ELEMENTARY TELEGRAPHY

H. W. PENDRY

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A MANUAL FOR STUDENTS

WRITTEN SPECIALLY TO MEET THE REQUIREMENTS OF THE ORDINARY GRADE OF THE SUBJECT AS PUBLISHED IN THE SYLLABUS OF THE CITY AND GUILDS OF LONDON INSTITUTE

BY

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PREFACE

The need of a volume dealing with the art and science of Telegraphy as a first text-book has been a want long felt by my colleagues, which is shared, we believe, by many experienced teachers.

The present work is an attempt to provide such an introduction, and, after devoting special thought to the question of order, an arrangement has been adopted which —if it varies somewhat from the common usage of the text-books—is at least based upon the experience of many years.

To a great extent the order in the Syllabus has been followed, this being most convenient to the candidates for examination, and doubtless will prove equally useful to the general student. A number of questions are appended to each chapter, from the conviction that such exercises are of considerable service in aiding the memory, and, when carefully selected, emphasize points which are frequently disregarded. They are in part original, and some have been selected from recent Examination Papers.

The student is strongly recommended to work these exercises systematically, and with regard to the application of mathematics, his attention is directed to the following opinions of two eminent authorities :—

"When you can measure what you are speaking about, and express it in numbers, you know something about it ; but when you cannot measure it, and when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind" (Lord Kelvin).

"The student of mathematics is accustomed to a chain of deduction where each link hangs upon the preceding; and thus he learns continuity of attention and coherency of thought" (Dr. Whewell).

The recent development of Central Battery working opens up remarkable possibilities, and the latest practice is described. In this connection the author begs to acknowledge his indebtedness to Messrs. Vyle and Smart, of the Engineer-in-Chief's Department, for information supplied.

To one feature of the book special attention is directed, namely, the excellent electros of keys, sounders, relays, and other items of telegraph equipment, which have been taken from the catalogues of the British Insulated and Helsby Cables Company. It will be observed that they include some recently designed instruments, and the writer wishes to acknowledge the courtesy of his old instructor, Mr. A. Brooker, of the Company, who furnished full information, and obtained permission to use the blocks.

The remainder of the illustrations and diagrams are from the author's own drawings, excepting Fig. 121 and the three sketches of the Hart plates, which were specially drawn for this book by the Hart Accumulator Company, to whom and to the Chloride Electrical Storage Company the author is indebted for the loan of the accumulator electros.

H. W. P.

London, 1910.

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ELEMENTARY TELEGRAPHY

CHAPTER I

PRELIMINARY :—THE FUNDAMENTAL PRINCIPLES OF ELECTRICITY IN ITS APPLICATION TO TELEGRAPHY

Electricity is an invisible agent or peculiar force as universal as light and heat, with which it is closely associated. Many authorities conclude from Prof. Maxwell's investigations and discoveries, together with the researches of Hertz, Lodge and others, that light itself is an electric phenomenon.

It is believed that when the effects are produced which we know as *electrical*, there is then merely evidenced to the senses a manifestation of an inherent condition of the substance previously latent. Also that when we produce electrification we have given nothing to the essential part, and that a body is *electrified* when the atoms, electrons or ultimate particles of matter have been, by an at present inexplicable stress or force, caused to alter their position with respect to each other, or, as it is termed, become polarized.

But while the exact nature of electricity is still unknown and its manifestations vary, being exhibited in different forms—Magnetic, Thermal or Electrolytic—it has been customary to speak of Electricity as if it had definite existence and were a fluid capable of flowing as a current. This simple assumption has greatly assisted in explanations of those portions of electrical science which have an immediate bearing on Telegraphy.

Two kinds or states of electricity always exist together (a simple proof of this follows a little later). The one state for convenience is called POSITIVE and the other NEGATIVE. These terms are entirely arbitrary, and must not be understood to mean that there is more electricity in the one state than in the other, or that one signifies more and the other less. They are, however, appropriate and useful, since if equal amounts of + and − are imparted to a body it gives no evidence of electrification, apparently the charges have exactly neutralized each other.

Bodies similarly electrified, either *positive* or *negative*, repel. Those dissimilarly electrified, one *positive* and the other *negative*, attract.

The electrical condition or potential of the earth is assumed to be neutrality or zero, and that of a body charged with positive electricity is said to be at a higher potential than the earth, while a negatively charged body is considered as having a potential lower than that of the earth.

In its most general meaning *potential* is a condition with power to do work. The intensity of the effects produced by a charge of electricity depends upon the potential of the charge, that is, its electrical condition relative to that of surrounding bodies. The movement of electricity between two points having different electrical condition, *i.e.* "potential difference" (P.D.), is an effort to restore electrical equilibrium, or common potential, and when a conductor intervenes the result is an electric current passing through, or by means of, the conductor. The real nature of the electric current is unknown, but it is now generally assumed that the medium through which the current is impelled is not in the conductor itself but in the insulating substance surrounding the conducting circuit. The conductor merely acts as a guide to the electric waves, keeping them directed along the circuit instead of allowing them to spread in all directions through the ether (element presumed to pervade all space and to constitute the medium of the transmission of light and heat) as happens in Wireless Telegraphy.

Substances which offer great resistance to the passage of electricity are called *insulators*: others, such as metals and saline solutions, have the property of allowing electricity to diffuse itself freely, and hence are termed *conductors*. The division of substances into conductors and insulators is not absolute. There are few, if any, bodies which are perfect insulators or which do not conduct *at all* in *any* circumstances, while the most perfect conductors offer certain resistance. The terms imply a difference in degree only. When a conductor is fixed upon or supported by a non-conductor it is said to be insulated.

Electricity can be developed in various ways, but for ascertaining effects of static charges probably the most ready means of generation is frictional, as by rubbing a piece of flannel on a vulcanite rod. The production of equal and opposite kinds can be proved by insulating the flannel from the hand with a sheet of india-rubber and placing rod, flannel and rubber upon the cap of an electroscope. There is no divergence. Remove the rod and the leaves diverge; prove charge positive by increasing the divergence with a known positively charged body. Now remove the flannel and bring the rod. The leaves then diverge with negative. The flannel and rod are therefore oppositely charged and the neutrality of leaves when both present demonstrates that the charges are equal.*

The electrical machine is the most convenient apparatus for developing electricity by friction, and electricity thus generated is named statical. When the tension between two static charges becomes so great as to cause a spark to pass between them the resulting restoration of electrical equilibrium is effected by what is known as an electric *discharge*. Before discharge, while the electricity is not in motion, it is said to be in the *static* condition; during discharge it is in the *dynamic* condition, because it then exercises force or power. (The words *static* and *dynamic* are derived from the Greek: the one means *standing* and the other *power*.) The application of electricity to telegraphy has been, however, chiefly dependent upon chemical means for producing electricity, and of this source the name voltaic is generally used. The apparatus for producing it is called a Voltaic pair or *cell*, and consists of two conductors, generally metals immersed in a liquid which acts, chemically, more upon one than upon

* Students are recommended to study these and other features of static electricity more fully with the aid of an elementary treatise such as the manuals by Poyser and Maycock.

the other. Several such cells constitute the arrangement known as a battery.

Zinc is the most common as one of the metals, and the greatest effect is obtained when the second metal of the pair is not acted upon at all by the liquid employed. One of the metals must be readily oxidizable, and the liquid must be capable of acting on the metal.

So long as the two plates are not connected by a conductor exterior to the liquid, the electricity produced remains in the *static* condition and, like frictional electricity, may be made to produce attraction and repulsion, so as to cause the gold leaves of an electroscope to diverge. But the tension or P.D. of voltaic electricity is feeble, so that unless a considerable number of cells are used a *condensing* electroscope is necessary to produce the effect. An electroscope of Lord Kelvin's was, however, sufficiently delicate to show attraction and repulsion where the tension was as feeble as one-tenth of a Daniell cell, and that without the aid of a condenser.

Although voltaic electricity is produced whenever the conditions just mentioned are complied with, there are many different forms of batteries. The *specific power* which each cell's combination possesses of causing the transfer of electricity from one place to another is called its *electromotive force.* This term, strictly, means any cause whatever by which a difference of potential is produced between any two points. When the plates of a cell are connected externally by a wire or other conductor the opposite potentials neutralize one another. They are, however, instantly restored by the chemical action, but the potentials are as quickly equalized, and so on. Thus a constant transfer or current is established and the electricity is therefore in the *dynamic* state.

The + electricity is supposed to emanate from the more oxidizable metal called the *positive* or *generating plate*, passes through the fluid known as the *excitant* to the less oxidizable metal called the *negative plate*, and thence by the connecting wire to the zinc again.

Observe, however, the following distinctions.

The last *negative plate* is called the *positive pole*, since by it the positive electricity *leaves* the battery and enters the external circuit, while for a similar reason the end of the battery (generally the zinc plate) at which the current returns to the battery is known as the *negative pole.* A point may therefore be considered as positive or negative according as we view the direction taken by the current *from* or *to* it.

The relative differences of potential of the following substances have been experimentally observed, and with any two of them when partially immersed in dilute sulphuric acid the current flows *through the cell* from the former to the latter

(1) Zinc	(2) Tin	(3) Lead	(4) Iron
(5) Copper	(6) Silver	(7) Platinum	(8) Carbon

The position of any substance on the list varies considerably with its condition, and the strength and nature of the liquid. The greater the distance on the list between any two bodies the greater the difference of potential.

The strength of a current depends upon two things: the *electromotive force* or P.D. and the *resistance* which this has to surmount. It is essential to know the relations which exist between these, and the Law enunciated by Dr. Ohm is that the strength of current which flows in a circuit varies *directly* as the electromotive force and *inversely* as the total resistance. It may be shown thus: —

$$\text{Current varies as } \frac{\text{Electromotive force}}{\text{Resistance}}.$$

That is, an *increase* in current results from an *increase* in the electromotive force, whereas an *increase* in the resistance *decreases* the value of the current. When the *units* of these functions are applied the Law may be expressed thus: —

$$\text{Current in Amperes} = \frac{\text{Electromotive force in Volts}}{\text{Resistance in Ohms}}$$

which is, however, universally abbreviated to

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

The Fundamental Principles of Magnetism in its Application to Telegraphy.

The peculiar phenomenon known as magnetism is first attributed to the natural magnetic ore called *lodestone*, which when freely suspended always pointed in a North and South direction, and to which pieces of iron and steel would adhere. It was observed that the same end always pointed to the North, and that if the North-seeking end of a second magnet be approached to the North end of the suspended magnet it would turn away or be repelled. The same resulted from the approach of two South-seeking ends. By experiment it may be learned that the attractive power of a magnet is greatest near the ends. To these points Dr. Gilbert gave the name of *poles*.

The first difficulty generally experienced is the confusion resulting from nomenclature of poles. The Chinese and French call the North pointing pole of the needle a *South* pole and the South-pointing pole a *North* pole ; Lord Kelvin styled the North-pointing pole "a true South pole," but common practice is to call the North-pointing pole the *North* pole *because it seeks the North.*

The North pole is generally marked by the letter *N* or by a file-cut, and is sometimes called the *marked*, while the other is named the *unmarked* pole of the magnet.

It has already been observed that *like* poles repel, and when two magnets are brought near to one another the *unlike* or dissimilar poles attract, *i. e.* the North pole of one will repel the North pole and attract the South pole of the other, and *vice versa*. But if a piece of iron or unmagnetized steel be used either pole will be attracted and no repulsion whatever will occur. Previous magnetization can therefore only be proved by obtaining *repulsion*.

Bodies attracted by a magnet, themselves attract the magnet with equal force. This mutual attraction is easily proved by balancing first an iron rod on a cork floating on water and noticing attraction by bringing a magnet near, then exchange iron with magnet, and same effect.

Magnetism acts by induction and through all substances not themselves capable of being magnetized. A compass in a wooden or brass box is as easily affected as if it were not so enclosed ; but if shut in an iron box a magnet outside would act on it indirectly only and feebly, if at all, through the magnetism induced in the iron of which the box is composed.

The vicinity of a magnet is pervaded by its influence, and this region is termed the *field* of the magnet, and pieces of iron and steel brought into this field exhibit magnetic properties. It was conceived by Faraday that this influence might be explained by *lines of force.* These are clustered together at the poles and from thence spread out in all directions, a definite intensity depending upon the distance from the poles. Some idea of the distribution of these lines is obtained by the arrangement of iron filings sprinkled on a sheet of cardboard placed above a magnet resting on table. The lines due to various combinations are indicated by Fig. 1.

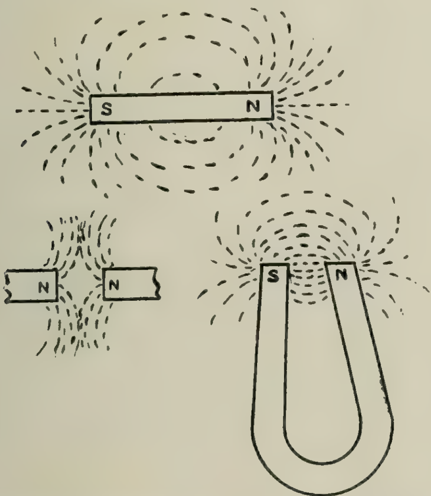


FIG. 1.—Representing the direction of the lines of force in the plane of the paper.

The force between two magnet poles is directly proportional to the product of their strengths and inversely proportional to the square of the distance between them. Expressed as an equation this becomes :—

$$\text{Force} = \frac{m \times m^1}{d^2}$$

where m and m^1 represent the respective strengths and d the distance.

A magnet acts upon iron by inducing an opposite polarity in the part nearest to itself, and in consequence the two dissimilar poles tend to attract each other. The opposite extremity of the piece of iron exhibits the same polarity as that of the magnet itself, and will attract a second piece of iron. Nearly all traces of magnetism in the iron cease as soon as it is removed from the influence or field of a magnet, for iron cannot retain magnetism or cannot be permanently magnetized when soft and pure. When hard or impure it retains a certain amount of polarity which is called *residual magnetism*. Size and shape also vary this property of retention. Steel acquires magnetism with greater difficulty, but retains it more or less permanently. The harder the steel and the longer the bar the more permanently will it retain its magnetism.

By a method of oscillations it is possible to compare the relative strengths of two magnets similar in mass and shape. A suspended magnet when moved from its position of rest will vibrate backwards and forwards with regularity and follows a law governing the oscillations executed by a pendulum swinging under the influence of gravity. It is *that the force producing the oscillations is proportional to the square of the number of oscillations in a given time.* In comparing the two magnets, first note the number of oscillations due to the earth's magnetic influence, which is combined with the force exerted by each magnet ; hence to ascertain them the earth's force must be deducted. For example, suppose number of oscillations due to the earth to be 10 in a minute, those with magnet x 20, and with magnet y 25 :—

$$x : y :: 20^2 - 10^2 : 25^2 - 10^2$$

$$400 - 100 : 725 \quad 100 \text{ i. e. } \frac{x}{y} = \frac{300}{625}$$

or y is a little more than twice the strength of x.

Magnetization is sometimes termed a "skin-deep" process ; hence to obtain strong magnets thin bar magnets are placed side on side with their similar poles in contact.

The theory of molecular magnetism is the one most generally accepted. It is that each particle of a magnetic substance has an absolutely constant inherent magnetic polarity, and that when a piece of iron or steel is apparently neutral its molecules are internally arranged so as to satisfy each other's polarity forming closed magnetic circuits or chains amongst themselves.

The molecular theory is supported by the fact that a click may be heard at the moment of magnetization and demagnetization of a bar, and also that heat is produced when a bar is rapidly magnetized and demagnetized.

The earth itself, as previously indicated, behaves as an enormous magnet, and objects upon its surface are constantly in its field and subject to its influence; consequently if magnetized bars are laid aside without regard to the direction in which their poles are placed they lose their polarity. To prevent this demagnetization armatures or keepers of soft iron are placed across the poles when not in use. The mutual induction of armatures and bars is more powerful than the inductive influence of the earth. The armature should always be slid off, never forcibly detached, as rough usage disturbs the polarization of the molecules.

The small bar magnets used in telegraph instruments and also in ships' compasses are designated *needles*, and as they are required to be set in motion by a slight force they must necessarily be short. They therefore lose their power readily and are easily demagnetized by heavy currents and lightning discharges—sometimes even reversed. Consequently there is a great advantage in making the moving parts of soft iron and pivoting them upon or near large permanent fixed magnets so that the needles may be magnetized by induction and the polarity be permanent. Also such bar magnets are placed N poles downwards in our hemisphere, but *vice versa* in South Africa and places in Southern hemisphere.

Units of Measurement.

Useful definitions. A *unit* is one or a single thing; for example, a *stone* or a *heap* of stones. Considered, however, as a collection of units a heap of stones would be more properly designated a *number*. When one number exactly contains another the latter is said to be a *measure* of the former.

To form an idea of the value of any quantity we must know what the unit is and have some conception of its magnitude.

At the beginning, students in Telegraphy frequently experience difficulty in connection with the abstract units employed therein. They would readily comprehend the concrete examples of the units and measures of *length*, for example inch and yard ; metre and kilometre, and of *time*, day and year ; but when ignorant of electrical quantities no idea is conveyed to the mind of the value of 100 ohms or 25 milli-amperes.

All physical quantities have two factors : (1) a *unit* and (2) a *measure*.

In order that agreement shall exist in science three fundamental units have, almost universally, been adopted in what is known as the C.G.S. (centimetre—gramme—second) system. These units being only interdependent are often styled *absolute*.

The unit of *length* is the *centimetre*, c.m. (·3937 inch). It is the hundredth part of the *metre*, which is the ten-millionth part of a quarter of a terrestrial meridian.

The unit of weight, the *gramme*, gr. (15·432 grains), is the weight in vacuum of a cubic centimetre of distilled water taken at 4 degrees Centigrade, its maximum density.

The unit of time, the *second*, being $\frac{1}{240}$ of the difference of time between the degrees of longitude.

From these other units have been derived, namely :—

Force. The unit of force is called the *dyne*, and it is that force which acting on a mass of 1 gramme for 1 second gives to it a velocity of 1 cm. per sec.

In London, the gramme is equal to 981 dynes.

Work or *energy*. The unit of work is the *erg*, and is the amount of work done through a distance of 1 cm. by a force of 1 dyne.

Electromagnetic Units and Standards of Electromotive Force, Resistance and Capacity.

The C.G.S. *unit of electromotive force* exists when the P.D. between two points is such that 1 erg of work has to be expended to bring a unit of positive electricity from one point to the other.

This unit is so small that for practical work electricians use the volt, which is 100,000,000 times greater. The connection between them is generally indicated by a system of index notation; thus the *volt* is said to equal 10^8 times the C.G.S. unit. In a similar way a thousand could be written as 10^3 and a million as 10^6, while fractional quantities have negative indices. Thus 0·1 or $\frac{1}{10}$ is written 10^{-1} and $\frac{1}{1000}$ (·001) as 10^{-3}. Examples of this convenient method will be supplied with other units.

The value of the *volt* is determined by means of a Clark's cell of standard specification, and is represented by ·6974 ($\frac{1000}{1434}$) of its electrical pressure at a temperature of 15° C. That is, the P.D. between the poles of the cell is 1·434 volts. *Volt* often represented by v.

Unit of current. If in a circular circuit of 1 cm. radius the current, passing through an arc 1 cm. in length, is able to exert a force of 1 dyne on a unit magnet pole placed at the centre of the circle, the current is said to be of unit strength.

The practical unit is the ampere, which is $\frac{1}{10}$th or 10^{-1} of the C.G.S. unit, and is the current which will, by electrolysis, deposit silver at the rate of ·001118 gramme per second from a silver salt dissolved in water.

Telegraph engineers use a sub-unit, the *milli-ampere* (the prefix milli denotes $\frac{1}{1000}$th part), which is written by abbreviation m.a. and sometimes also denoted by the Greek γ (Gamma).

Unit of resistance is possessed by a conductor if when its ends have unit difference of potential a current of unit strength flows through it. This unit is far too small for practical purposes and is replaced by the OHM, which is the amount of resistance offered by a filament of pure mercury 106·3 c.m. in length, weight 14·4521 grammes, uniform in cross-section and at a temperature of 0° C. The *ohm* is 1,000,000,000 or 10^9 times greater than the C.G.S. unit. Other measurements connected with the *ohm* are the microhm ($\frac{1}{1,000,000}$th part) and the megohm (which is 1,000,000 ohms). The *ohm* is usually denoted by the Greek letter ω (Omega), and the *megohm* by its capital (Ω). The ohm written backwards, *mho*, is termed the unit of *conductance*.

The relationship of the practical units of electromotive force, current and resistance is $\frac{1 \text{ volt}}{1 \text{ ohm}} = 1$ ampere, but Ohm's law previously quoted is only true when the quantities are expressed in these units. For example, although $C = \frac{E}{R}$ it must not be supposed to imply that a current of 100 m.a. $= \frac{100 \text{ v.}}{100 \,\omega}$ because 100 m.a. are $\frac{100}{1000}$ of an ampere; and of course similar treatment must obtain with regard to the use of the other auxiliary units: milli-volt, megohm, etc.

The *unit of quantity* is the amount of electricity conveyed by a unit current in one second. The practical unit is the *Coulomb*, which equals 10^{-1} or $\frac{1}{10}$th of the C.G.S. unit and may be expressed as $C \times t$ or the quantity which flows in a current of electricity lasting one second.

One *Joule*, the practical unit of energy, or heat developed, is the amount of work done when a pressure of *one volt* sends a *coulomb* of electricity through a circuit; i.e. CEt or C^2Rt $(E = CR)$. The practical unit of capacity, the *Farad*, equals 10^{-9} or $\frac{1}{1,000,000,000}$th part of the C.G.S. unit. A condenser has a capacity of 1 farad when a charge of 1 coulomb produces a difference of potential of 1 volt between its two coatings. The millionth part of a farad or *micro-farad* is most frequently employed as a unit.

Power.—The practical unit is the *Watt*, which equals 10^7 ergs, calculated by multiplying together volts and amperes being the energy due to a P.D. of 1 volt and a resulting current of 1 ampere. The watt also equals $\frac{1}{746}$ of a horse-power. 1000 watts are termed a *kilowatt*, and the *Board of Trade unit* of electric energy or *kilowatt-hour* is the quantity of energy supplied in one hour by a current at such a pressure that the product of volts, amperes and hours comes to 1000. For example: 100 volts 2 amperes for 5 hours.

Self-Induction.—The HENRY equals 10^9 C.G.S. units of self-induction. It is the inductance of a circuit in which, when the inducing current varies at the rate of 1 ampere per second, a counter E.M.F. of 1 volt is generated.

In connection with measurements it may be helpful to some students to be reminded of the facts relating to the treatment of ratios, equations and formulae. It would be out of place here to make more than a passing allusion to what properly belongs to the branch of mathematics, but on account of the importance of the subject the reader's attention is invited, especially as experience reveals considerable neglect on the part of a large number of students. A little consideration will convince of the power and utility of even an elementary study of mathematics and its ready application to all kinds of problems in Telegraphy of every-day occurrence.

The relation existing between two quantities of the *same kind* with respect to the number of times the one contains the other is called the *ratio* of the one to the other.

A field, say, of 10 acres is *ten* times as great as a field of *one* acre, that is, an area of 10 acres contains the area of one acre ten times. This ratio is expressed as 10 : 1 or $\frac{10}{1}$. The numbers representing the ratios are called the *terms* of the ratios. The essential condition of ratios is that the quantities compared must be of the same kind.

Proportion is the equality of ratios.

Example, as 4 : 8 so is 44 : 88. This may be written 4 : 8 : : 44 : 88, or $\frac{4}{8} = \frac{44}{88}$, because $\frac{4}{8} = \frac{1}{2}$ and $\frac{44}{88} = \frac{1}{2}$

4 and 88 are called the *extremes*, 8 and 44 the *means*, and it is always true in proportion that the product of the *extremes* equals the product of the *means*. Given three terms, therefore, the fourth can be calculated ; *e. g.* Find a number that bears the same ratio to 12 that 4 has to 6.

4 : 6 : : number required : 12

$\therefore$ 4 × 12 ÷ 6 = number required, or 8.

When two expressions are equal—as in the first example, 4 : 8 and 44 : 88—they are termed an *equation*. The unknown quantity is usually denoted by the letter x, the ratios are expressed as fractions, thus $\frac{4}{8} = \frac{44}{88}$, and the second example would be $\frac{4}{6} = \frac{x}{12}$.

The process of solving an equation depends only upon what are called self-evident truths or *axioms*:

1. If to equals we add equals the sums are equal.

2. If from equals we take equals the remainders are equal.

3. If equals are multiplied by equals the products are equal.

4. If equals are divided by equals the quotients are equal.

Consider the preceding example :

Multiplying both sides of the equation by 12 (axiom 3) we get $\frac{4 \times 12}{6} = \frac{x \times 12}{12}$. The factors 12 in the numerator and denominator of the right side cancel each other and the value of x is obtained by arithmetically reducing the left side or $\frac{4 \times 12}{6} = 8, \therefore x = 8$.

To solve $4x - 8 = x + 16$. In this case the unknown occurs on both sides of the equation, but following the reasoning supplied by the *axioms* we can transpose any term from one side to the other by simply *changing its sign*.

Subtract x from both sides of the equation and the expression becomes $4x - x - 8 = 16$ (axiom 2). Thus we see that $+ x$ has been removed from one side and appears as $- x$ on the other.

Then add 8 to both sides and we get $4x - x = 16 + 8$ (axiom 1).

This operation removes $- 8$ from one side and it appears as $+ 8$ on the other. By collecting the terms, $4x - x$ becomes $3x$, and $16 + 8$ becomes 24; the equation then reads $3x = 24$, and by using axiom 4 we deduce $x = 8$.

The statements that ratios are *directly* or *inversely* proportional present difficulty to the beginner, and we invite attention to the following considerations.

If 1 ton of coal cost 25 shillings, 2 tons will cost fifty shillings, 3 tons 75 shillings, and so on. Hence the *cost* is proportional to the *weight*, and an *increase* of one ratio involves an increase of the other. The proportion is then *direct*. In the same manner, other things being equal, the *amount* of work done is *directly* proportional to the *number* of workers.

But if 2 men do a piece of work in 6 days, 4 men can do it in 3 days, and 6 men would do it in 2 days.

Hence if we *increase* the number of men we *reduce* the time, and the proportion is then said to be *inverse*, for the ratio of the *time* is the ratio of the *men* inverted. Take the first two conditions: the ratio of time $= \frac{6}{3}$ or $\frac{2}{1}$ and the ratio of men $\frac{2}{4}$ $\frac{1}{2}$.

The student will readily call to mind many more examples of inverse proportion by which an *increase* of ratio involves a diminution of the other.

In an earlier statement Ohm's law was enunciated and the formula given $C = \frac{E}{R}$, and from the foregoing it is readily observed that an increase of E, while R remains the same, involves an increase of C, their ratio being in direct proportion.

Similarly if E is constant then a variation of R produces an *inverse* change in C; that is, if R be doubled then C is halved, and so on. The formula $C = \frac{E}{R}$ can become $CR = E$ by multiplying both sides by R, for $CR = \frac{E}{R} \times \frac{R}{1}$, and dividing this last result by C the expression becomes $R = \frac{E}{C}$.

The extent of variation, *i.e.* gain, loss, increase, or decrease, is not usually expressed at so much per unit, but at so much per cent., which is equal to the rate per unit multiplied by 100. For example, the current in a circuit increased from 80 m.a. to 100 m.a.; what is the percentage of the increase?

The increase $= 100 - 80 = 20$ units
,, on 80 units $= 20$,,
,, ,, 1 unit $= \frac{20}{80}$ or $\frac{1}{4}$ of a unit
,, per cent. $= \frac{1}{4} \times 100$, or 25%

Example 2.—The resistance of a circuit decreased from 100^{ω} to 72^{ω}; find the rate of the decrease per cent.

Decrease $= 100 - 72 = 28$ units
,, on 100 units $= 28$,,
,, ,, 1 unit $= \frac{2}{100}$ or $\frac{7}{25}$ of a unit
,, per cent. $= \frac{7}{25} \times 100 = 28\%$

Since the ratios of the rate per unit and the rate per cent. are equal, the above steps may in practice be omitted. For example, what percentage increase will result from the addition of 20^{ω} to a circuit already possessing 300^{ω}?

$$\frac{20}{300} = \frac{x}{100}, \; i.e. \; \frac{20 \times 100}{300} = x = 6\tfrac{2}{3}\%$$

Essential Qualities of Iron and Steel for Permanent, and Methods of Making Permanent, Magnets.

It has been previously stated that thin bars of steel can be more powerfully magnetized in proportion to their weight than larger masses; therefore when a strong permanent magnet is required it is generally made up of several thin plates producing what is called a *compound* or *laminated* magnet. The ends are usually fixed in pieces of soft iron which form pole-pieces. Magnets of the *horseshoe* pattern are three or four times as strong as bar magnets of equal dimensions. Examples of laminated horseshoe magnets occur in the Wheatstone ABC and the Hughes type-printing instruments.

The common practice with makers is to use an electromagnet for making permanent magnets.

An electromagnet in its simplest form consists of a hollow bobbin of insulated wire in which a core of soft iron is placed. During the passage of a current through the coil the core is magnetized. Generally two such coils are used and the cores being yoked together with soft iron form, when desired, a very powerful horseshoe magnet. The steel is moved over both the poles, from end to end across each in turn but in an opposite direction, to insure uniform magnetization. The reason for this reversing is given on page 7, where it was stated a magnet acts upon iron by inducing an opposite polarity in the part nearest to itself.

We have previously observed that in the *field* of a magnet *lines of force* pass out in the surrounding air. Now when a piece of iron is placed in the field many of these lines of force are disturbed, being diverted and concentrated through the space occupied by the iron. That is, more lines pass through the iron than previously occupied the same space of air. This results from the iron affording greater facility than the air, iron being a better medium for the magnetic flux. This property of iron is said to be due to its greater *permeability*, which is designated by the Greek letter μ (Mu).

In the case of iron the value of μ varies with the nature of the iron and also with the value of the magnetizing force becoming smaller as the point of *saturation* is reached. A magnet is said to be *saturated* when the degree of the induced magnetism is as much as it can permanently retain.

This variation of μ in iron is shown by the following results. A magnetizing force which produced 10,000 lines of force per square centimetre of a piece of annealed wrought iron produced 5 in air. But a force which would produce 50 in air will only produce 16,000 in the iron. This falling off constitutes an important difference between magnetic reluctance and electrical resistance, for while the latter remains constant however the E.M.F. and current are varied yet magnetic reluctance (indicated by the script letter $\mathcal{R}$) increases as the magnetizing force (also termed magneto-motive force, represented by letter $\mathcal{F}$) is increased and a limit is soon reached beyond which further increases do not produce much effect. For example, a force producing 666 in air only raised the value in the iron to 20,000.

Magnetic flux or total magnetic induction is measured in units called the *Maxwell* and represented by the Greek letter ϕ (Phi) while the relationship of $\mathcal{R}$, $\mathcal{F}$ and ϕ is expressed by the formula $\phi = \frac{\mathcal{F}}{\mathcal{R}}$.

Gilbert is the name given to the unit of $\mathcal{F}$ and the unit of reluctance, or the $\mathcal{R}$ of 1 cubic c.m. of vacuum is called an *oersted*.

Permeability, μ, is the converse or the reciprocal* of $\mathcal{R}$, reluctance. The density of the induction or the number of maxwells is usually represented by the letter B and the number of gilberts or force by H. The ratio of B to H expresses the value of the permeability, *i. e.* $\mu = \frac{B}{H}$.

The power of retaining magnetism permanently, varies with different magnetic substances: hard steel and nickel continue in magnetic condition with very little change, but

* Reciprocal of a number or quantity is unity (1) divided by that number, *e. g.* of 10 it is $\frac{1}{10}$, etc.

soft and pure iron practically loses its polarity as soon as the inducing force is withdrawn. The amount remaining is termed its *residual* magnetism. This retention not only varies with the quality of the iron but with its shape, being considerable if elongated, and especially if tending towards forming a closed magnetic circuit, like a soft iron ring.

Another curious phenomenon may be briefly mentioned. It has already been observed that the process of magnetization involves a rearrangement in the position of the molecules of the iron. If then it be magnetized in a reverse direction another rearrangement must take place. With a rapidly alternating magnetizing force the particles of iron are therefore in a state of continual motion. In this action two effects are evidenced: (1) the motion of the molecules lags behind the magnetizing force; and (2) energy is consumed in internal friction, with the result that the iron becomes heated. Prof. Ewing has given the name of *Hysteresis* to this *lagging* of magnetic effects behind their causes.

It is noteworthy that mechanical vibration assists both magnetization and demagnetization and lessens the *residual* and *hysteresial* effects.

Electromagnets and Simple Calculations Relating Thereto.

A spiral of wire conveying a current has for the time the properties of a magnet. The strength of the magnetic

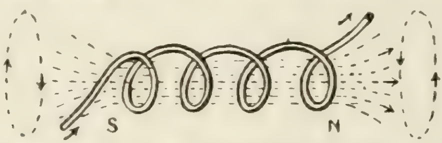


Fig. 2. Lines of force from current in a solenoid.

field due to this solenoid (Fig. 2) is dependent upon the strength of the current and the number of turns or convolutions. Its power for doing useful work is very small. When such a spiral is wound on a bar of soft iron the lines of force are nearly all concentrated through the iron, which thus becomes a temporary magnet. As previously mentioned such a combination is called an *electromagnet* and its polarity depends upon the direction in which the coil is wound. The electromagnet has all the properties of a permanent magnet so long as the current continues to flow, and it can be constructed to possess much greater power than it is possible to give to a permanent

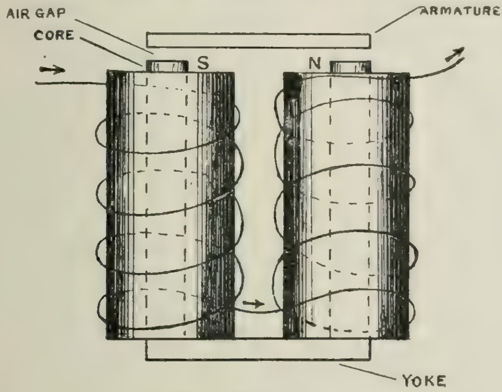


Fig. 3. Electromagnet.

magnet. Fig. 3 shows the common horseshoe form, the cores standing upon a connecting bar of iron, and the *armature* is fitted across both the cores in the same manner as the *keeper* of permanent magnets. The wire in the coils must be connected so that the windings would be continuous in one direction if the magnet were straightened out. Remembering that looking at the *S pole* of an electromagnet the direction of the current round it is the same as the movement of the hands of a watch (Fig. 4), it follows that at the *N pole* the direction is reversed. For if we examine the polarity of the magnetic field to a current by a simple rule first given by Ampère that if the observer suppose himself to be swimming in the wire in the direction of the current, with his face towards the magnet (in this case soft iron core), then the N-seeking pole will be in the direction of his *left* hand.

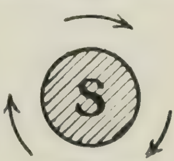


Fig. 4.

Let a single convolution of the wire pass through the plane of the paper at W, then small magnets near it would place themselves tangentially to circles of which the wire forms the common centre. According to Ampère's rule, if the current is passing from the reader, then the observer would pass through the plane of the paper head-foremost and the magnets would have their poles turned as at *n s*, Fig. 5.

Fig. 5.

Windings or spirals can be either right-handed or left-handed helices. In Telegraphy most of the apparatus is wound right-handedly, and it is useful to remember with such winding the point of *exit* of the current is always N polarity (see Fig. 3).

Also note that a *simple electromagnet always moves its armature one way, and that reversal of current makes no difference in the direction of the movement.*

The common expression of the law of the electromagnet is that its magnetism depends upon the strength of the current and the number of turns of wire in the coil. How this general statement is modified will be briefly considered.

With regard to the total magnetizing force of a *solenoid* carrying a current it is simply in proportion to the number of *ampere turns*, as the above law is concisely formulated. That is, a current of 5 amperes circulating in a coil of 500 turns gives exactly same force as 500 milli-amperes of current through 5000 turns. In both cases $C \times n =$ 2500 ampere turns.*

With the insertion of the iron core of the electromagnet the law of *ampere turns* is only true in certain circumstances—that is, if the current is not very strong and the core only slightly magnetized. It will be remembered that permeability of the core is not constant, depending upon the degree of saturation. Then again, consideration must be given to the amount of leakage of lines of force which increases with the distance of the air gaps in the magnetic circuit. This distance will also introduce an additional

* Strictly, the force of a coil is equal to 1·257 times the ampere turns.

reluctance, the permeability for air being 1, which is very much less than any magnetic materials.

(The greatly lessened attraction for the armature exerted by an electro-magnet when the distance between them is increased is therefore explained by the diminution of ϕ (gilberts) caused by the increase of $\mathscr{R}$, when the great reluctance of the air gap is thus introduced into the circuit.)

It is, however, very convenient to speak of *ampere turns* when expressing the relation between the strength of current and the amount of magnetism produced. The law is often used in equational form and expressed as $m = a C n$, where m is the strength of the poles, C the strength of current in amperes, and a is a constant depending on the form, mass and quality of the core. The strength of an electro-magnet is independent of the material and thickness of the wire forming the coil.

The iron chosen for the cores, yoke and armature should be as thick and permeable as possible and form, as a rule, almost a closed magnetic circuit. By this means, for a given number of ampere-turns of excitation, we are able to produce the greatest amount of magnetism.

The construction of telegraphic instruments is governed by the fact that the magnetic effect of a small current with many turns may equal a larger current with fewer turns. When a line wire is very long, the current will necessarily be feeble and the coil should consist of thin wire, which occupies little space and allows very many layers to be wound on the bobbin without increasing too much the distance from the core. When, however, the line is short, each layer of fine wire would probably decrease the current, by adding to the resistance of the circuit, more than would be made up by the multiplying effect of the increased number of turns, for a few such layers might double the resistance of the circuit. In such a case the use of a thicker wire might not materially diminish the current; for if, say, of three times the diameter its resistance per yard would be $\frac{1}{9}$th; and although, because of its size, the distance of each layer from the core rapidly increases, yet a sufficient number of turns may be employed without exceeding the distance at which the current acts with advantage.

An approximate rule for obtaining maximum power is when the electro-magnet is wound to a resistance equal to that of the rest of the circuit (battery, line, etc.). When winding bobbins of electro-magnets other factors besides length, thickness and resistance of wires used have to be considered. The height or distance between the cheeks, the radii of the layers, etc. (see Fig. 6). For telegraphic purposes the wire used on electro-magnets is usually copper and invariably covered with silk. As a general rule the diameters of the bobbins and the lengths of the electromagnet cores are in the ratios 2 : 5. If the wires are to fill the same total space and are of the same metal then the following are approximate rules for determining the number of turns and resistances.

(1) The resistance is *inversely* proportional to the 4th power of the diameter of the wire.

(2) The length, and hence the number, of turns is *inversely* proportional to the *square* (2nd power) of the wire's diameter. Also from (1) and (2) we obtain

(3), that the resistance is *directly* proportional to the *square* of the number of turns.

Expressed in formulae these statements become—

(1) $R = \frac{1}{d^4}$ (2) $n = \frac{1}{d^2}$ (3) $R = n^2$

The third equation is deduced after squaring the second one, which then becomes $n^2 = \frac{1}{d^4}$.

The application of the above statements affords important examples of the use and value of the elementary rules considered on pp. 13 and 14.

Now the *resistance* of a conductor varies *directly as its length* and *inversely as the square of its diameter.* That is,

$$R = \frac{l}{d^2}$$

The comparison of two wires of similar material is

$$\left.\begin{array}{l} R_1 = \frac{l_1}{d_1^2} \\ R_2 = \frac{l_2}{d_2^2} \end{array}\right\} \text{ or } \frac{R_1}{R_2} = \frac{l_1 d_2^2}{l_2 d_1^2} \quad . \quad . \quad . \quad (1)$$

Also consider that to fill the same space, if the diameter of the wire is greater, the length and number of turns will be reduced, and it is found that the total length of wire used is *inversely* proportional to the *square* of the diameter. Thus comparing two wires

$$\frac{l_1}{l_2} = \frac{d_2^2}{d_1^2}$$

and where n represents the total number of turns

$$\frac{n_1}{n_2} = \frac{d_2^2}{d_1^2} \quad . \quad . \quad . \quad (2)$$

Substituting the above value of l in the result (1) we have

$$\frac{R_1}{R_2} = \frac{d_2^2 d_2^2}{d_1^2 d_1^2} = \frac{d_2^4}{d_1^4}$$

The result (2) squared becomes

$$\frac{n_1^2}{n_2^2} = \frac{d_2^4}{d_1^4} \quad \text{therefore} \quad \frac{R_1}{R_2} = \frac{n_1^2}{n_2^2}$$

This last result proves—equation (3)—that the *resistance* of the windings of an electromagnet is *directly* proportional to the *square of the number of turns.*

It is possible to demonstrate the truth of this conclusion in another way: Suppose we have a coil of one ohm resistance with one turn of wire. Split the conductor into four wires and we then have four turns, but the area of each wire is one fourth in size. Resistance varies directly as length and inversely as area, *i. e.* $R = \frac{l}{a}$ (substituting the figures) $= \frac{4}{\frac{1}{4}}$ or $4 \times 4 = 16$. The number of turns have been increased from one to four and the resistance from one to sixteen, or as $1^2 : 4^2$.

Appended are a few examples showing how the foregoing rules are employed.

Example 1.—An electromagnet is wound to a resistance of 320^ω with wire 20 mils. diameter (" mil " $\frac{1}{1000}$ of inch). What diameter would the wire have to be in order that with the same weight of wire the resistance may be 20^ω?

Now with wire the *same weight* the resistance varies *inversely* as the *fourth* power of the diameter, because the weight of a wire $w = l \times d^2 \therefore l = \frac{w}{d^2}$ and substituting this value of l in the formula already known, *i.e.* $R = \frac{l}{d^2}$,

we have $R = \frac{\frac{w}{d^2}}{d^2}$ or $R = \frac{w}{d^2} \times \frac{1}{d^2} = \frac{w}{d^4}$

As weights given are alike $\frac{R}{R_1} = \frac{\frac{w}{d^4}}{\frac{w}{d_1^4}} = \frac{d_1^4}{d}$

or (substituting the figures given) $\frac{320}{20} = \frac{d_1^4}{20^4}$

$$\therefore d_1^4 = \frac{320 \times 20^4}{20} = 40 \text{ mils.}$$

Example 2.—Two electro-magnets similar in size have resistances of 1 and 16 ohms, the weights of the wires being equal. If equal currents are passed through the magnets, what will be the relative magnetic strengths of the two?

The magnetic strength varies as the product of the ampere turns or $C \times n$. We have seen that R varies as n^2

$$\therefore n = \sqrt{R} \text{ and } Cn = C\sqrt{R}.$$

The current is the same in both, hence the magnetic strengths are $\frac{C\sqrt{R}}{C\sqrt{R_1}}$ or $\frac{\sqrt{1}}{\sqrt{16}}$ *i.e.* 1 : 4.

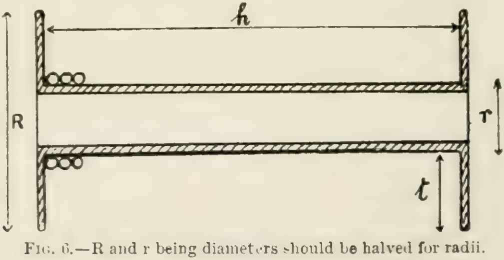


FIG. 6.—R and r being diameters should be halved for radii.

It was pointed out earlier that when winding bobbins of electromagnets it was necessary to consider the dimensions of the bobbins as indicated in Fig 6.

The total length of wire required to fill the bobbin of an electromagnet of given size is found as follows: —

Let r = the internal radius of the bobbin
R = the external radius
h = the height or distance between the cheeks
t = the thickness of the windings or depth of the coil
d = diameter of the wire
m = the number of layers
n = the number of turns in each layer
L = the total length of the wire

Evidently the length of one turn multiplied by the total number of turns will be the length of the wire. We must, however, first find the average or *mean* radius of the layers, which will be $\frac{1}{2}(R + r)$. Then as the length of a turn is 2π the radius, the average length of a turn is $2\pi\frac{R + r}{2} = \pi(R + r)$. The number of layers, m, is equal to t divided by the diameter of the wire, *i. e.* $\frac{t}{d}$, and the number of turns, n, will be equal to $\frac{h}{d}$. But as $n \times m$ equals the total number of turns we can substitute the above values and $n \times m = \frac{h}{d} \times \frac{t}{d}$ or $\frac{ht}{d^2}$. As t equals $R - r$ this becomes $\frac{h(R-r)}{d^2}$ and *the total length is the product of the mean radius and the total number of turns*, or

$$L = \frac{\pi h(R + r)(R - r)}{d^2}.$$

Now the product of the sum and difference of two numbers is equal to the difference of their squares, so we may rewrite the equation

$$L = \frac{\pi h(R^2 - r^2)}{d^2}$$

Note that should the total number of turns only be required when radii, height and diameter are given, it is as shown above $\frac{h(R - r)}{d^2}$. Also if dimensions are given with the diameter instead of the radius, then since $d = 2r$, the total length when $d\ d_1$ is the inner diameter and D the outer diameter will be $L = \frac{\pi h\ (D^2 - d_1^2)}{4d^2}$. Remember all quantities must be in the same units.

Example.—An electromagnet 2 inches long, one inch external and half-an-inch internal diameter, is to be fitted with wire 20 mils. in diameter: What length wire will be required?

First express the mils. in inches, *i.e.* ·02 inch; then

$$L = \frac{\pi 2 (1^2 - \frac{1}{2}^2)}{4 \times ·02^2} = \frac{3·1416 \times 2 (1 - \frac{1}{4})}{·0016} = \frac{3·1416 \times 2 \times 3}{·0016 \times 4}$$

$= 2945·25$ inches.

The *figure of merit* of an electromagnet is generally defined as the minimum value of the current which will cause it to work.

As examples, the Standard Relay has a figure of merit of ·5 m.a., and the 20 ohms Sounder should have a figure of merit of 55 m.a.

Sometimes, however, the figure of merit is indicated by stating the current required to produce certain result, as the deflection of a magnetic needle. In the case of the ordinary differential galvanometer, it should deflect 40° to 45°, with twenty milli-amperes through one coil.

Exercise I.

1. Describe how to study the magnetic field near a magnet. State the effect of a magnet on soft iron. The earth is said to behave like a large magnet; what is the effect of the earth on a bar of soft iron? How would you demonstrate this effect?

2. Sketch carefully, the lines of magnetic force due to a bar magnet (i) when it is placed on a wooden table, (ii) when it is placed on a thick plate of soft iron.

3. Describe experiments which show that when electrification is excited, either by friction or electrostatic induction, equal quantities of positive and negative electricity are produced.

4. Explain what is meant by the electromotive force between two points, and describe some method of obtaining

a constant electromotive force between two points connected by a copper wire.

5. A wire conveys a current: (*a*) what is the magnetic field produced; (*b*) could chemical action also take place, and (*c*) how could heat be developed?

6. Electromagnets have soft iron cores. What would be the effect (*a*) if hard steel cores, (*b*) if brass cores were substituted?

7. Give the names of the units of electromotive force, resistance, current, capacity, quantity. State also the names and relative values of the practical units derived from these.

8. Explain what you understand by Ampère's rule for direction of current, and show by sketch or description how it bears upon the effect of a current upon a magnetic needle (*a*) when the wire conveying the current is placed above the needle, and current flows from N. to S., (*b*) when wire is beneath needle and current from S. to N.

9. State the practical value of the so-called absolute system of units as compared with an arbitrary system.

10. How would you calculate the magnetic strength of a solenoid, the current and number of turns of the conductor being known? What is the effect of introducing a soft iron core?

11. A brass tube 500 cm. long and 2 cm. in diameter has to be wound with one layer of covered wire one m.m. in diameter over the covering. What will be the length of the wire? Ans. 330 m.

12. Two bobbins are wound with the same weight of wire, one being 4 mils. and the other 2 mils. gauge. What are the relative resistances? Ans. 1 : 16.

CHAPTER II

PRIMARY BATTERIES, AS USED IN TELEGRAPHY: THEIR CONSTRUCTION AND CHEMICAL ACTION

In the definition of a voltaic cell it has been already mentioned that the electrical energy is obtained by the decomposition of the constituent parts of the cell, also that it was convenient to regard the current as flowing from the positive potential to the negative.

It has been observed in a cell of simple form containing two clean plates, one of zinc and one of copper immersed in a solution of dilute acid, that there is chemical action between the liquid and the zinc, and also an apparent transference of hydrogen to the copper when the two poles are connected by an outside wire. The resulting electrical action, or flow of electricity in the conductor, exhibits certain phenomena, the principal effects being:—

(1) The conductor if thin is heated (*thermal* effect).

(2) A magnetic needle placed in the vicinity of the wire is deflected (*magnetic* effect).

(3) If the current is caused to pass through a suitable liquid (called electrolyte) it is decomposed (*chemical* effect).

Now if two isolated spheres are oppositely charged and joined by a wire (Fig. 7), the apparent transference of electricity speedily tends to produce an equilibrium of

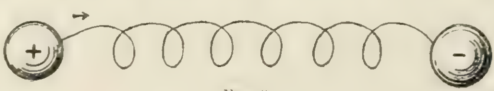


Fig. 7.

potential. This, of course, causes a cessation of the current —no P.D. exists.

A current can only continue so long as the ends of the wire are *kept* at different electric potentials.

The cell above mentioned is an attempt to insure a continuous current by maintaining a more constant P.D., and may be regarded as a generator of electrical energy. The zinc strip is observed to waste away, and this, no doubt, provides the power to produce certain electrochemical actions which are capable of constantly renewing the difference of potential.

As the current flows, however, and the zinc is being consumed, hydrogen is liberated at the copper plate, gradually covering it with a thin film of gas. This deposition has two bad effects, it introduces a high resistance into the cell, and as hydrogen is electropositive it also produces a reverse difference of potential, and tends to send a current opposing the true one. This effect, known as *polarization*, results in a rapid falling off in the effective E.M.F. of any cell in which it occurs.

Polarization is most successfully eliminated by using double cells. Other remedies for it chiefly consist of employing some substance which will combine with the hydrogen as soon as it is evolved, or while in its *nascent* state.

Another deleterious effect observed is caused by the impurities contained in the ordinary zinc plate. These pieces of other substances, generally tin, iron, other metals and arsenic, set up what is called "*local action*." These materials have a difference of potential from the zinc and local currents ensue between them, uselessly wasting the positive *plate*. *Local action* can be largely reduced by amalgamating the zinc with a coating of mercury. As the working of the cell goes on, this coating is maintained by the mercury parting with the zinc which is dissolved in the acid and uniting with the new surface portions of the plate and so tending to cover up the impurities again.

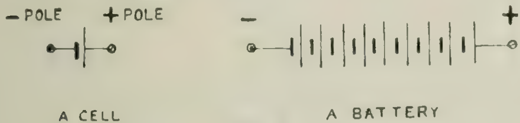


Fig. 8.

A cell is symbolically represented by a thick and thin line of different lengths, the former representing the positive *plate* and the latter the negative, while a battery is shown by a combination of these (Fig. 8).

Before continuing further, the beginner should be familiar with the following chemical terms :—

Molecule, the smallest particle of matter capable of free existence. It is generally formed of *two* elementary atoms, but in some cases three, four, or six. *Atom* was considered the smallest particle of matter that can enter into, or pass from, combination, but the discovery of Radium and other researches appear to indicate that the atom is composed of thousands of smaller particles called electrons. *Element*, a substance which has not yet been decomposed or resolved by chemical analysis, and is therefore presumed to be uncompounded. Some of these elements are here mentioned, each with its chemical symbol. Carbon, C ; Chlorine, Cl ; Chromium, Cr ; Copper, Cu ; Hydrogen, H ; Lead, Pb ; Manganese, Mn ; Mercury, Hg ; Nitrogen, N ; Oxygen, O ; Potassium, K ; Sodium, Na ; Sulphur, S ; Zinc, Zn.

A numeral placed after a symbol indicates the number of atoms in the compound, except that the figure 1 is not written, being understood. In any chemical equation, which is the form adopted to represent the chemical changes, every atom taking part in the reaction must be accounted for.

In the simple cell, if pure water (H_2O) were used the action would soon cease, because zinc oxide (ZnO) being insoluble would cover the zinc plate with a non-conducting compound. Hence generally a little sulphuric acid (H_2SO_4) is added which instead of zinc oxide deposits the soluble zinc sulphate ($ZnSO_4$). The dilute sulphuric acid also offers much less resistance than water. The action of the cell may then be represented as :—

$$Zn + H_2SO_4 + H_2SO_4 + Cu$$
$$= ZnSO_4 + H_2SO_4 + H_2Cu$$

It is important to note that the E.M.F. of a cell is independent of its *size* or *shape*, depending entirely on its constituents. With the same materials an egg-cup would furnish the same voltage as a barrel size. There is only this difference, that a large cell has more active material and hence lasts longer without renewal. Also that the larger the cell and the closer together the plates the smaller its resistance.

The conditions to be desired in a voltaic cell may be thus enumerated :—

(1) High and constant E.M.F.
(2) Internal resistance small and without variation.
(3) Low first cost and cheap maintenance.
(4) Small in size, easily and safely attended to.

It will be interesting to notice in the types of cells considered how these conditions are fulfilled—none possess all of them—and in Telegraphy the selection of any particular battery is determined by the character of the circuit or the work required.

Two important laws of chemical action in a voltaic cell and battery are :—

(1) The amount of chemical action in a cell is proportional to the quantity of electricity that passes through it. (Quantity is expressed in coulombs or ampere-seconds.)
(2) With a battery of cells joined in series the amount of chemical action is equal in each cell.

The DANIELL CELL, which has been extensively employed in Telegraphy, is constructed in a variety of forms, but the principle is the same in all.

Zinc and copper are used as the positive and negative plates respectively, but they are placed in different liquids which are separated by a porous inner cell or partition. The liquid surrounding the zinc is a dilute solution of zinc sulphate ($ZnSO_4$), that surrounding the copper a solution of copper sulphate ($CuSO_4$). (In the *Minotto* cell, a type of Daniell largely used in India, the liquids are kept from mixing by the difference in the *specific gravities* of the two solutions.)

A Post Office pattern of Daniell cell consists of a teak box divided into five or more compartments on the right of which is placed an unglazed porous earthenware pot (Fig. 9). The copper is a thin plate and is placed in the porous pot surrounded by a concentrated solution of copper sulphate, a few crystals of the latter being added to maintain the strength of the solution. The copper sulphate acts by combining with the hydrogen (compare with action of simple cell) that is liberated on the negative plate, forming sulphuric acid and depositing copper on the copper plate. This entirely prevents polarization, and the solution of $CuSO_4$ is known as the *depolarizer.* The zinc is in the form of a thick plate and is gradually dissolved in the zinc sulphate solution, forming more zinc sulphate, till the solution becomes concentrated and crystals are deposited. When this occurs the crystals must be removed, a portion of the liquid drawn off, and the cell refilled with water. The porous pot is coated with paraffin wax round the top and one side to prevent as far as possible the diffusion of the liquids, but in time this does occur, more

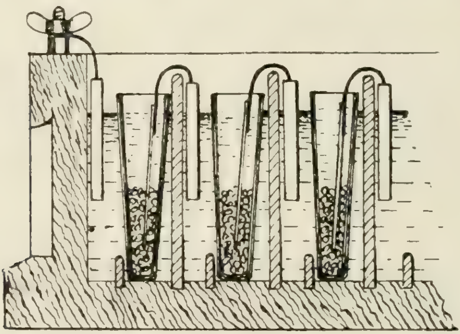


FIG. 9.—Daniell Battery.

especially when the cell is not being worked. One result is that copper becomes deposited on the zinc plate in the form of black mud, and when this appears the cell must be washed out and renewed.

The action of Daniell cell set up as above can be represented thus:—

$$Zn + SO_4Zn + SO_4Zn \,\|\, SO_4Cu + SO_4Cu + Cu$$
$$= ZnSO_4 + ZnSO_4 + ZnSO_4 \,\|\, CuSO_4 + CuCu$$

The change in the order of writing the symbols has been made to more clearly indicate the reactions.

In practice, advantage has been taken of the fact that $ZnSO_4$ is formed in the action of the cell, and should it not be required for immediate use the cell is made up by filling the zinc compartment with water. Then short-circuit (*i. e.* join poles with very low resistance) the cell for twenty-four hours.

The chemical action of the cell with only water supplied in the outer compartment is modified and may be represented as :—

$$Zn + OH_2 + OH_2 \mid SO_4Cu + SO_4Cu + Cu$$
$$= ZnO + H_2O + H_2SO_4 \mid CuSO_4 \; CuCu$$

The E.M.F. of the Daniell cell is 1·08 volts, and its internal resistance varies between 2^{ω} and 8^{ω} according to its condition and size.

The voltaic cell in most general use is of the LECLANCHÉ

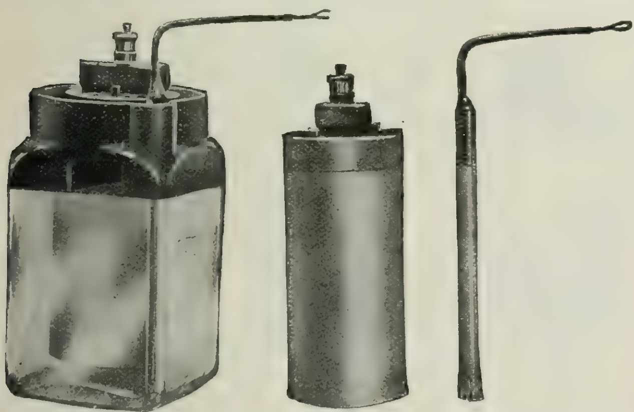


FIG. 10.—Leclanché cell. Porous pot. Zinc rod.

type, probably because there is no waste of materials when the cell is not actually at work, and it needs very little attention when required only for occasional use. Its chief defect is lack of constancy if the cell is furnishing much current.

In the Leclanché cell (Fig. 10) the positive plate is a zinc rod which is immersed in a solution of ammonium chloride (NH_4Cl), the ordinary salammoniac. The negative plate, carbon, is placed in a porous pot and surrounded with a mixture of broken carbon and coarse grains of manganese dioxide (MnO_2) in equal amounts.

The carbon plate or rod has a head of lead cast round the top, to which the terminal is connected. The upper part of the carbon and the lead are coated with paint or tar varnish, and the porous pot is sealed up except for a small vent hole.

The results of the action of the cell are : the formation of chloride of zinc, free ammonia is liberated at the negative plate, whilst the hydrogen set free from the salammoniac combines with oxygen of the dioxide of manganese, forming water and reducing $2MnO_2$ to a lower oxide, Mn_2O_3 ; the chemical formula of these changes being :—

$$Zn + 2NH_4Cl + 2MnO_2 = ZnCl + H_2O + 2NH_3 + Mn_2O_3$$

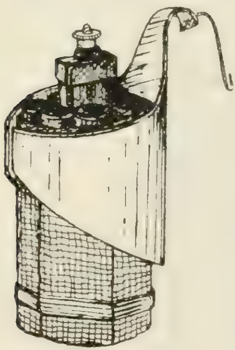


Fig. 11.—Leclanché agglomerate.

The liberated hydrogen does not instantly combine with oxygen of the depolarizer (MnO_2), and an accumulation of hydrogen occurs on the carbon after continuous working for a few minutes ; but this polarization speedily disappears if the cell be left to itself, and is not observed if the cell is only worked at intervals or with a very weak current.

The *agglomerate* form (Fig. 11) of Leclanché dispenses with the porous pot by using blocks of the mixed carbon and manganese which are placed round the carbon plate and held there by indiarubber bands, and sometimes by a canvas wrapping as well. In this case the zinc is cylindrical, almost surrounding the upper portion of the combination.

Dry cells are Leclanché cells in which the excitant (NH_4Cl) is made into a paste with some absorbent substance. As a rule the positive plate forms the case of the cell with the carbon rod in the centre surrounded by a damp black paste of carbon and manganese, and also, in some patterns, salts of iron, magnesium, silicon, etc. The make-up of the various dry cells is very similar. In the Obach type (shown by the sketch of a section, Fig. 12) the manner of fixing the brass terminal to the carbon rod is ingenious. The pin is inserted into a vertical hole and a molten alloy, composed of bismuth, lead and tin is poured around the pin. This alloy expands slightly in cooling and a perfect contact between the pin and the carbon is made. Dry cells are very portable, but deteriorate when stored, particularly in hot climates, and when exhausted they cannot be replenished but have to be replaced.

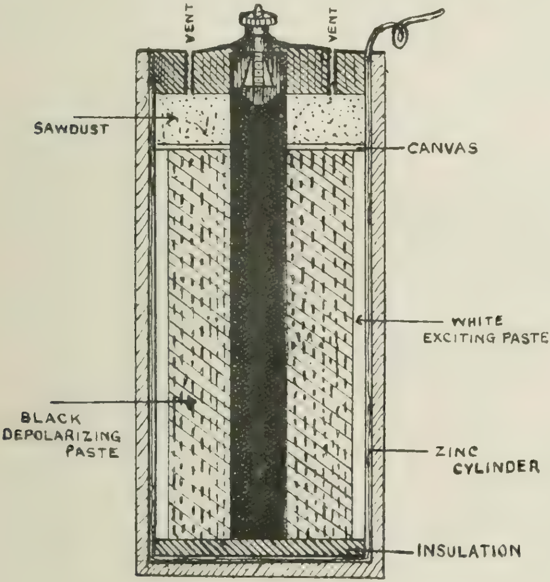


FIG. 12.—Obach dry cell.

The voltage of the Leclanché is about 1·6 at its best, but is usually reckoned as 1·45 or 1·5, and this is the case with each of its types. The internal resistance of the porous pot form is about 4ω, the agglomerate ·5 to 1ω, and the dry cells vary according to size, ranging between ·15ω for large to ·5ω for small patterns.

In the BICHROMATE cell the elements are zinc (amalgamated) and carbon, with chromic acid as the depolarizing agent.

The zinc stands in a porous pot with a small quantity of mercury and a weak solution of sulphuric acid. The carbon is in the outer earthenware jar, in which a similar but stronger solution of sulphuric acid and a quantity of bichromate of potash is placed.

The chemical actions of the cell are complicated, but are generally explained thus. *Zinc sulphate is formed by the action of the sulphuric acid in the zinc cell, and the liberated hydrogen acts with the mixture of chromic and sulphuric acids in the outer compartment forming water and sulphate of chromium.*

When the solutions become saturated a secondary action results in the deposition of chrome-alum crystals on the negative plate. These crystals should be removed, about half of both solutions withdrawn, and replaced with fresh solution of SO_4H_2 in the outer, and with water in the inner compartment.

If worked on circuits of low resistance, the Bichromate is subject to polarization, but there is no perceptible variation in its E.M.F. when working through a high resistance. Its E.M.F. is approximately 2 volts, and the internal resistance of the quart size averages 2^{ω}.

Batteries—Secondary Cells as used in Telegraphy.

Cells which generate electricity by internal chemical action are called *primary*. But chemical actions somewhat similar to those already described in the cells themselves are produced in the external circuit when the current is allowed to pass through certain compounds, and these chemical changes are capable of furnishing electrical energy. Hence the name "*secondary*," "*accumulator*," or "*storage*" is given to a cell which accumulates energy under the influence of a primary current.

The decomposition of substances by an electric current is known as *electrolysis*. The conductors by which the current enters and leaves the solution or *electrolyte* are called *electrodes*. Where the positive current enters the pole is called the *anode*, and the negative electrode the *cathode*. Whenever an electrolyte is decomposed by a current, the resolved *ions* (elements or groups of elements) have a tendency to reunite; this inclination or effect is said to be due to their *chemical affinity*.

The elementary principle of secondary cells can be observed by the electrolysis of water. Fill two test-tubes with water acidulated with a little addition of sulphuric acid to diminish the resistance of the water—which, if pure, acts as a non-conductor. The tubes are inverted over platinum electrodes placed in a vessel also containing acidulated water (Fig. 13). Platinum electrodes are preferred, as this metal is less oxidizable than others and resists every acid. The cells used for the electrolyzing current must have a minimum E.M.F. of 1·47 volts, which is the value of the affinity of hydrogen for oxygen, or the water will not be decomposed. Although a feeble current might flow at the outset with a smaller E.M.F., yet as soon as the opposing E.M.F. of polarization equalled that of the charging current the action would cease. The chemical decomposition is represented by the equation: $2H_2O = 2H_2 + O_2$, hydrogen being evolved at the *cathode* while oxygen becomes the *anion*.

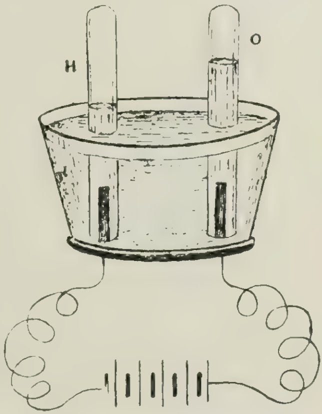


FIG. 13.—Electrolysis of water.

Then if the wires are disconnected from the battery and joined to a galvanometer a current will be observed flowing back through the electrolytic cell, the direction being from the hydrogen electrode to the oxygen electrode. The effect of polarization in the voltaic cells previously mentioned produces an opposing electromotive force in an exactly similar way.

The first remarkable use of this secondary E.M.F. was made by Planté in 1860, who devised cells capable of producing high chemical activity. The electrodes consisted of sheets of lead placed in dilute sulphuric acid. They were rolled up with narrow strips of felt placed between them (Fig. 14). A charging current liberated oxygen at the anode which, combining with the lead, formed peroxide of lead (PbO_2).

The reversal of the current reduces the PbO_2 to spongy lead by the action of the hydrogen which is now liberated at this new cathode, while the other plate (now the anode) becomes oxidized. By repeated reversals of current *the plate which last served as the anode* is deeply coated with PbO_2, while the cathode assumes a spongy metallic state and the cell is then "formed."

It is important to notice, however, that secondary cells do not store electricity, but they accumulate energy in the form of chemical work, and are then capable of furnishing electrical power.

The lengthy process of "forming" the Planté cell was modified by Faure, who used a paste of red lead as a coating for the lead plates. These pastes are more easily converted than the solid metal. When the charging

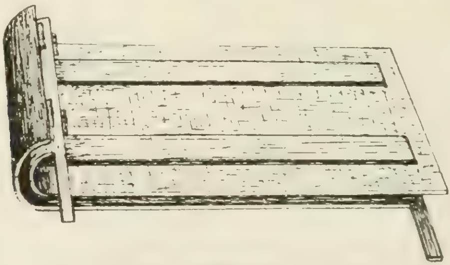


FIG. 14. Form of Planté's original plates.

current is passed through the cell the red lead at the anode is oxidized to PbO_2, but at the cathode it is first reduced to a lower oxide of lead (PbO) and then to the spongy metallic condition.

Accumulators may be divided into two classes: those in which the plates are "*formed*," and those in which they are "*pasted*."

Improvements of the "*formed*" or Planté type are designed to produce better mechanical structure of the plates with minimum weight of metal while obtaining maximum active surface. It was found that the repeated charging and discharging of the cell, while increasing its capacity, rendered the surface of the plates more porous, and the "formation" resulted in the disintegration of the plates owing to their weakened mechanical condition.

The "*pasted*" types have slight differences in their manufacture, many devices having been introduced to prevent the paste from falling away from the plates. The lead is cast in the form of grids, the small holes having inner projections, or are peculiarly shaped so that the paste is securely embedded in the interstices.

Some confusion occurs with students in distinguishing the positive and negative poles of a secondary cell. They recognize that the plate of the accumulator connected to the negative pole of the charging dynamo becomes the *positive plate* of the storage cell, while its negative plate is properly the *positive pole* when it is supplying power. By conventional usage, however, the poles and plates of the secondary cell are denoted by the polarity of the charging source. That is, the plate in connection with the positive pole of the dynamo is termed the *positive plate and pole*, while the other becomes the negative (as shown in Fig. 15).

FIG. 15.—Indicating the polarity of accumulators.

The chemical action of the pasted cells is generally considered as though one plate consisted of $PbSO_4$ and the other PbO, and the condition before charging may be represented as :—

$$\underset{\text{Negative.}}{PbO} + H_2SO_4 + H_2O + \underset{\text{Positive.}}{PbSO_4}$$

When charged, both "pasted" and "formed" cells are regarded as having identical chemical condition, and represented by equation it is :—

$$\underset{\text{Negative.}}{PbO_2} + 2H_2SO_4 + \underset{\text{Positive.}}{Pb}$$

By comparing the two above equations it can be seen that the density of the acid increases during the charging process ; therefore, as the *secondary* current produced in discharging the cell practically reverses the chemical action, the condition of the electrolyte serves as an index to the quantity of energy remaining in the cell. An hydrometer (Fig. 16) is used for testing the density of the solution the gravity of which is indicated by the scale of the hydrometer as it floats in the cell. The correct specific gravity of the electrolyte is usually about 1·2.

If discharged completely, the ultimate result would be as though both plates consisted of $PbSO_4$, and the solution devoid of sulphuric acid, *i.e.* $PbSO_4 + 2H_2O + PbSO_4$.

The cells, however, are never allowed to become exhausted. At the beginning of the discharge the E.M.F. is about 2·5 volts, but it drops rapidly to a little over 2 volts. The voltage is not allowed to fall below 1·8, and the average E.M.F. per cell is 2 volts. The condition of voltage is tested by a *voltmeter* or potential measuring galvanometer. For the E.M.F. of individual cells a small range instrument or cell-testing voltmeter is used, while for testing a number of cells, or the whole battery, a voltmeter is provided on the switchboard. When the E.M.F.

FIG. 16.—An hydrometer.

falls as low as 1·8, or the gravity of the solution is less than the limit specified by the maker, the cell is recharged. The plates then are re-formed into lead and lead peroxide and the solution resumes an increased density by the re-formation of sulphuric acid.

The capacity of a cell is stated in "ampere-hours," and a cell of 200 ampere-hours will theoretically give that product, namely, 2 amperes for 100 hours, or 50 amperes for 4 hours, etc.

In practice it is found, however, that the capacity decreases if the maximum discharge rate, as laid down by the makers, is exceeded, and secondary cells last longest and give best satisfaction when regularly employed and carefully attended to.

The loss of liquid due to evaporation is preferably made good with pure distilled water.

The most common trouble, "*sulphating*," is a whitish deposit or growth on the plates generally caused by excessive discharge.

Buckling of plates may be similarly caused, or by overcharging.

Short circuiting is usually due to bits of sulphate or fragments of metal falling down between the plates and bridging them over.

The advantages of secondary as compared with primary cells are :—

(*a*) Suitable for heavy continuous work.

(*b*) Much greater currents can be taken from them.

(*c*) Exceedingly low resistance (in Telegraphy generally negligible).

(*d*) Lower first cost.

(*e*) Lower maintenance cost.

(*f*) Smaller floor space.

(*g*) More satisfactory performance.

As an example of economies effected, it may be mentioned that some years ago the Western Union Company replaced 20,000 primary cells costing over £2000 with 3000 storage cells at a cost of about £1700.

Of the many various forms of modern storage cells the following are described, being patterns used by the British Post Office at important telegraph centres in substitution for primary batteries.

The Hart Accumulator.

The Hart cells, which are a special combination of the Faure and Planté types, have carefully prepared lead grids, it being essential for proper working of the cells that no impurities remain in the lead. Both the plates are strengthened by ribs which pass from side to side of plates, and the form of construction of the positives and negatives is shown in illustrations Nos. 19, 19*a*, 20.

The general appearance of the cells, which are in glass boxes, is shown in Figs. 17 and 18. The former gives an illustration of three cells of the T type. Fitted in a wooden framework placed in these cells are two upright sheets of glass, and the plates are suspended from them by projecting lugs which rest upon the top edges of the glass. In the S type (Fig. 18), which is smaller, the lugs support the plates by projecting over the sides of the glass boxes themselves. For connecting the plates and cells together, patent non-corrosive fittings are used, the metal being a special lead alloy which is not affected by the acid or the evolved gases. The plates are kept from touching each other by long strips of ebonite or glass tubes, although the most recent improvement is the use of patent sheet separators, which perfectly insulate the adjacent plates and prevent internal short-circuits forming across them. These separators consist of nitrated cellulose, which is not attacked

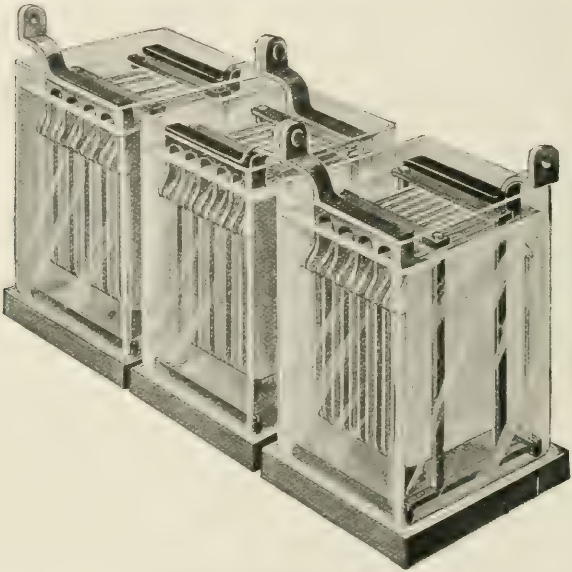


FIG. 17. Hart cells, "T" type.

by the sulphuric acid or gases produced during charging; they cover the surface of the plates and are used in conjunction with the existing separators, whether they be glass tubes or any other form.

The positive plate is known as the "Hart Demi-Planté plate," the grid being of the Planté type, but is not chemically formed, and is partially pasted with a special active material which is highly porous and at the same time very hard and durable. This active material insures the initial capacity being obtained, and as the working of the cell proceeds, the grid itself gradually becomes "formed," so that the capacity is maintained during the whole of the life.

Observe the formation of the positive grid (Fig. 19), and that the thin lead shelves are strengthened by ribs.

As soon as the cavities have been filled with the active material, to prevent it falling away, the complete plate is

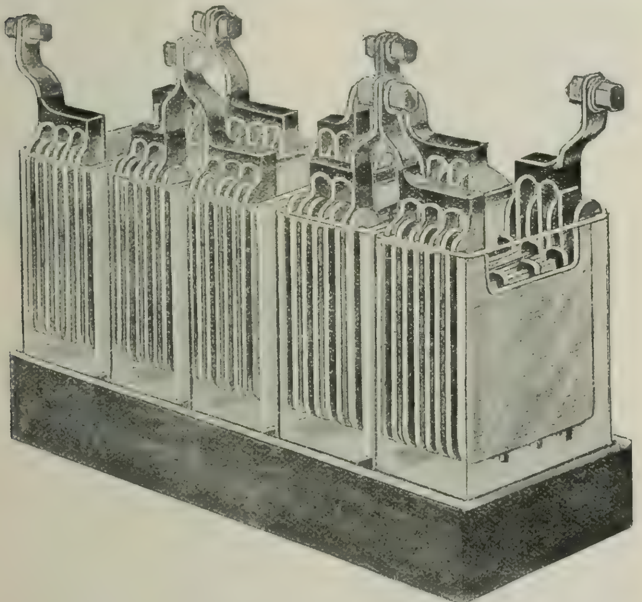


FIG. 18.—Hart cells, "S" type.

subjected to a rolling pressure, with the result that the edges of the grid strips are bent upwards (Fig. 19*a*); thus grid and paste are closely united, and appear to be one uniform mass.

It is claimed that this plate has at least two to three years longer life than a chemically formed Planté plate, as there is no danger of any impurity being left over from chemical formation. The solid diaphragm in the centre of the grid makes it exceedingly strong, so that it is impossible for a plate to buckle under normal working conditions, provided the maximum rates specified are not exceeded.

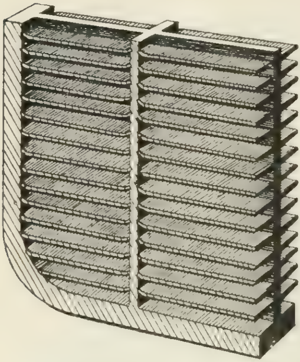


Fig. 19.—Hart positive grid.

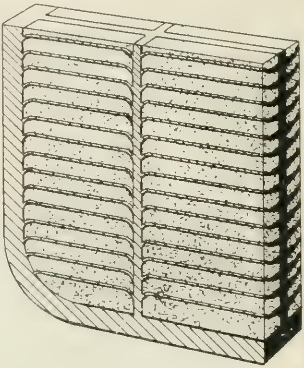


Fig. 19a.—Hart positive plate (grid pasted and rolled).

The negative plate is of the interlaced grid design and is the most modern form. The pellets are horizontal

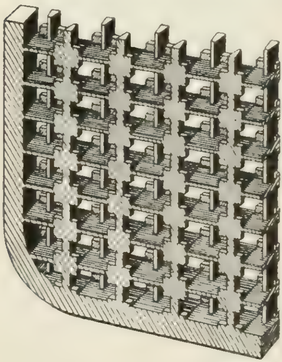


Fig. 20.—Hart negative grid.

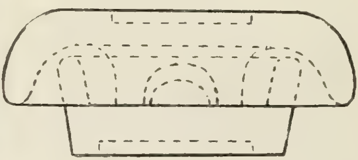


Fig. 21.—"Mushroom" insulator.

in one piece the full width of the plate, and are caged in by means of the vertical ribs alternating on either side of the grid (Fig. 20). The active material is specially prepared and does not contract during the course of working, so that the plates maintain full capacity.

The glass boxes containing the cells bed on a layer of sawdust in the trays which are supported on glass "mushroom" insulators (Fig. 21). These consist of two separate castings, the upper one standing in oil contained in the circular hollow of the base portion. The glass and oil together help to prevent leakage from the cell.

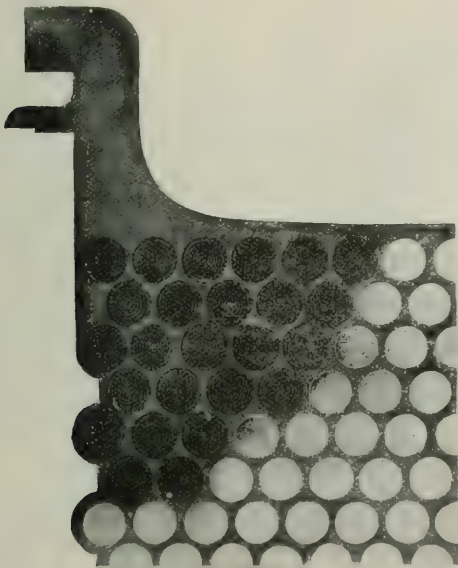


Fig. 22.—Portion of Chloride positive plate.

The "Chloride" Accumulator.

The name of the cell is derived from the employment of chloride of lead in forming the negative plate. The distinguishing characteristic of the positive plate is that it belongs to the Planté type, but is "built up," the plate consisting of a strong grid composed of a special lead antimony mixture which being inoxidizable is unaffected by the chemical changes taking place. Pure lead tape coiled into rosettes is pressed into holes in the grid, these being cast countersunk on both sides for the purpose. The rosettes are expanded slightly during the manufacture of the plate, thus being securely fixed in the grid, and as the acid can pass right through the rosette it insures an even working of the active material with a very low internal resistance. A portion of the positive plate is shown in Fig. 22. The negative plate is a radical departure from the

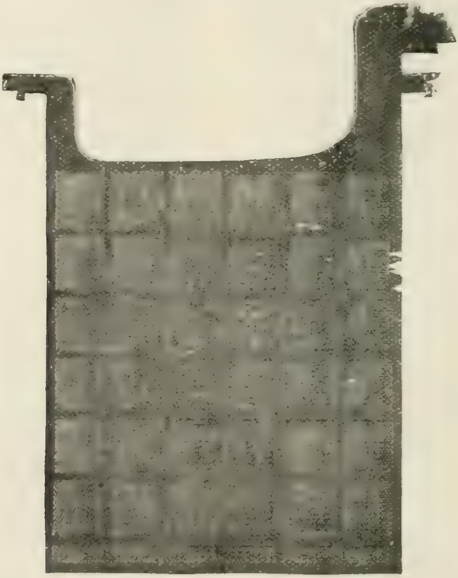


Fig. 23.—Chloride negative plate.

usual design, the frame being made in two halves riveted together after the insertion of the active material, which is thus contained in a series of small cage compartments or boxes. It will be noticed from the illustration (Fig. 23) that the outside of the plate is a finely perforated sheet of lead. The advantage of this "box" negative is that the capacity of the plate can be maintained constant over a long period of years. A special feature of the chloride accumulator is the separator, which consists of a thin sheet of wood of the same size as the plates. The wood forming the separator is subjected to a special treatment which renders it exceedingly porous and removes all substances deleterious to the plates. It has been found that this form of separator tends in a peculiar manner to maintain the capacity of the cell in a way not possible when either glass rods or ebonite forks are employed.

For telegraph work the chloride K.G.T. cell is specially suitable. Each cell contains two plates only, one positive and one negative, instead of one more negative plate than there are positive plates, as is usually the case. The

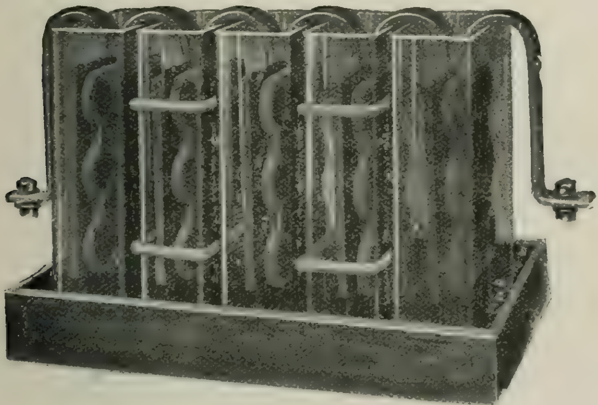


Fig. 24.—Chloride cells, K.G.T. type.

positive plate and the negative plate are burned to a lead connecting strap and are readily installed by bending the lead strap so that it rests on the edges of two adjacent glass boxes. They are conveniently arranged five in a tray (Fig. 24) so as to form 10-volt units, which are advantageous in certain conditions of working. Rubber rings are placed round each alternate box to avoid any possibility of surface leakage from cell to cell.

Grouping of Primary Batteries.

A battery, say, of four cells can be joined in three ways, and each arrangement may be useful for a particular purpose. Compare the examples in Fig. 25. Presume that four Leclanché cells are there represented, each cell having E.M.F. 1·5 volt and internal resistance 4^{ω}. In the first case (1) it will be observed that the energy of each cell is *added* to that of the others, and also that a current must pass through the *sum* of the individual resistances or 16^{ω}. The greatest current that such a battery can produce is when it is so joined and is *short-circuited*. Its total E.M.F is then divided by its total internal resistance, or

$$\frac{1{\cdot}5 \times 4}{16} = \frac{3}{8} \text{ ampere} = {\cdot}375 \text{ m.a.}$$

This is the maximum current that *any* number of such

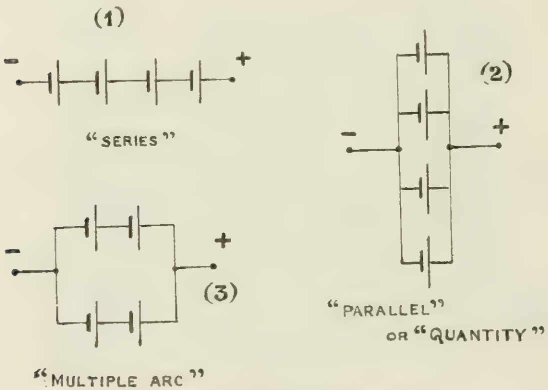


Fig. 25.—Arrangements of cells.

cells joined in series could furnish, for if twenty or a hundred be used the ratio of the E.M.F. and resistance is unaltered in value. Let C for one cell be $\frac{e}{r}$, then with n cells C becomes $\frac{e \times n}{r \times n}$, which, of course, equals $\frac{e}{r}$. A larger current can, however, be obtained with the cells arranged as in (2). In this case, although the E.M.F. of cells so connected is only that of *one* cell, yet the internal resistance is lessened by every cell added in parallel, and the combination in effect becomes as if one cell used with plates enlarged fourfold. If the internal resistance of one cell be represented by r, then for four cells the total becomes $\frac{r}{4}$, and for a number, n, it would be $\frac{r}{n}$. With cells joined for *quantity* their combined internal resistance is *the resistance of one cell divided by the number in parallel.* In example (2), then, the current is $\frac{e}{\frac{r}{4}}$, and substituting the values this becomes $\frac{1{\cdot}5}{1}$, or 1500 m.a.

Now consider whether (1) or (2) is the best for any particular circuit, say of 24^{ω}. The total resistance with cells in (1) would be $16^{\omega} + 24^{\omega} = 40^{\omega}$ and current $= \frac{1{\cdot}5 \times 4}{40} = 150$ m.a., while with cells as in (2) the current would be $\frac{1{\cdot}5}{1 + 24} = 60$ m.a. The inequality of these two results becomes greater as the resistance of the external circuit is increased, because the difference in the internal resistance of (1) or (2) becomes less appreciable when the battery is joined to a circuit of considerable resistance, and (1) gives four times the voltage of (2). The student is advised to verify this by selecting numerical examples.

Therefore it follows that with a comparatively large resistance the cells should be joined in series, and when the external resistance is small the maximum current is obtained with the cells connected in parallel. The governing rule for the arrangement of cells is that *the maximum current will be produced when the internal and external resistances are as nearly as possible equal.*

Sometimes it may be advantageous to join as in arrangement (3) series-parallel or multiple arc. For example, with an external resistance of 2^{ω}

the current in (3) is $$\frac{1{\cdot}5 \times 2}{\frac{4}{2} + 2} = 750 \text{ m.a.}$$

but with cells as in (1) $C = \frac{1{\cdot}5 \times 4}{16 + 2} = 333$ m.a.

and ,, ,, (2) $C = \frac{1{\cdot}5}{\frac{4}{4} + 2} = 500$ m.a.

Calculation of Number of Cells Required.

It was deduced from Ohm's law that $E = C R$, from which may be calculated the E.M.F. necessary to produce any current through a given resistance.

Before a cell or battery can urge a current through an external circuit some of its energy must be expended in forcing the current through the battery itself. Sometimes this is called the lost E.M.F. and it equals $C r$ per cell (C, current; r, internal resistance). The efficiency of the battery in the external circuit, R, equals $C R$. Thus *the energy expended in overcoming the resistance of a part of a circuit is equal to the resistance of that part multiplied by the current.* If the voltage per cell be e, then the E.M.F. available for the external part of the circuit is $e - C r$ per cell, or for n cells it is equal to $n(e - C r)$. Now, when cells are in series and joined to external resistance R the current produced equals $\frac{n e}{n r + R}$ and with all of their cells arranged for quantity $C = \frac{e}{\frac{r}{n} + R}$. It has been already stated that the best means for obtaining the maximum current is to arrange $\frac{n r}{m} = R$ (n being the number in series and m in parallel). Evidently, however, this is not the most economical arrangement, as 50 % of the energy is expended in the battery itself, for $C \frac{n r}{m} = C R$.

The formula for finding how to group a *given* number of cells and obtain the maximum current through a *given* resistance is

$$n = \sqrt{\frac{N R}{r}} \text{ where } N = n \times m \text{ or total number,}$$

$$\text{then } n = \frac{N}{m} \text{ and } m = \frac{N}{n}. \quad \text{Now } \frac{n r}{m} \text{ is to equal } R.$$

$$\therefore R = \frac{n r}{\frac{N}{n}} \text{ and } N R = n^2 r;$$

$$\text{therefore } n^2 = \frac{N R}{r} \text{ and } n = \sqrt{\frac{N R}{r}}.$$

Having thus obtained the *number of cells in series* it is easy to calculate the number of rows possible with the whole number of cells provided.

Example :—Find the arrangement of 24 cells each having an internal resistance of 2^ω which will produce the maximum current through an external resistance of 3^ω.

Number in series or $n = \sqrt{\frac{24 \times 3}{2}} = \sqrt{36} = 6.$

Therefore four rows of six cells in series.

We have previously seen that the E.M.F. available outside the battery is $n\,(e - Cr)$ and that also $C\,R$ equals the useful volts expended in the external resistance $\therefore C\,R = n\,(e - Cr)$. From this equation can be deduced the total number of cells, n, required to furnish the given current C. For if $C\,R = n\,(e - Cr)$ then $n = \frac{C\,R}{e - Cr}$.

This formula, which is convenient to remember, can be established by an application of Ohm's law, for $C = \frac{n\,e}{nr + R}$; hence $C\,(nr + R) = ne$ and $C\,R + Cnr = ne$,

$\therefore CR = ne - nCr$, i. e. $C\,R = n\,(e - Cr)$ and $n = \frac{CR}{e - Cr}$.

Note : it is very inadvisable to merely memorize formulae. They often prove of little benefit if remembered only by the letters which form the equations, and therefore the reasoning upon which they are based should always be understood. An example of this was furnished by some candidates' treatment of the following examination question.

"How many cells each of 2 volts E.M.F. and negligible resistance would be required to send a current of 30 milliamperes through an external resistance of 2450^ω?"

The formula $n = \frac{CR}{e - Cr}$ is not applicable in this case because the battery resistance r is negligible and therefore the factor Cr is eliminated. Thus $n = \frac{Cr}{e} = \frac{\cdot 03 \times 2450}{2} = 36{\cdot}75.$

Thirty-seven cells must be provided, which would give a little above 30 m.a.

In the case of secondary cells, their low resistance being generally ignored in such calculations, the required number is found in a similar way. Also observe that, with a negligible internal resistance, CR represents the total E.M.F. of the battery.

The battery resistance is generally small compared with the resistance of the line and instruments in an ordinary telegraph circuit, consequently the cells are arranged all in series. Occasions may, however, arise in which it is necessary to use cells of abnormally high resistance, and this could be remedied by joining a number of them in parallel rows. The current then furnished by n cells in series and m rows would be expressed : $C = \dfrac{ne}{R + \dfrac{nr}{m}}$.

Exercise II.

1. What forms of battery cells are used in practical Telegraphy? What is the electromotive force of each, and what special advantages does each possess?

2. Describe the simple voltaic cell. What is the object (i) of amalgamating the zinc plate, (ii) of using a battery with two fluids?—giving an example.

3. Explain what is meant by joining up battery cells for "quantity" or "in series," and show how to determine the total electromotive force and total resistance of the combination, the E.M.F. and resistance per cell of the battery being known.

4. Give a careful description and sketch of some form of galvanic battery with which you are acquainted, stating the chemical actions which go on in the battery. Indicate on your sketch the direction in which the current flows when the terminals of the cells are connected by a wire.

5. A battery of 12 equal cells, in series, screwed up in a box, being suspected of having some of the cells wrongly connected, is put into circuit with a galvanometer and two cells similar to the others. Currents in the ratio of 3 : 2 are obtained according as the introduced cells are arranged, so as to work with or against the battery. What is the state of the battery? Give reasons for your answer. (1 in opposition.)

6. A circuit is formed of six similar cells in series and a wire of 10^{ω} resistance. The E.M.F. of each cell is 1 volt,

and its internal resistance 5^{ω}. Determine the difference of potential between the positive and negative poles of any one of the cells. (5·25.)

7. Two cells arranged in series are alike in all respects except that in one the plates are twice as far apart as in the other. When the poles of the battery are joined by a copper wire the liquid in both cells becomes heated. In which is the rise in temperature the greater, and why?

8. Given two voltaic cells each 1·1 volts and 3^{ω} resistance, what is the strength of the current in milli-amperes when joined by a wire $9{\cdot}5^{\omega}$ (*a*) with one cell alone, (*b*) both cells in series, (*c*) both cells in quantity or abreast? (88 : 141·9 : 100.)

9. Of three cells, each 1 volt 1^{ω}, two are arranged in series, but the positive and negative poles of this battery are connected with the positive and negative poles of a third cell as in quantity. What is the current in the connecting wires, which have negligible resistance, and the P.D. between poles of the third cell? (333 m.a. 1·3 v.)

10. A telegraph line has a resistance of 1000^{ω} and the instrument, 200^{ω}, requires a current of 20 m.a. How many Daniell cells would be necessary (internal resistance 5^{ω} per cell)? (25.)

11. It is required to give a current of 25 m.a. in a circuit the resistance of which, exclusive of the battery, is 570_{ω}. How many cells each of 4^{ω} resistance and E.M.F. of 1·2 volts will be required? (13.)

12. (*a*) Having given eight cells, each of electromotive force of two volts and internal resistance of two ohms, what method of connecting the cells will give the greatest current through an external resistance of 4^{ω}? (*b*) What will be the current in milli-amperes? (Two rows of 4 : 1000.)

CHAPTER III

TELEGRAPH INSTRUMENTS

The Morse key in its simplest form as used in the Post Office is shown in Fig. 26. This "*single current*" key, as it is termed, consists of a single brass lever pivoted on a brass piece or "bridge" fixed on a wooden base. Its movement is restricted by contact stops which are platinum tipped;

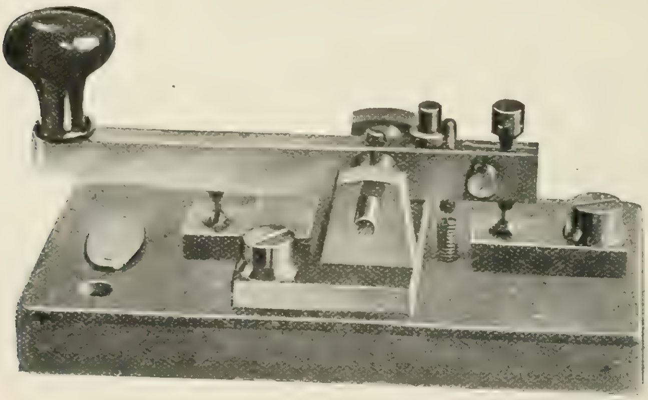


Fig. 26.—Single current key.

platinum is used being less oxidizable should sparking occur when the key is worked with large currents. Such oxidation introduces resistance at the points of contact, sometimes causing even a disconnection. The back contact screw carried by the lever is adjustable. The electrical connections of the two "stops" and the "bridge" are shown in Fig. 27. Normally the lever is held in contact with the back stop by the tension of an adjustable spiral spring.

Fig. 28 shows the ordinary pattern of the P.O. sounder, sometimes termed a "pony" sounder. It is a simple

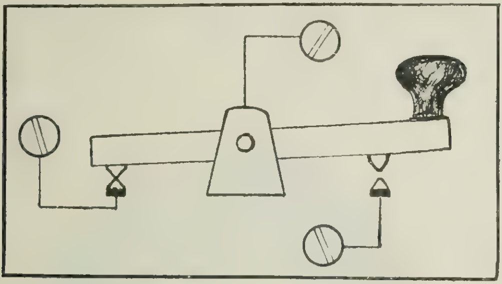


FIG. 27.—Electrical connections of S.C. key.

form of horseshoe electromagnet with the two coils connected in series and the ends of the wire joined to two

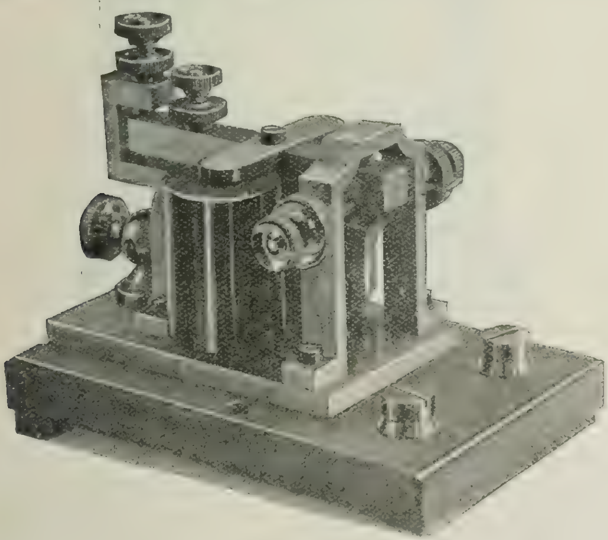


FIG. 28.—P.O. Sounder, 20^{ω} and 900^{ω}.

brass terminals on the base. The necessary adjustments are: The axle of the lever carrying the armature should be just free to move in the hollowed ends of the screw pivots which limit the sideway movement. The transverse screw carried by the lever regulates the distance of the attracted armature from the cores and the top front screw limits the amount of play given to the armature (about $\frac{1}{20}$ of an inch). Test the necessary air-gap distance

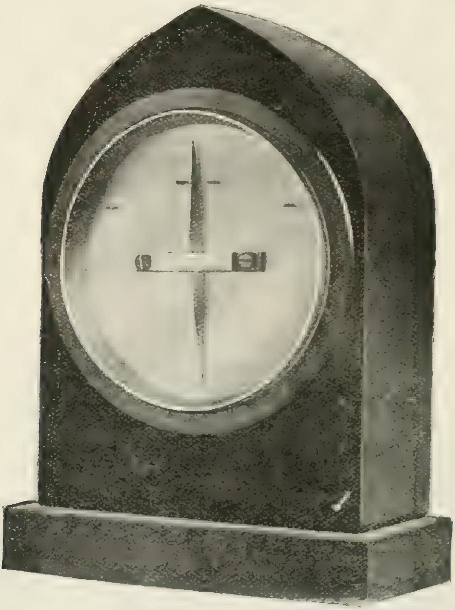


FIG. 29.—S.C. Galvanometer.

between the cores and the depressed armature with a piece of paper. All the adjustments are fixed with clamping screws. The tension of the spring is best regulated with working signals, but with a very strong current it may be better to adjust the armature further from the cores rather than employ excessive tension. Various windings of the sounder coils have been introduced. The pattern now used for direct working is known as the 20-ohm sounder, but like all later P.O. sounders it is provided with a by-path coil or shunt. The coils have a resistance of 21ω, the resistance of the shunt is 420ω, and the combined resistance becomes 20ω. The object of the shunt and its resistance values will be explained later. When properly adjusted this sounder should work with 55 m.a., and the working current supplied is between 60 and 80 m.a.

The "single current" galvanometer is an instrument designed to indicate the presence and direction of a current, being based on the principle of the deflection of a compass needle by the magnetic field set up when a

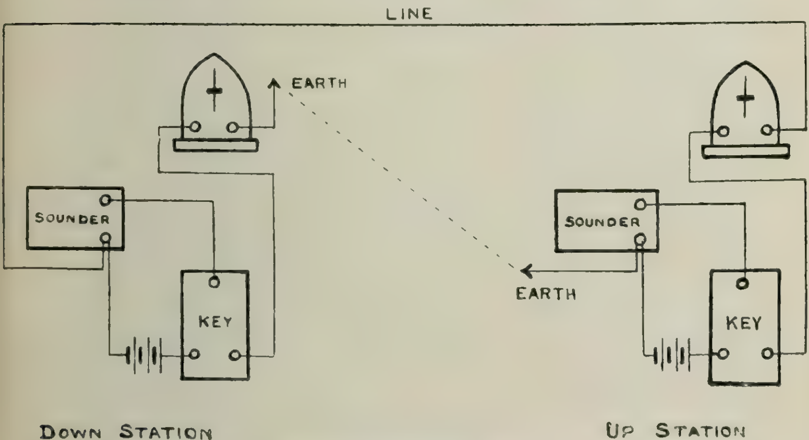


FIG. 30.—Direct sounder circuit.

current passes as described in Chapter I. The form used by the P.O. department (indicated in Fig. 29) has a polished mahogany case, a silvered dial with two ivory stop pins, and with two terminals fixed on the back of the instrument. The needle in the latest patterns is of soft iron and rendered magnetic by the proximity of two bar magnets (see description of Varley single needle). The two bobbins together have a resistance of 30ω, being joined in series. The needle should deflect to either stop-pin with about 10 m.a., *i.e.* the pointer should move to the right, when a current is flowing from the left to the right terminals of the galvanometer. That the deflection should thus correspond to the direction of the current is a general rule throughout the service with all galvanometers.

The three instruments above described are usually provided for direct sounder working between stations only short distances apart, and the simplest method of joining up such a circuit is shown in Fig. 30.

As a general practice, instead of a return wire, the ends at the terminal stations are each joined to an earth-plate, and the currents in completing their circuit are assumed to pass through the earth between these plates as if they were joined by a conductor of practically no resistance. Plates are always buried flat and upright, the object being to expose as large a surface as possible, and if the earth terminals of several circuits or wires are connected to one earth plate it should be large and buried deep in soil wet at all seasons. The contact between the soil and the plates introduces resistance, especially in dry rocky places, and generally a water or gas pipe is preferable to a plate, because of the larger surface supplied. A well-soldered connection should always be made, but avoid *leaden* pipes which have been fused by lightning discharges passing between them and adjacent conductors.

In the connections of telegraph sets the arrangement adopted is that the most important office should join the *positive* pole of the battery to line when key depressed, then, as explained earlier, the current is assumed to flow *from* this station along the line; hence this terminal office is denoted the "*up*" station, while the other extremity of the line is the "*down*" station. At any intermediate station the line is regarded as both "up" and "down" according to which terminal office it leads. With *earth return* circuits at the *up* office the *up* line terminal is connected to earth, but the *down* line terminal at the *down* office. See Fig. 30.

It is advisable to always trace the circuit with the positive current. For example, up station sending; from battery to front stop, to bridge, to galvanometer, to line. At down station current passes through sounder to back stop of key, thence via bridge, galvanometer to earth, returning to up station via the earth connection to negative pole of battery. Note the positions of the keys alters the path taken; at down station front stop is disconnected, while at up station the open back contacts disconnect the sounder.

It will be observed that no current traverses the circuit when neither station is sending, and this arrangement is termed "*open*" circuit working. Another system (shown in Fig. 31) offers considerable advantages where many intermediate stations are placed upon one wire. A continuous current flows when no work is going on, all the switches being closed. When any station wishes to signal the operator pushes the switch aside as station 3, the circuit is broken and the armatures rise. The signals are

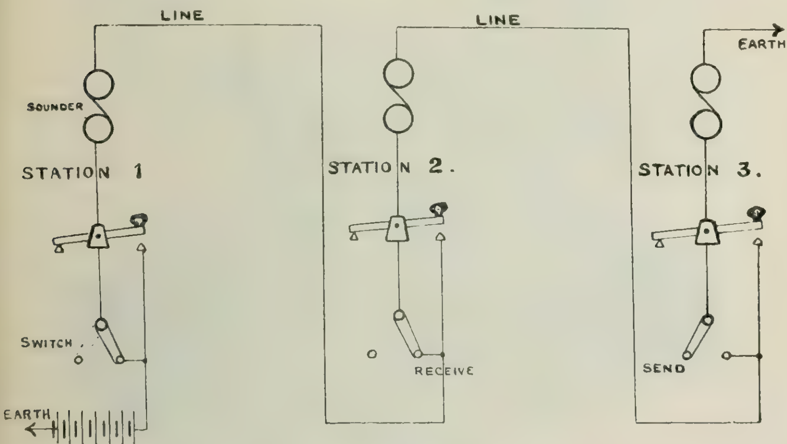


FIG. 31.—"Closed" circuit system.

then sent as in open circuit working, by the key completing the circuit for the battery, which may, however, only be provided at one office. An advantage is that the same value of current is received at any one station when either of the other stations is sending, and readjustment of the sounder is unnecessary; but a great disadvantage is waste of battery power, and a switch left over breaks the circuit, also a fault near the battery end may prevent any station working. Of course any break in the line is observed at all stations by the absence of the deflection on the galvanometers, if used, and the rise of the armatures.

The large currents required for direct working sounders cannot be obtained in circuits of more than a few miles without inconveniently increasing the battery power.

Hitherto it has been the practice when the line exceeded about 6 or 8 miles in length to replace the sounder with a relay, and work the actual reading instrument in a local circuit, but Vyle's direct-reading *polarized* sounder can be placed directly in the line circuit, and will give firm read-

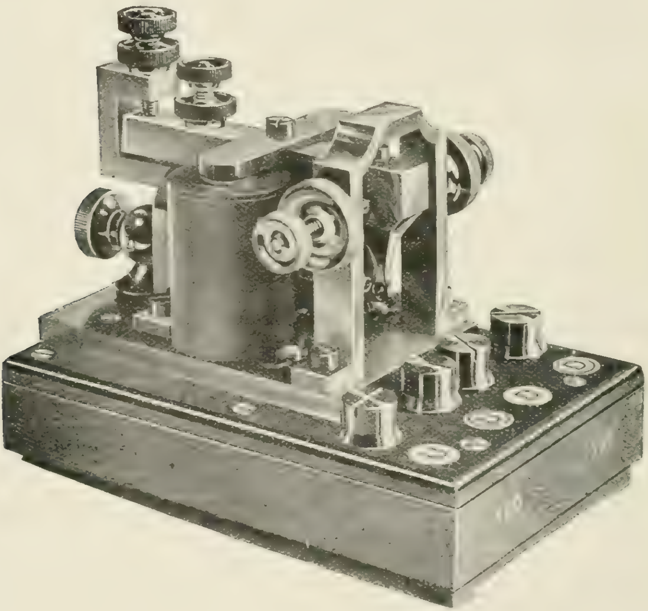


Fig. 32.—"Vyle" polarized sounder.

able signals with currents of *one-tenth* the value required for the ordinary sounder.

As will be seen from the illustration in Fig. 32, the polarized sounder in appearance resembles the ordinary instrument. The soft iron yoke is replaced by a strong horseshoe magnet (Fig. 33) which induces a polarity in the cores equal to the magnetism produced by 40 m.a. of current. The magnetism of the cores and the tension of the antagonistic spring exert opposite effects on the lever of the sounder. If a current traverses the coils in such a direction that it tends to strengthen the magnetic effect of the cores, the armature is attracted; while if the magnetic effect is weakened, the spring tension predominates, and the armature lever banks against the upper stop. When the effects due to the permanent magnetism of the cores and the spring tension are equal, the condition of maximum sensitiveness exists. With sounders so adjusted the armature remains on whichever stop it is placed by the hand. It was found that in many instances such a condition caused the operator to imagine the polarized sounder

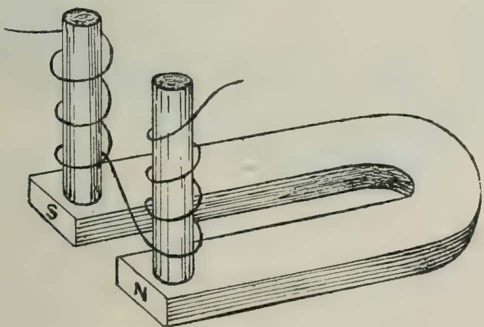


FIG. 33.—Magnet and cores of polarized sounder.

required readjustment, with the result that afterwards unsatisfactory signals were received. This led to the design of the pattern shown in Fig. 34, which is a modified and in some respects an improved form of the instrument.

The usual adjustable studs between which the lever plays are replaced by fixed stops, thus preventing alteration in the adjustment by the operator. With single current working sufficient spring tension is given to insure a decided return of the lever to the upper stop when the line current ceases.

Several thousands of the Vyle polarized sounders are already in use. For the various requirements of practical work it was found that a *differential* winding of $500^{\omega} + 500^{\omega}$ gave best results, although two other patterns are in demand for special purposes: namely, a differentially wound instrument of $100^{\omega} - 100^{\omega}$, and a single winding of 5400^{ω}

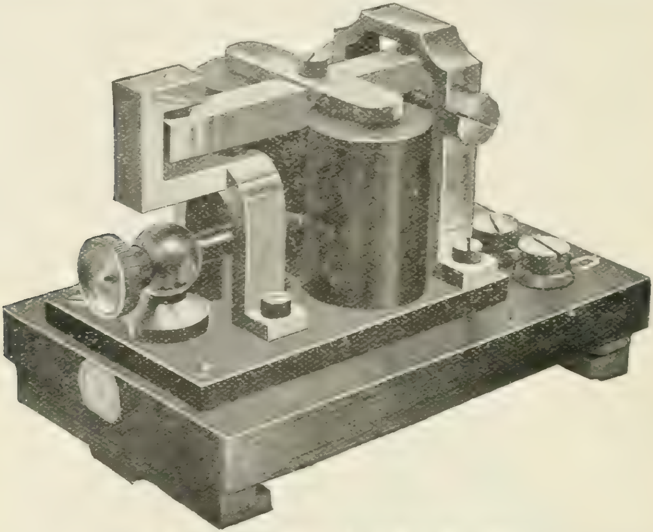


FIG. 34.—Polarized sounder with fixed adjustments.

shunted with a resistance of $27,000^{\omega}$ giving a combined resistance of 4500^{ω}.

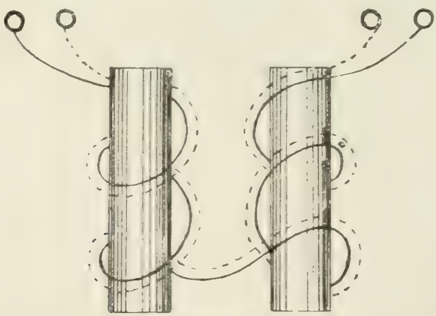


FIG. 35.—"Differential" winding.

Differential winding is the term used when each bobbin of the electromagnet is similarly wound with *two* wires side by side so that they are of the same length, resistance.

and average distance from the core, thus giving equal magnetic effect. There are *four* ends, and when two

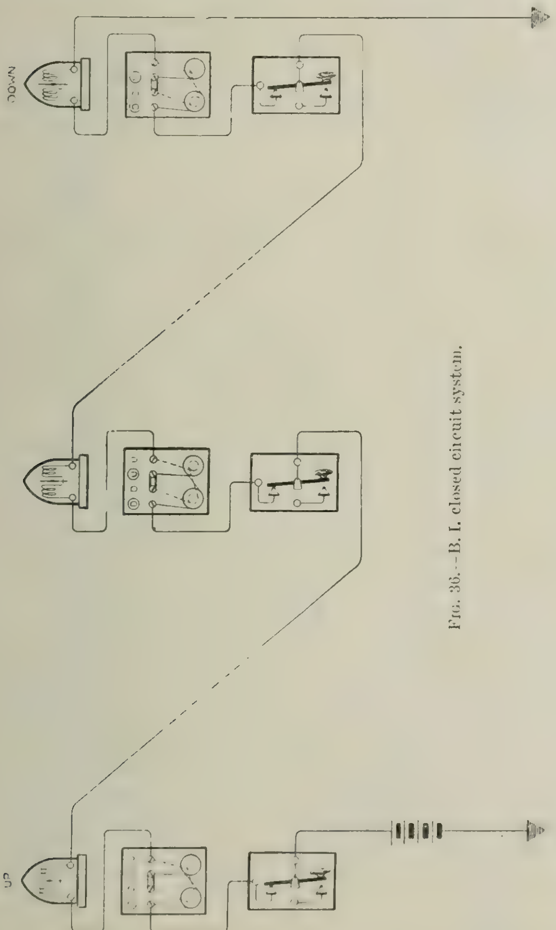


FIG. 36.—B. I. closed circuit system.

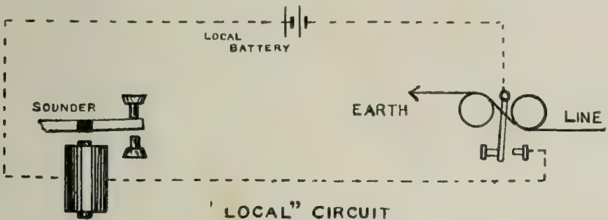
bobbins are used, as in most instruments, the finishing ends of one bobbin are joined to the beginning ends of the other, making two continuous paths each comprising one wire on both bobbins. In the case of the polarized sounder one wire terminates at *D* and *U*, the two ends of the other wire being brought to the terminals marked (*D*) (*U*). It will be noticed by reference to Fig. 35 that a current passing through each path in contrary directions will have equal and opposite effects, but if unequal currents traverse each winding, the electromagnet is actuated by the *difference* between them, hence the term *differential* is applied to this form of winding, which is adopted in many telegraph instruments.

For single current *open circuit* work ng th ne diagram of the connections is used with th le as shown in Fig. 30, except that, a t replaces the sounder.

For *closed circuit* working the polarized sounder is used in a very simple and thoroughly efficient method shown in Fig. 36, which illustrates the "B. I." closed circuit system. No switch is used at either station, and thus is eliminated a source of much trouble and delay hitherto frequently arising from an operator leaving his switch open and breaking the circuit. The battery serving the whole system may be inserted at one point, or if the insulation of the line is low, can be divided and distributed at favourable points. It will be noticed that the back stop and lever of key are normally in circuit, and the battery is connected so that the permanent current is in a "spacing" direction, *i. e.* from "*D* circle" to *U*, and the armature levers of the polarized sounders remain against the top stop. By the depression of the key at any station the current ceases to flow and the armature lever is brought down by means of the magnetism induced in the core by the permanent magnet. Good reliable signals are obtained when the spacing current does not exceed 10 to 15 m.a. and no appreciable advantage is gained by exceeding the latter value.

Relays.

On all but short lines the receiving instrument was formerly a relay, which itself gives almost inaudible sounds, but by its action opened and closed a "local" circuit in which the reading sounder and a battery were placed (see Fig. 37).



"LOCAL" CIRCUIT

Fig. 37.

A diagrammatic v of the construction of the Post Office standard rela is shown in Fig. 38. The cores of

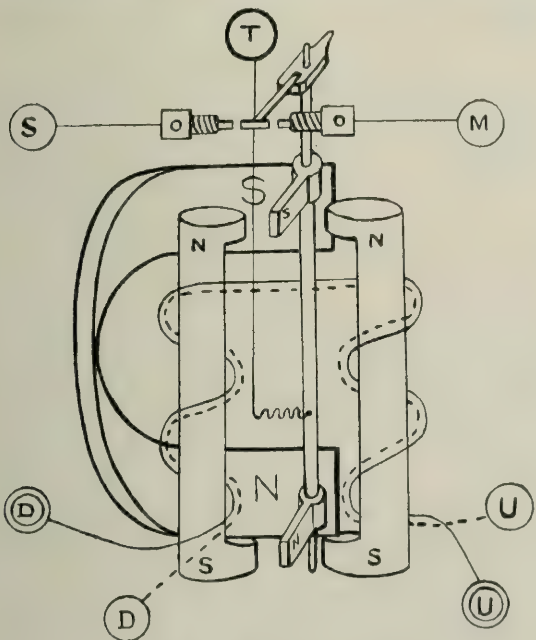
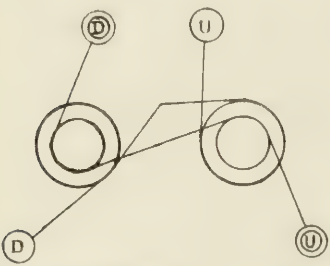
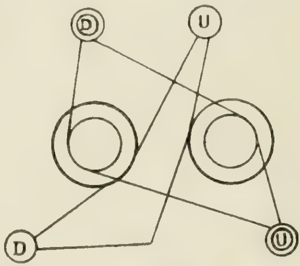


Fig. 38.—P.O. Standard relay.

the two electromagnets are polarized by a horseshoe permanent magnet which for convenience is bent round the left-hand bobbin. The N pole of the magnet is the lower one, and near the poles, fixed on a vertical brass spindle carrying the tongue, are two short soft iron armatures. The cores of the bobbins are extended by polepieces, and are thus adjacent to the free ends of the armatures. The magnetic condition of the armatures and cores is indicated in the figure; the latter have a permanent polarity equal to the magnetic effect of 18 m.a. of current, and if the armatures are exactly central, equal attraction is exerted, but a very slight displacement causes a movement in the direction of the nearer pole until the tongue rests against one of the stops. For single current working the armatures are placed nearest to the left-hand polepiece, so that when





"A" windings. FIG. 39. "B" windings.

the current ceases the tongue returns to the spacing contact. A positive current entering at (U) will strengthen the polarity of the right-hand core and weaken the left-hand or, if strong enough, reverse it. The attraction and repulsion of the four polepieces tend to make the relay very sensitive, and its figure of merit is ·5 m.a. with coils in series. The *direction of the movement of the tongue* and armatures of the relay *depends upon the direction of the current*, and this is true of all *polarized* instruments. Already this has been observed with the polarized sounder. But the direction of the current makes no difference in the working of a *non-polarized* instrument; its armature is attracted by the effect of either current, because *when no current is flowing no magnetism exists*, or, as the term implies, it is non-polarized. The tendency to take up a definite position or "*bias*" is given to the relay tongue by a milled headed screw which moves the carriage carrying the two contacts *S* and *M*. The coils are differentially wound, as in the case of the polarized sounder. Two patterns of the standard relay are in use, "A" and "B," the latter being slightly higher; and the difference in the windings is very noteworthy (see Fig. 39). In the "B" type each bobbin winding is taken separately to the terminal connections; this gives the advantages of half resistance and lower self-inductance while maintaining the same figure of merit by the increased height of the cores.

The unit of self-inductance, the *henry*, is the value of the inductance of a circuit in which a counter E.M.F. of one volt is generated when the current varies at the rate of 1 amp. per second. The rise of a current to its full value is impeded by the opposing E.M.F. generated by the lines of force cutting through the adjacent turns of the windings. See example in Fig. 40, where a current moving from + to − induces a momentary counter or opposing current. At the instant the primary current ceases the lines collapse, and so cut the turns in a reverse direction, then the induced current travels so as to continue the originating current and prevent its immediate cessation. With an electromagnet, the value of the self-inductance depends upon the value of the current used, owing to the variation in the permeability of the iron, as the magnetizing force changes. For a current of 20 m.a. the self-inductance of the "A" pattern is 3·25 henries, "B" 2·14 henries.

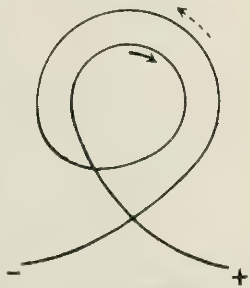


FIG. 40.—Showing self-inductance.

The *self-inductance* of an electromagnet with its coils in parallel is one quarter of the value with its coils in series, for the *effective* number of turns is halved and the self-inductance of a coil varies directly as the *square* of the number of turns. When in parallel the *effective* number of turns is halved, because with two wires side by side the current traverses both at the same instant. The induced currents are developed by the momentary changes in, or starting and stopping of, the current, and the instantaneous effects due to the passing through of the lines of force, with two wires in parallel, act together and become as if created by a single conductor of doubled size.

This halving of effective turns only applies to the momentary effects of self-inductance. The magnetic field generated by steady currents is proportional to the actual number of turns, which remains the same whether joined in series or parallel.

The following interesting experiment (Fig. 41) illustrates the effect of self-induction. The relay is adjusted neutrally. Sounder 1 is joined across (U) and D so that self-induction discharge from it may take place through the relay and

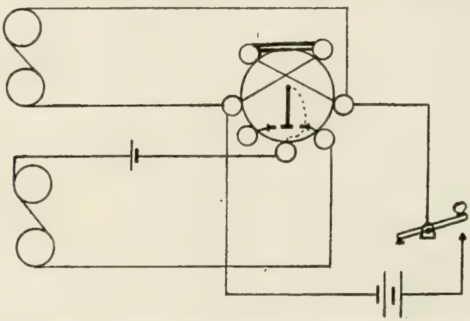


FIG. 41.—Self-inductance experiment with relay and two sounders.

move tongue to spacing when the signal ceases, and relay then is ready to repeat the next signal to sounder 2 when key is again depressed.

In the local circuits the effect of the considerable inductance of the sounder was sparking at the contact points of the relay, and they were consequently oxidized. This trouble has been practically eliminated by the provision of suitable shunt resistances on the sounder coils, thus substituting another path for the circulation of the induced currents, which previously passed across the air gap when the tongue was moving from the marking stop.

In single current circuits the relay coils should be joined in *multiple* when the resistance of all the circuit, excluding the relays, is less than half the total series resistance of all the relays in the circuit. Otherwise the coils should be connected in *series*.

Brass straps are provided, and by them the electrical connections are made as shown in Fig. 42.

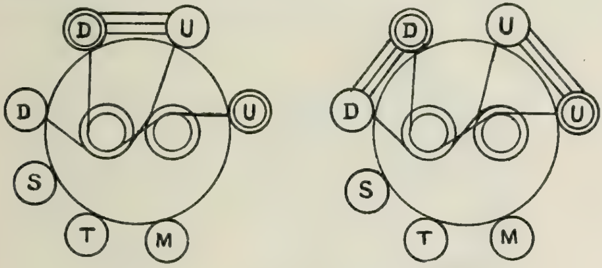


Fig. 42.

Currents required when coils in multiple :—

Standard A, 20 to 30 milliamperes.
Standard B, 30 to 40 milliamperes.

Currents required when coils in series :—

Standard A, 10 to 15 milliamperes.
Standard B, 15 to 20 milliamperes.

The standard relay is adjustable neutrally, that is, when its tongue will remain on the stop where it was last placed

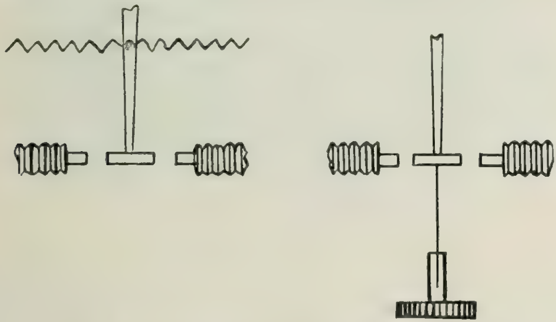


Fig. 43.—Mechanical bias of Standard neutral relays.

(by current or the hand), but in the standard neutral relay a central position of the tongue is obtained by mechanical means. In one pattern two helical springs act on opposite sides of the tongue, and in the other a flat spring is attached to the front of the tongue, and the tension or sensitiveness of this spring is adjusted by varying the length capable of movement (Fig. 43).

FIG. 44.—Non-polarized relay "B."

A *non-polarized* relay in appearance like the standard relay is shown in Fig. 44. Its two soft iron armatures are in two sections brazed together with a layer of spelter to break the magnetic circuit and assist in producing more rapid demagnetization. The pole pieces are shaped so as to bring the cores near to the ends of the armatures

(Fig. 45). The local circuit remains open when the tongue is held by the spring against the left-hand stop. A current of 6 m.a., *spacing* or *marking*, will work the relay, which can be biassed against 15 m.a. This size, called the B, has six terminals; another of larger dimensions, non-polarized relay C, has seven terminals, will work with $4\frac{1}{2}$ m.a., and can be biassed against 10 m.a. Both B and C are differentially wound with resistances B $200^{\omega} + 200^{\omega}$, C $500^{\omega} + 500^{\omega}$.

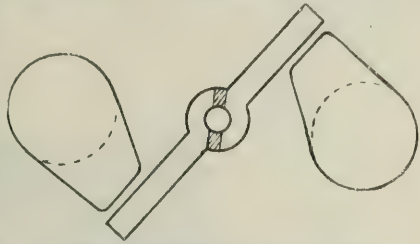


FIG. 45.—Armature and pole pieces of N.P. relay, "B" and "C" patterns.

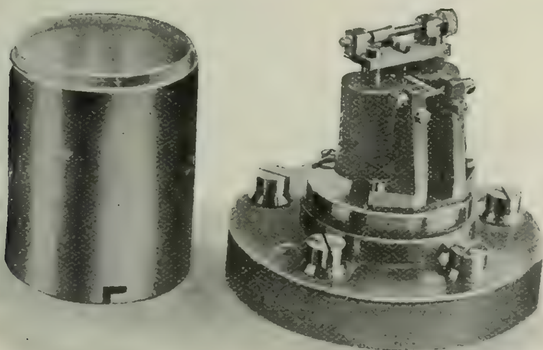


FIG. 46.—Non-polarized relay "D."

A small non-polarized relay called D (illustrated in Fig. 46) has five terminals for simplex working. Resistance of coils 200^{ω}. It will respond to current of 2 m.a. and can be biassed against 15 m.a.

Keys.

A form of key designed for special use with a double battery is illustrated in Fig. 47. It is termed "single current key with switch," and has four terminals whose

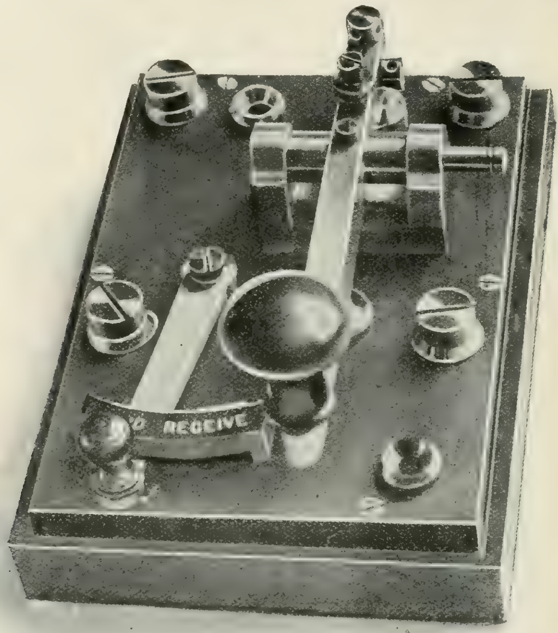


Fig. 47.—S.C. key with switch.

internal connections are varied by the movement of the switch, as can be traced in Fig. 48. With the switch to "send" the action of the key places first one battery and then the other in connection with the line, while with the switch to "receive" the batteries are disconnected, and the line is joined to the receiving instrument.

The illustration (Fig. 49) shows a key in very general use, being suitable for simplex, duplex, or quadruplex

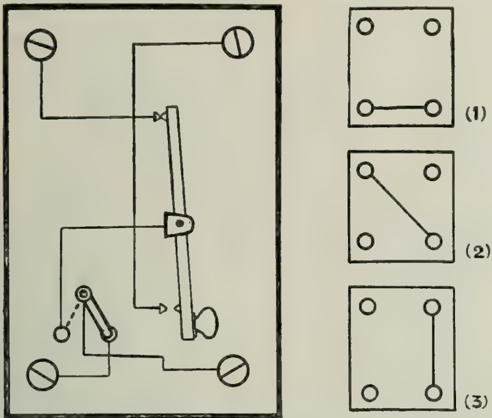


FIG. 48.—Connections of 4-terminal key. (1) Switch to "receive"; (2) switch to "send," lever at rest; (3) switch to "send," lever depressed.

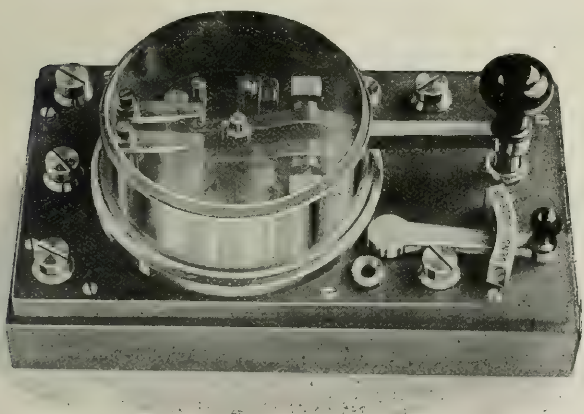


FIG. 49.—5-terminal D.C. key with adjustable contacts.

circuits. With adjustable contact screws, platinum contacts, mounted on an ebonite slab fixed on a polished mahogany base, the "Double current key, five terminal," as it is called, is a most convenient piece of apparatus; as can be seen from the diagrams (Fig. 50) the battery can readily be reversed or cut out of circuit without disconnecting the circuit.

A reversing key without switch, of special construction, is shown in Fig. 51 with cover removed. This key is pro-

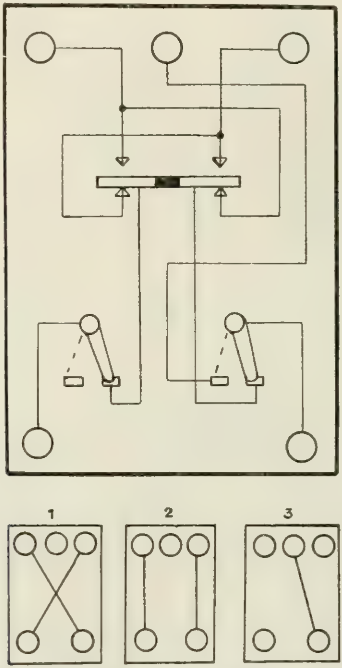


FIG. 50—Internal connections of 5-terminal key. (1) Switch to "send," lever at rest; (2) switch to "send," lever depressed; (3) switch to "receive."

vided with four battery terminals, two line terminals capped with ebonite, and each half of the key can be used independently if desired. As will be seen by reference to sketch (Fig. 52), the upward movement of the lever, caused by depression of key, makes contact with the thin strip before it raises the latter from its normal contact, which joins the other battery pole to the line (see Fig. 53). By this means the disconnection of the line cannot occur, as one contact is made before the other is broken.

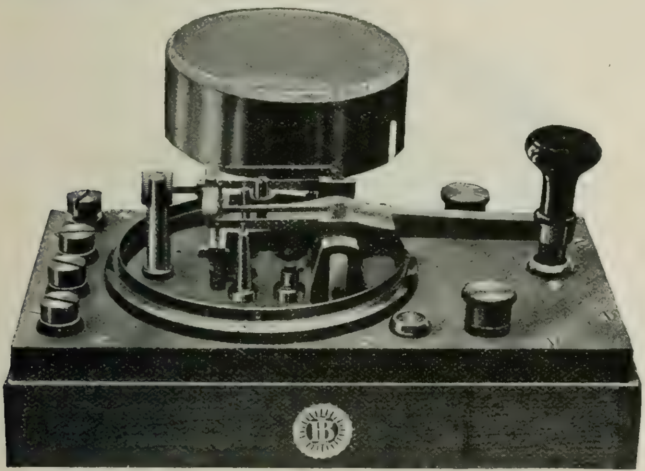


FIG. 51.—6-terminal reversing key.

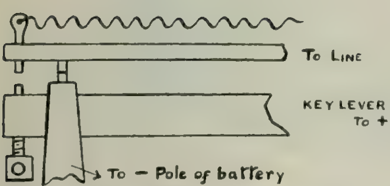


FIG. 52.—Note : When key depressed + to line before – contact broken.

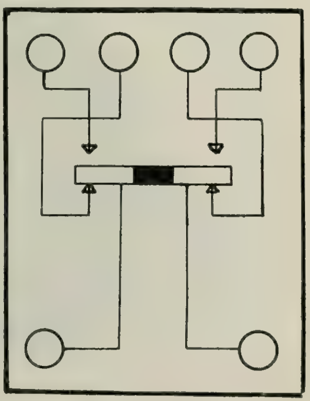


FIG. 53.—Connections of 6-terminal reversing key.

SIMPLE SWITCHES.

There are three forms of two-way switches in common use distinguished by the number of their terminals. The three-terminal switch is shown in Fig. 54. Owing to the general use of the six-terminal switch (Fig. 55), with such

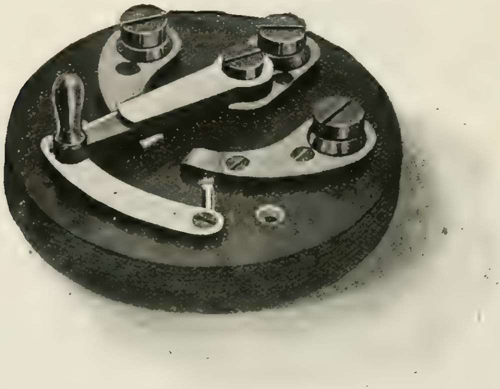


FIG. 54.—3-terminal 2-way switch.

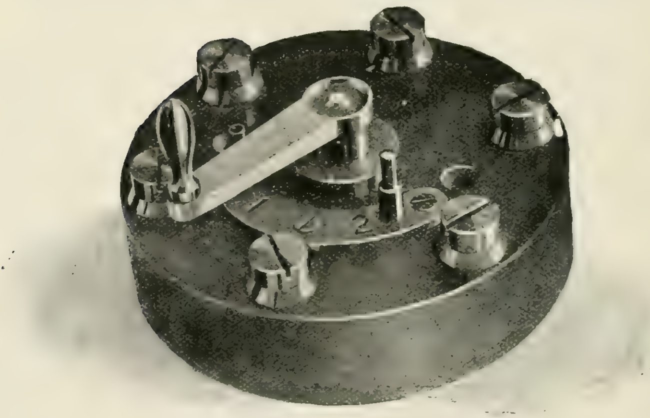


FIG. 55.—6-terminal "Simplex Duplex" switch.

circuits it is termed the "simplex duplex" switch, but its positions are now marked 1 and 2 to adapt it for many other purposes requiring a double two-way change. The terminals occupying positions corresponding to XII and VI on a clock face are joined to the adjacent left or right terminals according to the placing of the lever.

Similar in construction, but with nine terminals, is a switch which provides three two-way changes. Its con-

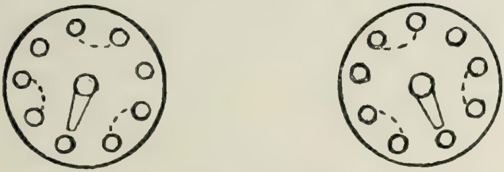


FIG. 56.—Connections of 9-terminal switch.

nections are shown in Fig. 56, and it is noteworthy that the lever, when moved, points to a disconnected terminal and that three pairs are formed with one of the disconnected terminals intervening.

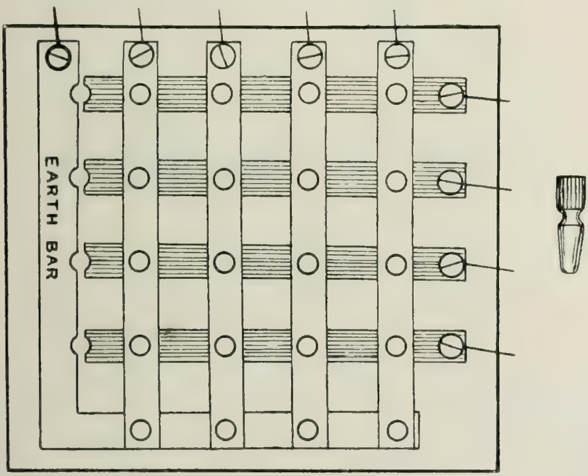


FIG. 57.—4-line peg switch or commutator.

The *Universal switch*—sometimes also termed the *peg commutator*—enables us to connect any one line joined thereon to any other of the lines. Four sets of metal rods or brass bars (Fig. 57) insulated from each other are fixed at right angles; holes are drilled through both sets, so that when the peg is placed in any one of the upper holes, it can be passed through the corresponding hole in that bar of the lower set which is directly under it. Thus connection between any of the upper bars and the lower ones may be changed as desired. Such a peg switch may be designed for a number of combinations, but a lever switch is more readily manipulated and is not so liable to be left carelessly so as to disconnect a line.

The Single Needle.

This instrument has considerably gone out of use, its

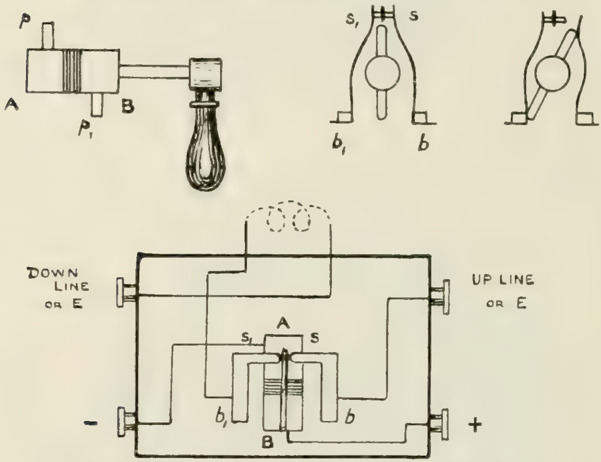


Fig. 58.—Connections of "drop-handle" single needle.

retention upon the railways being no doubt due to the fact that it is easily learnt, requires no adjustment, and that, because the needle will work with a great margin of difference in the value of the currents received, it allows a large number of stations to be linked together. The *drop-handle* form of the sending part is still in favour with these companies, and this description is primarily intended for their operators. The arbor of the handle consists of two separate conducting parts (*A* and *B*, Fig. 58) separated by boxwood or ebonite. To *A* the negative pole of the battery is joined, while the positive pole is connected to B. S and S_1 are two steel springs each in connection with the brass pieces b and b_1, and the springs are normally in contact by means of the metal bridge piece. The continuity of the line is thus maintained through the coils of the receiving portion of the instrument which is joined between the down line terminal

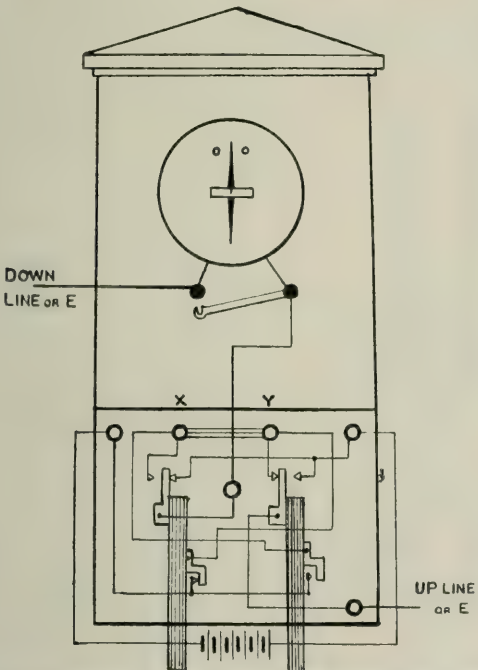


FIG. 59.—Connections of single needle, left-hand tapper depressed.

and b_1. A metal pin, p, is fixed on A, and a similar projection p_1 is fitted beneath B. When the handle is at rest these projections remain between the springs and brass pieces without touching either. The effect of the movement of the handle, say to the left, is to put p in contact with S and p_1 against b_1, sending a positive current to the down line, while turning the handle to the right places p against S_1 and p_1 touches b, thus joining the positive to the up line. In this way the direction of the current is reversed.

The sending portion of the "tapper" form of single needle is called a commutator, and consists of two keys the mechanical details of which cannot be shown so as to clearly indicate also the electrical connections. It is possible, however, to identify the action of the two keys by considering the connections shown in diagram (Fig. 59), bearing in mind that each key has two distinct electrical portions—a back lever and a front contact piece. The left tapper is shown depressed and the positive pole is joined to the down line via the back lever, while the returning current passes from the up line to the back contact of the right tapper, thence to the front contact of the left tapper to the negative pole. The altered conditions — when, instead, the right tapper or key is depressed— can readily be traced. Should both tappers be depressed at the same time the connections of the commutator are now so arranged that the battery cannot be short-circuited. The terminals X Y permit the introduction of a night bell when the strap is removed.

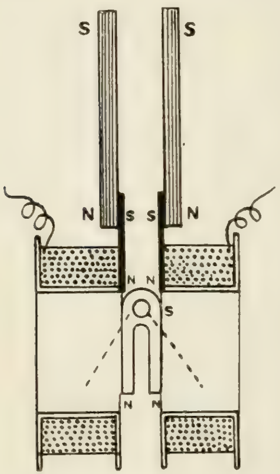


FIG. 60.—Permanent magnets, iron cheek pieces, and induced needle of Varley pattern.

The receiving part of the single needle is practically a special form of the S.C. galvanometer previously described. To remove the liability of demagnetization of the small needle formerly used, Mr. Varley designed an arrangement of bar magnets and a soft iron needle which owed its polarity to their influence. This form of induced needle is illustrated in Fig. 60. $N S$ and $N_1 S_1$ are two bar magnets with like poles adjacent to which soft iron strips are fixed; these, passing through the cheeks of each bobbin, are in close proximity to the needle, which is like an inverted letter **U**.

Another form of induced needle, devised by Mr. Spagnoletti, employs two horseshoe magnets and a paddle-shaped needle of soft iron magnetically divided by a layer of spelter (zinc). The similar poles of the magnets are adjacent, and they are placed above and below the soft iron axle as shown in Fig. 61. By induction the lower end of the needle becomes north polarity and the upper portion south. The shape of the needle secures a firm impact upon the stop pins while the horseshoe magnets retain their magnetism for a very long period of time.

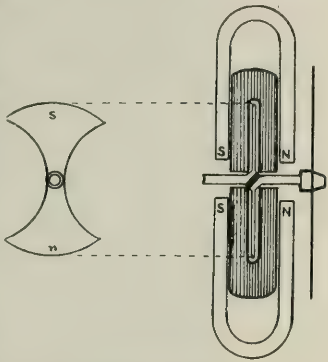


Fig. 61.—Spagnoletti induced needle.

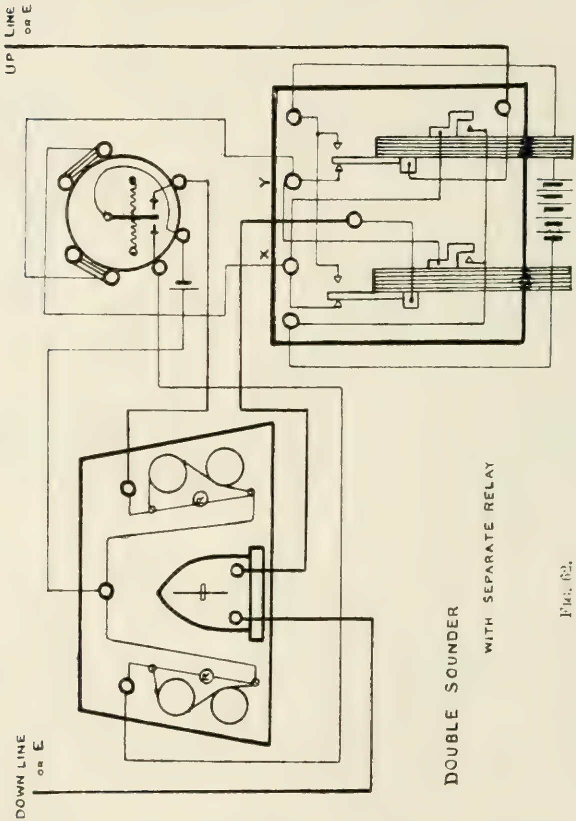
The coils of the single needle have a resistance of 200^{ω}, and current required is 15 to 20 m.a., although figure of merit is 3·06 m.a. Two sounding pieces are now often fixed adjacent to the stop pins or in place of them, and as each gives a different sound when struck by the indicating pointer the proper signals can be distinguished and the needle becomes an acoustic instrument.

The Double Sounder.

This combination, hitherto termed the double plate sounder, consists of a standard neutral relay (see p. 69) with two plate sounders in its local circuits, a S.C. galvanometer, and the sending part is a single needle commutator. The two sounders are fitted in a sounder screen in which the galvanometer is also placed. The left plate is of steel, and its sound, when struck by the hammer fitted to the armature, corresponds to "dots," while that of the brass plate on the right indicates "dashes." The total resistance of the sounders, which have 420^{ω} shunts, is 20^{ω} each; one is connected to the terminals *DU* on the relay, and the other to (*D*) and (*U*); that is, between the relay coils joined in parallel. Current required 14 to 17 m.a. The connecting strap of the two inner back terminals

(*XY*) of the commutator must remain opened or the relay would be cut out (see diagram, Fig. 62).

The direct working polarized double sounder is illus-



DOUBLE SOUNDER WITH SEPARATE RELAY

Fig. 62.

trated in Fig. 63. Resistance between the terminals is 430$^{\omega}$, working current 10 m.a. The apparatus works perfectly in the line circuit, without relay or local battery, and is consequently admirably adapted for railway systems.

Fig. 63.—Polarized double sounder.

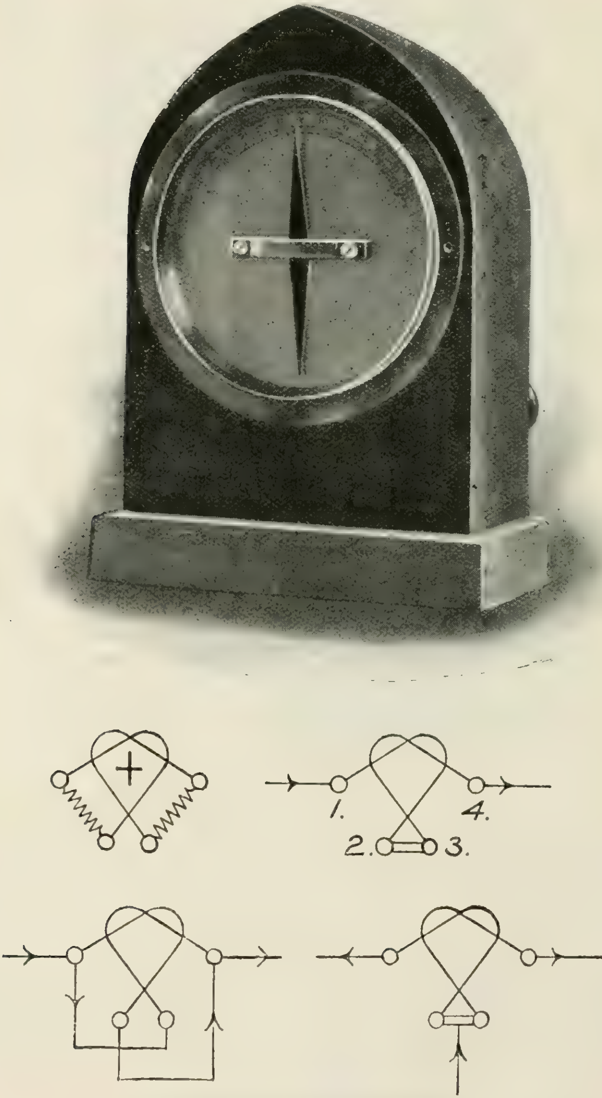


FIG. 64.—P.O. differential galvanometer.

Galvanometers.

The P.O. pattern of differential galvanometer is illustrated in Fig. 64. The needle is either of the Varley or Spagnoletti induced types previously described, although in the former the bar magnets are placed below the coils instead of above them as in the case of the single needle. From the diagrams accompanying the figure it will be noticed, being differentially wound, that if unequal currents pass in opposing directions through the coils then the deflection corresponds to the *difference* in the value of the two currents. Resistance of each coil 50^{ω}, shunted with 300^{ω}, making resistance of each 43^{ω} approximately. Thus

Resistance of galvanometer with coils in series 86^{ω}
" " " " " " parallel $21{\cdot}5^{\omega}$.

Deflection should be 40° to 45° with 20 m.a. through one coil. Top of needle is deflected to right when current passes from 1 to 2 or 3 to 4. Except for very small deflections the values of the currents producing them are not proportional to the number of degrees indicated.

The Tangent Galvanometer.

The chief feature of this instrument is that when the two directive forces—that due to the earth's magnetism and that exerted by a current —are acting at the same time upon the small magnet needle then it takes up a position where these two forces balance. The lines of force due to the earth are equidistant and parallel, and to insure the same condition with the lines of force developed by the current the needle must not exceed $\frac{1}{8}$ to $\frac{1}{10}$ of the diameter of the coil. The accompanying sketch (Fig. 65) shows how these relative sizes enable the field, due to the current, to be uniform at the centre where the needle turns. The

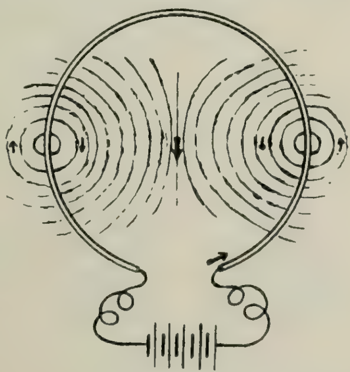


Fig. 65.

Post Office form of the instrument shown in Fig. 66 is differential, each coil having a resistance of 160ω and so connected that when terminals (2) and 3 are joined the coils are in series between terminals 1 and (4).

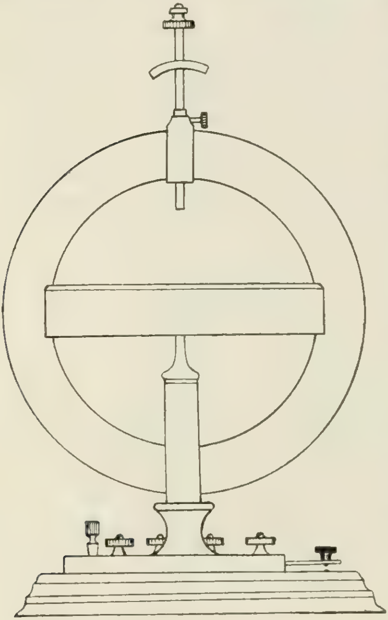


Fig. 66.—P.O. form of tangent galvanometer.

The shunt coils, giving values $\frac{1}{5}$th, $\frac{1}{10}$th, $\frac{1}{20}$th, $\frac{1}{40}$th, $\frac{1}{80}$th, $\frac{1}{160}$th, and $\frac{1}{320}$th, can be placed in parallel with the circuit of the coils by the insertion of a brass peg, and by this means comparatively heavy currents (ranging up to 800 m.a.) can be measured with fair accuracy.

The readings on the tangent galvanometer are not proportional to the angle of deflection in the ordinary circle degrees—for example, deflections of 30°, 45°, 60° are not produced by currents in the ratios $\frac{2}{3}$, 1, $\frac{1}{3}$, but to the values of the tangents of the deflected angles, *i. e.* ·577, 1, 1·73; thus

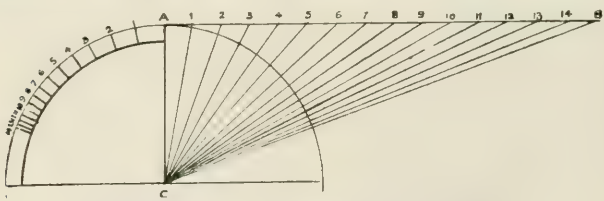


Fig. 67.—Illustrating the construction of a tangent scale.

a deflection of 60° represents a current value three times greater than that producing 30°. Instead, however, of ascertaining the values of deflection by reference to a tangent table, a scale is formed on the instrument so that they are indicated by the pointer.

If a line be drawn at right angles to the radius of a circle (Fig. 67), and equal lengths are marked off, then lines drawn from the centre to these points intersect the circumference.

Now the tangent of an angle is proportional to the value $\frac{\text{perpendicular}}{\text{base}}$, *i.e.* for $AC2$ it is $\frac{A2}{AC}$, for $AC3$ $\frac{A3}{AC}$, and so on. The particular length marked off divided by the radius of the circle thus gives the value of the tangent of the angle of deflection, and a direct reading of this proportion can be obtained by marking the circle where the lines cut the

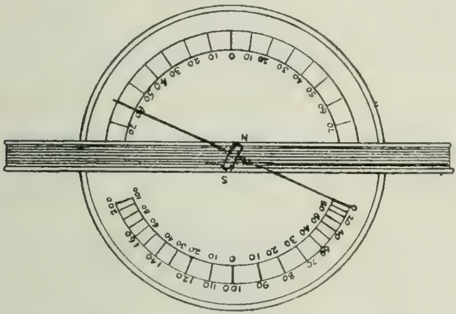


FIG. 68.—The tangent galvanometer scales.

circumference. The number of such divisions indicated by the pointer represent proportonal current strengths.

The sensitiveness of the needle is varied by using a small curved bar magnet fitted on a stalk so as to be above the needle. When the similar poles of this controlling magnet and that of the needle are adjacent the latter will more readily respond to the influence of the current, because the influence of the earth is more or less negatived, and of course the needle's sensitiveness is less when opposite poles are adjacent. The required degree can be obtained by raising or lowering the controlling magnet.

In making tests, care must be taken that the pointer stands at zero when no current is flowing, both when the controlling magnet is removed and when it is replaced.

The dial is divided into two separate scales (Fig. 68), one semi-circular scale giving the ordinary *degrees* marked on both sides of a zero as in the case of the differential galvanometer, while the other semi-circle gives the marking of the tangent divisions. This scale is prepared with an *inner* and an *outer* range. The inner divisions have values starting from a central zero to 100 on each side, whereas the outer or *skew* scale has zero on the right 100 mark and re-numbers the divisions, thus making the left extremity 200. To bring the pointer to rest over the *skew* zero the instrument is turned through an angle of 60°. It will be observed that near the inner zero and at 100 on the skew

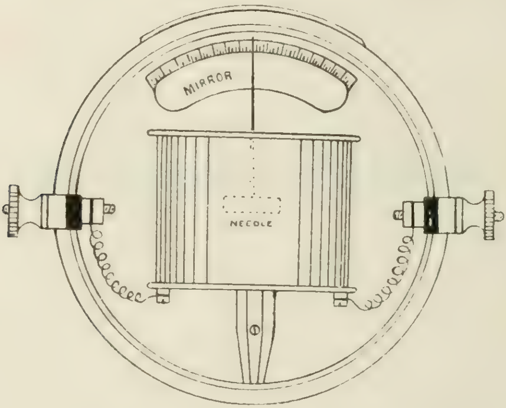


FIG. 67. Horizontal galvanometer.

scale the divisions are farther apart, and consequently deflections in that vicinity can be accurately read. Besides obtaining a greater range with the *outer scale*, in some cases using the "skew" zero gives increased sensitiveness. The normal adjustment should be such that a "sealed standard cell" in good condition will give about 80 divisions on the outer scale with no shunt. This enables actual values of current to be compared.

The key provided on the base is to enable the needle to be quickly brought to rest. The depression of the key short-circuits only one coil (2) (4).

A mirror is placed near each scale so that correct reading is insured by observing that the pointer obscures its reflection.

The horizontal galvanometer (Fig. 69) is most frequently used in connection with the Wheatstone Bridge. It has a single flat coil with a small magnet about an inch in length pivoted like a compass needle. Fitted to the magnet is a very light pointer which projects over a scale and mirror, the latter to avoid parallax error when taking readings, as

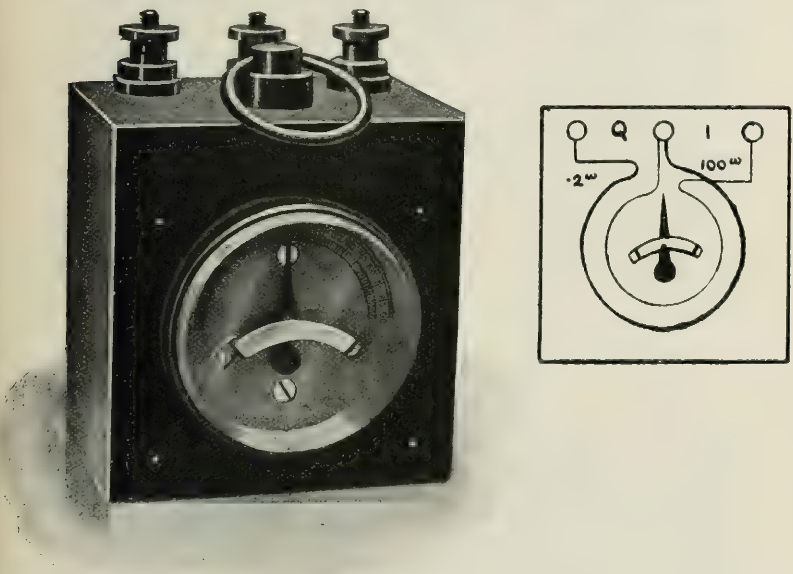


FIG. 70. Q and I detector.

explained previously. The case, which has a glass cover and a small window to admit light upon the scale, is moved until the pointer is at zero and the magnet rests in the magnetic meridian. The P.O. instrument wound to a resistance 800ω produces a deflection of 10 divisions with E.M.F. of 1 Daniell cell through 52,000ω. Other windings, or a D'Arsonval type, are sometimes used.

Perhaps the most generally convenient galvanometer is the small Q and I Detector used by linemen. This detector (illustrated in Fig. 70) has two windings, the *Q* (quantity) coil having a resistance of $\cdot 2^{\omega}$, and the *I* (intensity) coil 100^{ω} resistance. The needle may be of the Spagnoletti or Varley induced types. About 140 m.a. through the *Q* coil should produce a deflection of between 20° and 30°, while 10 m.a. through the *I* coil should cause a deflection of from 40° to 50°.

In some patterns either one or both coils are provided with shunt resistances, which are inserted by means of switches placed upon the top of the case.

Another form of galvanometer common in laboratories, but of very little use in practical telegraphy, is the *astatic*, shown in principle by Fig. 71. It generally consists of two flat coils of wire and two magnetic needles so pivoted that they move horizontally one within and the other above the coils. The poles of the needles are dissimilarly placed, that is, N above S, and *vice versa*, and by this means the

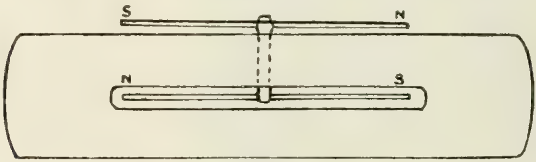


FIG. 71.—Astatic galvanometer.

directive force of the earth's magnetism is practically eliminated, consequently the needles can respond very easily to the effect of a current. Sometimes they are suspended by a thin wire or silk fibre instead of being pivoted. The greatest defect of the astatic galvanometer is its sluggishness in returning to zero.

A *ballistic* galvanometer differs from an ordinary astatic galvanometer in the fact that it possesses a heavy needle made nearly spherical. The needle takes a relatively long time to swing, and the peculiar shape reduces the resistance of the air to a minimum. In an ordinary galvanometer it is desired to bring the needle to rest as soon as possible, but in the ballistic galvanometer, since the quantity of electricity passing is calculated from the amplitude of the first swing, it is desirable to check or damp the needle as little as possible. Since the charge and discharge of condensers consist of momentary impulses, the slow movement of the ballistic galvanometer makes it a very convenient instrument for measuring their relative capacities (see Condenser Testing).

The Thomson galvanometer, prototype of the mirror or reflecting galvanometers, was invented by Lord Kelvin. Instead of employing a pointer, as in the galvanometers already considered, a ray of light from a lamp is reflected on to a scale placed some feet distant. The needle consists of three or more pieces of magnetized watch spring fixed on the back of a small mirror which is suspended by a single thread of torsionless silk, and so arranged as to

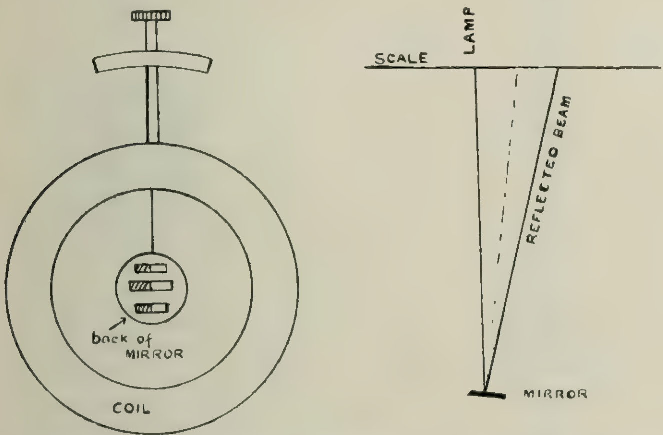


FIG. 72.—Simple form of Thomson galvanometer, and principle of reflection.

indicate its movements by the beam of reflected light. It can be seen by reference to Fig. 72 that a deflection of the needle is greatly magnified in the movement of the spot of light on the scale. For general working or testing the Thomson galvanometer consists of a coil of wire wound to a resistance of from 2000^{ω} to $10,000^{\omega}$. A controlling magnet is fitted on a stem above the coil. To make the instrument *dead beat*, and thus prevent the mirror oscillating to and fro when deflected, the mirror is enclosed in a brass or copper tube. The eddy currents generated in the tube and the opposition of the closely confined air both combine to make the mirror move gradually, and if the damping effect is considerable it will stop "dead" in its final position, returning to zero when the current ceases.

A more delicate form of instrument has four coils, within which are two discs carrying the small magnets, but placed so that the *N* poles on the top disc are over the *S* poles of the lower disc, thus forming an *astatic* combination (Fig.

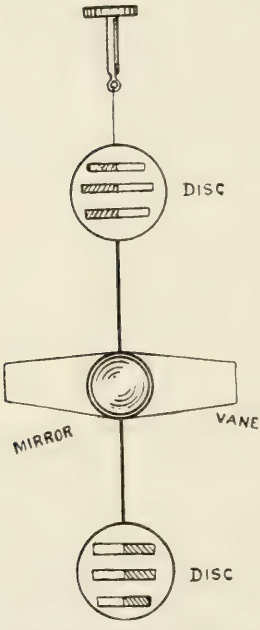


FIG. 72*a*.—Astatic form of Thomson galvanometer needles.

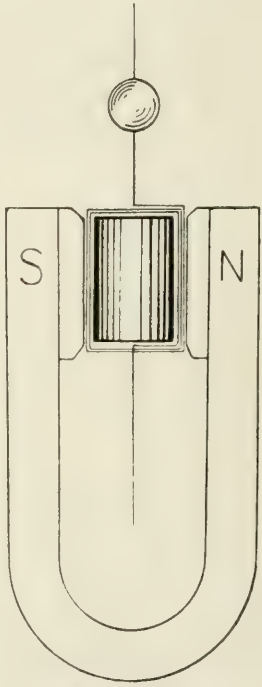


FIG. 73.—The constituent parts of the D'Arsonval galvanometer.

72*a*). The mirror is fixed on the same suspension, so as to move with the magnet needles, and reflects the beam of light through an opening between the double coils. An aluminium vane tends to steady the swing of the combination. The sensitiveness of the galvanometer is adjustable by a pair of "scissors" controlling magnets.

The *D'Arsonval* belongs to the class termed *moving coil* galvanometers. In the forms already considered the magnet moves and the coils are fixed, whereas in the D'Arsonval type the suspended coil rotates between the poles of a large fixed horseshoe-shaped magnet. The movable coil is of rectangular shape (as shown in Fig. 73), formed of a number of turns of fine wire, in some cases wound upon a light aluminium frame so that "eddy currents" may be set up in the frame and assist to damp the swinging motion of the coil. The magnetic field of the magnet is maintained as uniform and strong as possible by suitably designing the poles, and further concentrated by placing within the coil a small cylindrical piece of soft iron, fixed so as to allow the coil freedom of movement. When a current traverses the coil it tends to set itself with its plane at right angles to the direction of the field between the poles of the permanent magnet. This motion is resisted by the torsion of the suspending wire, and the coil almost immediately takes up a position in which the twisting of the wire balances the force due to the mutual action between the magnet field and the current's field. The movement of the coil is indicated by the reflection of a mirror as with the Thomson galvanometer.

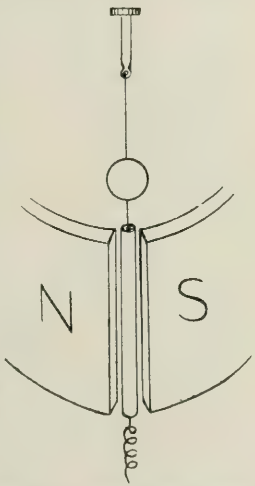


FIG. 74.—Principle of the Ayrton and Mather galvanometer.

A special type of D'Arsonval galvanometer, in which the mirror is replaced by a pointer and the coil is pivoted, is now sometimes used instead of the horizontal galvanometer shown in Fig. 69.

In the Ayrton and Mather type of moving coil reflecting galvanometer the permanent magnet forms a hollow cylinder with a very narrow air-gap between the poles (as shown in Fig. 74). The coil, in the shape of a long narrow rectangular winding with no iron core, is enclosed in a thin silver tube so that the movement of the coil is thoroughly damped by the "eddy currents" which are set up in the tube when it rotates or swings in the magnetic field between the poles.

The Weston voltmeter is a moving coil galvanometer with its scale marked to give direct voltage readings. The movable coil consists of a number of turns of fine wire wound upon a flat rectangular aluminium frame which is delicately pivoted at the top and the bottom in jewelled bearings fastened to the polepieces. A soft iron cylinder concentric with the curved surfaces of the pole-

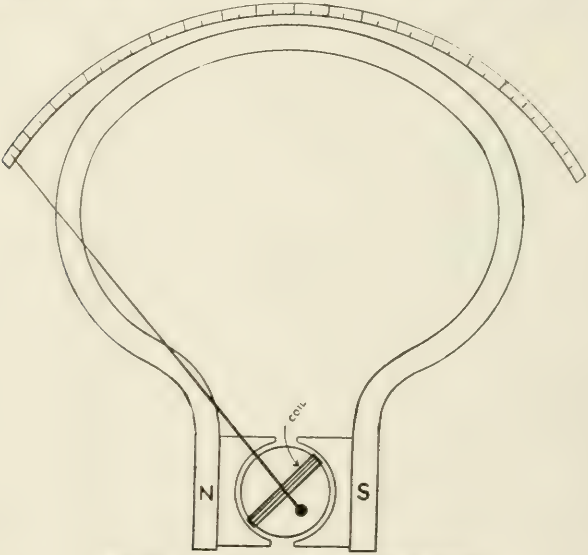


Fig. 75.—The elements of the Weston voltmeter.

pieces insures the concentration of the field of the large permanent magnet shown in Fig. 75. The movable coil is controlled by two flat spiral hair-springs which are wound in opposite directions; consequently, when one is twisted up by a movement of the coil, the other is untwisted. These springs are also made to serve the purpose of leading the current into and out of the coil. The deflecting force is the interaction between the field due to the current traversing the coil and the radial field in air gap of the permanent magnet, while the controlling force is the torsional reaction of the spiral springs. An aluminium pointer moves over a graduated scale and mirror indicating, when the coil is deflected, the E.M.F. in volts.

A similar instrument is designed for giving by direct readings the value of the currents in amperes or milliamperes. In these "ammeters" the movable coil only carries a small fraction of the main current, substantial shunts being connected in parallel with the coil and so introduced that the readings of the instrument give an exact measure of the currents. If the ammeter had a

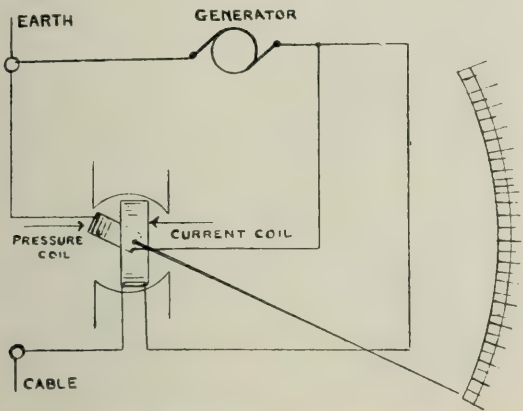


FIG. 76.—Coils and connections of the megger.

high resistance it would reduce the strength of the current when placed *in the circuit*, consequently the coil is wound to a fraction of an ohm. But a voltmeter is always joined as a *shunt to the circuit* where a measurement is desired, and has a very high non-inductive resistance joined in series with it. The variation in P.D. then caused by the connection of the voltmeter is negligible.

The "Megger" is an instrument recently introduced to measure the insulation resistance of underground cables. It is a combination of a *double* moving coil and hand-dynamo, having a scale calibrated to indicate resistance values from 50,000$^{\omega}$ to 100 megohms. The moving portion of the galvanometer consists of two coils rigidly connected together and to a pointer (Fig. 76), the coils being pivoted to rotate in the field of powerful bar magnets concentrated by a hollow iron cylinder. The "pressure" or voltage coil is joined as a shunt across the generator like a voltmeter, whilst the "current" or ammeter coil is connected in the direct circuit to the line. A current passing through the latter coil tends to set the pointer at zero on the scale, and force acting upon the "pressure" coil tends to move it in the opposite direction; consequently the actual position of the pointer is due to the resultant of the two opposing forces. If the insulation of the line is low the "current" coil prevails and a low reading results, but should the insulation be high less current flows through the "current" coil and the "pressure" coil tends to deflect the pointer along the scale.

The testing current is produced by the magneto generator, and the maximum voltage which the P.O. Megger is permitted to generate is 500 volts.

Shunts and Their Use.

For calculating the strength of the current in a circuit it is necessary that the total resistance in the circuit should

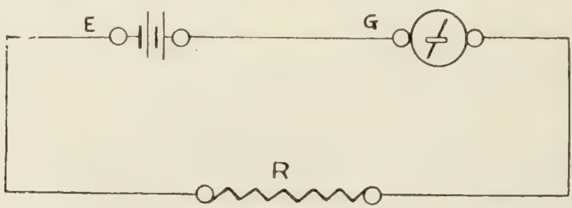


Fig. 77.

be considered. In Fig. 77, a battery of E volts and internal resistance r^{ω} is joined in circuit with a galvanometer G^{ω}, and resistance R^{ω}, then by Ohm's law $C = \frac{E}{G + R + r}$. Whatever the relative values of the different resistances, the current is the same in all parts of such a circuit. This is, however, not the case when more than one path occurs in a circuit, as in Fig. 78, where several resistances are in parallel. Between A and B are four ways totalling increased facility to the passage of the current, and the sum of their combined resistances is less than that of the best conductor amongst them. When such "*multiple*" paths have equal resistances, then the combined or *joint* resistance (JR) is equal to the resistance of one of them divided by the number in parallel. For example, of ten such circuits of

$$50^\omega \text{ each the } JR = \frac{50}{10}, \text{ or } 5^\omega.$$

The facility offered by a conductor to the current is termed its conductance and is the inverse of resistance; its unit being the "mho" (ohm reversed). The relationship between resistance and conductance can be expressed as follows:—

$$\text{Resistance} = \frac{1}{\text{Conductance}}, \text{ and}$$

$$\text{Conductance} = \frac{1}{\text{Resistance}}.$$

The total conductance of several wires in parallel is the *sum* of their separate conductances.

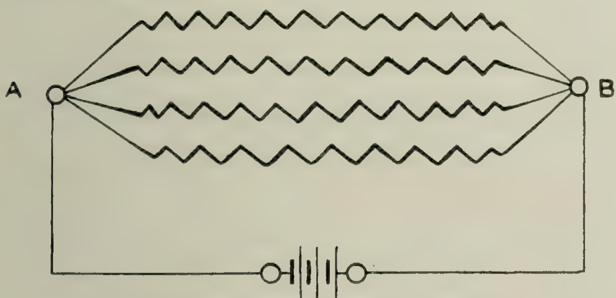


FIG. 78.—Four resistances joined in "multiple."

If in Fig. 78 the four paths are 2^ω, 3^ω, 4^ω, 5^ω, then the total conductance is

$$\frac{1}{\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}} = \frac{1}{\frac{77}{60}} = \frac{60^\omega}{77}.$$

The combined resistance of two circuits in parallel is equal to their product divided by their sum, that is, for 25^ω and 75^ω, $JR = \frac{25 \times 75}{25 + 75} = 18{\cdot}75^\omega$. The current divides between a number of paths in parallel in direct proportion to their respective conductances. With two resistances in parallel of 32^ω and 40^ω a current of 144 m.a. would divide as 80 m.a. and 64 m.a. because the conductances are as $\frac{1}{32} : \frac{1}{40}$ or $\frac{\frac{1}{32}}{\frac{1}{40}} = \frac{5}{4}$. To ascertain the division of currents with several unequal branches or paths (as in Fig. 78) it is necessary to express the ratios of the conductances by using a common denominator, *e.g.*—

$$\tfrac{1}{2} : \tfrac{1}{3} : \tfrac{1}{4} : \tfrac{1}{5} = \frac{30 : 20 : 15 : 12}{60}.$$

Then of each division of the current into 77 parts the first takes $\frac{30}{77}$ and the last $\frac{12}{77}$, *i.e.* if the total current be 385 m.a. the division would be 150 m.a., 100 m.a., 75 m.a., and 60 m.a. The most common examples of the application of the above principle are to be found in connection with the shunts applied to reduce the current passing through a galvanometer. The range of the unshunted P.O. tangent galvanometer is from about $\frac{1}{80}$ of a m.a. to $2\frac{1}{2}$ m.a., but by means of its shunts currents up to 800 m.a. can be measured. The resistance of the galvanometer in the first example is 320^ω, but in the last it is only 1^ω. As indicated in previous paragraphs, joining a resistance in "multiple" with the coil of the galvanometer will reduce its resistance, the combined value being $\frac{G \times S}{G + S}$. Unless the resistance of the circuit external to the galvanometer is high, then the introduction of the shunt will reduce the total resistance in the path of the current so much that a stronger current will flow. For example, if the external resistance is 100^ω with the unshunted and shunted tangent galvanometer mentioned above, then the total resistances are $100 + 320 = 420$ and $100 + 1 = 101$, and the total currents in the two cases will vary as 101 : 420. Thus instead of $\frac{1}{320}$ part of 101 flowing through the shunted galvanometer we have $\frac{1}{320}$ of 420, or approximately 1 : 4. If the external resistance be 6000^ω the currents will then be as 6001 : 6320, or approximately 1 : 1·05, hence the greater the external resistance the less is the change in the strength of the current. On the other hand, if the external resistance is negligible then the currents will be 1 : 320, but as only $\frac{1}{320}$

of the latter flows through the galvanometer coil the current value is the same therein as when it was unshunted.

Example.—A battery of 10^{ω} is connected to a galvanometer of 5000^{ω}; will the deflection obtained be altered by the introduction of a $\frac{1}{10}$th shunt?

On account of the low resistance of the battery, the whole of its E.M.F. is available for the external circuits, and the currents flowing will be inversely proportional to their resistances, which are 5000 + 10 and 500 + 10. Currents therefore vary as 510 : 5010, or approximately 1 : 10, but in the second case only $\frac{1}{10}$th of the current flows through the galvanometer, the deflection of which remains practically unaltered.

If G and S represent the respective resistances, then the ratio of their conductances is $\frac{1}{G} : \frac{1}{S}$ or $\frac{S}{G \times S} : \frac{G}{G \times S}$, and if the current be considered as composed of G and S parts, then S parts pass through the galvanometer whilst G parts are shunted. When the tenth shunt is used, $G + S$ parts are equal to $10\,S$ and the current flowing through G is $\frac{S}{G + S}$ or $\frac{S}{10S}$, that is $\frac{1}{10}$th of the total current. *The shunt is named by the proportion of the current it allows through the galvanometer.* Hence in this case the value of the current in the undivided circuit is found by multiplying by 10, which is termed the *multiplying power* of the shunt. From what has already been shown, it should be evident that this S must have a value $\frac{1}{9}$th of G, and similarly $\frac{1}{20}$th and $\frac{1}{100}$th shunts are respectively $\frac{1}{19}\,G$ and $\frac{1}{99}\,G$. Calling the multiplying power of the shunt m, the general rule is expressed:— $S = \frac{G}{m - 1}$ (I). Then since $S(m - 1) = G$, and $Sm = G + S$, it follows that $m = \frac{G + S}{S}$ (II). The combined resistance of G and S is $\frac{G \times S}{G + S}$, i.e. $= G \div \frac{G + S}{S}$; but $m = \frac{G + S}{S}$, therefore the joint resistance $= \frac{G}{m}$ (III). The results I, II and III are important.

We have already noticed the circumstances in which the introduction of the shunt caused an increase in the value of the current, and to prevent such variation, *compensating resistances* have been designed to maintain the resistance of the galvanometer part of the circuit constant. Such resistances must of course equal the *difference* between the unshunted galvanometer and the joint resistance of the galvanometer and its shunt. With the $\frac{1}{10}$th shunt on the tangent galvanometer this would be $320 - \frac{320}{10} = 288^{\omega}$.

Ordinary shunts must bear a fixed relation to the

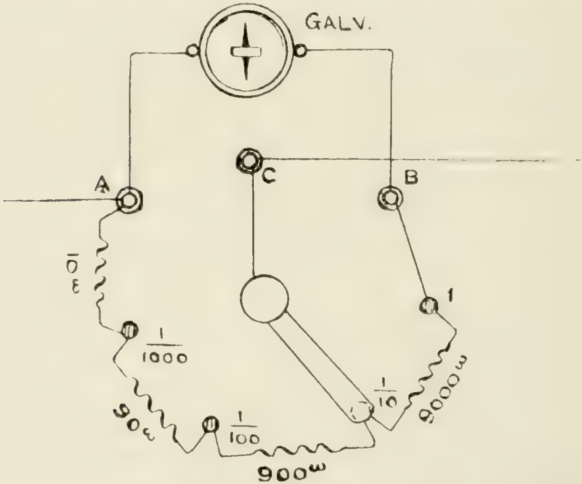


FIG. 79. "Universal" shunt.

resistance of the galvanometer with which they are used. That involves the measurement of fractional parts of an ohm, as, for instance, the above $\frac{1}{10}$th shunt should have a resistance $35{\cdot}56^{\omega}$, a very awkward value to measure.

The "*Universal Shunt*" devised by Prof. Ayrton can be used with any galvanometer, and as there are no fractional parts of ohms in the values the coils can be more easily adjusted. The general principle is indicated in Fig. 79. The coils are joined between *A* and *B* and across the terminals of the galvanometer, while one end of the main circuit is also connected to *A*, but the other end is joined to C, which is in connection with a sliding contact lever capable of moving over the studs between which the shunt resistances are fixed. Only the coils between A and C are in the shunt, the coils between C and B being added to the resistance of the galvanometer circuit. Therefore the value $G + S$ is constant, whatever the position of the lever, and since the multiplying power of the shunt is $\frac{G + S}{S}$, then it follows that m is the shunt resistance divided into a constant number. Suppose the lever to be on stud 1, then m is $\frac{G + 10,000}{10,000}$, the galvanometer being shunted with the whole of the shunt coils. When the lever is turned to stud $\frac{1}{10}$, S is 1000 and $G + S$ becomes (G + R) + S or $(G + 9000) + 1000$, while m equals $\frac{G + 10,000}{1000}$, which is ten times the multiplying power in the first case. Thus the value of the numerator is $G + 10,000$ in whatever position the lever is placed, whose function is to alter the value of S in the denominator. Other values of shunts may be introduced besides those indicated in Fig. 79.

With this Universal shunt, however, the rule that joint resistance equals $\frac{G}{m}$ does not obtain, the ratio being $\frac{(G + R)}{m}$. This numerator varies with each shunt, consequently the value of the current in the main circuit changes unless the circuit resistance is very high.

Five illustrative worked examples follow :—

Example 1.—A galvanometer of 5000 ohms resistance and shunted by a resistance of 500 ohms gives a deflection of 300 divisions. What shunt will be required to reduce the deflection to 100 divisions with the same current?

At first the current through G is in the proportion $\frac{S}{G + S} = \frac{500}{5500} = \frac{1}{11}$ which is the value of the shunt. The current is then reduced to $\frac{1}{3}$ of 300 divisions, therefore the shunt value will be $\frac{1}{3}$ of $\frac{1}{11} = \frac{1}{33}$, and since

$$S = \frac{G}{m - 1} \therefore S = \frac{5000}{32} = 156{\cdot}25^{\omega}.$$

Example 2.—A galvanometer and shunt have a joint resistance of 15^{ω}. If the resistance of the galvanometer is 1000, what is the resistance of the shunt?

Let R represent the combined resistance, then

$$R = \frac{G \times S}{G + S}, \text{ i. e. } R\,(G + S) = G\,S \text{ and}$$

$$R\,G = G\,S - R\,S, \therefore S = \frac{R\,G}{G - R}$$

substituting the figures $\dfrac{1000 \times 15}{1000 - 15} = 15{\cdot}23_{\omega}$.

Example 3.—(*a*) What is the combined resistance of the P.O. tangent galvanometer with the *tenth* shunt and the resistance of the latter?

(*b*) What proportion of 20 m.a. will flow through the galvanometer with the above shunt, and what is the general formula employed in such cases?

(*a*) Joint resistance $= \dfrac{G}{m} = \dfrac{320}{10} = 32^{\omega}$

$$S = \frac{320 \times 32}{320 - 32} = 35{\cdot}56$$

(*b*) Current in galv. $= \dfrac{S}{G + S}$ of total current

$$= \frac{35{\cdot}56}{320 + 35{\cdot}56} \times 20 = \tfrac{1}{10} \times 20 = 2 \text{ m.a.}$$

The proportion of current flowing in the shunt would be $\dfrac{G}{G + S}$ of the total current.

Example 4.—A galvanometer of 5000^{ω} is connected in circuit with a wire of 10,000; what is the percentage change in the main current by shunting the galvanometer with $\frac{1}{10}$th shunt?

The total resistance of the circuit with the galvanometer unshunted is $15{,}000_{\omega}$. When shunted the total resistance becomes 10,500. Then 10,500 : 15,000 :: 100 : 142·85, or an increase of 42·85%.

Example 5.—A current of 28 amperes divides between four wires of $2{\cdot}5^{\omega}$, 10^{ω}, 25^{ω}, and 50^{ω} connected in parallel; determine the current in each branch.

Since the currents divide proportionally as their conductances, which are ·4, ·1, ·04, and ·02, and 28 amperes are proportional to the total conductance or ·56, therefore currents are

$\frac{\cdot 4}{\cdot 56}$ of 28 = 20 amps. $\frac{\cdot 1}{\cdot 56}$ of 28 = 5 amps.

$\frac{\cdot 04}{\cdot 56}$ of 28 = 2 amps. and $\frac{\cdot 02}{\cdot 56}$ of 28 = 1 amp.

Note, the drop in volts across each conductor is proportional to $C\,R$ and the same for each branch, being $20 \times 2{\cdot}5 = 5 \times 10 = 2 \times 25 = 1 \times 50 = 50$ volts.

Resistance Coils.

The metals, although classed as conductors, offer certain resistances. The resistance offered by a centimetre cube of a substance is termed its specific resistance, and, taking the value of pure copper to be unity, the comparative values of the metals most used are approximately as follows :—

Copper	1	German silver	13
Aluminium	1·8	Platinum silver	15
Platinum	5·5	Platinoid	23
Iron	6	Manganin	24
Tin	8	Eureka	30

Resistance also varies according to the temperature of the substance ; that of metals increasing with a rise in temperature, although with alloys very much less than with pure metals. German silver has $\frac{1}{10}$th of the variation of copper, while platinoid has about a half of the variation of German silver, and the variation of eureka and manganin is practically nil. Resistance coils are tested at a temperature of 60° F. (15·6 C.). The temperature variation of copper is nearly ·43% per degree centigrade. When used for resistance coils the low values are generally composed of thick wire, whereas for high resistances wire of finer gauge is used. Besides allowing for more accurate adjustment of actual lengths required, this distinction in the employment of thick and thin wires provides for the probable strengths of currents therein and the economy of size and cost.

A very reliable and convenient form of a set of resistances is shown in Fig. 80. This resistance box is termed a "retardation coil" owing to the purpose for which it is

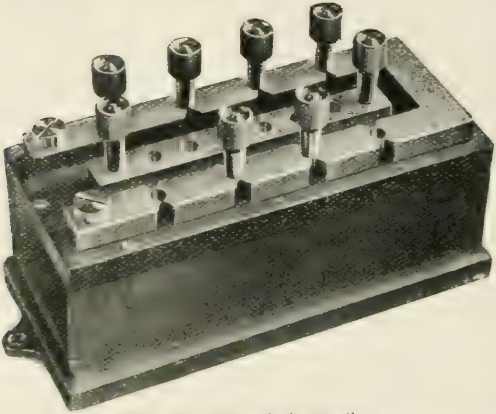


Fig. 80.—"Retardation" coils.

used in duplex working. It consists of eight coils having respectively 10^{ω}, 20^{ω}, 30^{ω}, 40^{ω}, and 100^{ω}, 200^{ω}, 300^{ω}, 400^{ω}. These values provide a range from 10^{ω} to 1100^{ω} by steps of 10^{ω}. The coils of platinoid wire are double wound upon the bobbins and so joined that the effects of self-induction are eliminated (see Fig. 81). The wire is insulated with one or two layers of silk and connected between the brass blocks fitted on the ebonite top. By removing any of the circular brass pegs the coil of the value marked is inserted; thus in Fig. 80 a total resistance of 500^{ω} has been placed in the circuit. The pegs should fit tightly and be inserted as if by screwing, then with all the pegs in position the resistance between the terminals of the brass block will be negligible. Another set of resistances known as a "condenser coil" having seven

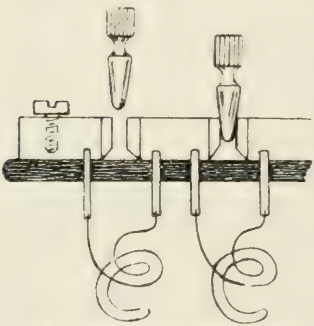


Fig. 81.—Elements of "double wound" resistance coils.

values is illustrated in Fig. 82. The resistances are 50^ω, 100^ω, 200^ω, 300^ω, 400^ω, 1000^ω, 2000^ω, and give a range from 50^ω to 4050^ω by gradations of 50^ω.

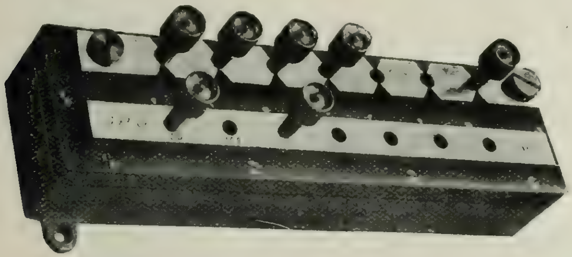


Fig. 82.—"Condenser" resistance coils

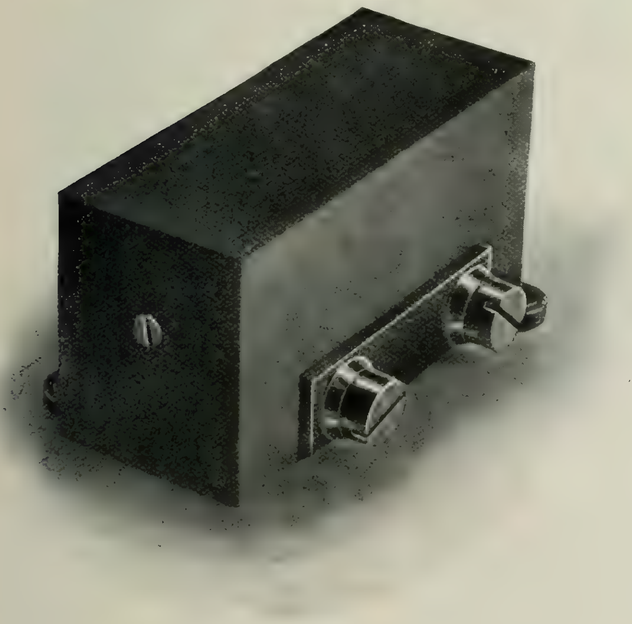


Fig. 83.—Metal-cased resistance.

In Fig. 83 we have an illustration of a coil wound non-inductively on a brass bobbin enclosed in a brass case with the terminals mounted on an ebonite strip. This is usually termed a "metal case resistance" and the values of the coils are chosen to provide a protective resistance in certain "universal battery" leads, as will be explained in that section. The metal case promotes radiation of the heat developed.

The rheostat, a very convenient form of a double set of resistance coils, gives generally a range from 0 to 8430^{ω} by steps of 10^{ω}. The "C" pattern, with coils in a circular

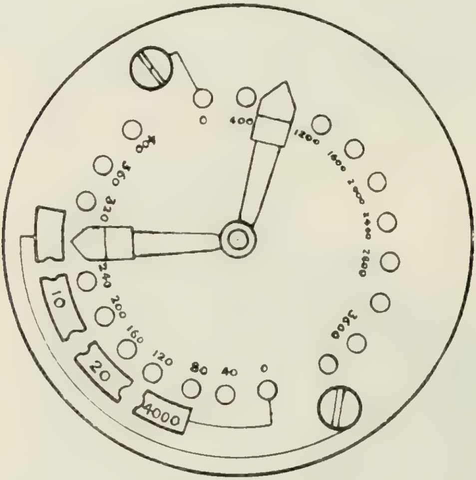


Fig. 84.—Plan of rheostat "C."

brass case, has two contact arms arranged so that each moves over one half of the contact studs. The ten coils of one semi-circle are of 40^{ω} each, while the value of each coil in the other semi-circle is 400^{ω} and the maximum obtainable by the arms is 1400^{ω}. Three additional resistances, 4000^{ω}, 20^{ω}, and 10^{ω}, provided on the base, are inserted by withdrawing the pegs. The connections of rheostat "C" are shown in Fig. 84.

The standard pattern, rheostat "D," is illustrated in Fig. 85. The contact studs are larger and are arranged in two circles on the ebonite top. Reliable connection is obtained by the radial arms consisting of three phosphor bronze strips bent so that each separately touches the contact studs.

The coils are of platinoid wire, silk covered, wound on four bobbins. One contains the 10^{ω} and 20^{ω} coils wound with 24 mil gauge, and another carries the 40^{ω} resistances of 14 mils diameter. The third bobbin is wound with two

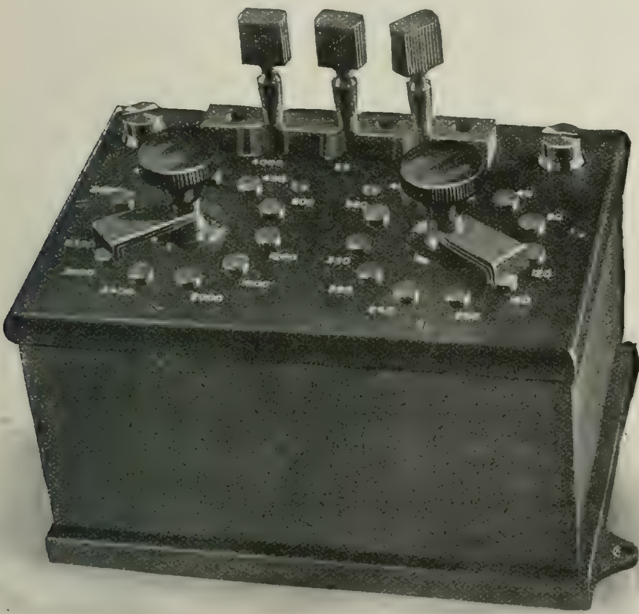


FIG. 85.—Rheostat "D.

thicknesses, the coils connected to the studs marked 400^{ω}, 800^{ω}, and 1200^{ω}, are of wire 10 mils in diameter, while the remaining 400^{ω} coils are wound with wire of 8 mils diameter. One bobbin carries the 4000^{ω} coil which is wound with wire of 5 mils thickness. The 400^{ω} and 40^{ω} bobbins after being wound are dipped into melted paraffin wax. The whole of the coils are enclosed in a polished mahogany case. Fig. 86 is a diagram of the internal connections of this pattern.

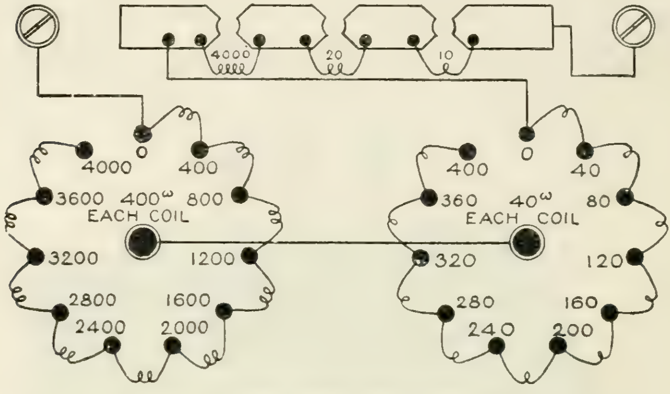


FIG. 86.—Internal connections of rheostat "D."

CONDENSERS.

A condenser, in principle, consists of two conductors separated by a dielectric and arranged so that a charge upon one conductor induces a charge upon the other. There is no flow of electricity through the dielectric, but an inductive action across it. Such an arrangement is depicted in Fig. 87.

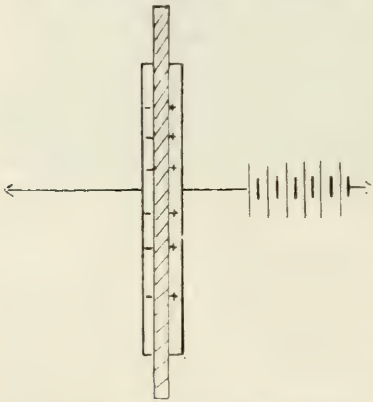


FIG. 87.—Two metal plates, *A* and *B*, with a sheet of glass, showing the elements of a condenser.

A and *B* are two metal plates separated by a sheet of glass. Let *A* be earth connected while *B* is joined to a battery or other source of energy. The positive charge on *B* acts across the glass, and the nearer surface of *A* is negatively electrified, but the induced positive is neutralized through the earth connection.

A's negative reacts on *B*, which is rendered capable of receiving a further charge, and so on. By these reactions the charges on *A* and *B* accumulate or are *condensed*.

The *capacity* of a condenser depends upon :—

(1) The size and form of the plates or conductors.
(2) The thickness of the dielectric ; and
(3) The inductive capacity of the non-conductor.

The condition (3) depends upon the power possessed by the substance for transmitting the inductive action across it. The specific inductive capacity values given by different authorities vary considerably ; but, approximately, the more important materials may be compared as follows : Air, 1 ; paraffin wax, 2 ; glass, 3 ; mica, 5. The last substance is the most satisfactory dielectric used, but the high cost of mica renders it prohibitive except for standard condensers.

The ordinary condensers for telegraph purposes have for many years been manufactured by sheets of tissue paper infused with paraffin wax being placed alternately with sheets of thin metallic foil. The odd numbers of the tin-foil sheets were bunched and joined to one terminal, the even numbers being connected to the other terminal. The slow process of assembling the sheets, one by one, with 250 separate pieces required to make up a 1-microfarad plate rendered the labour cost high, and the percentage of failures through short circuit or low insulation was considerable.

The new method of condenser manufacture introduced and patented by Mr. G. F. Mansbridge consists in the use of "tin-foil paper" of the same character as that employed for tea wrappers, but very carefully prepared to insure good metallic surface and the electrical continuity of the tin film. The paper is used in long strips, and for telegraph condensers two foiled papers are placed with their metallic sides alternating.

Two interleaving sheets of plain paper are used so that the dielectric on each side is made up of one body paper and one plain paper. Strips of copper foil about ½ inch wide are slipped between the foiled surface and the interleaving paper and protrude about 1 inch so as to serve as a soldering point for the terminal connection. The condenser plates and papers, having been rolled up together, are passed through complete and thorough drying processes. They are then soaked for two hours in hot paraffin wax, following which they are subjected to certain pressure adjusted to provide that a good body of wax remains in the paper and maintains its insulation and capacity for many years.

Besides being cheaper, lighter in weight, and smaller, condensers made of foiled paper have the peculiar advantage of possessing to an almost perfect degree, the property which in a pneumatic tyre is called self-sealing. Consequently they are practically proof against short circuit and can be subjected to much higher voltages than is permissible with those made from metallic foil, any

FIG. 88.—2 m.f. condenser.

momentary short circuits produced by a disruptive discharge being instantly and automatically sealed. This automatic sealing is brought about in the following way: owing to the extreme thinness of the conducting film, the small quantity of heat generated at the point of short circuit by the sudden discharge of the condenser through that point is sufficient to cause the film of metal immediately surrounding the point of breakdown to be fused into minute globules. The separation of these globules from each other and from the surrounding metallic surface effectually isolates the point of breakdown, and the defect is thus instantly sealed up.

Condensers after having been tested for capacity, electrification, and insulation are made up into various forms and values. A very convenient 2 m.f. condenser is illustrated in Fig. 88. The condenser chiefly used for balancing

FIG. 89.—7·25 m.f. condenser.

purposes in duplex circuits is divided into two sections which can be used separately, but if joined by the strap shown in illustration Fig. 89 and Diag. 90, it has a total capacity of 7·25 m.f. by steps of $\frac{1}{4}$ m.f. The capacity may be varied by *inserting* pegs between the brass bar which carries one terminal and the brass blocks. The other terminal of the condenser is insulated and alone on the ebonite slab. In some cases, as with subterranean cable

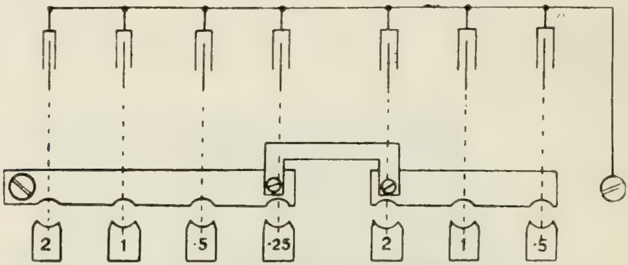


FIG. 90. Connections of 7¼ condenser.

circuits, it is necessary to use a condenser divided into three sections. The capacity values of this "triple" condenser are indicated in Fig. 91. Bear in mind that

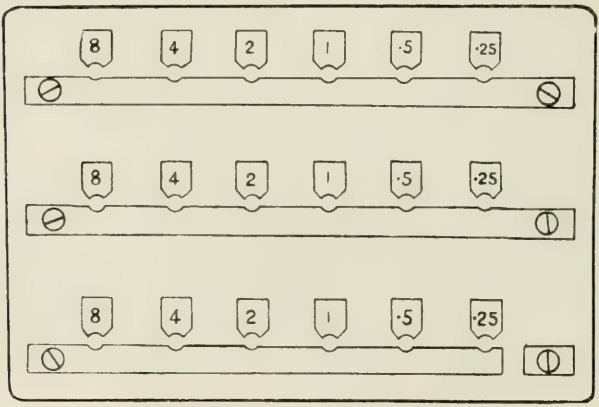


FIG. 91. -Values of "Triple" condenser.

capacity is added by *inserting* the pegs, not —as in the case of resistances—by withdrawing them.

CAPACITY TESTS.

When a condenser is charged there are equal quantities of positive and negative on its two plates. If these plates are connected through a galvanometer the condenser is discharged in a very brief interval, and by observing the swing of the galvanometer we can measure the quantity passing in the discharge. Now quantity, Q, depends upon capacity, K, and potential or E.M.F., V, as expressed in the

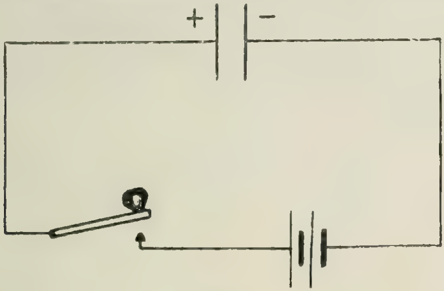


Fig. 92.

formula $K = \frac{Q}{V}$. If each condenser is charged to equal differences of potential by using the same battery, then the deflections of the needle will depend upon their relative capacities. With a condenser connected as in Fig. 92, when the key is depressed there occurs a rush of current

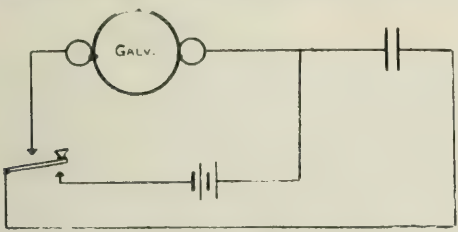


Fig. 92a.

into the condenser to satisfy its capacity; but all flow of current ceases when the full difference of potential has been attained, and when the key is raised the condenser will remain charged. If the battery, the condenser, and a ballistic galvanometer be placed in the circuit (Fig. 92a) depress key and charge the condenser. When the key rises to the top contact, the discharge passes through the galvanometer.

Take several readings of the discharge and compare their mean with that of the readings of a second condenser, which replaces the first one. The throw of the needle is proportional to their respective capacities.

To comply with the requirements of the Post Office specification the capacity of each section of a condenser is measured through a carefully calibrated reflecting galvanometer by taking the discharge after the section has been charged for a period of 10 seconds with an electromotive force of 30 volts.

The *insulation* test is made with an E.M.F. of 400 volts,

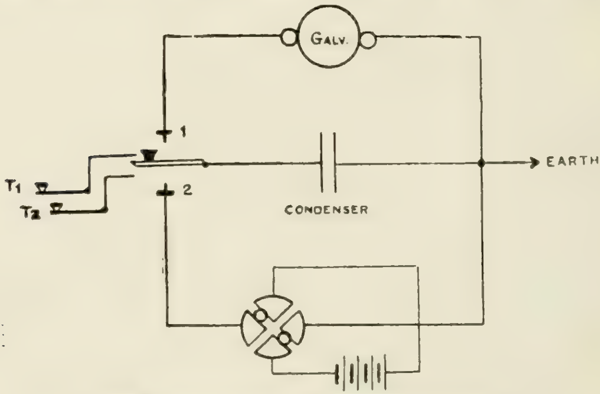


FIG. 93.—Discharge key and condenser capacity test.

and the minimum insulation allowed is 1000 megohms per microfarad, so that a 5 m.f. condenser should have at least $\frac{1000}{5}$, or 200 megohms insulation resistance. The reading is observed one minute after the battery is first applied to the condenser. This stipulation is very important owing to the phenomena of dielectric polarization termed electrification. The first deflection observed when the battery is connected to the condenser becomes gradually less as if the insulation resistance steadily improved. This *gradual* reduction of leakage during a continued application of the battery is evidence of the good condition of the dielectric, and irregularities in the fall are taken to indicate the existence of defects in the insulation.

For the purpose of these tests a primary or secondary battery giving at least 400 volts is required, and in addition to the reflecting galvanometer with the universal shunt box, short circuit and reversing keys or discharge key.

The latter is provided with two *trigger* hooks, and can be placed in three positions. Fig. 93 gives a diagrammatic view of a discharge key joined up for testing.

On pressing down the lever it makes contact with stud

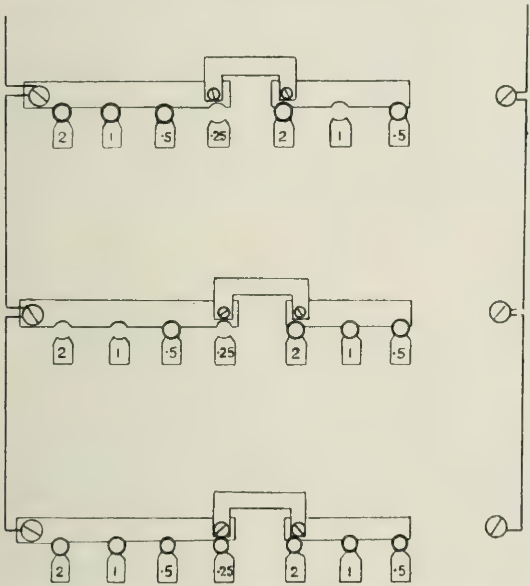


Fig. 94.—Three 7¼ m.f. condensers in "Quantity" for 17·25 m.f.

2, and is held in that position by trigger T_2; it is then in the "*charge*" position. By depressing T_2 the lever is released from 2 but is prevented from touching 1 by trigger T_1. This breaks the battery circuit, the lever being in the insulate position. When T_1 is depressed the lever rises at once and makes contact with stud 1. If it is required to discharge the condenser at once, by depressing T_1 a small piece of metal engages with T_2, moving it at the same time and allowing the lever to rise against the top contact. A battery reversing switch or key is also provided.

The capacity of a condenser varies directly as the extent of the surfaces of the opposing plates and condensers are generally joined for *quantity*, that is, with all the outer coating terminals connected together, and similarly the inner plates. Three $7\frac{1}{4}$ m.f. condensers joined to *add* capacities are shown in Fig. 94, and the total capacity inserted is 17·25 m.f. But condensers may also be joined in *cascade*, and the combined capacity is then less than the smallest condenser. The value of this capacity is calculated in the same way as combined resistances. For example, three condensers joined as in Fig. 95, having capacities of 2 m.f., 3 m.f., and 4 m.f. respectively, combined in cascade give a value equal to $\frac{1}{\frac{1}{2}+\frac{1}{3}+\frac{1}{4}}$, or $\frac{12}{13}$ m.f.

The joint capacity of *two* condensers in cascade is

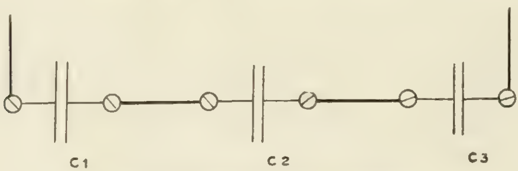


FIG. 95.—Three condensers in cascade.

ascertained like joint resistance of two conductors in parallel, namely, by the product of their respective capacities divided by their sum.

The use of condensers in central battery systems, cable and duplex working, will be explained in those sections.

INSPECTION AND TESTING OF TELEGRAPH INSTRUMENTS.

The figure of merit of the various instruments required for practical purposes in telegraphy should be ascertained by arranging a circuit of the particular instrument in series with a battery and rheostat. Before placing new apparatus in working circuits it should be thoroughly examined for mechanical and electrical faults,—platinum contacts clean, all adjustments true with pivots and bearings having minimum free movement. Instrument coils are tested for continuity and resistance, and insulated parts should have a minimum insulation resistance of a megohm. With new apparatus lacquer may have to be removed to insure proper electrical contact.

Two tests are made with differentially wound instruments: (1) for equal magnetization, in which the coils are placed in series with a key and battery; (2) for equal resistance by joining the coils in parallel. These connections are shown in Fig. 96, and if the instrument is unaffected

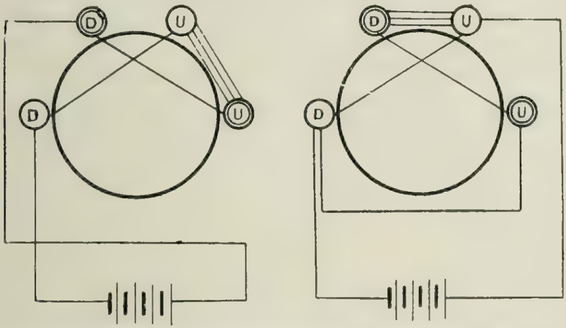


FIG. 96.—Standard relay as connected for differentiality tests.

by the same current passing in opposite directions in the first test, and by equal currents in the second, it proves satisfactory differentiality.

EXERCISE III.

1. (*a*) What are induced and uninduced needles? (*b*) Why are the Spagnoletti and Varley needles so shaped?

2. Compare the ordinary and polarized sounders, indicating their essential differences, with advantages and disadvantages.

3. A sounder requires 200 ampere-turns; how could this value be provided?

4. When is a relay employed, and what is its function? Is the line current increased by its introduction?

5. Is the statement correct that a relay only marks with a marking current; would reversing the "local battery" correct reversed signals? Explain fully.

6. Define the "Henry": what percentage decrease in the value of the self-induction of pattern "B" from pattern "A" of the standard relay?

7. How is self-inductance eliminated in resistance coils? Supply sketch.

8. Describe a non-polarized relay; can it be biassed? Give reasons for your answer.

9. What is a rheostat? Describe the pattern "D," and furnish a diagram of its internal connections.

10. Draw a diagram of S C simplex circuit (sounder or polarized sounder) with three stations. What happens if the up station depresses key while the intermediate office is sending? Explain fully.

11. Describe a sounder. How would you proceed to adjust one that was unreadable?

12. Give a plan, sketch or diagram of two $7\frac{1}{4}$ m.f. condensers, indicating therein what values you would use, and how you would connect them to obtain a total capacity of 10·5 m.f.

13. A condenser of unknown capacity is joined in cascade with a condenser of 30 m.f., and their joint capacity is 12 m.f. What is the unknown capacity?

14. What is the object of providing the capacity of a condenser in sections? Describe a "triple" condenser.

15. Describe briefly the theory, construction and use for telegraph purposes, of (i) an ammeter, (ii) a voltmeter, and (iii) a megger.

16. Describe the 5-terminal D C key with diagram of connections in each position. If the key was only sending out one current, how would you trace the fault?

17. What are the essential features of a tangent galvanometer as regards size and shape of the coil and needle? Give reasons.

18. Explain object and use of (i) skew scale, (ii) mirror, and (iii) controlling magnet of tangent galvanometer.

19. If a tangent galvanometer indicates 120 divisions with the 20th shunt, what is the total value of the current, and does the insertion of the shunt decrease the deflection to $\frac{1}{20}$th of its previous value? Explain fully.

20. The resistance of a galvanometer is 100^{ω}, and it is connected in circuit with a battery of 15 volts and 5^{ω} internal resistance. The galvanometer is shunted so that

$\frac{1}{10}$th of the total current flows in it. Find the resistance of the shunt and the current in the battery.

21. A battery of 1^ω is joined to a galvanometer of 4^ω and a resistance coil of 2^ω, and the reading is 100 divisions. What will be the reading if the galvanometer is shunted with 4^ω? (70 divisions.)

22. A battery of very low resistance is connected with a galvanometer of high resistance, and a deflection is produced. A shunt is now connected across the coils of the galvanometer and the deflection remains practically unaltered. Explain exactly why this is the case.

23. An accumulator of 10 cells is connected to two wires of 1000^ω and 2000^ω respectively. What current passes through each circuit, and how would these currents be affected if a resistance of 500^ω is connected across the battery terminals?

CHAPTER IV

TELEGRAPH LINES

Aerial.—Hitherto open lines have been preferred without hesitation, when there has been a choice, owing to their lower first cost, better electrical characteristics, and also because they are more accessible. But the invention and improvement of air-space cables, and the more general use of metallic return circuits, has led to a great extension of underground lines in the United Kingdom. Also the cost of maintenance of air lines in exposed districts, the unsatisfactory behaviour of those circuits, in bad weather, and the fact that when installing a large underground system the cost was less than that for overhead lines; all these disadvantages have been contributing factors in causing the aerial lines to lose their precedence. Nevertheless, in many circumstances it may still be more satisfactory and economical to use an air line such as are in England erected upon roadsides, railways, and canal banks. Routes must always be very carefully selected, as straight as possible, and upon public rather than private property on account of the trouble and difficulty experienced in the matter of wayleaves. For several reasons the sides of a railway provide the best facilities. In large towns the choice is between overhouse or underground; with the former the lines crossing thoroughfares must be from 30 to 35 feet above the ground. There is the further trouble with overhouse lines of damage to roofs and chimneys. Care must be taken with all aerial lines to prevent them falling in the public way if the poles and wires become broken.

The conductor chiefly used for telegraph lines has been iron, galvanized to prevent it rusting, of varying gauges according to requirement, and usually distinguished by their weight in lbs. per mile.

GALVANIZED IRON WIRE.

Weight per mile.	Diameter in mils.	Breaking weight in lbs.	No. of twists in 6 inches.	Ohms per mile.
600	209	1800	19	8·88
450	181	1350	23	11·84
400	171	1200	24	13·32
200	121	600	30	26·64
60	66 (used for binding and jointing.)		25 in 3 inches	

A range is allowed on the values of these standards.

In all overhead lines it is of the utmost importance that efficient joints should be made in the conductors and that the conductors should be thoroughly well bound to the insulators. The best style of joint is undoubtedly the Britannia joint (illustrated in Fig. 97).

The method of binding an iron wire to an insulator is shown in Fig. 98. Two laps of binding wire are taken round the line wire at *A*. The inner end is then taken round the neck of the insulator to the under side of the line wire at *B*, and after one complete lap is then taken back round the insulator to *A*, and lapped on the line wire for about a dozen turns to *C*. The other end of the binding wire is then taken from the under side of the line wire at *A* round the neck of the insulator to the upper side of the line wire at *B*, and then similarly lapped over the line wire to *D*.

For *insulators*, white porcelain has given best results, although glass, earthenware, and ebonite have also been used. The *Cordeaux* form (shown in Fig. 99) is termed a *double shed* insulator. The inner cup is kept dry during wet weather and so maintains its insulation, while the surface and shape of the outer cup assists the cleansing action of the rain. The screw thread allows the insulator to be removed from the bolt. When wires have to be terminated sometimes a Langdon insulator is used. The double-shed form with three grooves is shown in Fig. 100. The P.O. *terminal* insulator is a strong double-grooved form of the Cordeaux type (see Fig. 101).

The *spur* or *side knob* insulator is of the form shown in Fig. 102. The grooved boss fitted on the outer cup is

Fig. 97.—Britannia joint.

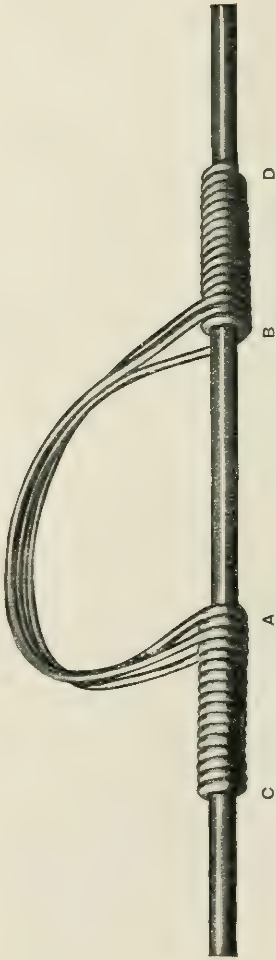


Fig. 98.—Method of binding an iron wire to insulator.

for the attachment of wires carried away in a vertical direction.

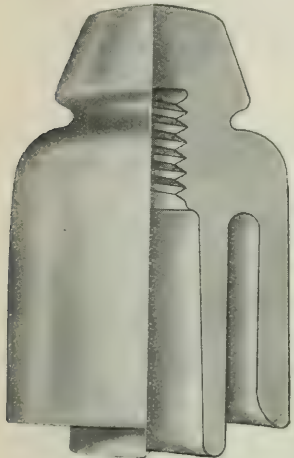


FIG. 99.—Cordeaux insulator.

FIG. 100.—Langdon insulator.

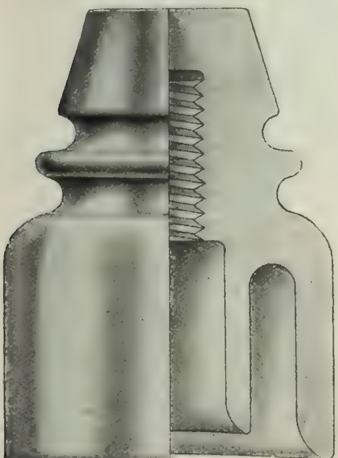


FIG. 101.—P.O. terminal insulator.

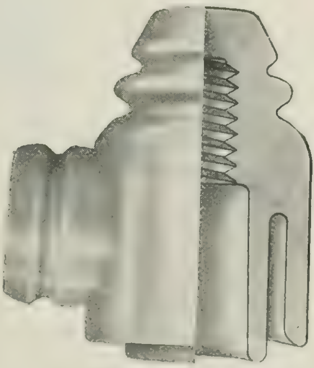


FIG. 102.—Spur insulator.

Where a line terminates and a covered leading-in wire is used then an insulator of special form invented by Messrs.

Sinclair and Aitken is provided (see Fig. 103). It is made in two parts which screw together; the inner cup has a deep groove cut to accommodate the covered wire so that it is well protected from the wet when the outer shed is screwed into position. This insulator is specially designed for use

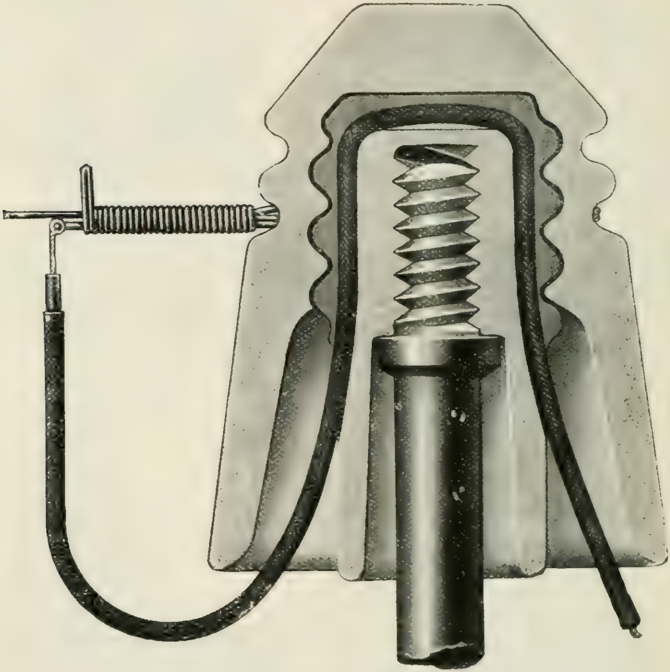


FIG. 103.—The Sinclair-Aitken leading-in insulator.

with rubber insulated leading-in wires; where paper insulated lead-covered leading-in wires are employed another form of the S.A. insulator is provided.

Copper wire.—Owing to its superior electrical qualities copper is preferred to iron for long telegraph circuits. The following table shows the requirements of the different gauges employed.

HARD DRAWN COPPER WIRE.

Weight in lbs. per mile.	Diameter in mils.	Breaking weight in lbs.	No. of twists in 6 inches.	Ohms per mile.
800	223	2400	15	1·09
600	193	1800	20	1·46
400	158	1250	25	2·19
300	137	950	30	2·92
200	112	650	20 } in 3 inches	4·39
150	97	490	25 } in 3 inches	5·85
100	79	330	30 } in 3 inches	8·78

A range is allowed on some of these standards.

The high tensile strength of hard drawn copper wire is imparted solely by the mechanical process of drawing it through dies slowly decreasing in diameter, and as a consequence the greatest proportion of the strength is near the surface of the wire, so that even a deep scratch on the wire at right-angles to its length will appreciably decrease the tensile strength, especially if the wire be also slightly bent or twisted at that point.

Further, if the wire be heated to any extent—for example, in the process of soldering a joint—the particles which have been forcibly arranged in a certain position by the drawing process rearrange themselves into a more or less crystalline condition, and the result is always a reduction in the tensile strength of the wire, the amount of reduction depending on the degree to which the temperature has been raised. Copper wire, therefore, must be handled with greater care and skill than is necessary with iron wire, and it also needs special protection from chafing against the neck of the insulator. With a moderate amount of care, however, many miles of copper wire can be erected without the slightest risk of failure.

In binding copper wire to an insulator, it is necessary, as previously stated, to protect the conductor from chafing, and a good method is shown in Fig. 104. A soft copper tape is first bound round the conductor for a distance of several inches, the ends being tightened up with pliers so that the

FIG. 104. Method of binding a copper wire to an insulator.

tape does not lie slack on the wire. A special binder is then employed made of copper wire flattened out at the ends and well annealed. This binder is placed round the neck of the insulator and the flattened ends brought one over and one under the line wire and twisted round over the layer of tape (as shown in Fig. 104). The binder is so made that about one turn of the unflattened wire passes round the conductor on each side and the ends of the binder should be twisted round the conductor in the same direction as the preliminary layer of tape; no soldering is needed.

Wood poles.—Whenever circumstances permit, wooden poles, on account of their cheapness, are employed for supports on telegraph lines.

The timber generally used is either red fir or larch wood, preferably of Norwegian growth, or grown under similar conditions as regards soil and climate. All poles should be straight and free from large or dead knots, with the annular rings closely pitched, indicating slow growth. The butt of the tree should be sawn across at the end, but it should not be reduced in diameter.

Creosoting is the most successful of the many preservative processes which have been devised with the object of prolonging the life of the wood poles. A number of poles are placed in a cylindrical vessel from which the air is exhausted, thus extracting the greater part of the moisture from the timber, and hot creosote is forced into the timber under pressure. About 10 lb. of creosote per cubic foot of timber is necessary to insure good results.

The dimensions of the poles on any line vary according to the number and size of the wires and the general local conditions. It should be remembered that as the height of the wires is increased, the diameter of the poles must be

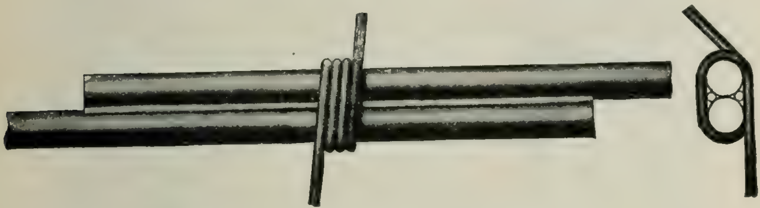


FIG. 104*a*.—Jointing of large copper and iron wires.

increased, but no general rule can be given for the height of the lowest wire on a line, this being governed entirely by local conditions.

Poles are usually set at a distance of from 60 to 75 yards apart, and on lines without curves the span is frequently increased to 80 yards. Wood poles should be planted to a depth of from 4 to 6 feet, the exact depth depending on the length of the pole and the character of the soil.

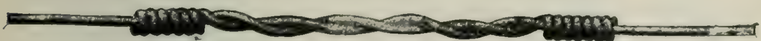


FIG. 104*b*.—Jointing of phosphor bronze wire.

The top of the pole should be protected from the weather, as timber is particularly vulnerable at the end grain; in ordinary cases a sheet metal or cast iron pole roof is employed, or a wooden finial where an ornamental finish is desired.

A single wire is sometimes carried on an insulator fixed at the top of the pole by means of a *saddle bracket* (Fig. 105); in such cases the sheet metal pole roof is fixed by the coach screws which hold the saddle bracket. On curves an iron saddle stay is employed with this bracket to prevent the bracket and the insulator bolt canting, the stay being secured to the pole by coach screws passing through triangular wooden blocks. When a line of wires is carried round the outside of a curve on a road, the insulator nearest the road on each arm is provided with a guard to prevent a loose wire overhanging the roadway and becoming a source of danger to traffic. This guard may be of the hook or hoop type, a disadvantage of the latter being that it assists the accumulation of snow.

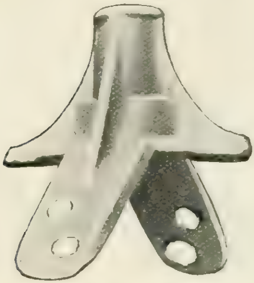


Fig. 105. Saddle bracket.

At angles and on curves the line wires exert a lateral pull on the pole, and in order to take up this stress, the pole is usually provided with a *stay* or a *strut*, the former being a device for taking a tensile stress and the latter a thrust. If the lateral pull is slight only one stay is used, but, where necessary, the size or the number of stays is increased. The upper end of the stay should be attached to the pole as near as possible to the resultant point of the combined lateral pull of the line wires. If the stay is fitted much above or below this point, the pole is subjected to a bending movement. The method usually adopted for fixing the lower end of a stay is to anchor a stay block under undisturbed soil, as shown in Fig. 108. A sound piece of an old pole 4 to 6 feet in length is frequently used for a stay block. The stay rod is screwed at its upper end for tightening purposes, and is provided with a ratchet nut which engages upon a bow (Fig. 106) to which the stay wire is spliced. Care should be taken that the stay clears the line wires by not less than four inches; where this clearance cannot conveniently be allowed a *stay crutch* or *outrigger* (Fig. 107) should be fitted to carry the stay clear of the line wires, as shown in Fig. 108, which also illustrates the positions of the other fittings, including pole steps. The illustration shows a wooden telegraph pole carrying twenty-five line wires, and this may be considered as a typical case of good overhead construction. The six oak arms are 48 inches long $\times$ $2\frac{1}{2}$ inches $\times$ $2\frac{1}{2}$ inches. The arms should always be fixed on one side (the "up") of the pole as shown, the pole being slotted to a depth of half the width of the arm. Each arm is fixed by a pole arm bolt, the nut and the large thick washer bearing against the arm. Whenever a pole is cut, for example, for the purpose of fitting an arm or a pole roof, the surface exposed by cutting should be coated with a mixture of tar one part, creosote two parts. The earth wire consists of galvanized iron wire weighing 400lbs. per mile. A short length is loosely coiled at the base of the pole and the wire is fixed at the back of the pole (or on the side remote from the roadway) by means of staples. It is then bent round the arm bolt so as to lie between the head of the bolt and the washer at the back of each arm and carried to the top of the pole as shown, to form a more or less efficient lightning conductor. All the arm bolts are thus electrically connected together and to earth. Each arm is also earth wired with No. 12 S.W.G. (standard wire gauge) soft galvanized iron wire. One turn of the wire is stapled round the arm between each pair of insulators, and the wire is also brought round the arm-bolt hole. The washer under the nut bears on this part of the wire, and consequently all the arm wires are also connected to earth. The chief advantage of earth-wiring is to prevent direct leakage between wire and wire, but of course it tends to lower the insulation resistance. The arms are fitted exactly 12 inches apart on the pole, and the

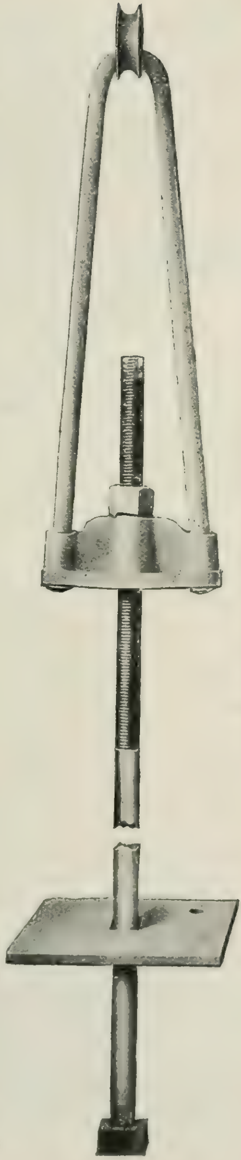


Fig. 106.—Stay rod with bow and ratchet nut.

pairs of insulator bolts on each side of the pole are set exactly at 12-inch centres, consequently the line wires on each side of the pole are symmetrically placed, each wire forming the corner of a 12-inch square. (This arrangement is necessary in the case of telephone lines if they are twisted, as they should be, to neutralize inductive effects.)

A *stay* is always used to support a pole on curves and angles in preference to a *strut*, but where there is not

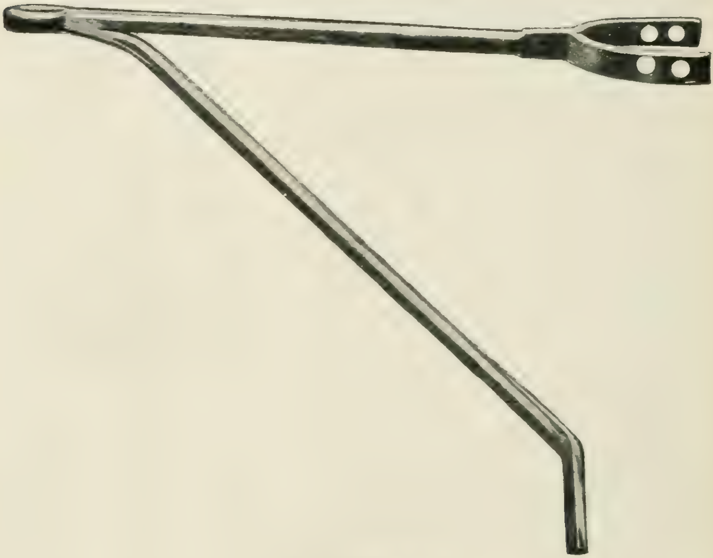


FIG. 107.—Outrigger.

sufficient space on the outside of the curve for a stay it is necessary to use a strut, which is placed on the inside of the curve. The strut should meet the pole as near to the resultant point as possible, and it is obvious that the angle between the pole and the strut should be as great as the conditions permit. An example of a strutted pole is given in Fig. 109. In this case the strut is of similar timber and dimensions to the pole itself. The top of the strut is shaped to fit the pole, which should not be cut to receive the strut, as such cutting would weaken

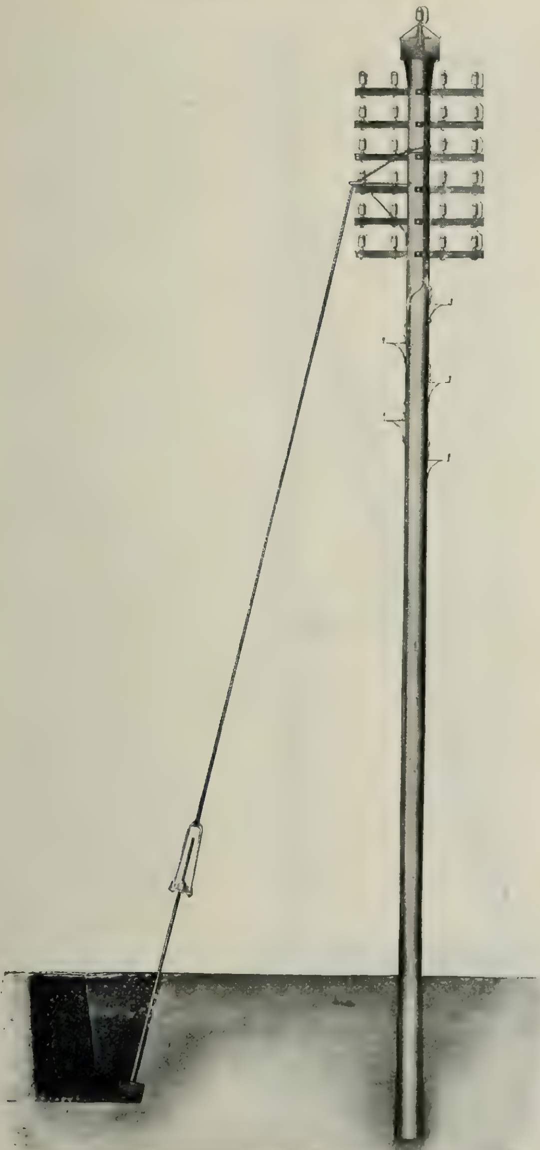


FIG. 108.—A 25-line wooden pole, with stay fitted on outrigger.

FIG. 109.—Pole with strut.

the pole at a point where great strength is needed. The stresses tend to force the strut into, and lever the pole out of, the ground, and in order to counteract this tendency stay blocks are fitted (as shown in Fig. 109) near the ends of the pole and strut. The scarfed end of the strut should be well coated with tar and creosote, and this end of the strut is then bolted to the pole. About midway between this point and the ground line is fitted a tie bolt.

In positions where the stresses are too great for ordinary single poles and where it is not possible to use stays or struts, *A poles* are frequently employed. A good example of an A pole is given in Fig. 110. The structure consists of two similar poles, scarfed and bolted together at the top, each pole being reduced sufficiently to form a joint varying in length from five to six feet, care being taken that the diameter of each pole is not reduced to less than two-thirds of its original dimension. The scarfed ends are coated with the tar and creosote mixture and are then bolted together by two diameter bolts. About half-way down the pole is fixed a tie-bolt with washers and distance tube. The bottom of each pole is notched to receive a pole brace, from six to eight feet long, which is fixed to the poles by diameter bolts, and on very heavy lines or at curves *kicking blocks* should be placed at right angles to the brace block, one above and one below the brace, as shown in the illustration, the lower block being placed on the inside of the curve. Oak arms 57 inches long, bored to carry 4 insulators, are used with A poles.

H poles are frequently employed on very heavy lines where provision has to be made for a large number of wires and in situations where the conditions demand a pole of considerable strength. As shown in Fig. 111, this structure consists of two similar poles erected 18 inches apart and braced together by a system of *trussing*. The bottom of each pole is notched to receive a timber brace, which is secured to the poles by diameter bolts, and at curves additional security

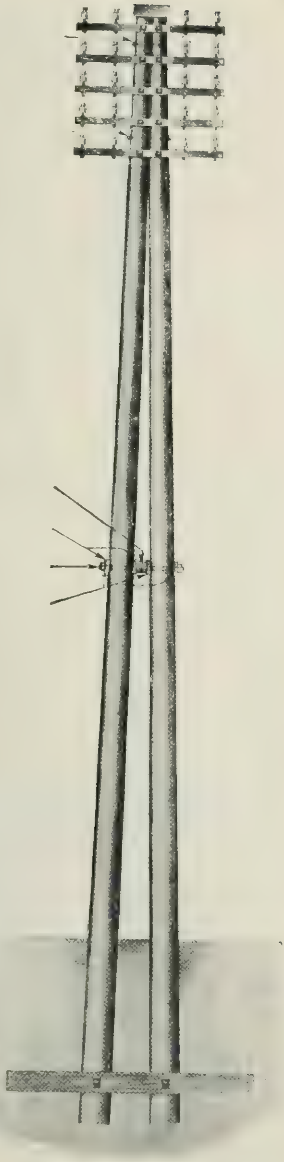


Fig. 110.—" A " pole.

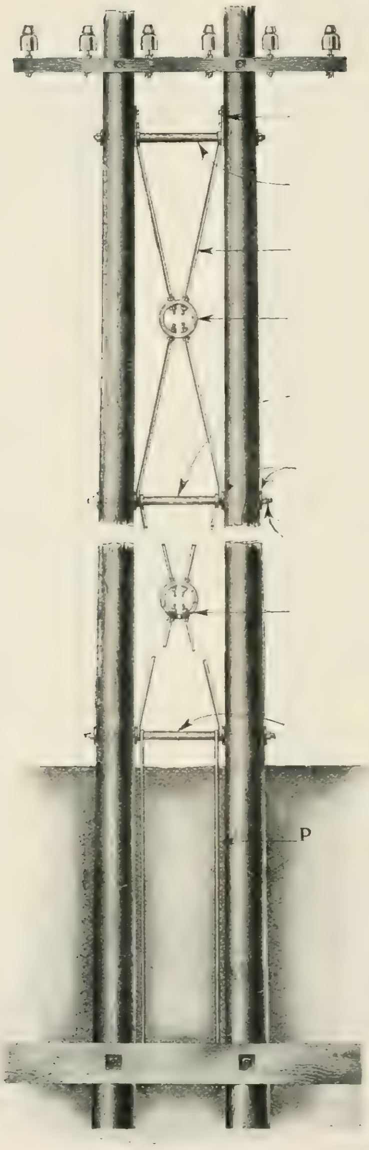


FIG. 111.—"H" pole.

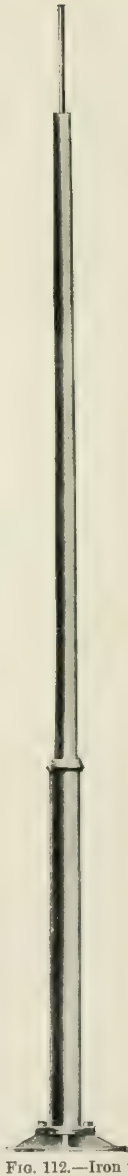


FIG. 112.—Iron pole with foot plate.

against lateral displacement is obtained by means of kicking blocks placed at right-angles to the ends of the timber brace, the lower block being placed on the inside of the curve. The *trussing* consists of horizontal tie bolts with washers and distance tubes. Between these tie bolts diagonal truss rods are fixed. The truss rods are secured at one end by the tie bolt and the other ends are united by a steel truss ring.

Oak arms 72 inches or 76 inches long, bored to carry 6 insulators, are invariably used with H poles.

Iron poles.—Although the initial cost of iron poles is considerably greater than that of wood poles of the same height and strength, iron poles possess numerous advantages and are frequently employed, especially in countries where wood is unsuitable owing to climatic conditions, the attack of insects, or transportation difficulties.

In cases where a line has to be erected over very rough or mountainous country iron poles possess a distinct advantage, as being composed of two or more sections they are conveniently handled. In many localities iron poles are also more durable and their use undoubtedly minimizes the cost of renewals and repairs ; and as their diameter is smaller than that of wood poles they offer less resistance to the wind, and consequently there is less risk of the line being wrecked through violent storms. Two types of poles are illustrated in Figs. 112 and 113, one fitted with a ribbed foot plate and the other with a pile base ; the poles fitted with a foot plate form a very rigid structure capable of withstanding sudden and heavy strains. Poles with a pile base possess the great advantage of being suitable for driving into the ground, thus obviating the expense of digging holes. They are also very firm and rigid directly they are erected, as the surrounding soil is not disturbed, and the wires can therefore be safely suspended at once.

Earth borers (Fig. 114) are devised to reduce the labour and cost of pole setting. In lightand sandy soils and where no greater depth than four feet is required these tools have advantages. The rotating motion conveyed by the handle heaps the earth upon the blade of the borer, which is then removed. By means of a long bar the soil is loosened before the borer is again inserted.

Fig. 113.—Iron pole with pile base.

Fig. 114.—Earth borer.

Hamilton pole (Fig. 115).—This type of iron pole has been specially designed for use abroad, and is constructed to combine strength and durability with lightness, portability and simplicity of construction. The poles are composed of 8-feet lengths of riveted steel tubes. These are either galvanized or heated and dipped into tar, the former process being more durable, although the latter cheapens the first cost. Each tube slips over the other and is strengthened on the inside by means of a stiffening ring. A pointed cap fitted to the top of the pole is detachable and may be taken off while the cap is driven on. The tubes of corresponding dimensions are perfectly interchangeable, therefore erection is readily carried out without skilled labour. Care should, however, be taken to see that the riveted seams are placed on alternate sides of the pole (as shown in Fig. 115). The corrugated base plate and the root of the pole are of tarred cast iron and are therefore unaffected by climatic influences. Three holes are drilled in the side of the root to allow trapped water to escape. The base plate screws on to the cast iron root (as shown in Fig. 115). For shipping the tubes are telescoped into one another, so that each pole then occupies a space 8 feet long by the diameter of the largest tube.

Overhouse lines.—When it is necessary to support a line of wires from the top of a building, parallel light tubular poles are invariably used (Fig. 116). These are supported by chairs which are placed on the roof, a layer of felt and sheet lead being interposed between the chair and the roof. The felt prevents any noise in the house due to the vibration of the wires, and the lead provides a firm seating for the chair and a protection for the felt. Such iron poles must have at least four stays, and longer poles made up of two or three tubes should have at least eight stays. Combination roof poles consist of two or three sections telescoped together, the length of the joint being 2 feet.

Aerial cables, " dry core " with a covering of vulcanized indiarubber and an outer covering of ozokerited tape or a still more durable pattern of lead-covered cable, are useful for overhouse and under bridges. Not being strong enough to support themselves they are suspended from a number of steel wires by raw-hide slings (Fig. 117). The hook is slipped over the suspender and then turned.

FIG. 115.—Hamilton pole.

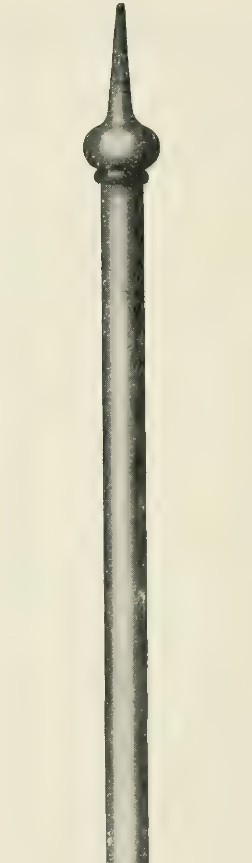


FIG. 116.—Overhouse iron pole.

Game guards.—In some districts the birds are warned of the presence of the line wires by small aluminium flags, which are attached to them so as to swing quite freely. Fig. 118 shows how the game guard is attached to a copper wire by means of a binder.

Wiring.—The coils of wire for the lines are supplied on drums which can be fitted on handbarrows. One end is drawn out and taken over the pole arms for some little distance. The wire is then pulled up and stretched by means of tension ratchet and draw tongs. The proper sag or dip is a matter of great importance, and allowance has to be made for the temperature at the time of erection. At 22° F. the tension applied should be one-fourth of the breaking strain (see Tables): this precaution must be taken, otherwise a line erected in summer might break with the next winter's frosts. The following formulæ give the relation between the length of the span, weight of wire, and stress:—

FIG. 117.—Aerial cable suspension

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

Where l = length of span in feet.
w = weight of one foot in lbs.
s = stress in lbs.
d = dip or sag in feet.

Lines are numbered as shown in sketch Fig. 119. When a wire is run on a saddle it is invariably known as *o*, then looking at the "up" side of the pole—that is the side facing the up-station—they are numbered as in the figure.

Underground lines.—Prepared guttapercha covered wires have been the form of cables for underground work. These were generally laid in cast-iron pipes as far as possible under the footway upon the roads at a depth of two feet. Flush boxes were provided at distances of 100 yards or less apart.

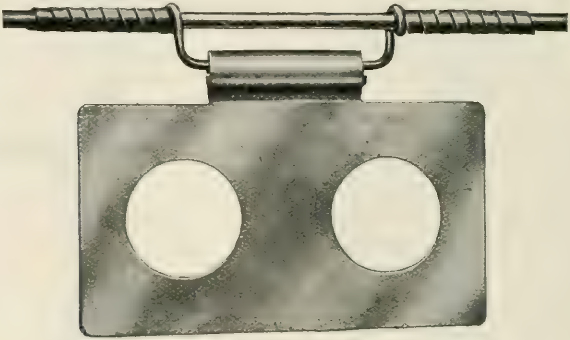


FIG. 118. Game guard.

The form of cable now used for underground work is variously termed "dry core," "air-space," and "paper"; its efficiency depends upon the presence of dry air between the paper insulated wires. The conductors, which are of the highest conductivity copper wire, vary in gauge, and the cables are frequently of a composite type with multiple twin wires and single screened conductors. As an example, one pattern contained twenty-eight 200 lb. conductors twisted in pairs, fifty-six 150 lb., also multiple twin, and thirty-four 70 lb. single screened conductors.

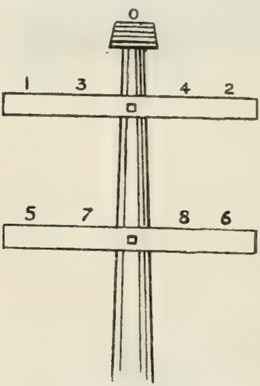


FIG. 119. -The numbering of telegraph lines.

Other patterns of cables conforming to the same general conditions are made differing only in the means employed to obtain a continuous loose wrapping of paper on the wires, thus providing as great an air space as possible and a reduced capacity. The paper used for "pairs" is distinguished by various colours, which may be red, white, blue, or green, and there is also a colour difference in the cotton thread which is wound to keep the paper in position. The wire bound with the red string is always the *A* wire of the pair, that lapped with white string forming the *B* wire.

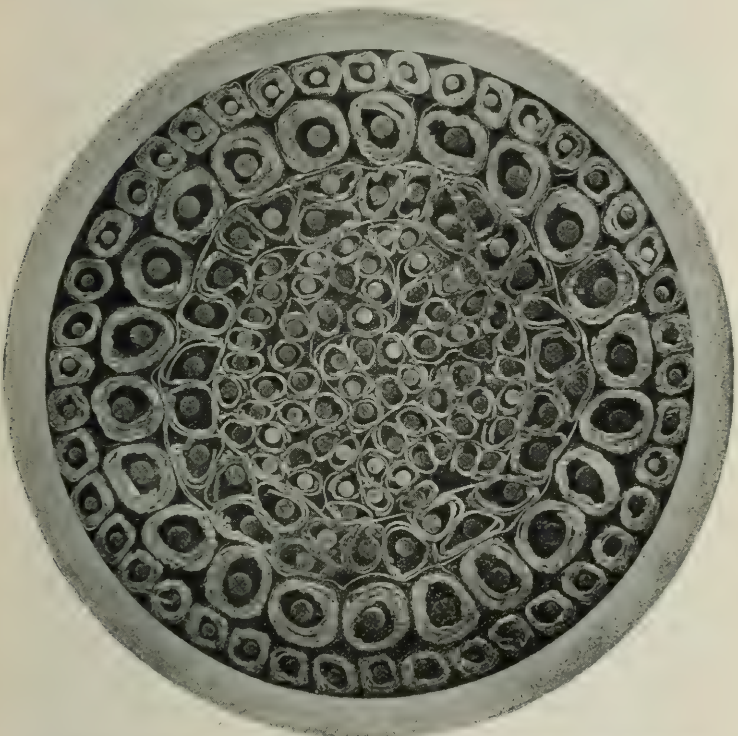


Fig. 120.—A full-sized section of a composite telegraph and telephone cable made by the British Insulated & Helsby Cables. Considerable quantities of this cable are in use by the British Post Office on their underground routes. The cable illustrated contains pairs of 150 lb. and 100 lb. conductors; twenty-two single "screened" conductors weighing 200 lbs. per mile, for telegraph purposes, and forty-two single-screened 70 lb. conductors—162 wires in all.

The single conductors have, in addition to the paper wrappings, a spiral wrapping of copper tape which forms a continuous conducting tube. These screened conductors are generally placed in an outer ring and their copper wrappings have direct earth connection by contact with the lead sheathing. The copper tape prevents variations of potential, within or without the conductors, interfering with one another according to the principle demonstrated by Faraday's experimental researches. The lead sheathing forms a continuous tube, thus preventing the ingress of moisture.

A specimen section of a large "dry core" cable is shown in Fig. 120. The sheathing of some cables is an alloy with 3% tin which is stronger than lead alone and also better resists corrosion or chemical action. In America much trouble has occurred through faults produced by the electrolytic action of stray currents from electric supply systems. The lead tubing is perforated, permitting the admission of moisture and thus breaking down the insulation. Water will find its way into the cast-iron pipes, and chemical action can then take place between the iron and lead. The admission of moisture is prevented as much as possible by packing the lids of joint boxes with yarn, grease and whitening; also large quantities of petroleum jelly are used when drawing in the cables, thus giving the lead a protective covering. Leakage currents are diverted by connecting or "bonding" the lead sheaths and iron pipes together by means of thick copper wire or bands and making good earth connections at suitable intervals.

Jointing must have special attention owing to the hygroscopic character of the paper. A thoroughly dried paper sleeve is first drawn over the paper covering of one of the wires to be jointed. The two conductors are bared, cleaned and then tightly and evenly twisted together; possible injury to them by pliers must be carefully avoided. The twist turned back parallel to the length is not soldered, and the paper sleeve is brought over the joint and tied. All the joints are not made at one point, and the diameter of the splice is kept as small as possible by suitable space being given. A final paper wrapping is given to the whole of the jointed wires, and over all a lead sleeve is pulled, the latter being secured to the lead sheathing by a plumber's wiped joint.

The lead sleeves are provided with a screw cap air nozzle and the joints are tested by the use of air pressure and soap suds. At stations the cables terminate in *connection boxes.*

These consist of cast iron boxes having two compartments separated by a perforated cast iron sheet or diaphragm. Electrical connection between the two chambers is provided by insulated metal pins which are fixed airtight in the perforations. The cable conductors are soldered to the connection pins, whose other ends are joined to the leading-in wires which consist of silk and cotton covered conductors in leaden-sheathed cables. The lid of a cable connection box is fixed by nuts, bolts, and lining to insure the compartments being perfectly airtight.

Submarine cables.—Fig. 121 gives a full-sized section of a submarine cable of the type recently laid between Great Britain and the Continent. The four seven-strand copper conductors offer a resistance of about 6^{ω} per mile and the mileage capacity and weight are about ·25 m.f. and 140 lbs. respectively. Each conductor is insulated with three alternate layers of guttapercha and Chatterton compound. The four cores are wound helically round a centre of tarred hemp and then covered with a layer of cotton tape treated with ozokerit. Over this is wound a brass ribbon as a protection against the teredo, a submarine boring worm. The cable is then sheathed with sixteen tarred galvanized iron wires and given a final covering of two layers of yarn which has been soaked in a mixture of pitch, bitumen and resinous oil. The shore ends are more strongly armoured by a number of external steel wires.

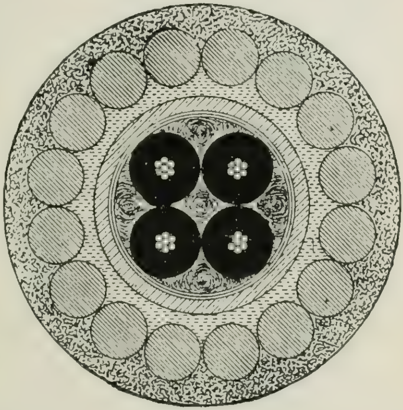


FIG. 121.—Section of a 4-conductor submarine cable.

A short length of "air space" cable was tried to the Isle of Wight (3 miles) in 1897, and some have since been laid across the Irish Sea.

The number of cables in the world is estimated at about 2000, and of course they vary somewhat in construction. The "all-British" Pacific cable is perhaps the most interesting, and the greatest length yet laid in one piece occurs in one part of this cable, the section from Fanning Island to Vancouver, which are distant about 4000 nautical miles.

Testing Instruments employed, and Methods of using them in the Simpler Tests.

The *Wheatstone Bridge*, one of the most useful of testing instruments, is formed by a combination of resistance coils. Three separate sets are provided, and for measuring the value of an unknown resistance the four are so placed that when balanced with the three known

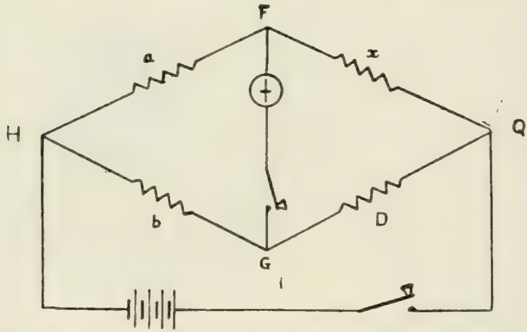


Fig. 122.—Conventional arrangement of Wheatstone Bridge balance.

values the fourth can be calculated. This is conveniently explained by means of a parallelogram, although in practice it never bears this form. Consider Fig. 122. The two circuits *HaFxQ* and *HbGDQ* have the same difference of potential at the ends *H* and *Q* with the negative battery pole at *H* and the positive at *Q*. Therefore along each path it is possible to find points having a corresponding fall in potential, and should a galvanometer "bridge" two such points, then no deflection would result, but if there is a potential difference between points so joined then a current passes. Let *a* be 100^ω and *x* 1000^ω; *b* 1000^ω and *D* 100^ω; also consider the battery reversed, *i.e.* with the positive pole at *H*. Then, since *the E.M.F. expended, or the fall of potential, in any part of a circuit is directly proportional to* *the resistance of that part as compared with the remainder of the circuit*, it follows that more E.M.F. is used in x than in a, and also a greater fall in b than in D. Consequently F is at a higher potential than G, and if the E.M.F. is 22 volts at H the difference between F and G is 18 volts. For $\frac{a}{x} = \frac{1}{10}, \frac{b}{D} = \frac{10}{1}$, and for every 11 units of voltage the proportions used are a 1, x 10, b 10, and D 1. Now let a and b be 1000^{ω}, x 1000^{ω}, but D 100^{ω}, then in the upper path half the fall occurs between H and F, because a and x are equal, but in the other path $\frac{10}{11}$ E.M.F. are expended in b, therefore F is still at higher potential than G. If,

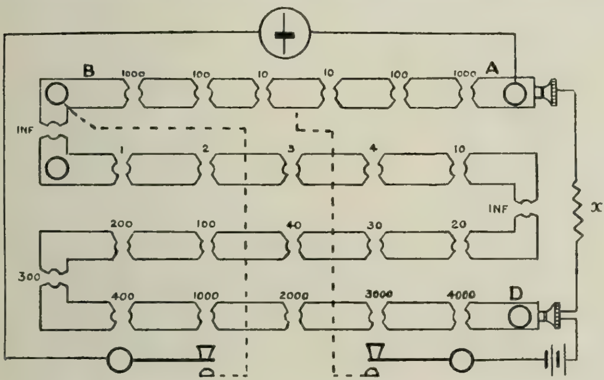


Fig. 123.—Diagrammatic plan of Wheatstone Bridge with resistance values.

however, we then make x 100^{ω} and D 1000^{ω} a current will pass from G to F. It is evident therefore that the resistances may be so adjusted that F and G have the same potential and no current pass through the galvanometer. This denotes a balance, and the following proportion is then true :—

$$a : x :: b : D \text{ or } \frac{a}{x} = \frac{b}{D} \therefore x = \frac{aD}{b}.$$

In the actual instrument (shown diagrammatically by Fig. 123) the three resistances a, b, and D are in a box. Their values are varied by using brass pegs fitting between brass blocks arranged in four rows. The sections a and b are called the "ratios" and D the "rheostat." The best resistances to use in the ratio arms may be determined by experiment, but as a general rule, the higher the resistance (x) to be measured, the higher should be the values of a and b. To avoid possible induction effects upon the needle of the horizontal galvanometer used in "bridge," the battery key should be first depressed and not raised until after the galvanometer key, which should be only momentarily depressed. The theoretical range of values measurable by the Wheatstone Bridge is from $\frac{1}{111}^{\omega}$ to $1{,}233{,}210^{\omega}$, but in practice small values would be measured more accurately by means of a "*slide wire*" or *metre bridge*. A straight german-silver wire is fixed on a board parallel to a metre scale and the ratios are formed by the position of a slider or key to which the galvanometer is attached.

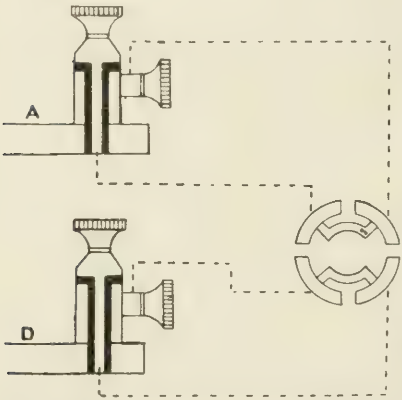


FIG. 123*a*. Double terminals of Wheatstone Bridge and reversing switch.

When testing with the Wheatstone Bridge the resistance to be measured is joined as shown in Fig. 123. At the points A and D there are two terminals insulated from each other by an ebonite tube, and by using the reversing switch (Fig. 123*a*) the connections between these terminals are changed over. Thus the direction of the testing current through x may be reversed without altering the pole of the battery or affecting the direction of the galvanometer's deflection, which would probably tend to confusion.

Test for line or conductor resistance.—When there are several wires between two stations the individual resistance of any of them can be obtained best by avoiding the use of earth return. The distant station is requested to bunch them together and the testing office then measures the resistance of two at a time with the Wheatstone Bridge. Say, for example, there are three wires a, b, and c. Measure the loop of a and b, a and c, then b and c. The result of the first two pairs added together is $2a + b + c$; from this subtract the value of the third pair, $b + c$, and the remainder is twice a. In a similar manner the resistance of any of them could be calculated.

The position of an earth fault can be found by looping the faulty wire with another good conductor. The resistance of the metallic circuit thus formed if not recorded is first measured by connecting both wires to the Wheatstone bridge in the ordinary way (Fig. 123), the one earth in the circuit, at the fault, having practically no effect. Then the positive pole is earthed (Fig. 124) and with a balance the

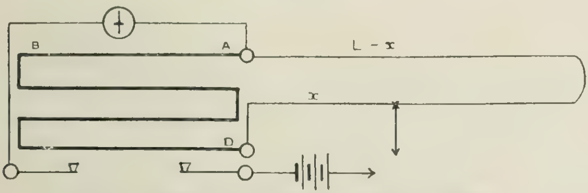


Fig. 124.—Varley loop test for position of earth fault.

following proportion exists: (let L be the ascertained value of the loop and x the portion from D to the fault)—

$$\frac{a}{L - x} = \frac{b}{D + x}, \therefore a(D + x) = b(L - x) \text{ and}$$

$$aD + ax = bL - bx, \text{ i.e. } ax + bx = bL - aD, \therefore x = \frac{bL - aD}{a + b}.$$

If the ratios are equal then $x = \frac{L - D}{2}$ or $\frac{\text{loop} - \text{rheostat}}{2}$.

Dividing the result of this "loop test" by the conductor resistance per mile gives the distance of the fault from the testing station.

In some cases the Wheatstone Bridge can also be employed for testing the *insulation resistance* of a line. The conductor is disconnected at the distant station and the positive pole is earthed. As the resistance to be measured is generally greater than the range of the rheostat arm, the ratios a and b are adjusted, a being the greater. The value obtained is the total insulation resistance of the whole line and must be *multiplied* by the length of the line in *miles* if the insulation resistance per mile is required.

To test for a contact.—The distance of a contact fault can be ascertained by using a Wheatstone Bridge and having one of the lines earthed at the distant end where

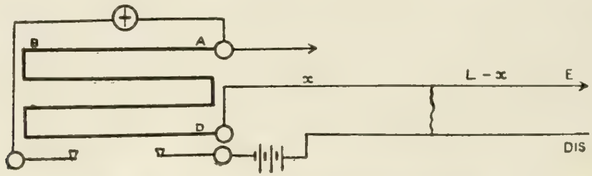


FIG. 125.—Varley test for position of contact fault.

the other is disconnected (see Fig. 125). It should be observed that A is direct to earth and that the battery lead is via the disconnected wire and through the contact. Presuming that the resistance (L) of the earthed wire is known or calculated, then, when balanced, $\frac{a}{L-x}=\frac{b}{D+x}$, etc. If a third wire is available it should in preference be

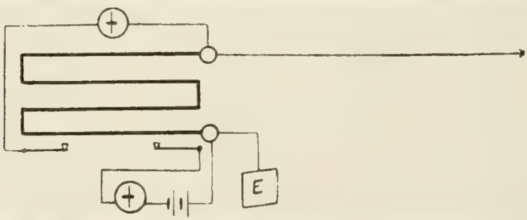


FIG. 126.—Pomeroy's first test for resistance of earth connection at E.

used and joined to A while the distant station loops it with the wire previously earthed.

Method of testing earth.—To obtain the value of the earth connection resistance at an office two tests have been devised.

In the *first test* the connections are made as shown in Fig. 126 with a line (L resistance) earthed at its far end while the earth plate (whose resistance is required) is joined to D. When balance obtained—

$$\frac{a}{L+x} = \frac{b}{D} \text{ or } aD = b(L+x), \text{ i.e. } aD = bL + bx.$$

With the *second test* another line is used as a battery lead which must have an earth connection at a place apart from the other two, the connections being as in Fig. 127. Then when balanced $\frac{a}{L} = \frac{b}{R+x}$ or $aR + ax = bL$. Subtracting this result from that of the first test $aD - aR - ax = bx$, hence $a(D - R) = x(a + b), \therefore x = \frac{a(D-R)}{a+b}$. Note the value of the rheostat is not the same in both tests, hence the use of

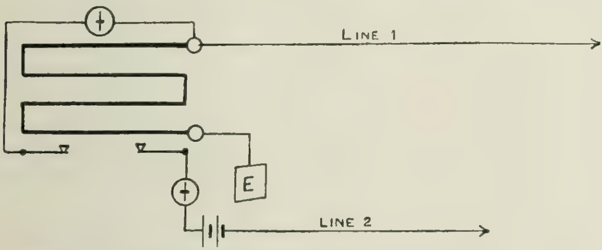


FIG. 127.—Pomeroy's second test for resistance of earth connection at E.

D and R; also that the battery pole is changed to insure the current shall be in the same direction at the earth plate in both tests.

Submarine cable tests.—When a cable is being laid a constant test is applied to ascertain the condition of the conductor and its insulation. The ship is generally regarded as the testing station except in the case of very long cables, when tests for continuity and insulation are made at both ends. If a cable is only of moderate length and contains several conductors, these are joined in series with a small battery and galvanometer on board the ship, while the "shore" has also a galvanometer in the circuit. Any break in the conductor will be observed by the failure of the permanent current and the absence of the proper deflections on the galvanometers. A continuous test is also applied to the insulation of the cable by the high E.M.F. of a 200-cell battery with one pole earth connected. The shore end of the cable being always insulated, the leakage of current through the covering of the cable to the sea is observed by the deflection of a very sensitive galvanometer. Any abnormal change in its indications as the cable is being submerged points to the existence of a fault and its position is at once sought for. Should an injury expose the conductor we have an earth fault whose locality may be ascertained by using the Wheatstone Bridge and the loop test. The resistance of the cable thus determined will, in conjunction with the observation at the shore end, give the required data for calculating the position of the leak. If the conductor is broken within the cable so as to cause a disconnection the distance of the fault can be found by ascertaining the capacity of the cable in the same way as when testing the capacity of a condenser (see p. 113).

An earth fault in a short cable can be masked for a short time by using a positive current, which has the effect of creating an oxide of the metal at the broken point, thus sealing up the fault temporarily, although the conductor is gradually eaten away. A negative current has a reverse effect and by opening the fault will thus entirely break down communication. For this reason cables are tested with negative currents to line which may discover small faults that positive currents would seal up.

As an instance of the durability of cables insulated with indiarubber it may be mentioned that a few years ago a cable was raised after twenty years' submersion in the West Indian waters. It was still in perfect electrical condition; the copper conductor had not suffered from the action of any sulphur in the rubber and the state of the insulation was mechanically good.

Insulation resistance testing. Every line has two separate and distinct resistances: (1) that of the conductor, which is the resistance of the wire itself; (2) that of the insulation, which is the condition of the dielectric acting against the escape of the current to earth. The latter may be the resistance of a cable covering or of pole insulators on an aerial line. If the insulation was perfect (an impossibility) no loss of current would occur; the received current would equal the current sent. The value of the insulation resistance, if below 1 megohm, may be determined by the Wheatstone bridge, as already described.

The "*megger*" (p. 95) can be used for measuring resistances between 50,000$^{\omega}$ and 100 megohms, and is simpler and more accurate for high resistances than the Wheatstone bridge. The generator must be driven at a fairly uniform speed at, or above, the prescribed number of revolutions per minute, to maintain a constant voltage. The resistance can be read off the scale without any calculation.

When testing a cable in good condition it is observed that the first rush of the current due to the capacity *gradually* decreases, and after one minute's application of the voltage the insulation resistance appears to reach a normal value. This apparent improvement of the insulation is due to the effect known as "*electrification*," which is mentioned earlier. For ordinary insulation tests it is sufficient to take the readings after one minute's electrification.

For the common faults in land lines the procedure is as follows :—

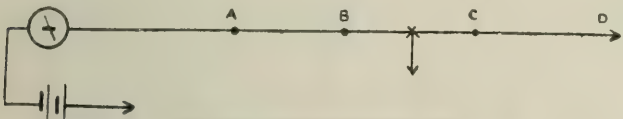


FIG. 128.—Localizing earth on a line.

Localizing earth on a line (see Fig. 128).—Station *D* is asked to *disconnect*. A current is sent from the testing station through a galvanometer and the degree or distance of fault roughly judged by the deflection obtained. The stations from the terminal inwards disconnect successively, when advised, the testing office awaiting the reply, say from *C*, and testing before communicating with *B*. It will be then ascertained that the fault is in the section beyond the last disconnection by the removal of the galvanometer's deflections.

In the case of a *disconnection*, testing outwards, the stations are asked in turn to *earth* the line, and the presence of a deflection proves the continuity of the circuit, whilst the absence of a deflection will denote the faulty section. To reduce the number of tests a central station may be first advised. When testing for *contact*, get a station through which both wires pass, and beyond the fault, to disconnect both lines. *Put an earthed galvanometer in one* *line and an earthed battery in the other* (see Fig. 129). The intervening stations, inwards, disconnect both lines until the deflection is removed, thus indicating the fault in the section beyond the last disconnection.

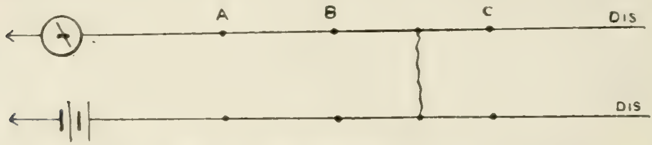


FIG. 129.—Localizing contact on a line.

Faults in instruments can be located by remembering the connection of the apparatus or referring to a diagram and observing the effect of sent or received signals. Also with short lengths of covered wire the apparatus connections may be bridged to discover the faulty instrument. A

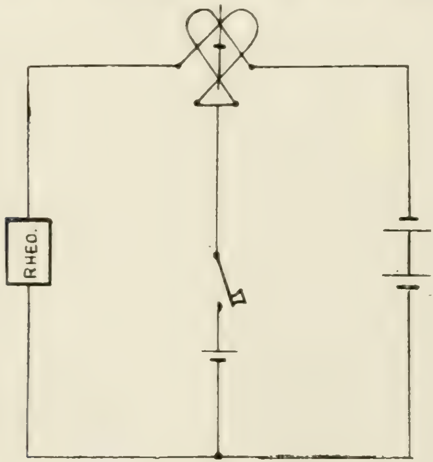


FIG. 130.—Differential test of battery resistance.

reasonable application of the rules above given for faults in lines will enable similar troubles in working sets to be readily traced.

Measurement of battery resistance.—A very simple method is indicated in Fig. 130, if an even number of cells are to be tested. Place the two halves in opposition and balance the resistance of the whole with a rheostat through a differential galvanometer.

The half deflection method is suitable for high resistance such as that of a primary cell or battery. Join it in series with a key tangent galvanometer and rheostat (as shown in Fig. 131). Suppose with no resistance in R and using the $\frac{1}{320}$ shunt a deflection of 140 divisions is obtained, and then to halve the deflection 20^{ω} is inserted. Now the halving of the deflection indicates half the current, and this would result from doubling the resistance previously in the circuit. That is, the *added resistance* equals the former total resistance or $20^{\omega} = G + x$. The shunted galvanometer equals 1^{ω}, $\therefore x = 20 - 1$. If resistance, say 30^{ω},

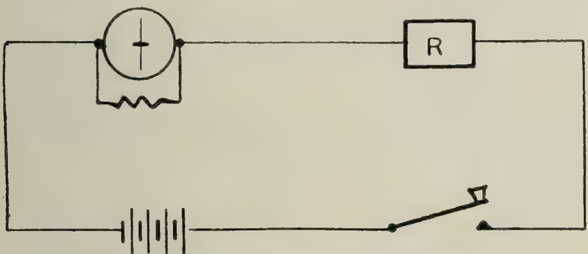


FIG. 131.—Half deflection test of battery resistance.

is inserted in R to obtain a suitable deflection before halving, and to reduce a deflection of 120 divisions to 60 divisions R was increased to 100^{ω}, then the *added resistance* is still equal to the amount previously in the circuit. That is :—

$$70^{\omega} = R + G + x = 30 + 1 + x, \text{ or } x = 70 - 31.$$

The internal resistance of a secondary cell, or cells subject to polarization, may be determined by means of an ammeter and voltmeter. First taking the E.M.F. reading, e_1, when the cell is not working. Next the E.M.F., e_2, and also the current, c, when the battery or cell is joined to a known resistance. As the difference in voltage between the open and closed circuit is due to loss in forcing the current through the internal resistance (x) then $x = \frac{e_1 - e_2}{c}$

For example, if $e_1 = 5$ volts $e_2 = 4$, and c 5 amperes, then $x = \frac{5 - 4}{5} = \cdot 2^{\omega}$.

Measurement of E.M.F. of batteries. The simplest means is by using a voltmeter and obtaining direct readings, but two other methods are very practical with primary cells and batteries.

(1) The *direct deflection* or *equal resistance* method depends upon the fact that if the resistance of a circuit is unaltered then the current therein will vary directly as the E.M.F. In practice a tangent galvanometer is used with a rheostat and the circuit resistance made sufficient to render the different values of the cells' internal resistance negligible. Consequently with different cells substituted in a circuit of given resistance the different currents and their deflections will be in relative proportion to the varying voltages of the cells.

(2) *Equal current* method. In this test the cell or battery is joined to a galvanometer, key and resistance (as in Fig. 131) although the galvanometer need not be a tangent. A suitable deflection is obtained by inserting resistance in *R*. With the different cells the resistance is varied to produce the same current, therefore by Ohm's law the different voltages are in direct proportion to the resistances.

Exercise IV.

1. Describe the earth wiring of a telegraph pole, with sketch.

2. (*a*) What descriptions of timber are ordinarily used for telegraph poles in Great Britain? (*b*) Describe concisely one method of preserving such poles from decay.

3. Sketch and describe a "stay" and a "strut"; explain how fixed, and the circumstances which determine their use.

4. Explain how a copper wire is attached to an insulator and supply a sketch.

5. How would you localize an earth fault in an underground wire if you had another available?

6. If three lengths of cable having respectively an insulation resistance of 300, 400, and 500 megohms be joined in a continuous length, what will be the insulation resistance of the whole cable? (127·6 Ω)

7. Explain briefly the meaning of insulation resistance,

and what is the relation between the "total insulation" of a circuit and the "insulation per mile"?

8. What are the values of the resistances in the three arms of the Wheatstone bridge? How would you measure $\frac{1}{111}^{\omega}$ and $1{,}233{,}210^{\omega}$, the extreme limits theoretically possible?

9. Given four wires *a*, *b*, *c*, *d* between two stations, find the resistance of *d*.

10. Show how to test for contact when a third wire is available.

11. Explain how to find the resistance of an earth connection.

12. How would you test the internal resistance of a battery of 10 Daniell cells?

13. Why is it necessary in localizing a contact fault to use an earthed galvanometer and an earthed battery?

14. A contact exists in the apparatus of a D.C. dx. Universal battery set. How would you localize it?

15. A battery of 5^{ω} resistance has its poles connected by a resistance of 10^{ω}. The potential difference between the poles is observed to be 15 volts; what is the E.M.F. of the battery?

16. Describe the process for laying and jointing a dry core cable.

17. Give a description of an iron pole suitable for overhouse lines and the method of fixing.

18. How would you measure the following resistances by means of a Wheatstone Bridge: 5^{ω}, 5000^{ω}, and $500{,}000^{\omega}$?

19. Describe, with sketch, one of the following types of insulator: "Langdon," "side knob," or "Cordeaux."

CHAPTER V

TELEGRAPH SYSTEMS

The Simpler Systems of Manual Telegraphy

In single current working it is necessary to provide the receiving instrument with opposing spring tension or definite bias to insure the resumption of the normal or spacing position after the cessation of the line signal. This antagonistic condition is constant, and therefore variations in the value of the received current produce irregularities in the signals recorded; hence this system requires the strength of the current from the various stations in the same circuit to be maintained approximately equal and unvarying. Owing to the leakage from aerial lines in wet weather it is stipulated in the United Kingdom that whenever it is not certain the insulation of the line and the condition of the batteries can be maintained at the highest standard without special expense, single current circuits of 10 miles or more should not be established.

Single current working is also unsatisfactory upon any but very short lengths of subterranean and submarine cables owing to their electrostatic capacity. The distortion and retarding effect in such cables being approximately twenty times that of the same length of aerial line wire. (In this connection it may be mentioned, however, that the behaviour of cables is now being improved by a practical application of Prof. Pupin's theory of loading cables with inductance coils at uniform distances apart.) The capacity of a line must be satisfied before the maximum value of the current is received at the distant end, and not only does this charging of the line occupy definite time, but the discharge must also occur before the next signal can be properly received. Putting the line to earth at the sending end after each signal provides a fall to zero potential. But if, instead of earthing the line, the battery pole is changed, this imposes a reversed potential equal to twice the previous difference. For, suppose at first the positive pole be used, then when line earthed the fall of potential is positive to zero. The application of the negative pole instead of earth gives the potential value of the battery *below* zero and the fall is from positive to negative, or double what it was before, and the discharge of the line is hastened.

In consequence, therefore, of the increased speed of working attained, the more constant adjustment of apparatus possible and greater economy effected, double current working is almost always adopted in the Post Office service for direct working circuits. The difference between single

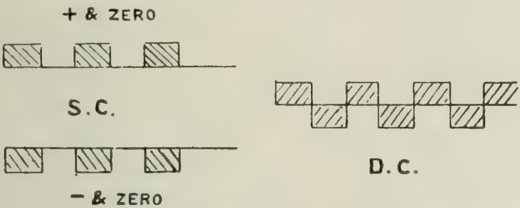


FIG. 132.—Theoretical representation of single currents and double currents.

and double current systems is shown diagrammatically in Fig. 132. Between the signals in the former there are intervals of no current or zero periods, whereas in D.C. working the periods of one current alternate with another in reverse direction, so that practically there is always a current on the line, and signals are formed by changing its direction. Consequently by this system variations in the strength of the current are self-adaptive, equally affecting both directions, and *polarized* receiving instruments can be worked without bias (their most sensitive position). There is a further advantage of D.C. working in connection with the limited use of *non-polarized* instruments. It is that therein the amount of *residual magnetism* (the polarity remaining after the withdrawal of the magnetizing force) due to the first current is rendered ineffective by the reversed induction of the succeeding current.

The diagram, Fig. 133, shows the connections of a D.C.

circuit, relay with sounder. The galvanometer is the S.C. pattern.

With the key-switch in the sending position the two internal switches make contact with their right-hand studs, disconnecting the relay and joining the battery to the line (see Fig. 50).

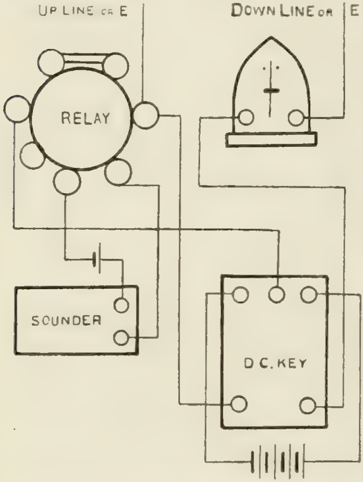


Fig. 133.—D.C. relay and sounder simplex.

The key contacts are adjusted to give a small break before reversing. Working currents required are:—

Standard relay "A" with coils in series
7 to 10 m.a.

Standard relay "B" with coils in series
10 to 15 m.a.

and double these values with the coils in parallel. The E.M.F. necessary is provided by using large Daniell cells, the number being calculated to allow an additional 25% for leakage and other losses. At the present time the polarized sounder is replacing the relay with excellent results. The relay, besides requiring a local battery, is a delicate instrument for the unskilful to adjust, and with the same allowance of line currents the polarized sounder has a margin of 50% for working signals.

Differential Duplex.

Hitherto the methods of working considered have been "simplex," which only admit of signalling in one direction at a time. Duplex telegraphy enables messages to be sent in both directions simultaneously on the same circuit. The "differential" system requires the use of differentially wound receiving instruments. It has been observed in connection with them that if equal currents flow in the two coils but in opposite directions the resulting magnetic effect is nil.

The connections of differential duplex are such that two circuits of equal resistance are open to the *sent* current through its own receiving instrument, which is unaffected because the coils are divided each in one of the two circuits. The theoretical connections of this arrangement with polarized sounders is shown in Fig. 134.

To simplify the description a single current key and battery are given, but few, if any, S.C. duplex circuits are now used in the Post Office telegraphs. One winding of the polarized sounder is joined to line and the other to a rheostat in which is inserted a resistance equal to the

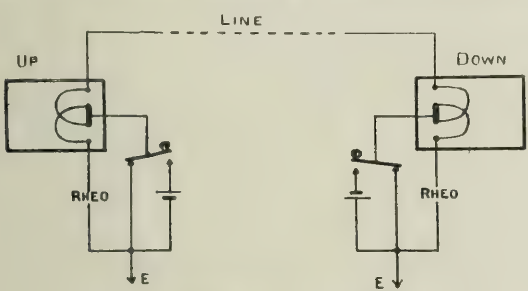


FIG. 134.—Theoretical diagram differential duplex.

line plus the distant stations apparatus through which the line current travels. The branch path through the rheostat is known as the "compensation" or artificial circuit.

When up station's key alone is depressed the current flows to strap joining (*U*) and *D*, dividing half to line, thence through down station via *U D* of polarized sounder (marking), back contact of key and earth to earth at up station.

The other part of current through *Rheo* unites with the returning line portion, and both return to the negative pole of the battery. Equal currents flow through (*U*) to (*D*) and *D* to *U* of the up station's instrument, and therefore there is no movement of the armature. Similar action occurs when only the down station's key is depressed, except that the direction of the line portion of the current is to earth, returning via earth at up station back contact of key, (*U*) to (*D*) (marking), line and *U* to *D* of own instrument opposing the effect of the half current which passing through *Rheo* returns by (*D*) to (*U*). There the two portions combine and return through the depressed key to the negative pole.

Now suppose both stations depress their keys at the same instant. The two line currents being in the same direction combine, and at each station the value of the current in the line coil of the polarized sounder is twice that in the coil placed in the compensation circuit. The movement of the armature is caused by the *difference* in the currents, which corresponds to the effect produced when one station sends alone.

With double current duplex working, the D.C. key is used, the switch being kept in the "send" position. The currents passing to line with the keys at rest are both in the "spacing" direction, and being added together they preponderate over the effect of the half current circulating in the compensation circuit, thus producing a spacing result at each station. When both keys are simultaneously depressed the combined line currents are in the "marking" direction, and out-weigh the influence of the compensation currents. With one key at rest and the other depressed the line currents oppose each other ; this enables the compensation current at each station to operate. Where the key is at rest the effect is "marking," and at the other station, where the key is depressed, the result is "spacing."

In the above explanation of the differential duplex the line and artificial circuits were considered as equalized by the resistance inserted in *Rheo*, but this can be the case only on short aerial lengths. The character of a line depends also upon the amount of electrostatic capacity it contains, and a satisfactory duplex balance is not obtained unless compensation has been provided for this disturbing element. The behaviour of the line may sometimes be imitated by connecting a condenser of suitable capacity across the rheostat. By this means the effects of the impulses of the current, caused by the line's capacity, are neutralized by the charge and discharge of the condenser, and the receiving instrument at the sending end is not affected by the movements of the key.

The following diagrams and explanations may serve to indicate how this capacity compensation may be considered :—

Fig. 135. When key depressed there is an initial impulse of the current charging the condenser before the current passes through the resistance *R*. The E.M.F.

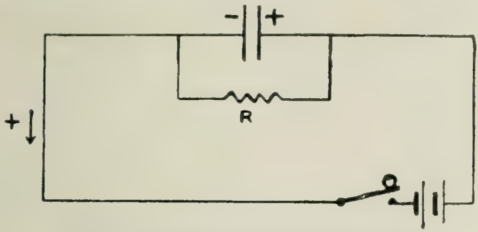


FIG. 135.—Condenser charge and discharge—I.

applied to the plates of the condenser varies according to the resistance in *R*. For if *R* has no resistance then no fall of potential occurs and the condenser remains uncharged. Conversely with considerable resistance there is a loss of volts in *R*, and a corresponding potential

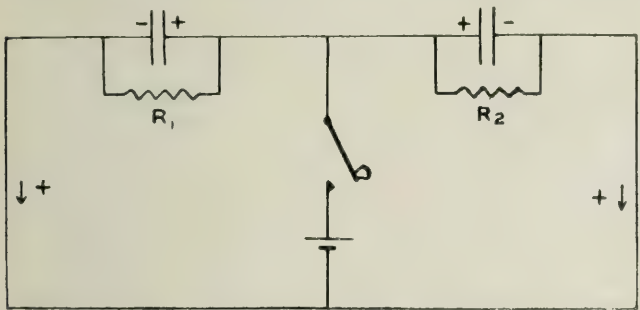


FIG. 136.—Condenser charge and discharge—II.

difference between its terminals and the plates of the condenser. The repelled + impulse passes to the negative pole of the battery. When the key is released the two plates of the condenser discharge through the resistance and neutralization results.

Fig. 136. In both the circuits the conditions and results are as in the previous example : the initial impulses

from the condensers passing to the battery and the neutralization of the condensers taking place through R_1 and R respectively.

Fig. 137. This diagram illustrates the charge on line and in artificial circuit when key depressed. The begin-

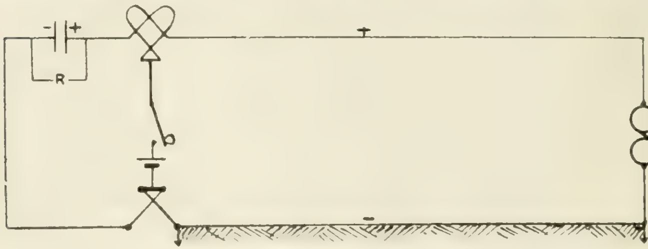


FIG. 137.—Condenser charge and discharge—III.

ning + impulses from earth and compensation circuit pass to the battery through the polarized sounder or relay coils, producing equal and opposite effects. When key is released the condenser neutralizes through R and the line charge (the sending end being disconnected in the battery path) passes through the distant station's apparatus to earth.

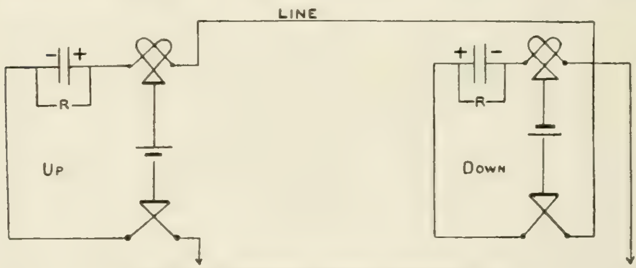


FIG. 138.—Condenser charge and discharge—IV

This releases the negative charge on the earth's surface, which is then neutralized. The potential of an earthed point in a circuit is considered as zero.

Fig. 138. When both keys of a D.C. duplex circuit are connected as shown in this diagram, that is, up station depressed, down station at rest, each end of the line is at positive potential and it is charged positively, while the condensers are charged as shown. When the up station's

key reverses there are two paths open to the condenser's discharge, namely, through R, or through key and battery. It is generally assumed that all passes through the latter path, neutralizing the effect on the galvanometer of the line's discharge as they both proceed to the negative pole of the battery. The positive pole of the battery being joined to the "split" of the receiving instrument neutralizes there the discharges of the condenser and earth which take place through its coils producing equal and opposite magnetic effects. The recharged condenser's + may be considered as inducing negative on the opposite side, and similarly the earth's surface, being now positive, also induces negative on the wire (see Fig. 137). The charges at the down station are not disturbed. Both the condenser and line discharges and recharges are caused by the reversal of the battery; it is therefore only essential to consider the station at which tbe key is changed in position. Now it is necessary that the condenser's action shall balance the effects of the line, not only in quantity, but also in time or distribution, and in the case of a line of considerable length its charge and discharge is not instantaneous but gradual. Further, it may be considered as piecemeal, that is, the effect of the distant capacity operates subsequent to that of the nearest portion. This is imitated in the artificial circuit by introducing adjustable resistances in series with the condenser such as the retardation coil (Fig. 80) and when necessary, also placing condenser coils (Fig. 82) between the sections of the condenser. The effect of inserting resistance is to slow down the rate of charge and discharge of portions of the condenser and thus compensate for the disunited effect of the capacity of the line.

A complete duplex set is shown in diagram Fig. 139. It includes a simplex-duplex switch to enable the change in connections to be made for single working and so economize the battery power when the amount of traffic is not considerable. The differential galvanometer, besides indicating the values of the currents and the condition of the line, greatly assists in obtaining an accurate balance. For example, an upward movement of the needle after depressing the key denotes too much resistance in the rheostat (an aid to memory is:—when movement upward or to the *Right*, *Reduce*, and for the contrary of course increase).

The capacity is then adjusted by observing the *momentary* "kicks," but in this case an upward movement indicates too little capacity in the compensation, that is, the movements due to inaccurate capacity balance are the *reverse* of those produced by unbalanced resistance. A disconnection in the compensation circuit or an earth fault upon the line causes the sending station's signals to be correctly received at own end, but a disconnected line reverses the sending marks. A heavy loss, preventing satisfactory duplex, will, however, generally allow simplex working; the current then passes through both coils of the receiving instrument and so produces twice the magnetic effect upon the cores.

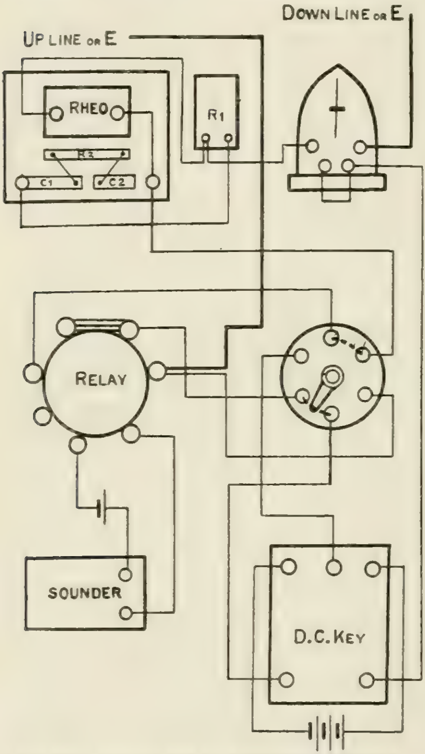


FIG. 139.—D.C. dx. and sx. independent batteries

Besides resistance and capacity, the character of some circuits is affected by the amount of *inductance* they possess. Inductance is usually denoted by the first letter in Lenz's name, *L*, and it depends upon the permeability of the circuit and the surrounding medium. It may be negative or positive in its effects, according as it assists or opposes the current that produces it. We have noticed that *capacity* causes an initial rush of current, but *inductance* produces an opposite effect, namely, to impede the rise of the current; and in many respects they act in an exactly opposite manner, and so can be made to compensate for each other's effects. When the first long underground circuits were established, considerable difficulty was experienced owing to induction. The circuits running parallel for many miles reacted upon each other, causing false and mutilated signals. The most effective and economical of the various methods tried was the employment of the Vyle polarized sounder. The inductance of the instrument is 62 henries, and owing to this very useful property, circuits which previously were balanced by means of triple condensers and condenser coils could be balanced by means of a single condenser. The polarized sounder also allows the balance of a duplex circuit to vary considerably without necessitating a rebalancing adjustment.

It has been found advantageous to learn the connections by giving letters to the six terminals of the two-way switch shown in Fig. 55: *D R U L S K*:—*D*, to *(D)* of P.Sdr. or relay; *R*, to rheostat; U, *U* of P.Sdr; *L*, left of key; *S*, "split" of P.Sdr; *K*, back centre of key.

Current required must be calculated for duplex conditions, namely 20 to 30 m.a. through one winding; note—one coil of P.S. or relay at both offices enters into the calculation of resistance. For circuits less than 150 miles in length large Daniell cells and for over 150 miles bichromate are used.

"Bridge" Duplex.

Among the points of difference between the differential and the bridge systems are:—(1) In the former the receiving instrument is undisturbed by outgoing signals owing to the currents dividing equally between its two coils, one of which is placed in the artificial circuit and the other in the line, whereas in the bridge method this is attained by both the coils of the receiving instrument being placed *between* or *across* the two circuits. (2) The neutral condition of the differential instrument depends upon *equal currents*, but in the bridge system the instrument is unaffected when the points it bridges have *equal potentials*. And (3) since a received current passes through the coils in series there is no need for a bridged instrument to be differentially wound.

Referring to Fig. 140, observe that the balancing resistance in the rheostat, say at A, is made up by inserting a value equal to the line (l^ω) added to the joint resistance of the branch Hb (h^ω) and the path through P which is the resistance of QE (R^ω) combined with

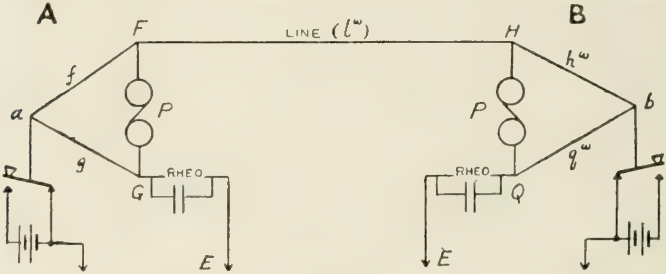


Fig. 140.

Qb (q^ω) added to P. The resistance of the bridge path can be expressed as $P + \frac{Rq}{R+q}$, and therefore

$$A\text{'s } Rheo = l + \frac{h\left(P + \frac{Rq}{R+q}\right)}{h + P + \frac{Rq}{R+q}}$$

Perhaps substituting numerical values will help to elucidate this algebraical statement.

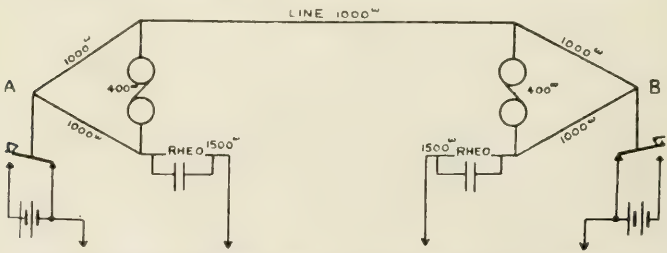


Fig. 141.—Principle of bridge duplex, with examples of relative resistances.

Let the line be 1000_ω, the receiving apparatus 400^ω, and the duplex resistances 1000^ω, then Rheos equal 1500^ω (as shown in Fig. 141).

Now consider the potential conditions with the reversed battery poles of the double current system of working which is generally adopted.

Case I, where both stations' keys are at rest and the joining up such as to produce spacing direction of current through the receiving instrument. This places the negative pole at station A to point a, and positive pole at station B to point b (Fig. 140). Let each E.M.F. be 100 volts, then the fall of potential in the *line path* between b and a is from + 100 to − 100, or a total P.D. of 200 volts. Of this two-fifths are used in f and h respectively, so that the potential at H is + 100 less 80 or + 20, and the potential at F is − 100 less 80 or − 20. Through each *artificial circuit* the P.D. is 100 and zero, one being negative and the other positive. The potential at G is − 60 and at Q + 60, therefore G is 40 volts *lower* than F, whereas Q is this value above H, and currents pass as indicated in Fig. 142.

Case II, with one key depressed (say at A) and the other at rest. The potential at both ends of the line is + 100, thus no fall can occur between a and b, consequently the points F and H are each + 100. In the balancing paths, however, the P.D. remains 100 to zero and G and Q have a potential of 60, therefore currents pass as shown in Fig. 143.

Case III.—When both keys are depressed the impressed voltage at b becomes negative, consequently the fall is from + 100 at a to − 100 at b, or 200 volts. The potentials at the various points correspond to Case I with reversed signs and "marking" currents pass as shown in Fig. 144.

At present the "bridge" method of duplex is chiefly used on cable circuits, and the effects of their considerable electrostatic capacity can be compensated for by placing condensers across the duplex resistances (f, g, h and q). These "*signalling*" condensers can be adjusted so that the time occupied in charging and discharging the circuit can be very considerably reduced. Until the condensers are fully charged the duplex coils may be considered as having no resistance, and in order to satisfy the full absorbing power of the condenser's capacity the applied E.M.F. is pressed forward or drawn out with considerable impetus. Thus this action is of very great value in hastening the charge and discharge of the line. The capacity of the signalling condensers has a disturbing effect upon the formation of the in-coming signals, but this can be rectified by placing

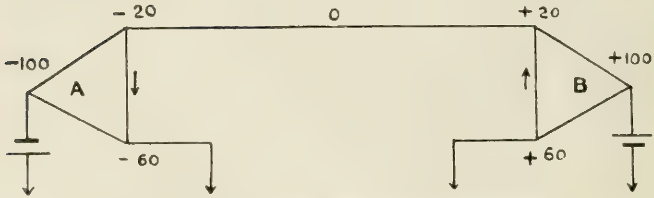


Fig. 142.—*A* and *B* at rest, "spacing" at both stations.

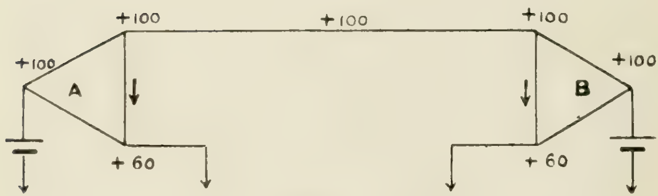


Fig. 143.—*A* depressed, "marking" at *B*,
B at rest, "spacing" at *A*.

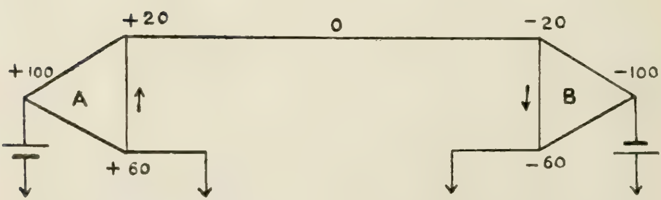


Fig. 144.—*A* and *B* depressed, "marking" at both stations.

a shunted "*reading*" condenser in the bridge path. The increase of the line's capacity by the introduction of these condensers may generally be compensated for by increasing the capacity of section C_3 of the "triple" condenser.

Central Battery Systems.

The remarkable and rapid development of central battery telegraph working which has taken place in the British telegraphs within the last few years contains the application of new ideas, and the close attention of every student is invited to the methods here described. The success of the introduction of central battery working has led to its

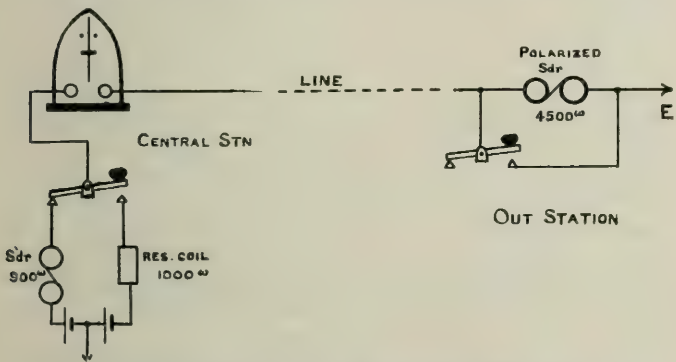


Fig. 145.—A simple C.B. circuit using a permanent line current.

extension in other directions, and the system is being copied by several other administrations. Some notice has already been given to the "closed circuit" system of working, which is in some respects a central battery system, although apparently never developed quite in the manner now effected in this country. The first striking feature of the system is that the source of power is centralized at one station and there are no batteries at any of the other offices. There is, therefore, the manifest advantage of saving in battery accommodation with the initial cost of installation and the expense of maintenance. Also a cause of failures is removed, apparatus of simpler character can be employed, and fewer adjustments are needed.

As an example of possible economies it may be mentioned that in London the introduction of the C.B. system in the metropolitan area abolished scattered groups of batteries on more than 1000 telegraph circuits, replacing them by a single group of accumulators installed in the central battery station. And the further extension of the system has now already banished some tens of thousands of primary cells with a yearly saving of thousands of pounds for battery maintenance.

One of the earliest methods is shown in diagram Fig. 145, where at the central station a galvanometer, S.C. key, 900^{ω} sounder, and a 1000^{ω} resistance coil are connected to a double battery of + 38 volts and − 40 volts. Normally there is a permanent current of about 6 m.a. passing to line via the sounder and galvanometer. At the out station this current flows through the 4500^{ω} polarized sounder in a "spacing" direction. The depression of the key at the central office changes the direction of the current by joining the − 40 volt battery to line through the 1000^{ω} resistance and causes the polarized sounder to "mark." When the key at the out station is depressed the short-circuiting of the 4500^{ω} polarized sounder reduces the line resistance by that amount and the current is increased to 35 m.a. which actuates the 900^{ω} sounder. The disadvantage attending this simple arrangement is that during idle periods the battery is uselessly expended, and with many such circuits there would be a considerable loss.

The central battery omnibus circuit arrangement devised by Mr. Mercer, of the Engineer-in-Chief's Department, obtained the system of double current working from a single pole battery by producing reversing condenser impulses. The out stations are connected as leak paths on the main line, but each branch is interrupted or broken by the insertion of a condenser, so that the central station's battery would not furnish a continuous current if the insulation of the line was perfect.

The original arrangement has been modified, and the apparatus now used is shown in diagram Fig. 146. At the central office a battery of 80 volts is connected to the line through a 1000^{ω} metal-cased non-inductive resistance coil and a S.C. galvanometer. The rest of the head office apparatus is identical with that supplied to the out stations, namely, a single current key, a 4500^{ω} polarized sounder with fixed adjustments, and a 4 m.f. condenser. The principle underlying the working is that a condenser having been charged, is potentially a battery, and remains so until discharged. Thus in the absence of any leakage the application of the central station's E.M.F. charges each condenser up to a value of 80 volts. The depression of any key puts the line to earth at that point. If this occurs at an out station each condenser discharges through its own polarized sounder, giving a momentary current. Now with a neutral adjustment the effect of this impulse is to bring the armature sharply down, where it remains, not by virtue of any current continuing in the coils, but by being, in that position, more under the influence of the magnetism than the control of the spring tension. To terminate the

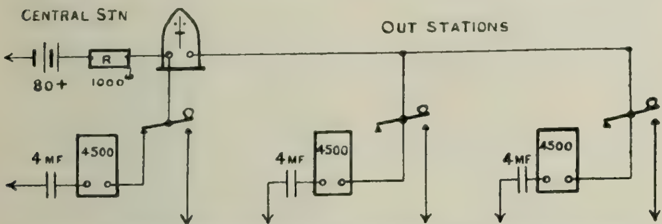
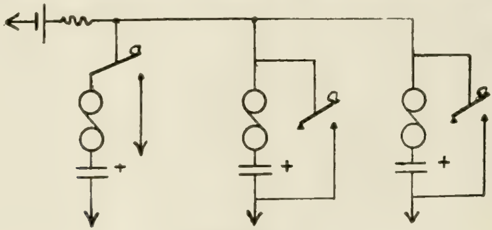
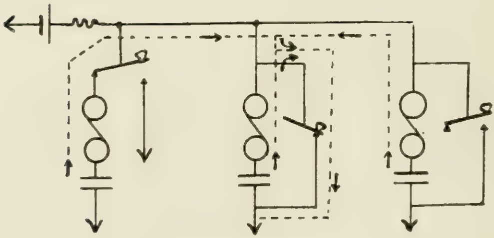


FIG. 146.—C.B. omnibus circuit ordinary arrangement with polarized sounders having fixed adjustment.

signal, whether dot or dash, it is only necessary for the key to rise, charging the condensers again in the reverse direction and giving the equivalent of a spacing current. At the out offices the connections are such that each station's sending is recorded upon its own polarized sounder as well as at all the other sounders in the circuit; this indicates to the signalling station that everything is in order and dispenses with the use of a galvanometer. At the central office, however, the polarized sounder is joined, not to the middle of the key, but to the back stop, and therefore that instrument is not actuated by the working of its own key. The galvanometer shows the condition of the line, short deflections accompany the working impulses, and a continuous deflection, when no traffic is passing, indicates the amount of leakage. Much attention has been given to the problem of the character and value of the resistance placed in the battery lead, and Mr. E. V. Smart has demonstrated how to calculate the best resistance for working conditions. That if no resistance is placed in the battery lead then the





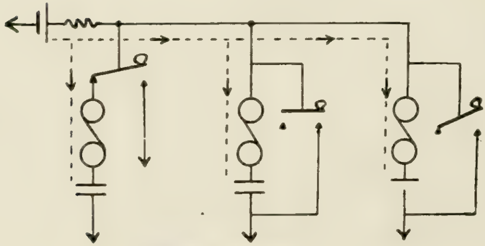


Fig. 147.—Illustrating charge and discharge of omnibus circuit.

depression of an out station's key does not alter the potential at the head office, consequently no signal produced. If an exceedingly high feed resistance be inserted then almost a complete discharge occurs at the head office.

The best value is that which allows for falling insulation resistance due to bad weather conditions and consequent loss. It is found that the weakest point in the system is the working from the furthest out station to the head office, and the minimum insulation allowable is three times that of the conductor resistance. The most satisfactory results are obtained with a feed resistance of 1000^{ω}. Then with a line of 1000^{ω} and two out stations 500^{ω} apart the depression of the head office key gives a current of 80 m.a., the working of the nearest out station's key allows a current of 52 m.a., and the terminal out office obtains a value of 39 m.a. Fig. 147 shows the directions of charge and discharge when the intermediate station is working.

Upon a line where the insulation loss is very great, satisfactory working has been found possible by providing a special set at the head office. With this arrangement it is possible to work to and from any out office, even though the change of potential at the head office produced by an out station's key be only 2 volts.

By means of the six-terminal reversing key (shown in Figs. 51, 2, 3) the head office works double current outwards. The impulses through the polarized relaying sounder cause strong signals to be recorded on the ordinary polarized sounder. Owing to the method of joining up no local battery is required; for when the relaying sounder's armature is against the spacing contact the + 80 battery charges the 4 m.f. condenser through the 1000^{ω} resistance coil. The depression of an out station's key allows the charge in the 8 m.f. condenser to pass through the polarized relaying sounder, thence via the 6-terminal key and galvanometer to line and earth at the sending station. The relaying sounder is set neutral, consequently the momentary current causes the armature to bank against the marking stop and thus provide a path to earth for the discharge of the 4 m.f. condenser. The 4500^{ω} polarized sounder is also set neutral with fixed adjustments and it responds to the magnetic effect of the discharging impulse. When the signal is terminated by the rise of the distant station's key the magnetism of both the polarized relaying sounder and the ordinary polarized sounder is reduced by the recharge of the respective condensers, the springs predominate and retract the armatures. Thus the line signals are recorded on the reading instrument. The full connections of this special head office set are shown in Fig. 148. No alteration is made in the out station's apparatus, but the reduction of the feed resistance to 800$^{\omega}$ permits a current of about 60 m.a. when the key is down at the intermediate station, and 43 m.a. at the terminal office.

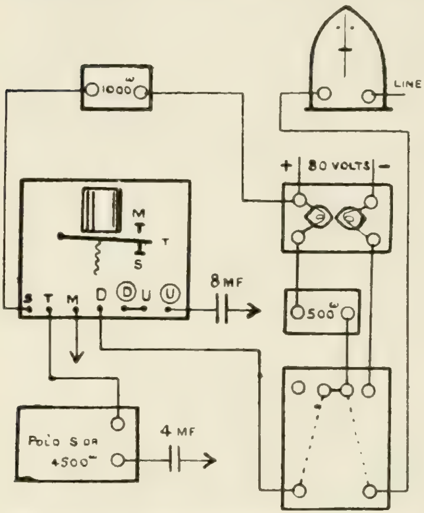


Fig. 148. C.B. omnibus circuit Head office *special set* with polarized relaying sounder 500$^{\omega}$ + 500$^{\omega}$ allowing great length and leakage.

In this omnibus system the internal resistance of the battery plays a most important part, and therefore secondary cells are best. Primary batteries may in some positions be more economical, but it is found that a maximum loss of 10 volts in the battery is all that can safely be allowed when polarized sounders of 4500$^{\omega}$ are used.

The Hay Central Battery Duplex.

Several forms of duplex have been introduced with C. B. working, but with only partial success until Mr. C. E. Hay, of the Engineer-in-Chief's Department, devised the following system, which has displaced the earlier methods and is extensively used on short lines having no insulation losses.

It will be observed from the theoretical diagram (Fig. 149) that at the head office the standard relay occupies the place of the galvanometer in a Wheatstone Bridge arrangement. The two ratio arms are of 1000$^{\omega}$ resistance, one is connected to the line, the other to a fixed resistance of 1250$^{\omega}$. The line resistance is made up to 350^{ω}, by the insertion, if necessary, of a resistance coil in the line path at the head office. At the out station the apparatus includes a differentially wound polarized sounder $500^{\omega} + 500^{\omega}$, a single current key, and a 500^{ω} resistance coil. The middle of the key is connected to the "split" of the sounder coils and the front contact to earth. The normal resistance of the line path is therefore $350 + 500 + 500 + 500^{\omega}$, or 1850^{ω}. Consequently there is a want of balance and the potential at *A* is higher than at *B*. This causes a permanent current to flow through the galvanometer coils and the relay in a spacing direction, that is, from *D* to (*U*) terminals. The polarized sounder at the out station is joined up so that the magnetism due to the inducing magnet and that due to the

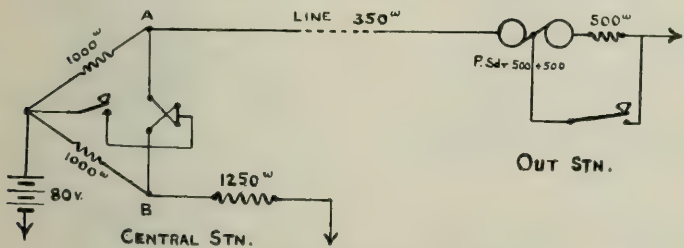


FIG. 149.—Theoretical diagram of Hay C.B. duplex.

permanent line current are about equal and the necessity to "bias" the sounder is reduced to a minimum.

When *key depressed at out station*, *A* to earth then becomes 850^{ω}, but *B* to earth is always 1250^{ω}, so that their ratios are now 2 : 3 (normally they are 3 : 2). The potential at *B* therefore is now higher than *A*, and thus current flows through relay (*U*) *D* (marking).

When *key depressed at central station*: This places the relay coils in parallel with the ratio arms—increases the line current from 25 m.a. to 40 m.a. and operates the sounder at the out station. The out station's key is at rest, and consequently, although the current is augmented, it divides unequally the larger part passing through the relay from (*D*) to (*U*) with a spacing result.

When *both keys depressed simultaneously*, then the previous reduction of resistance is still further diminished by the "cutting out" of 1000$^\omega$ resistance at the out station, and the line current is now 80 m.a. The potential of B is higher than A, as already explained, therefore the preponderating current through the relay coils produces marking. The polarized sounder responds to the effect produced by the line current, although it only traverses one winding, because the magnetization produced is equivalent to that of 40 m.a. through both windings. At the head office the standard relay actuates a 900$^\omega$ sounder, which is joined in a local circuit in the usual manner. Thus it is seen that by simply working

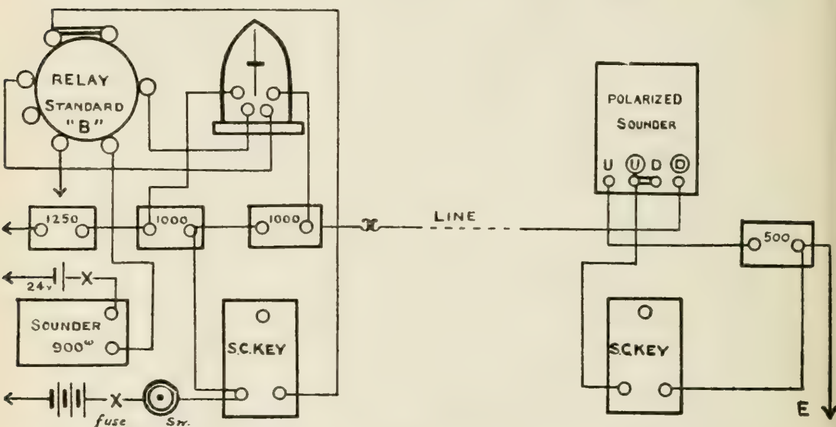


FIG. 150.—Connections of Hay C.B. duplex (line + x = 350$^\omega$).

a single current key the out station produces the effect of a double current on the relay at the head office; that the action of the receiving instrument at either office is independent of the movements of the key at that station, and therefore the essential condition for accurate duplex working has been achieved.

The working connections are shown in diagram Fig. 150.

VYLE AND SMART'S CENTRAL BATTERY DUPLEX.

In this, the most recent duplex with the central energy system, the inventors, Messrs. C. C. Vyle and E. V. Smart, have succeeded in producing a method of working suitable for either long or short distance circuits. It possesses some distinct advantages over the Hay system—the working *from* the head office is on the double current system; it is satisfactory with a large amount of line leakage, and it lends itself to an extraordinary degree for the requirements of concentration or the emergency of Wheatstone working.

The principle of working and essential connections are shown in Fig. 151. The arrangement at the central office is similar to that of an ordinary differential duplex but with a non-polarized relay ($500^{\omega} + 500^{\omega}$) and the 6-terminal

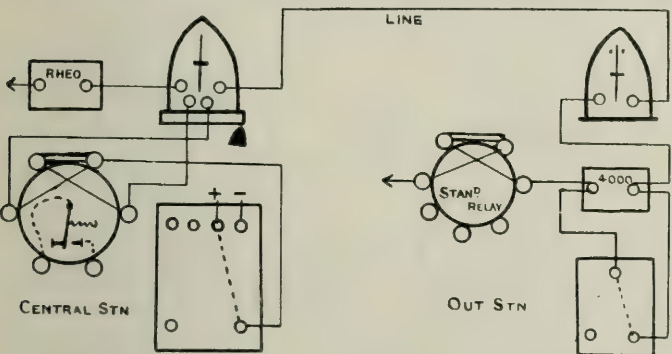


Fig. 151.—Skeleton connections of Vyle and Smart's C.B. Duplex. (*U*) and *D* of standard relay at out stations should be crossed.

reversing key. At the out station a S.C. galvanometer, S.C. key, and standard relay "B" ($100^{\omega} + 100^{\omega}$) are joined in series with a fixed resistance of 4000^{ω} connected between the galvanometer and the line terminal of the relay. At the outset sufficient resistance is inserted in the rheostat at the central office to cause a current to pass out to line showing a deflection of 55° on the differential galvanometer. This generally results from the addition of 4000^{ω} to the normal line balance with the out station's key at rest. When, however, the insulation is low the out office key is depressed and resistance is inserted in the condenser coil there (see Fig. 153) and equalized in the central office rheostat to give the line more current and thus compensate for the loss through leakage. With the out-office key depressed the proper resistance balance is shown by the needle of the differential galvanometer remaining vertical, and the central office can then balance the static condition of the line in the usual way. With the circuit in its normal condition, that is, with both keys at rest and an E.M.F. of 80 volts, the current in the line path will be about 45 m.a. At the central office about one-third of this value circulates in the artificial branch, and the difference between the unequal currents passing through the coils of the differentially wound 500ω + 500ω non-polarized relay is sufficient to overcome the tension of the spring and hold the tongue away from the *local* circuit contact. The line current traverses the coils of the standard relay in a spacing direction. With a momentary short-circuit, which is indispensable, the depression of the 6-terminal key changes the direction of the currents, not their value; the non-polarized relay is therefore unaffected, but the out station's relay responds.

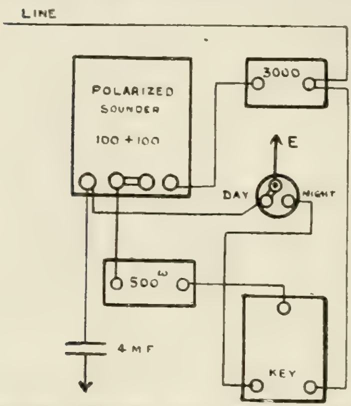


Fig. 152.—Out station, Vyle and Smart's C.B. duplex and simplex for short and underground circuits.

If the out station alone is signalling the depression of the key there throws the 4000ω resistance and the condenser coil into the line circuit. This restores the zero balance at the head office; the currents there then divide equally, the cores of the non-polarized relay are demagnetized, and consequently the spiral spring causes the tongue to make contact with the marking stop and so operates the reading sounder.

When both stations send simultaneously the current reversals actuate the instrument at the out office, and the restoration of balance effectively controls the movement of the non-polarized relay at the central office. It may be observed that the out station receives two strengths of current, owing to the alteration in value when its own key is depressed, but the relay responds equally well to both.

In the case of circuits of forty miles and under it has been found possible to replace the standard relay and local circuit at the out station by a polarized sounder. The difference in current strengths and the consequent varying attraction of the armature of the polarized sounder is compensated for by placing the 4 m.f. condenser on the earth side of the polarized sounder (Fig. 152) and joining 500^{ω} resistance between the key and the "split" of the coils. The stronger impulse then passes through one coil and the weaker through both, consequently the volume of sound is constant. On the longer circuits where the relay is employed sufficient sound is produced in the 20^{ω} sounder if the local circuit E.M.F. is provided by a 3-cell dry battery. Of course the local circuit of the non-polarized relay at the central office comprises the usual 900^{ω} sounder and 24-volt battery.

Some interesting developments of C.B. working are appended, but they are intended for the information of the more advanced students, being beyond the prescribed range of the ordinary grade syllabus. A very recent arrangement of the Vyle and Smart C.B. duplex provides for simplex working and can also be used on a concentrator. The apparatus is shown in the diagram (Fig. 153). Note that 80 volts positive are used as the spacing current, the necessary change in connections being made on the relay at the out station. For simplex working + 40 volts are provided instead of the + 80 to reduce the amount of loss that may occur through leakage and further economy effected by interrupting the circuit with a 4-m.f. condenser. At the central office a 9-terminal switch is used for making three necessary changes in the connections for duplex or simplex. The alterations required for simplex working are: + 40 substituted for + 80, the artificial circuit is disconnected, and the local sounder circuit is changed over from the "marking" to the "spacing" contact of the non-polarized relay. At the out station a 3-terminal switch suffices, and when moved into the simplex position it transfers the earth connection from the relay to the front stop of the key. The relay is then joined into the condenser, the other terminal of which is connected to earth through a 4000ω resistance coil. In some cases, however, provision is made for night calls by replacing this resistance coil with a polarized sounder circuit "B" pattern, which is extended into a suitable position

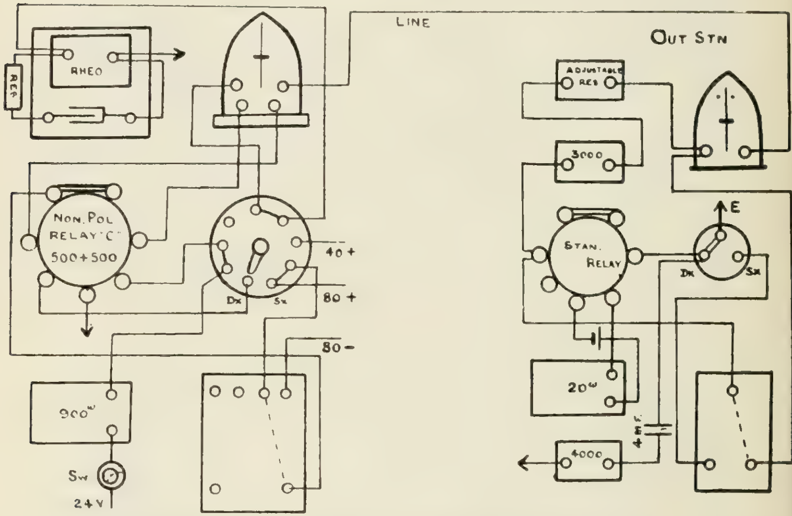


FIG. 153.—Connection of Vyle and Smart's C.B. duplex and simplex.

for that purpose. The details of these changes can be perhaps better understood with the following theoretical diagram of the simplex conditions (Fig. 154). At the out station with the relay adjusted neutrally it follows the movements of the out station key. This is a test of neutrality, but a slight spacing bias given will remove them, and yet signals received from the central office are still good. When at simplex then, normally, only the current due to leakage, if any, flows from the + 40 volt battery whose E.M.F. charges the out station's condenser. The spring of the non-polarized relay holds the tongue in contact with the M stop, having practically no opposition. The depression of the out station's key puts the line direct to earth, and a current of 25 to 35 m.a., according to line resistance, flows through the non-polarized relay attracting the armatures and closing the local circuit. The depression of the central office key joins − 80 volts to the circuit, discharging and recharging the out station's condenser, both effects occurring in the "marking" direction through the relay there.

As arranged for the C.B. concentrator the line terminates at a switch spring while the head office set is connected to the tip of a peg. When employed for short or underground circuits the rheostat, retardation coil and condenser have

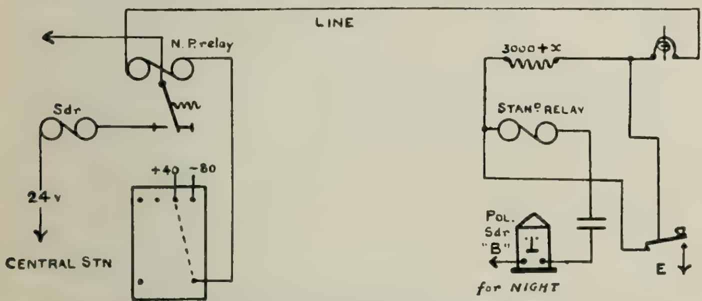


Fig. 154.—Skeleton connections of Vyle and Smart's C.B. simplex with extension sounder at out station for night calls.

fixed values, and the out station's relay is replaced by a polarized sounder joined as shown in diagram Fig. 152.

The remarkable adaptation of the central battery system in circumstances of special emergency is illustrated in Fig. 155. Many towns which may be temporary centres of telegraph pressure have only C.B. omnibus out station sets. In these cases, if it is desired to extend the circuit or to provide for Wheatstone working, the following arrangements will be found suitable. A local head office which is usually the terminal on the C.B. circuit may become an out station and the line extended to a distant head office—a more convenient transmitting centre—where an ordinary duplex set modified can be used. By this means distances of several hundred miles have been covered. No. 1 station is the ordinary C.B. omnibus set. No. 2 station shows the same set, but with a Wheatstone transmitter and galvanometer added for Wheatstone working to the head office. No. 3 provides for Wheatstone working to and from the head office. To adapt an ordinary Wheatstone duplex set for these special requirements the following

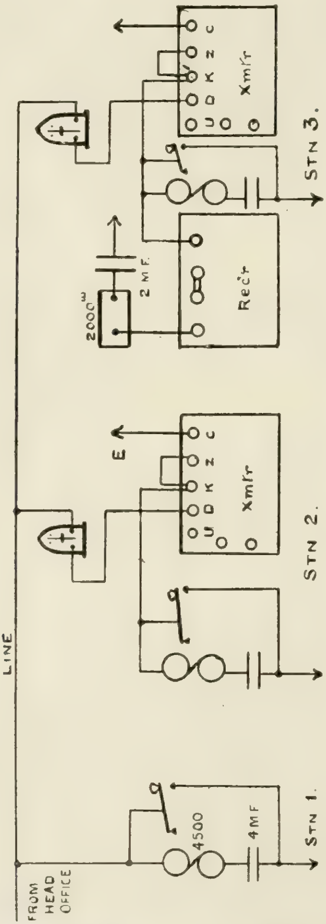


Fig. 155.—Special arrangements for Wheatstone at stations working on C.B. omnibus circuits.

changes and adjustments are necessary:—At an up station reverse batteries; at a down station reverse *D* and (*U*) of relay. Switch must remain at duplex. ert 8000$^{\omega}$ in the rheostat, 4 m.f. in the condenser, and 500ω in the retardation coil at the outset. The maximum resistance in the compensation path will insure a large preponderance of current passing out to line amply sufficing to reach the most distant station. The resistance may be made afterwards approximately twice the resistance of the line. The head office can obtain a balance by the out station depressing key—if more than one out station take two balances; first to the nearest and then to the most distant station. The rheostat should then have a value double that of the mean balance.

Perhaps a still more interesting application of the C.B. system on a short or underground line is the following

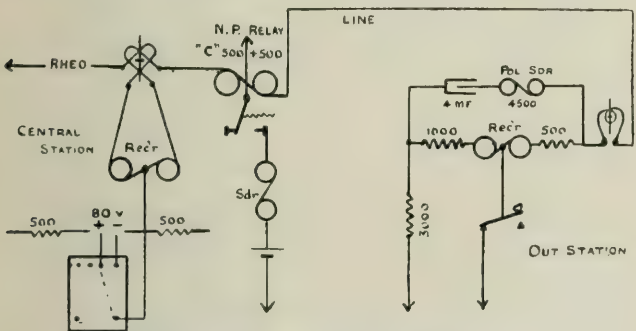


FIG. 156.—C.B. Wheatstone and key: theoretical connections.

arrangement, which provides for key simplex or duplex; duplex with Wheatstone from the central office and key working from the out station; or Wheatstone simplex from the out station, the central office being able to stop the transmitter when necessary. To accomplish these advantages several conspicuous novelties have been introduced. The theoretical diagram is given in Fig. 156. At the central office a double battery of 80 volts with 500ω in each lead is joined to a transmitter, 6-terminal key, Wheatstone receiver, and differential galvanometer to rheostat and line. After leaving the galvanometer the line path is through a non-polarized relay in the local circuit of which the 900ω sounder and usual 24-volt battery are joined. With 3000ω in the rheostat a good current passes to line via the N.P. relay whose tongue is forced to the spacing stop. The line

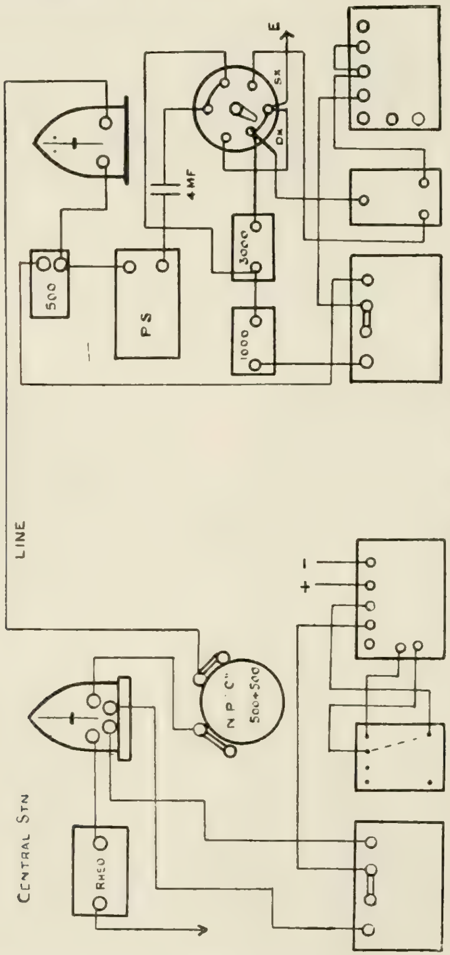


FIG. 157.—C.B. Wheatstone and key: full connections.

current, at the out station, passes through S.C. galvanometer, a 500^{ω} resistance coil, one winding of the Wheatstone receiver, and thence via bridge of key and its back stop to earth. No local battery is required on the receiver, owing to the provision of a 4500$^\omega$ polarized sounder and 4 m.f. condenser, and one of the prominent features of this arrangement is the singular manner in which they are connected between the line and earth.

Placing them across the receiver and the resistances 500$^\omega$ and 1000$^\omega$ insures sufficient potential difference between the condenser plates to obtain accurate signals on the polarized sounder, when the central office sends, whatever may be the position of the out station key. Also it is noteworthy that splitting of signals by the movements of that key is impossible. Any disconnection therein automatically

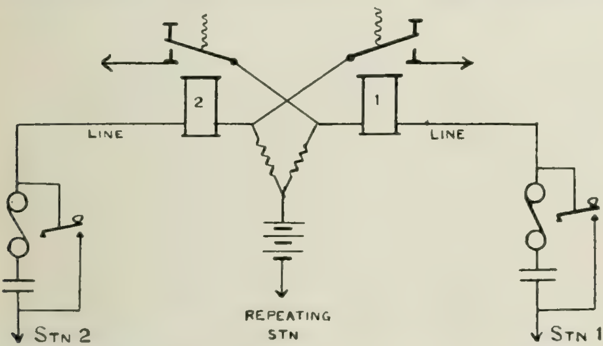


FIG. 158.—C.B. repeater with polarized relaying sounders: showing the only battery in the circuit.

diverts the current through the receiver coils and the two resistances, 1000$^\omega$ and 3000$^\omega$, to earth. The current is thereby reduced but this is compensated for by the effect then produced in both windings of the receiver. For duplex, adjust rheostat with out station's transmitter running, until signals are good on the receiver at the central office. The action of the transmitter is of course similar to that of the key—merely throwing into the circuit the extra resistance—and at the central office the resistance of the rheostat is made just sufficient to secure an excess of current through its own receiver in the "marking" direction. This is arranged for by joining the (*U*) to (*D*) winding in the rheostat or compensation path, which then offers the least resistance. The usual adjustment of the non-polarized relay is made so that the weakened line current, consequent upon the movements of the out station's key, will enable the spring to place the tongue on the "*M*" contact and close the local circuit. The full connections of this arrangement, which can be used also on a concentrator, is shown in Fig. 157.

As a conclusion to this description of C.B. systems it may be worth while to notice another direction of development, namely, that of relaying or translation. The principle of a C.B. repeater is shown in the theoretical diagram Fig. 158. At the repeating office an earthed battery is joined, through a resistance and a polarized relaying sounder, to each line. The terminal stations are fitted with a polarized sounder, condenser, and S.C. key. Suppose station No. 2 depresses the key; this earths the

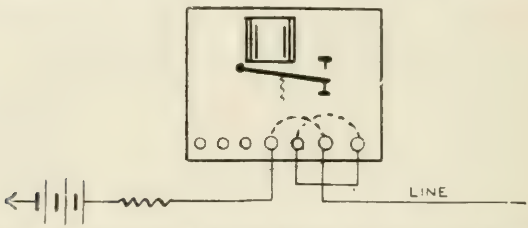


FIG. 159.—Method of joining polarized relaying sounders on C.B. repeater.

line, and a current passes out from the repeating station through relaying sounder 2, whose armature is consequently attracted. The condenser at station No. 1 is enabled to discharge through the earthed connection thus given at the repeating station, and the movements of the key at station No. 2 are correctly reproduced on the polarized sounder at station No 1. The signals in the other direction are similarly repeated. Attention is directed also to the means by which the discharging condenser impulses are made non-effective upon the polarized relaying sounders. For example, it is essential that when station No. 2 is sending the P.R. sounder 1 should not be actuated by the condenser discharge of station No. 1. This is prevented by joining the coils of the P.R. sounders in the manner shown in Fig. 159.

Universal Battery Working.

For many years there have been arrangements made for supplying the E.M.F. of one battery to several circuits simultaneously. This method of working differs from the C.B. and "closed circuit" systems in that the latter provide one source of power for *all the stations* in the circuit, whereas a *universal* battery supplies the power for several sets of instruments *in the same office.*

The internal resistance of a battery required for universal purposes is a matter of considerable importance. For when several circuits are joined to a battery of appreciable resistance, then a variation of current occurs in the lines according to the number working simultaneously. This will be evident if the values of the currents then obtained are considered. For example, let a battery of 40 volts E.M.F. and internal resistance 100^{ω} be joined to nine circuits of 900^{ω} each. The current in one line working alone is $C = \frac{40}{900 + 100} = 40$ m.a., and when all are working total $C = \frac{40}{100 + 100} = 200$ m.a., and of this $\frac{1}{9}$, or 22·2 m.a., pass into each circuit. With four times as many circuits the total current becomes 320 m.a., but only $\frac{1}{36}$th part of this is taken by each. Now let the battery be of negligible resistance, then it matters not how many lines work at the same moment, the value of the current in each is unaltered. Take, for example, the previous first and last cases; with one wire $C = \frac{40}{900} = 44$ m.a., and with 36 equal lines $C \frac{40}{25} = 1600$ m.a., or $\frac{1600}{36} = 44$ m.a. in each. Very early this distinct advantage of secondary cells over primary batteries led to the introduction of the former for the purpose of universal battery working. With, however, only five or six lines it is possible to work them from a primary battery, but even then the circuits must not differ in resistance by more than 25%, and best results obtain when artificial resistances are placed in the circuits to make them nearly correspond. The resistance of the primary battery must always be much below the joint resistance of all the circuits connected to it. With the introduction of secondary cells it became possible to extend the universal battery system, and in most large offices the whole of the circuits are supplied thereby. This, however, entailed a number of alterations in the connections of the circuits

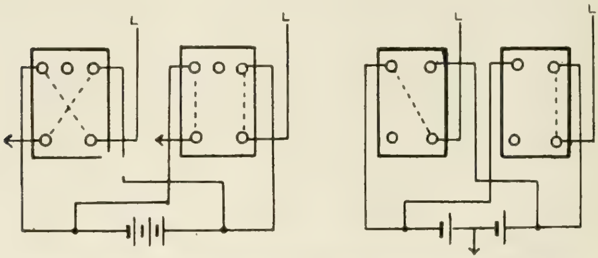


FIG. 160.—D.C. universal battery: showing necessity for double battery.

and the provision of fuses or cut-outs, generally short thin pieces of lead or tin-lead which melt with abnormal currents. Such may readily result from the presence of faults and cause injury to cells, or a fire might be produced.

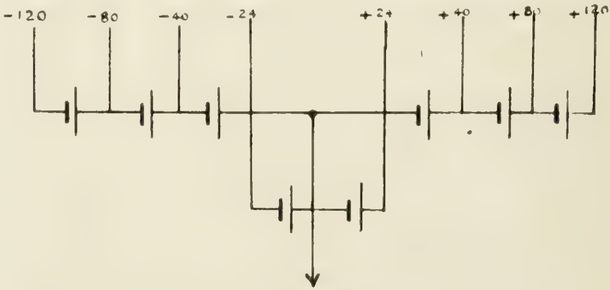


FIG. 161.—Arrangement of voltages in use.

In circuits where both poles of the battery are utilized, then universal working also entails the supply of double battery power—that is, for example, in cases where a primary or independent battery of 50 volts could be used, then the E.M.F. necessary with a universal battery would be 100 volts, halved to provide + 50 and − 50. The need for this and altered circuit connections will be apparent when diagram Fig. 160 is considered, which represents portions of two D.C. sets. Suppose that while one key is depressed the other is at rest, then both poles of the battery are joined through the local earth connection and it is short-circuited. To prevent this the S.C. key with switch (Fig. 47) is used on all D.C. circuits at terminal offices using a universal battery. The manipulation of this key joins either pole alternately to line, but uses only one at a time, the battery being divided and earthed at its centre. The standard plan of applying the different voltages to the circuits from a secondary cell installation is shown in diagrammatic form by Fig. 161. For main batteries six sets of twenty cells are joined so as to give the voltages indicated. Two extra sets are provided for the purpose of recharging the cells. To secure an equal share of the work for each set they are switched regularly into positions relatively changed until each in turn is thrown spare for recharging.

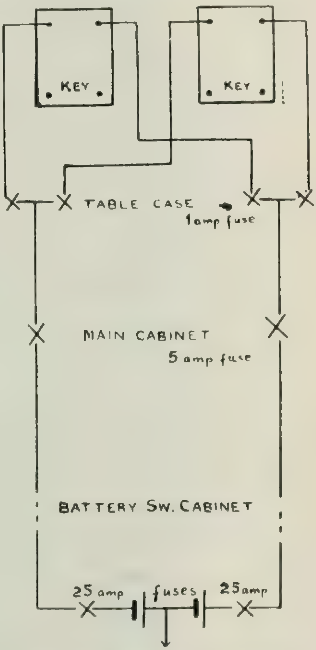


Fig. 162.—General distribution of power and fuses.

Three fuses are placed in each battery lead between the cells and the instruments: on the battery rack, one of 25-ampere value, 5-ampere on the main cabinet in the instrument room, and 1-ampere on the table distributing case. The general arrangement is shown in Fig. 162. As an additional protection, resistances are placed at each instrument in the main battery leads of the value of 2^{ω} per volt of the power used, and thus provide that the current shall not exceed half an ampere if a short circuit occurs on the instrument side. From the switch cabinet in the battery room the power leads pass to the main cabinet

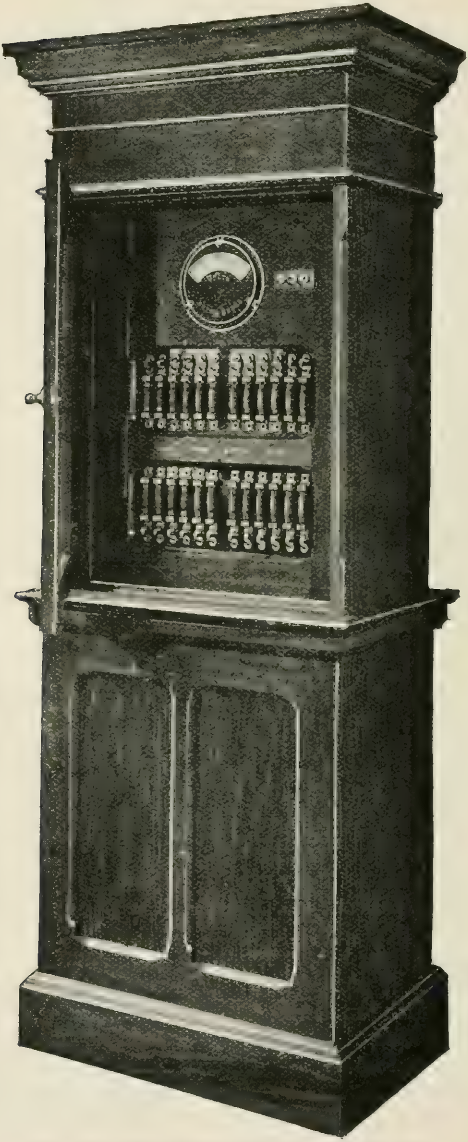


FIG. 163.—Main battery cabinet in instrument room.

in the instrument room (shown in Fig. 163), which shows four groups of six combined fuse-holders and test holes. To the latter the table distributing lead is joined and the withdrawal of the *U* link enables the circuit to be disconnected without interfering with the fuse, which is of the 5-ampere fibre tube type. The voltmeter is provided with three test holes to enable it to be joined to the various circuits by means of a cord having two pegs. A distribution and fuse case (such as shown in Fig. 164) is generally

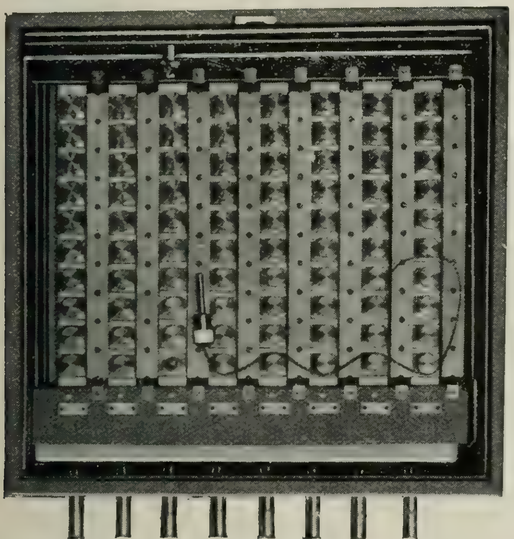


Fig. 164.—Table distribution and fuse case.

provided for every third table in the instrument room, and to them are brought the 8 or 10 voltage leads from the main cabinet, while the outgoing wires pass to the various instruments on the tables supplied. For each voltage in use two vertical bus bars are provided, mounted on the back of porcelain blocks, through which pass ten 1-ampere glass tube fuses held in spring contact with the bus bar and a square socketed cap on the front of the porcelain block. The instrument leads are attached to these square terminal caps at the side and a removable brass cap locks the fuse in place; this cap is taken off and the fuse removed when it is desired to disconnect the battery from any particular instrument (see Fig. 165). If it is then desired to change the voltage on that instrument lead a

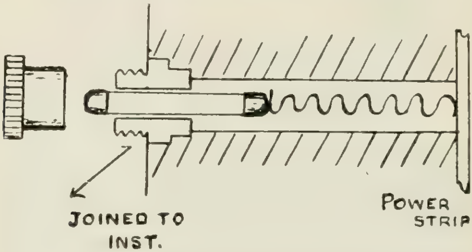


FIG. 165.—Universal battery fuse and terminal cap in table case.

flexible cord with screw cap at each end is used to join the lead to another voltage. One of the caps is sometimes provided with an ebonite pin to prevent a fuse being left in the normal hole.

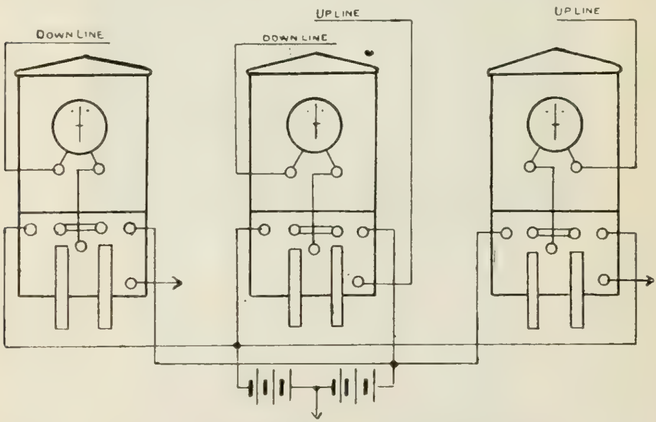


FIG. 166.—Connections of three universal battery S.N. sets.

In an earlier installation now being superseded by the above, each instrument table had a distributing case, the power being supplied by means of test holes and U links, and the 1-ampere fuses were provided in a separate box at each instrument.

For single needle circuits universal battery system primary cells are usually employed. The following alterations are necessary at "up" and "down" offices: The front contact screw of the left-hand tapper is raised, to prevent contact when the tapper is depressed, and a plug is placed under the back spring of the right-hand tapper to cause a disconnection there. Commutators used at intermediate offices require no alteration.

The resistances of the different S.N. circuits worked from the same set of batteries must be approximately equalized for the reasons already given. Note that at an intermediate office the coils of the needle (200^{ω}) are in the down section of the line. The connections required for the three different stations are shown by corresponding sets in the same office (Fig. 166). Double sounders (900^{ω}) usually take the place of single needle instruments at offices where secondary cells are installed for the universal batteries. Their commutator contacts are adjusted as in the manner specified for S.N. circuits.

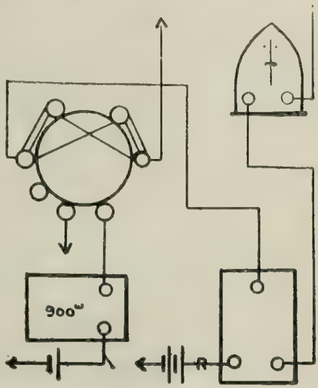


FIG. 167.—Universal battery: S.C. up station. For down station change battery pole (*U*) and *D* of relay and galvanometer terminals.

In the battery leads of less than 80 volts metal-cased resistances (Fig. 83) are used instead of "resistance lamps." Both are primarily intended as protective resistances, and so that a short circuit in the instrument shall not produce more than ·5 ampere, their value is never less than 2^{ω} per volt of the power used. The tongue of the relay (T terminal) is earth connected, and the pole of a single earthed battery is joined to the sounder coils. Each of the battery leads passes through a 1-ampere fuse before reaching the instrument.

S.C. relay and sounder circuits have their connections affected by the introduction of secondary cells, and the "up" and "down" stations are joined as shown in Fig. 167. When polarized relays are used "down" sets cannot be worked from the same battery as "up" sets, because only one pole of a single battery is available (either + or −), the other being earthed. The up

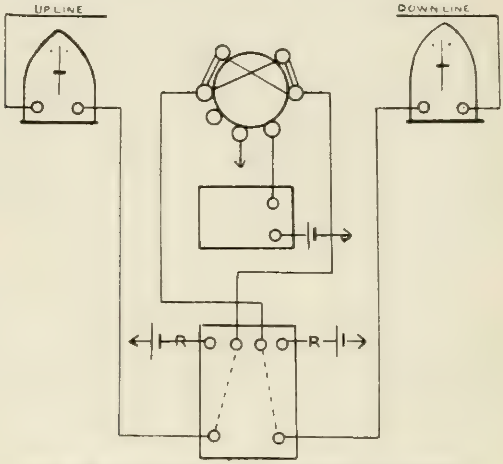


FIG. 168.—Universal battery: S.C. intermediate station.

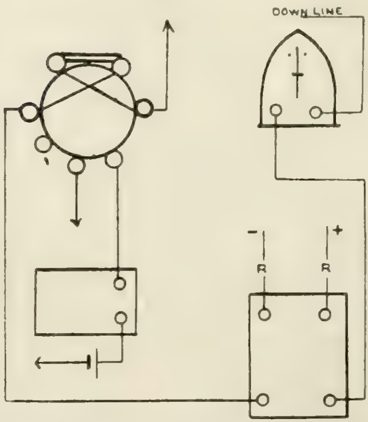


FIG. 169.—Universal battery: D.C. up station. For down station reverse battery (*U*) and *D* of relay and galvanometer terminals.

set requires positive, while the down set uses negative, consequently two separate batteries must be provided. An intermediate station S.C. would be connected as in Fig. 168. At each station the relay and sounder could be replaced by a polarized sounder with manifest advantages. The same remark applies to the D.C. circuits on the universal battery

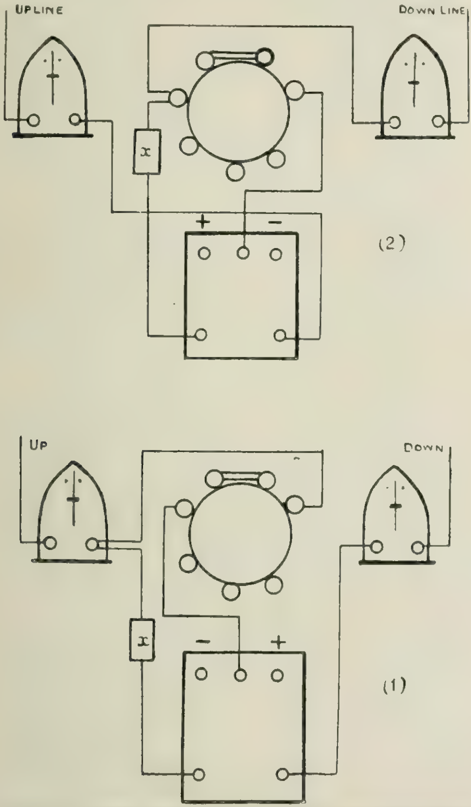


FIG. 170.—Connections showing changes at intermediate station D.C. universal batteries.

system whose connections are shown in Fig. 169. At an intermediate station, if the resistances of the sections are not approximately equal, a "coil resistance various" is placed in the smaller. The changes necessitated by this provision are indicated in the two sets shown in Fig. 170, according to the section equalized: (2) if the down line is the smaller; (1) when the resistance is placed in the up section.

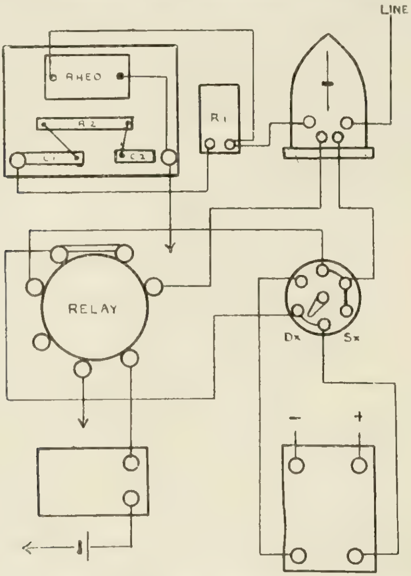


FIG. 171. Differential duplex: universal batteries up station.

The differential duplex as adapted for the universal battery system need only be considered as arranged for double current. The up station connections are shown in Fig. 171. To assist the memory the 6-terminal switch may be lettered *G O R S L D* (as shown in Fig. 172, where *G* is the galvanometer connection; *O* is nothing; *R* right of key; *S* split of relay; *L* left of key; *D* down of relay). For a down office four crosses in the connections must be made:—

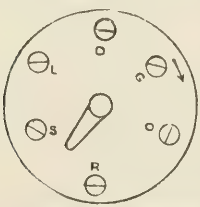


FIG. 172. 6-terminal switch on U.B. duplex up station.

D and (*U*) of relay
\+ ,, − ,, key

Wires on the two upper terminals of galvanometer.
,, ,, lower ,, ,,

The current required is 20 to 30 m.a. through one winding, and note that one coil of relays at both up and down offices is in the line path, and must be included in the calculation for resistance. Exactly the same calculations are necessary when the polarized sounder replaces the relay.

Simple Methods of Cable Working.

The speed of working in submarine cables depends primarily upon the length, capacity and the resistance of their conductors. It may also be modified by other conditions, such as inductance and leakance—but usually for telegraph purposes the two latter are neglected. The electrical constants which vary the character of each cable exist in differing proportions according to its type, and therefore speed is connected with the manufacture. The celebrated KR law first formulated by Lord Kelvin expressed the speed as being inversely proportional to the product of the capacity, K, into the resistance, R, of the cable. Therefore speed has roughly been considered as varying according to the square of the length with cables similar in construction. For with twice the length the capacity is doubled and the resistance is doubled. The KR for a single line and earth circuit compared with a looped or metallic circuit between the same stations is now estimated as being in the ratio $\frac{KR}{\frac{2}{3}K.2R}$ or $1:1\frac{1}{3}$.

It has already been shown that, where capacity exists, charge precedes current and the speed of working is determined by the time required to cause a sufficient potential difference at the distant end to affect the receiving instrument. In a long cable, should the battery be disconnected before the current has appeared at the distant end, the charge still travels onward. If the cable is earthed at the sending end after each signal the charge can escape thence also. Should the battery be reversed the nearest portion of the first charge is met and neutralized by the reversed charge, which itself also progresses. Thus a cable may be positive in one part of its length and negative in another, or even, if long, may be traversed by successive charges either alike or of opposite sign, in the manner of waves. Owing to the effect of a cable's capacity the current only gradually reaches its maximum and the production of a signal is retarded; further, when the battery has been removed the signal is prolonged, especially if the cable is not earthed at the sending end between each signal. A reversed current sent after each signal neutralizes a portion of the charge and the effect of prolongation is minimized. If an ordinary relay were used the armatures would not respond until the current had attained sufficient strength to act, and the signal would not cease until the current had sufficiently diminished. Consequently such an instrument at the end of a long submarine cable would require the application of considerable E.M.F., which would jeopardize the safety of the cable besides reducing the speed of working. With a reflecting galvanometer, however, a signal is indicated when the strength of the current varies in the slightest degree; usually only a few cells of the Daniell type are employed. The signals are produced at the sending end by a double sending key, or pair of tappers like those of a single needle. The syphon recorder has practically replaced the mirror as a receiving instrument. In it (as in a D'Arsonval galvanometer) the coil is movable and the magnet is fixed. When reversed signals are received the coil moves from side to side and by means of a thread connecting them causes a corresponding movement of the syphon. This consists of a very thin glass tube bent so that one end dips into a vessel containing ink while the other faces the paper and is so arranged as to be free to move across or in a direction at right angles to the length of the slip. Continuous vibrations are imparted to the syphon and the ink is thrown on to the paper in a shower of small dots. When the slip is caused to travel onwards and the syphon is moved from side to side it will trace lines upon the slip and thus the movements of the coil are recorded on the paper.

Many devices have been proposed for hastening the discharge of a cable and produce "square" signals by *curbing* them. Among such arrangements was a *curb-key* designed to send alternate currents of varying duration. The use of condensers of suitable capacity, besides very materially obviating interferences by earth currents, tends to fix the *zero* point. The signals are thus given by short impulses, and no continuous current can flow as a condenser is inserted at each end of the cable. In accordance with traffic requirements hand signalling is generally replaced by automatic working and the principal cables are worked duplex on the bridge system.

A cable from Ireland to Nova Scotia belonging to the Direct United States Cable Company was the first ocean cable to which duplex working was applied. Its conductor resistance was about 7000$^{\omega}$ with a capacity of about 980 microfarads. The working speed through this line was found to be about 100 letters per minute each way, or very nearly twice the speed with simplex working.

Exercise V.

1. (*a*) What is meant by :—

    I. Open circuit working.
    II. Closed ,, ,,
    III. Double current ,, ?

    (*b*) Is the single needle a double current or a single current system?

2. Explain briefly the differential system of duplex working.

3. Diagram and description of rheostat "*D*," tracing the path of the current when the value in the rheostat is 5050$^{\omega}$.

4. Describe the various parts of apparatus required to instal a double sounder as used by the Post Office.

5. Give a diagram of the apparatus and connections of a D.C. polarized sounder duplex circuit.

6. Give a list of the instruments required for D.C. relay and sounder duplex circuit, and specify the function of each.

7. Trace the path of the discharge of a condenser in D.C. duplex, illustrating your answer with a diagram of the necessary parts.

8. What changes are made for D.C. differential duplex in the universal battery system?

9. With both stations joined as in previous question, what indications would you expect if the down station

had the strap of the relay open? Give reasons for your answer.

10. Explain the relation between the fall of potential and resistance, and show how this is applied in the Hay central battery duplex.

11. Describe the bridge duplex, and explain why the receiving instrument need not be differentially wound.

12. Diagram D.C. duplex, universal batteries, polarized sounders, and both stations. Trace with arrows the currents with up key depressed, down key at rest, and explain how signals are received.

13. In differential D.C. duplex, universal system, with relays; what resistance would be required in the rheostat to obtain a balance if the line is 1125 ohms resistance?

14. State briefly what effects would be observed in the above circuit when (*a*) line is disconnected, or (*b*) wire broken at a rheostat terminal, or (*c*) the up station's key switch is over to "receive." Give reasons for your answers.

15. In emergency how would you replace a 4-terminal key with a 3-terminal or a 5-terminal key? Give diagrams with your explanation.

16. Explain the C.B. omnibus condenser system, with diagram.

17. Give an explanation, with diagram, of the Vyle and Smart method of C.B. duplex working.

18. Detail the arrangement of the fuses and other protection supplied for circuits working on a universal battery of secondary cells.

19. If you have to work a number of circuits from one battery on the universal system, show by a numerical example that the battery resistance must be low so that the current may not materially vary, however many circuits are worked.

20. Trace briefly the distribution of power, in a secondary cell installation, from the cells to the instrument.

21. Describe with sketches the table distribution case, and show how a change of power is effected.

22. Supply a diagram of a D.C. circuit, three stations, each universal battery, showing the special connections at the intermediate office when the down section of the line has the lower resistance.

23. Five wires of 600^ω each are connected to a battery of 8·5 volts and 10^ω resistance on the universal system; what is the current (i) in each line? (ii) What will it be if one line is disconnected? (iii) What will it be if two lines are disconnected? (10 m.a., 10·1 m.a, 10·2 m.a.)

24. Six circuits of 600^ω each supplied on the universal system; what must be the greatest resistance that a battery can have so that the current may not vary more than 25%? (13^ω nearly.)

CHAPTER VI

MISCELLANEOUS

Earth currents.—It is generally possible, in the United Kingdom at least, to consider the earth connections at different stations as being at a common potential, but more distant points on the earth's surface are found to have different potentials, and therefore currents would pass in lines connecting them. Magnetic storms, such as are observed frequently in the Arctic regions when the aurora is of a rapidly varying character, sometimes extend over very large areas and disturb telegraphic communication by producing earth currents. In November 1903 a total cessation of telegraph business resulted for about twelve hours in England and some other countries of the Continent. The most recent similar disturbance occurred on September 25, 1909, and the aurora was then observed in Scotland, Switzerland, Italy, France, and South Africa. Undoubtedly these storms are connected with variations in the radiation of the sun, whose dark spots are at such times more in evidence.

When circuits are interrupted by earth currents the best method for restoring communication is generally by forming a metallic circuit—using a second wire and removing the earth connections.

Another means is the use of condensers, as in the submarine cable working, and thus breaking the continuous circuit. In the latter case the receiving instrument must be adjusted neutrally so as to respond to the impulses and form correct signals. Details of alterations required, with various types of circuits, to restore and maintain communication during the prevalence of earth currents are given in Plate 25A of "Telegraph Diagrams" of the G.P.O. 1906 edition.

Methods of protecting Lines and Apparatus from Lightning and Power Circuit Currents.

The possibility of contacts between telegraph and power wires such as electric light and tramway circuits is provided for as regards aerial lines by the regulation that *guard wires* must be erected and maintained at places where there is a liability of contact with such overhead conductors. The risk of damage to apparatus, shock to operators, or even a fire has been safeguarded by the provision of fuses, heat coils, and protectors. At small offices

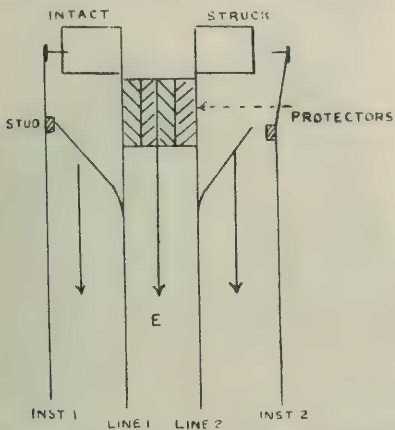


Fig. 173.—Arrangement of heat coil and protector for two lines and instruments.

a combination of these are supplied in fire-proof cases, but in larger stations they are fitted on a test and cross-connection frame in a basement fire-proof chamber to which also the underground wires are first led. The glass tube cut-out is a thin fuse wire "blowing" at 1 ampere. The heat coils are small brass bobbins wound with fine wire to 15^{ω} or 25^{ω}. The line is connected to the coil wire, the other end of which is soldered to the bobbin, while the instrument is connected to a pin secured to the bobbin by a special kind of solder of a low fusing point. A current of 250 m.a. passing for 30 secs. is sufficient to melt the solder and enable a spring to pull the pin out of the bobbin and disconnect the instrument. In some patterns the line is also earthed when the heat coil "strikes." The lightning protectors are generally "D" pattern, which consists of two oblong carbon plates about $1\frac{1}{2}''$ by $\frac{1}{2}''$, separated by a sheet of mica having three small circular holes to provide air gaps. The line wire is connected to one plate by a spring, which also keeps the combination together and places the other carbon plate against the tinned brass plate, which is earth-connected. The arrangement of these devices is shown diagrammatically in Fig. 173, where a combination heat coil and protector-strip is shown as used for two wires.

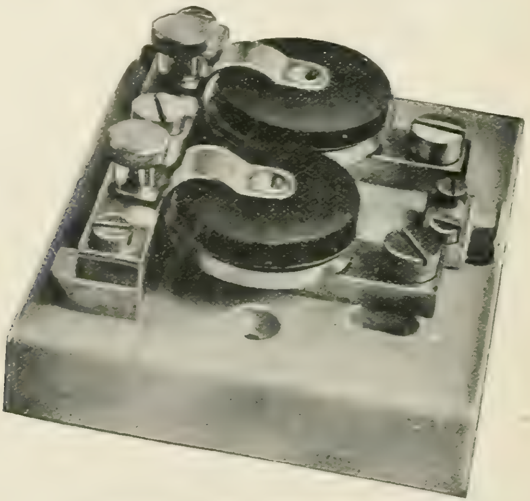


FIG. 174. "C" type lightning protectors.

Two protectors of the "C" type are shown in Fig. 174, with the iron cover removed. A sheet of mica is placed between two carbon plates. The lower plates are fitted in tinned brass holders connected to screw terminals, while the other carbon plates are held by spring clips joined to the earth-connected brass bar.

Test board.—From the fire-proof chamber the wires, with silk and cotton flame-proof insulation, are taken in lead-covered cables to the test board of the pattern shown in

Fig. 175. Here the normal connection of the lines and instruments is as shown by Fig. 176. The switch springs

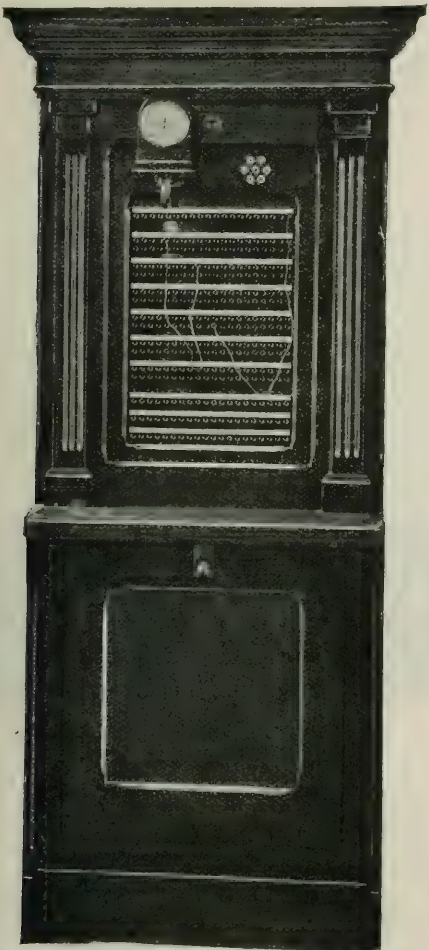


FIG. 175.—Switch spring test board.

of the line connection are joined by their inner contacts to the inner contacts of the instrument springs, and when everything is in order no connections usually appear on the face of the board. For special purposes, tests or crosses, pegs and cords are used, and when a peg is inserted the springs break contact with their inner connection, and the line or instrument can thus be separately employed for special requirements. A galvanometer and a test-hole tablet are provided for making the different localization tests. In large offices several panels like that illustrated would be required, and the further provision of a divisional test board is sometimes found convenient as an intermediate and local testing point between the main board and the instrument tables. The wires serving the instruments are distributed from a connection strip of the

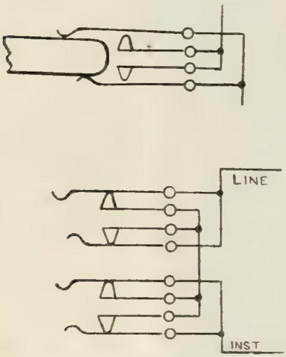


FIG. 176. Normal connection of test springs, and effect of inserting peg.

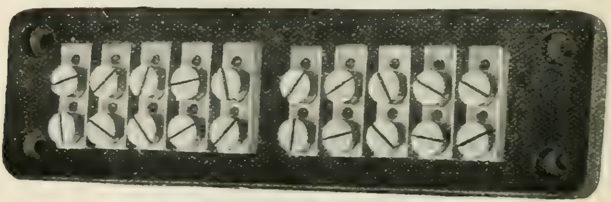


FIG. 177. – Instrument connection strip.

form shown in Fig. 177, which is fixed on the underside of each table and affords a ready means for making local changes of sets. At the tables also the main earth-connec-

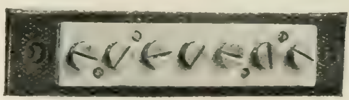


FIG. 178. – Earthing strip.

tion is obtained for each instrument by an earthing-strip, such as is shown in Fig. 178.

APPENDIX

QUESTIONS SET AT THE CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS IN TELEGRAPHY, ORDINARY GRADE

1908

1. A galvanometer of 200 ohms resistance is placed in series with a battery whose electromotive force is 27 volts and resistance 15 ohms and a resistance coil of 500 ohms, and the deflection is observed. The resistance coil is short-circuited and the same deflection as before is produced by shunting the galvanometer. Find the resistance of the shunt.

2. (*a*) How many cells, each of 2 volts electromotive force and negligible resistance, would be required to send a current of 30 milliamperes through an external resistance of 2450 ohms?

(*b*) Show why it is that a larger number of circuits can be worked on the universal system from secondary than from primary batteries having the same total electromotive force.

3. (*a*) Sketch and describe the Post Office standard relay.

(*b*) Show by what path or paths the lines of force of the permanent magnet find their way from one pole to the other.

4. Describe devices used in the protection of lines and apparatus from (*1*) lightning, (*2*) power circuit currents.

5. (*a*) What determines whether a telegraph pole should be strutted or whether it should be stayed?

(*b*) Show how each is effected in practice.

(*c*) What are longitudinal stays and for what purposes are they erected?

6. An earth fault exists in an underground wire; describe how to localize the fault, (*1*) if no other wire is available, (*2*) when a second wire is available for the purpose of the test.

7. (*a*) Give a diagram of a double-current duplex circuit for a line over 200 miles in length.

(*b*) What are the paths of the static discharge of the line and of the condenser in a double-current duplex circuit?

8. Describe and illustrate central or common battery working on a 4-office circuit.

9. (*a*) What are the essential features of:—(*1*) a bichromate cell; (*2*) a Leclanché cell; (*3*) any form of dry cell in use for telegraph purposes?

(*b*) Give, briefly, the uses to which each class is put.

10. Describe and illustrate the method of winding resistance coils used for testing purposes: explain the necessity for the method of winding employed and say of what material the wire is made.

11. Give a description, with sketches, of a polarized sounder, and enumerate its advantages for telegraph purposes.

12. (*a*) Show how to calculate the quantity of wire required to fill the bobbin of an electromagnet of a given size.
(*b*) What is meant by the "self-induction" of an electromagnet?

1908 SPECIAL EXAMINATION

1. (*a*) What are the essential qualities of iron for electromagnets?
(*b*) If you were provided with a low electromotive force, would you use thick or thin wire for winding an electromagnet, the remainder of the circuit being of negligible resistance? Give the reason for your answer.

2. Describe any two methods of measuring (*1*) the electromotive force, and (*2*) the internal resistance of a battery.

3. Give a brief description of the Wheatstone A B C instrument and explain the principle of its working.

4. Describe and illustrate the construction of a paper-core lead-covered cable for telegraphic purposes, a portion of the cable to be employed for loop working and a portion for single wire circuits.

5. Show diagrammatically how three double-current simplex circuits (up, down and intermediate offices) of unequal resistance can be worked off one battery, and explain any steps that it may be necessary to take to secure good working.

6. Compare the relative advantages of differential and bridge duplex working, giving a simple sketch to illustrate each system.

7. How would you localize *earth*, *contact* and *disconnection* respectively on a long aerial line?

8. (*a*) Describe the construction of the latest type of condenser.
(*b*) State the more common uses and functions of condensers in telegraphy.

9. Give a description of any form of secondary cell in use for telegraphic purposes, and explain its chemical action.

10. (*a*) What are earth currents?
(*b*) How can their disturbing effects on the working of a long telegraph circuit be eliminated?

11. Describe, with sketch, a protector for submarine cables.

12. A wire having a resistance of 48 ohms is so arranged as to form a complete square, *A B C D*, the ends being connected at *A*. Find the resistance when a current enters at *A* and leaves at the diagonally opposite point *C*, and state the effect of joining *B* and *D* by a resistance of 24 ohms.

1909

1. Three circuits which are being worked on the universal principle from a primary battery have external resistances of 800, 900 and 1000 ohms respectively; if the electromotive force of the battery be 50 volts and its resistance 100 ohms, calculate the current which passes in the circuit of highest resistance (*i*) when it is working alone, (*ii*) when the three circuits are working simultaneously.

2. What are the most commonly employed substances for insulating aerial bare wires? Sketch any form of insulator and explain the method of binding a copper wire to the same.

3. Give a diagram of a double current differential duplex circuit requiring two retardation coils, and explain the action when both keys are depressed simultaneously.

4. Describe, with illustrations, any form of non-polarized relay employed for telegraphic purposes, and state its uses.

5. What are the practical units of resistance, current and electromotive force? What is the standard for the unit of resistance and how is it related to the absolute unit?

6. How would you ascertain the locality of a contact between two wires if a third good wire were available for testing purposes? Give an example.

7. Describe, with diagram, any simple method of telegraphic working through a long submarine cable.

8. What number of bichromate cells would be required to work a simplex Wheatstone circuit with three stations, *A*, *B* and *C*, the distance between *A* and *B* being 105 miles, and between *B* and *C* 90 miles, the line wire being of copper weighing 300 lbs. per mile?

9. What is a differential galvanometer? Give a sketch of the induced needle and explain why a permanently magnetized needle is not employed.

10. (*a*) Explain briefly the most usual method of preserving wooden poles, and state what are its advantages over other methods.
(*b*) State the relative advantages of wood and iron for poles.

11. Give a sketch of the combined protective apparatus consisting of lightning protector, fuse and heat coil, and state what are the functions of the two latter.

12. Define (*i*) polarization and (*ii*) local action, and state how they are overcome in the bichromate, the Leclanché, and the Daniell cell.

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1. Mention some of the effects of an electric current by means of which its presence can be detected and its strength measured.

2. The coils of a post office standard relay are connected to a Daniell cell of 5 ohms resistance; calculate the relative magnetic effects when the coils are joined (*a*) in series, (*b*) in parallel.

3. A battery of unknown resistance is producing a current of 20 milliamperes through an external circuit of 1000 ohms. When a second circuit of 1000 ohms is connected to the battery the current passing in the battery is increased to 35 milliamperes. Calculate the resistance of the battery.

4. Give diagrammatic sketches showing the connections of (*a*) the ordinary double current key and (*b*) the single current key with switch. Which is used for "universal" working, and why?

5. Explain, with the aid of diagrams, the principle of the tangent galvanometer. Why should the needle be small, and why cannot a deflection of 90° be obtained on an ordinary tangent galvanometer?

6. How is a universal *local* battery connected to a number of sounders (worked by relays), and what is the essential point in the battery in order that the arrangement may work satisfactorily?

7. How is a polarized relay set neutral? Explain the adjustments of the relay.

8. What are the functions of an "earth" wire on a telegraph pole? What is the effect of a bad earth? Give a sketch showing how the earth wire is fixed from the butt to the roof of a pole having arms on it.

9. Give a sketch showing how a heavy pole can be erected by means of ladders and a pole cart.

10. Describe, with sectional drawing, the construction of a submarine cable. Why is the conductor of stranded wire?

11. State the value of the current required to work (*a*) an ordinary sounder, (*b*) a polarized sounder, and (*c*) a standard relay. Explain why the values differ.

12. What is meant by "up" and "down" offices? Give a diagram showing three stations connected together for working on the double current Morse system.

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