in diminishing the weight upon the supports.

Iron expands $\frac{1}{14616}$ of its length, or about $4\frac{1}{10}$ inches per mile for every ten degrees of heat.—(*Culley.*)

THE END.

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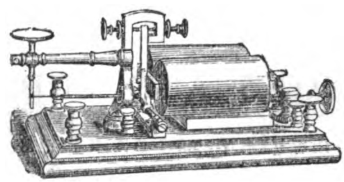

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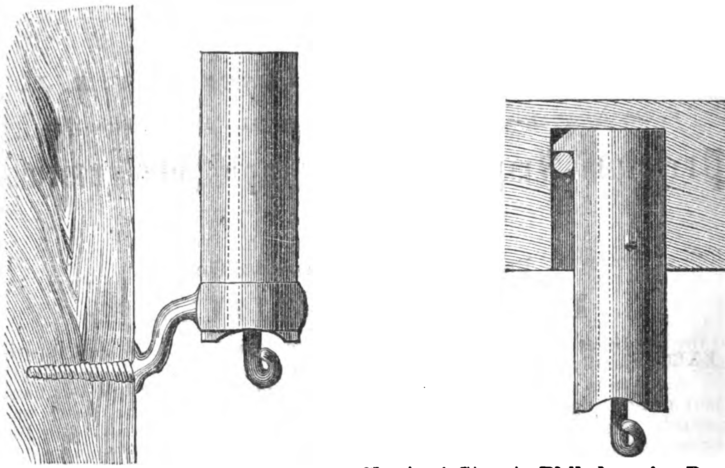

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