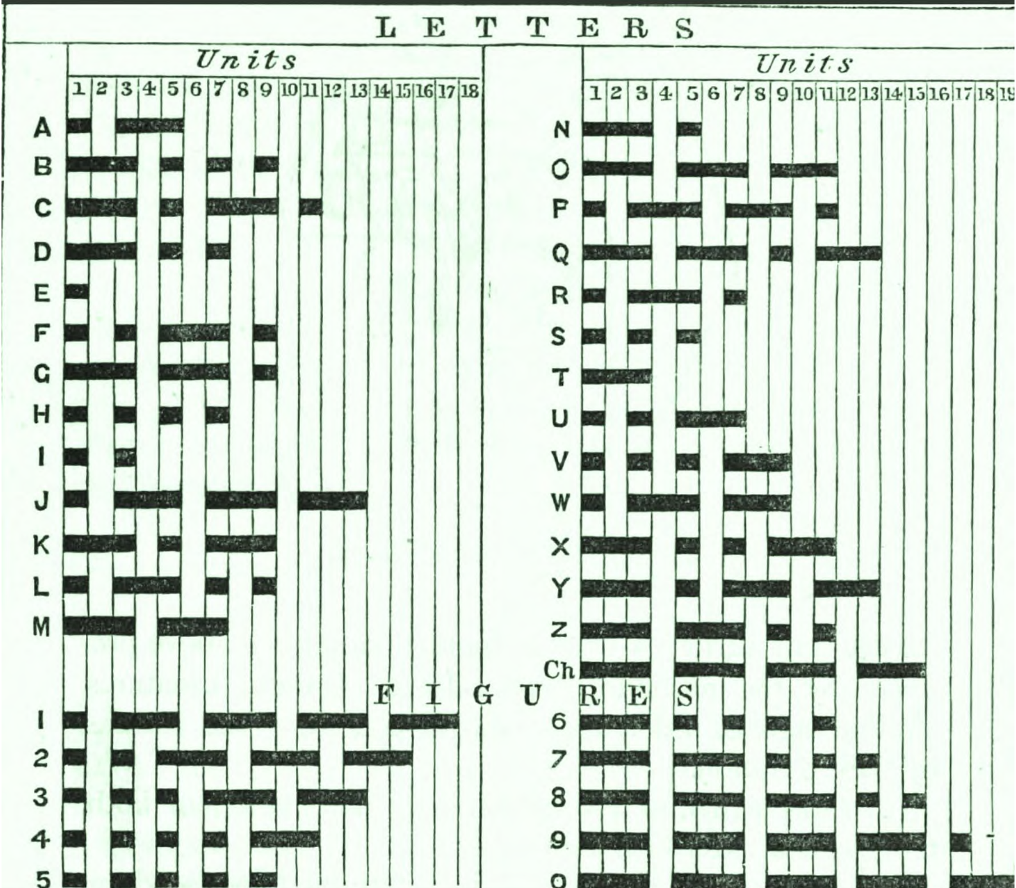

Manual of telegraphy

W. Williams

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TELEGRAPHY

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MANUAL

OF

TELEGRAPHY

BY

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PREFACE.

THE FOLLOWING MANUAL has been written by order of the Director-General of Telegraphs in India, and is based on the substance of the papers on technical subjects, set by the Author, at the general examinations of the Indian Telegraph Department. These subjects embrace a general description of the various **instruments, batteries,** and **circuits** which the telegraph official may be called upon to deal with, **faults** which may be met with, and their **remedy**; the **conservancy** of, and **modes of testing lines, batteries, instruments, lightning conductors**, and **earths**; the general principle of **telegraph working** in its various forms; the **electrical phenomena which interfere with communication** and the various methods by which their **obstructive effect is overcome.**

The objects of the manual are as follows:

First. **To afford the staff a means of self-education in practical telegraphy.**

As the conduct of telegraph circuits and apparatus is ruled by electrical phenomena, these are explained in detail, it being essential that they should be clearly understood in order that the instruments specially designed to utilise or overcome the effects of such phenomena be also understood.

Second. **To serve as a primer and companion to the departmental 'Testing Instructions.'**

With this view, unnecessary details are herein avoided ; but *principles*, by which alone electrical facts can be accounted for, are explained fully and in simple language which, it is hoped, will be found intelligible to all readers.

It is believed that the manual will fall into the hands of many whose opportunities of education in telegraphy have been limited, and who, perhaps, late in life aspire to become something more than manipulators ; and while the main object of the book is to open the way for such to an intelligent understanding of those details of telegraph work which may have been looked upon merely in the light of rule-of-thumb processes, it is further hoped that it may encourage a systematic study of the science, for its own sake, outside the limited scope of a technical manual.

Third. **For the instruction of probationers.**

The contents of the book are made progressive so far as is possible in a work of the kind ; any allusion to a subject or phenomenon not noticed in an earlier part of the treatise being connected therewith by a marginal reference. The marginal *titles to paragraphs* are inserted with the object of affording the Instructor material for questions in the examination of training-classes.

Fourth. **To form a text-book of ready reference.**

The *alphabetical index* is framed with this object; and, further, the subjects are arranged under their several heads, as specified in the *table of contents.* Section **A** is devoted to the definition of all the most important **technical terms** in general use, a clear notion of such terms being an important step towards the comprehension of electrical reasonings generally.

Appendix A comprises those **laws** which determine the strength of electric currents, in whatever circuits they may exist; the **principles** on which duplex and other systems of working are based; the strength of electro-magnets; the influence of derived circuits, extra currents, and all those properties on which the speed and efficacy of signalling depend.

Appendix B contains the **mathematical solutions**, by the simplest step-by-step processes, of the **formulæ** used in the book. It is believed that this appendix, in conjunction with the preceding one, will be found of value in showing how a knowledge of electrical laws, combined with an elementary knowledge of algebra, makes the solution of most electrical formulæ easy, explaining the *meaning* of those used in testing, and enabling the student to originate formulæ for himself in the course of his own tests or other electrical work.

N.B. References herein to 'Testing Instructions' relate to the second edition of that work, published in 1878.

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SECTION A.

DEFINITIONS

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INTRODUCTORY REMARKS.

Electricity and the Electric Current.

SECTION A.

THE following are simple definitions of technical terms, which, though in everyday use in telegraphy, are far from being generally understood.

It is of great importance that the telegraphist should begin by making himself perfectly familiar with these terms, for a clear comprehension of them removes much of the difficulty often experienced in understanding electrical phenomena both in practice as well as in theory.

In regard to the latter, as treated of in books, and more especially in 'testing' and other departmental instructions, many points will become clear and easy of comprehension, which in the absence of such elementary knowledge are found difficult and obscure, because they contain terms, unfamiliarity with which attaches to them a degree of supposed difficulty which they do not really possess.

It is not within the design of this manual to discuss the various hypotheses and theories propounded to explain the **existence of electricity.** Suffice it to say that, like *light*, it is a natural agent, the effects of which are developed by *force.*

This force may be in the shape of chemical action, heat, or other agency, the result being that, by its exercise on a certain body, that body exhibits properties such as those of attraction or repulsion, the production of a spark, the deflection of magnetic needles, the magnetisation of iron, &c.; by virtue of which it is said to be electrified, or to be in a state of electricity, or, in more definite language, **manifests an electric potential.**[1]

[1] Def. 3.

Practice shows that whenever electricity is developed in a body, by any means whatsoever, that body assumes two different electrical states or 'potentials,' equal in amount but

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opposite in kind, termed for the sake of convenience positive (+) and negative (−) respectively, these potentials of different sign being analogous to the north and south polarity of an iron bar which has undergone the process of magnetisation;[1] the tendency of the equal + and − potentials always being to unite and restore equilibrium when afforded the means of doing so by a conducting medium.

[1] Def. 39.

As explained above, electricity is generated by different means; the form of electricity with which we have principally to deal in the following pages, viz. that mainly used for telegraphic purposes, is known as *galvanic*,[2] or *voltaic*, or *dynamic*, or *current electricity*.

[2] So called from Galvani, whose discovery led to the voltaic pile, the first form of chemical battery made.

The two last terms imply motion, and convey the idea that electricity is a current, which flows like a river; hence in telegraphy 'the current' is universally referred to as flowing from one point to another, as this term is found to express most simply the phenomena observed when a telegraphic signal formed at one end of a line is reproduced at the other.

The student will, however, discover that this is a misnomer when, for example, he goes on to observe the electrical phenomena of duplex telegraphy, in which signals are transmitted from both ends of the same wire at once; and in order to prevent subsequent confusion, arising from a wrong conception of what a '*current*' really is, it should be clearly understood from the outset that electricity does not actually travel, but that what is described as the 'passage of the current' is simply an electrical change of state such as that described above, resulting from the tendency of + and − potentials to combine through a conductor and restore equilibrium.

Every change does not necessarily signify the restoration of equilibrium by the combination of + and − potentials, for if two bodies exhibiting different degrees of potential of the same sign be connected together by a conductor, the potentials will become equalised in precisely the same way as two bodies of water would find the same level when connected by a canal.

The term 'current' may thus always be understood to signify such change of potential, whether from + to −, or from a greater + to a less +; its direction being determined with reference to *the fall* of the greater + potential.

SECTION A.

Bearing these remarks in mind, allusion to the '*electric current*' and its '*direction*' as described in the following definitions, and to its action and the laws which govern it, as explained in subsequent paragraphs, need create no misunderstanding by reason of the use of the term.

ELECTRICAL.

Electric Quantity.

1. Electric quantity is the amount of electricity present in an electrified body. As applied to galvanic electricity it represents the current available, and is that property of it which manifests itself in signals, deflections, or, in fact, work of any kind.

The force with which that work is done depends firstly upon the difference of potentials which gives rise to its E.M.F.,[1] and secondly upon the resistance opposed to it;[2] E.M.F. tending to strengthen or increase the quantity of current, and resistance tending to reduce it.

[1] Defs. 4–6, and § 14.
[2] Def. 10.

This is, in fact, the truth expressed by Ohm's law:—

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

* Law 1, App. A.

where C represents the strength or quantity of the current,

E „ its E.M.F.

R „ the resistance it has to overcome.

Unit of Quantity or Current.

2. The unit of quantity or current is called an **Ampère, Weber,** or **Oerstedt.**

Potential Tension or Intensity.

3. Potential, as the term implies, is the *power* which any quantity of electricity has for doing work. As stated in the foregoing introductory remarks, a body which shows signs of electricity is said to manifest an electric potential; and, just as a magnet assumes a north and south pole, so does the electrified body assume two different states of potential, the one + and the other −, the tendency of the + being always to fall to the −. Now in this fall work is done, as it would be in the case of a volume of water the fall of which through a pipe was used to raise a fountain; and just as, in this case, pressure causes the water to flow through the pipe, so does *potential*, or *tension*, or *intensity*,

SECTION A.

as it is sometimes called, cause a quantity of electricity or a current of electricity to flow along a conductor.[1]

[1] Def. 8.

The standard by which potentials are compared is that of the earth, which is taken as zero; so that in speaking of the potential of the current at any point, the difference of potential between that point and the ground is understood, being in kind + or −, according as it is above or below the potential of the earth.

Current.

4. Now it is obvious that in the case of the water pipe the flow of the water is from the end where the pressure is greatest towards that where it is least; so with electricity, the direction of its *apparent* flow, called a **current,** is from that part of a conductor at which the potential is greatest to that where it is least.

Difference of Potential.

5. And upon this **difference of potential** depends the *force* with which the current flows, and by which it overcomes obstacles to its passage, this power of overcoming resistance[2] being termed **electromotive force** (generally written **E.M.F.**).

[2] Def. 10.

E.M.F.

6. From what has been said above, it is clear that if the potential at two points of a conductor be equal, there can be no current, in the same way that if there were equal pressures at two ends of a water pipe no water would flow out of it.

On the other hand, it follows that the strongest flow of current (**E.M.F.**) is obtained when the difference of potentials is greatest.[3]

[3] § 14.

Unit of E.M.F.

7. The standard or unit by which various E.M. forces are compared is called a '**volt.**'

Conductor.

8. The current has been described above as flowing through conductors, **a conductor** *being any substance offering a passage to the flow of electricity.*

Conductivity.

9. The property admitting of this passage of electricity through a substance is called **conductivity.**

Resistance.

10. The reverse, that is, the property exhibited by some substances *which resists the passage of electricity*, is called '**resistance.**' Thus, *conductivity* and *resistance* are the converse or *reciprocals* of one another.

Insulators.

11. The above property of resistance is possessed by all substances more or less, but those showing it to the greatest degree are called **insulators.**

Unit of Resistance.

12. The unit by which resistances are most commonly

measured is called an **ohm**, or British Association unit (**B.A.U.**). There are other units of less common use.[1]

Circuit.

13. An electric **circuit** consists of a battery (of whatever form) and everything between its two poles which takes a part in conducting the current.

Electrification.

14. Is the term applied to the condition of a body which is charged with electricity or electrified; e.g. supposing a current to be applied to the conductor of an insulated telegraph cable; the cable is then said to be in a **state of electrification.**

Capacity.

15. The quantity of electricity which a cable or land line or any other conductor thus holds is called its **capacity.** The same is implied by the term **electro-static capacity** or **inductive capacity.**

Unit of Capacity.

16. The unit by which capacity is measured is called a **farad,** or more generally for convenience a **microfarad.**[2]

Dielectric.

17. In an electrified cable induction[3] takes place between the conductor inside and the water or earth outside the cable; in just the same way as it does between the inner and outer plates of a Leyden jar,[4] the insulating medium through which this action takes place being called the **dielectric.**

Thus the dielectric in the case of the cable would be the *indiarubber* or *guttapercha*; in that of the Leyden jar, *the glass*; in that of a land line, *air.*

Specific Inductive Capacity.

18. On the dielectric depends this inductive effect, and air being taken as the standard dielectric, the **specific inductive capacity** of any insulating substance is *its power of effecting induction as compared with air.*

Galvanic Polarisation.

19. A galvanic cell or battery is said to be **polarised** when hydrogen in its *free* or *uncombined* state is deposited in bubbles on the negative plate.[5] The first effect of these bubbles is to enormously increase the internal resistance of the battery, and, as a natural consequence, to reduce the current thereof, or even to stop it altogether.

Again, they have the effect of altering the potential of the negative plate, the surface of which is no longer that of the metal—e.g. copper in a Daniell's battery—but a complete surface of innumerable hydrogen bubbles which assume a potential closely resembling that of zinc; the original difference of potential between the copper and zinc plates being thus destroyed, no current flows at all.

1 Def. 34.

2 Def. 34

3 § 114.

4 § 115.

5 § 4.

SECTION A.

Batteries of low internal resistance, or joined through low external resistance, polarise more readily than when the resistance of the circuit is high;[1] and, conversely, polarisation can be reduced or prevented altogether by the insertion of resistance; so, when the poles of the battery are disconnected, the bubbles of hydrogen disappear.

The injurious effects of free hydrogen and the means adopted to overcome them will be more fully discussed under the head of '*Batteries.*'[2]

Constant Batteries.

20. Those batteries in which polarisation, or any other cause which would render the E.M.F. variable, is prevented are called **constant batteries.**

Multiple Arc.

21. Suppose two points, *a* and *b*,[3] to be joined by two or more conductors; these conductors are said to be joined in **multiple arc,** and form

Derived Circuit.

22. a derived or divided circuit.

Extra Current.

23. Is the name given to the instantaneous current produced by the inductive action of a current upon itself.[4]

Return Current.

24. When observed in a telegraph line it is what is technically called a **return current.**[4] The current of discharge from a line[5] is also termed a return current.

Solenoid.

25. A solenoid is a helix or spiral of wire conveying a current, the coils being equal in size, and wound at right angles to a common axis, and so close to one another that the currents circulating in them may be considered parallel. The ends are brought back to the middle of the coil and parallel to its axis with this object, that the current flowing in from the ends towards the middle may counteract the opposite and parallel current in each of the portions between successive coils.

Such an arrangement behaves like a magnet, exhibiting polarity, and following the laws of attraction and repulsion of magnets.

Electrolytic Action.

26. Electrolysis is the name given to a property which the electric current possesses of decomposing compound liquids into their component elements or groups of elements which are called **Ions,** the one appearing at the **anode** or *positive electrode* (i.e. the continuation of the + pole of the battery),[6] the other at the *negative* or **kathode.** The liquid decomposed is called an **electrolyte.**

Electrolytic action takes place at every point of leakage in a telegraph line or cable, causing at such point a

[1] §§ 173, 174.

[2] Sec. B.

[3] See fig. 38, § 163.

[4] § 119.

[5] § 112.

[6] § 1.

Section A.

deposit, the nature of which depends on which pole of the battery is joined to the line (the other pole being connected with the earth);[1] if copper, then oxygen is deposited, forming an oxide which tends to increase the resistance of the fault; if zinc, hydrogen is deposited, reducing the resistance of the fault—in other words, the insulation of the line or cable at that point.[2]

Constant of Galvanometer.

27. The constant of a galvanometer may be described as that current which produces unit deflection on that particular galvanometer—e.g. a deflection of 1° on a reflecting galvanometer,[3] 45° on a tangent galvanometer (tan $45° = 1$), or 90° on a sine galvanometer (sin $90° = 1$).

Osmose.

28. In all two-fluid batteries there is a tendency for the liquid surrounding the active plate to mix with that in which the negative plate is immersed, through the diaphragm or porous material which separates them.[4] This action is called **osmose,** and tends to impair the efficiency of the battery, as it causes chemical action to take place, and this again causes useless consumption of material. The Daniell,[5] which is a two-fluid battery, is subject to this fault, which is shown by the copper solution rising higher in the cell than the zinc solution.

Earth Currents.

29. Earth currents, called also **natural currents,** are observed in telegraph line circuits,[6] and are *caused by difference of potential*, either between the earth at two different stations, or between different points of the line subject to different temperatures. They may *also be caused by induction* from passing clouds. They tend to strengthen or weaken the signalling currents in the line, according as their direction is the same or contrary to that of the battery currents; and, being variable in their nature, they interfere with the permanent adjustment of receiving instruments.[7]

Differential.

30. The term **differential,** as applied to any system of working or to any instrument, implies that two circuits are open to the passage of the current; as, for example, in the differential galvanometer,[8] the *difference* of current in either circuit working the needle or producing a signal.

Null Method.

31. In those differential circuits which are so arranged that the currents are equalised and neutralise one another, thus producing no movement of the needle, such a system is called a **Null method.**

Astatic.

32. A pair of magnetic needles so suspended as to be

[1] §§ 176–177.
[2] § 194.
[3] § 156.
[4] § 1.
[5] § 5.
[6] § 173.
[7] §§ 58–87.
[8] § 165.

SECTION A.

parallel to one another, with their poles in opposite directions, is called an **astatic system,** because it stands apart from the directing influence of the earth's magnetism. Galvanometers in which such a system is used are called *astatic galvanometers.*[1]

[1] § 154.

Amalgamation.

33. Ordinary commercial zinc, when used as the active plate of a galvanic battery, is liable to be uselessly wasted by local action,[2] the result of foreign matter or irregularities in the surface of the plates. To remedy this, they are, when required for batteries in which the zinc plate has to be immersed in acid, subjected to the process called **amalgamation** as follows :—The zinc plate is first cleaned with sulphuric or hydrochloric acid, and then rubbed with mercury, which unites with a little pure zinc, and forms an amalgam, which is spread over the surface of the plate uniformly. The best way of rubbing the mercury on is by means of rag bound at the end of a stick.

[2] § 33.

By amalgamating ordinary zinc, it is given, so far as its surface is concerned, all the properties of pure zinc, which is not used owing to its much greater cost.

Units.

34. A unit is a *standard* by which measurements are compared; as, for example, a *foot* for *length*, or a *lb.* for *weight.* For scientific measurements the **metre** (=39·37 inches) is usually chosen as the unit of **length** ;

the **gramme**	,,	,,	**weight** (=15·43 grains Troy);
the **second**	,,	,,	**time** ;
the **ohm** or **B.A.U.**	,,	,,	**resistance** ;[3]
the **volt**	,,	,,	**E.M.F.** ;
the **Ampère, Weber,** or **Oerstedt**	,,	,,	**quantity** or **current** ;
the **Farad**[4]	,,	,,	**capacity.**

[3] Siemens' unit = ·9564 of an ohm [1·0456 s.u. = 1 ohm]. Varley's unit = 25 ohms.

[4] Or micro-farad.

1° may be considered the **unit of deflection** for a reflecting galvanometer ;[5] 45° for a tangent ; and 90° for a sine galvanometer, tan 45° and sin 90° being = 1, respectively

[5] § 156

The following prefixes are commonly used :—

micro	meaning	one **millionth** part ;
mega	,,	one **million** times ;
milli	,,	one **thousandth** part ;
centi	,,	one **hundredth** part.

Thus—

a microfarad means 1 millionth of a farad;
a megohm „ 1 million ohms;
a millioerstedt „ $\frac{1}{1000}$th of an oerstedt;
a centimetre „ $\frac{1}{100}$th of a metre.

Absolute or Metrical Units.

35. For practical purposes, it is usually sufficient to know the value of an electromotive force as expressed in *volts*, or of other electrical quantities in terms of one or other of the electrical units mentioned above; for theoretical purposes, however, it is obviously of great advantage to be able to express such quantities in terms of the general units of *mass*, *length*, and *time*, without being obliged to employ arbitrary co-efficients, in themselves sources of error.

In the system of **absolute units,** a gramme is chosen as the unit of mass, a metre of length, and a second of time, the fundamental unit of force being '*that force which, acting upon a gramme of matter for a second, generates a velocity of a metre per second.*' According to this system,

1 ohm = 10^7 or 10,000,000 absolute units approximately.
1 volt = 10^5 or 100,000 „ „

Thus—

$$1 \left\{ \begin{matrix} \text{Ampère,} \\ \text{Weber, or} \\ \text{Oerstedt} \end{matrix} \right\} = \frac{10^5}{10^7} = 10^{-2} \text{ or } 0{\cdot}01 \quad \text{„} \quad \text{„}$$

In the more recent system, known as the **centimetre-gramme-second or C.G.S. system of units,** the fundamental unit of force is '*that force which, acting upon a gramme of matter for a second, generates a velocity of a centimetre per second.*'

The advantage of employing the centimetre instead of the metre as the fundamental unit of length is that the unit of mass is (in the C.G.S. system) identical with the mass of the unit of volume of water (the standard of specific gravity), the mass of 1 cubic centimetre of water being approximately 1 gramme. According to the C.G.S. system,

1 ohm = 10^9 C.G.S. units approximately.
1 volt = 10^8 „ „

Thus—

$$1 \left\{ \begin{matrix} \text{Ampère,} \\ \text{Weber, or} \\ \text{Oerstedt} \end{matrix} \right\} = 10^{-1} \quad \text{„} \quad \text{„}$$

SECTION A.

Resultant Fault.

36. However many forces may act upon an object, it can only take up one fixed position. A *single* force applied in a certain direction can produce the same result.

This single force is termed the **resultant** *of all the forces.* The same term is applicable to electrical forces; for example, a telegraph line containing many points of leakage would be subject to a certain loss of current; the same result precisely might be produced by one single leakage, which would represent the resultant fault or loss of current due to the leakage all along the line. Thus, '*The resultant fault of any line or cable is that fault which, if applied alone to the line at the proper point, would produce the same effect with respect to the sent and received currents as all the actually existing faults do.*'[1]

Conjugate Conductors.

37. '*In any system of linear conductors, any pair of conductors are said to be conjugate to one another when a variation of the resistance of, or the E.M.F. in the one causes no variation of the current in the other.*'[2]

Reduced Length.

38. Every resistance which may be measured must obviously correspond with the resistance of a certain length of a standard conductor, so that resistance may thus convey the idea of *length*; for example, in the case of a telegraph line made up of wires of different gauges, and consequently each offering a different resistance per mile, the whole resistance may be expressed in terms of that of a standard wire;[3] that is to say, the actual resistance of any line must represent the resistance of a certain length of wire of the standard gauge. This length is called the **reduced length** of the line.[4]

[1] Schwendler (t. 1, App. xi. a).

[2] Brough (t. 1, p. xii. vol. 1).

[3] In practice No. 1 wire I.W.G. is taken as the standard, the resistance of which = 252 ohms, or 264·24 s.u. at 80° Fahr.

[4] The convenience of reducing resistance to *length* for testing purposes will be seen hereafter (Sec. F).

MAGNETIC.

Polarity (Magnetic).

39. A magnetic substance is said to be **polarised** when it assumes equal and opposite *poles*, called *north* and *south*, the former being that which would turn towards the north pole of the earth, and the latter towards the south, if the substance were free to move. Between the poles (generally midway) there is a point at which no magnetic force is exhibited; this is called the **equator** or **neutral line.** A piece of steel exhibiting these properties is called **a magnet,** and an imaginary line drawn from pole to pole would represent what is called the **axis** of the magnet.

SECTION A.

Magnetic Field.

40. The space in the neighbourhood of a magnet through which its influence is felt is called a **magnetic field.**

Magnetic Induction.

41. Certain magnetic substances, such as soft iron, become magnetised when placed in a magnetic field; the property by which this phenomenon occurs is called **magnetic induction.**

Magnetic Meridian.

42. The magnetic meridian of any place is indicated by the position a magnetic needle, free to move in a horizontal plane, would take up at that place.

Coercive Force.

43. There is a force which is exhibited in magnetic substances, notably in hard steel, which resists the process of magnetisation: this is called **coercive force,** which has the further property of causing magnetism once acquired to be retained. In perfectly soft or pure iron this property is scarcely perceptible.

Residual Magnetism.

44. A bar of *perfectly* soft iron, exhibiting no coercive force, would be capable of instantaneous magnetisation and demagnetisation on the application and withdrawal of any magnetising influence, such as a current or inducing magnet;[1] but, according to the degree of coercive force in the bar, so would it retain, after the removal of the magnetising current or magnet a trace of its magnetism, taking an appreciable time to fade away, this remanent trace being called **residual magnetism.** It is obviously a source of retardation in all electro-magnetic instruments;[2] the property is, however, utilised in the D'Arlincourt relay.[3]

Portative Force.

45. The portative force of a magnet is represented by the weight which it can carry.[4]

Magnetic Moment.

46. The magnetic moment of a magnet is determined by multiplying the strength of the poles into the length between them.

Saturation point.

47. By the process of magnetisation[5] it is possible to impart to a bar of steel a greater amount of magnetism than it will permanently retain; the result being that a portion of the newly acquired magnetism will disappear, leaving the bar permanently magnetised to an extent less than that exhibited immediately after it was magnetised: the point at which the magnetism remains constant is called the **point of saturation.**

[1] §§ 49–54.

[2] § 56.

[3] § 131.

[4] Law 26, App. A.

[5] § 238 (d).

ELECTRO-MAGNETIC.

SECTION A.

Magnetic Inertia

48. It is found in practice that the soft iron core of an electro-magnet takes time both to receive and to part with its magnetism, by virtue of what is called **magnetic inertia.**[1] Its retarding effects are felt more in the process of *magnetisation* than in *demagnetisation*, as soft iron parts with its magnetism more quickly than it acquires it; so, when received currents follow one another in rapid succession, the core of the electro-magnet may not have time to be saturated,[2] and so not be able to exert its full attractive force.

The stronger the current,[3] and the shorter the iron core, the less the magnetic inertia, and, consequently, the more rapid the magnetic action.

Amperian Currents.

49. Ampère attributed all magnetic phenomena to electricity, assuming each individual molecule of a magnetic substance to be traversed by a closed electric current, the direction of these **amperian currents** being in conformity with Ampère's law.[4]

Vibration or Oscillation.

50. By a single **vibration** or **oscillation** of a magnetic needle is understood its motion from its maximum deflection on one side of zero to the same limit on the other.

1 § 121 (b).
2 Def. 47.
3 Defs. 1-4.
4 Law 13, App. A.

SECTION B.

TELEGRAPH BATTERIES

TELEGRAPH BATTERIES.

Current mainly due to Chemical Action.

SECTION B

1. A battery may be composed of one or more cells, each of which consists, generally, of two conducting plates (usually two dissimilar metals) immersed in liquid. Now any two dissimilar metals placed in an acid which can chemically affect either or both of them, manifest different electric potentials; and when the poles, i.e. the extremities of the metal plates outside the liquid, are joined by a conductor, the tendency of these potentials is to unite and produce equilibrium by the fall of the higher to the lower, which necessarily results in a '*flow of current*,' as described in Section **A** (Introductory Remarks); the chemical action which goes on in the cell, however, maintains the initial difference of potential between the poles, the degree of this difference depending mainly upon the readiness with which one metal (the active or electro-positive, as it is called) is attacked by the acid, as compared with the other or electro-negative plate.[1]

Investigations have proved that the mere contact of two dissimilar metals also causes them to assume different potentials, but the effects manifested from contact alone bear no proportion to the results of chemical action.

E.M.F. Dependent on Chemical Combination.

2. Now the force of this chemical action constitutes the electromotive force of the cell, a property of the highest importance in the construction of any form of battery, for it is that on which the effective strength of the current directly depends.[2] It is desirable, therefore, to select materials which combine to develop this property to the greatest degree, which, as has been shown above, is done by employing a combination in which the active plate is highly electro-positive as compared with the negative plate.

[1] It is customary to call the electro-positive or active plate the + plate, and the electro-negative the − plate, and to consider the current as generated by and starting from the former in the direction of the arrow shown in fig. 43, § 173, sec. D. The direction of the current outside the liquid would, therefore, be from the extremity of the − plate, which is called the + pole, to the extremity of the + plate, which is called the − pole.

[2] Law 1, App. A.

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The following list represents an electro-chemical series of metals, arranged, according to a determination of Faraday, in the order of the relative potentials they exhibit when immersed in dilute sulphuric acid, each being electro-positive to that which follows it on the list, so that the greatest difference of potential obtainable would be exhibited if the first and the last were taken to form a pair :—

+ Zinc. Tin Lead Iron Nickel Bismuth Antimony Copper Silver −

The above order slightly varies with different acids, but always holds good for the same combination, so that the E.M.F., so long as nothing occurs to affect its constancy, is always the same for any particular combination.

Current Strength Directly Proportional to E.M.F., and Inversely to Resistance.

3. Electromotive force, however, is not the only property which has to be considered in the composition of a battery cell, for although, according to Ohm's law, the **strength of current** elicited is *directly* **proportional to E.M.F.**, it is at the same time *inversely* **proportional to resistance,** and this latter property, as relating to the internal resistance of the cell, is dependent not only upon the *nature* of the materials used for the plates, but also upon their size, their form, the mechanical arrangement of the cell and the nature of the liquid in which the plates are immersed. Pure water offers very high resistance ; the addition of acids reduces this, but the resistance even of acid solutions is very high as compared with that of metals.

Considerations in the Choice of Battery Material.

4. Again, the **cost** of materials requires consideration. Looking at the foregoing list (para. 2), though the best effects as regards E.M.F. would be obtained by the use of a zinc and silver pair when immersed in dilute sulphuric acid, it might obviously, for purposes of economy, be advantageous to select some other metal for the negative plate. Next above silver on the list we find copper, which is considerably less costly than silver, and which, when combined with zinc as the positive plate and immersed in dilute sulphuric acid, is productive of good electromotive force, and forms one of the simplest and earliest galvanic elements devised. Such a combination, however, in common with all single-fluid arrangements, is productive of *polarisation* ;[1]

[1] Def. 19.

and here another and highly important point for consideration, in regard to the construction of telegraph batteries, is introduced. The chemical action which takes place in the form of cell above described, when the poles are joined, is as follows:—The solution is decomposed, hydrogen being liberated at the copper or negative plate, to which it adheres in the form of bubbles, and oxygen combines with the zinc or active plate to form zinc oxide, which is again dissolved by the acid of the solution forming sulphate of zinc, this action being thus attended by consumption of the zinc plate. The acid, however, is also consumed, and this, as will be understood from what has been said above (para. 3), must result in a corresponding increase of the resistance of the cell. But this is not all; for the E.M.F. is impaired and rendered *inconstant* by the deposition of free hydrogen on the negative plate, giving rise to polarisation, as described in def. 19 (Sect. **A**).

Again, the free hydrogen thus deposited has the further property of reducing metals from their salts, and tends to cause the deposition of zinc (from the sulphate of zinc in solution) on the copper plate, which, being thus faced with zinc, assumes the potential of the zinc plate, and this results in the destruction of the E.M.F. of the cell, which depends on the *difference* of potential manifested by the respective metals.

For telegraph batteries, therefore, which are required for continual work, it is obvious that these injurious effects, resulting from the deposit of hydrogen, should be prevented.

Various forms of battery aim at effecting this in various ways. In Daniell's battery it is done by the introduction of a second liquid containing a copper salt, by which the liberated hydrogen, instead of collecting in bubbles on the negative plate, is employed in depositing metallic copper thereon, thus preventing the inconstancy and loss of E.M.F. which would be caused by the deposit of free hydrogen.

Minotti's form of this battery is that which has been hitherto adopted, almost universally, for telegraphic purposes in India; but before describing this in detail it may be well to draw attention to some of the most important or typical forms of battery, as described briefly in the following paragraphs, with the object of illustrating how, by each

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combination, the properties essential to the acquisition of a strong and constant current are obtained.

It will be observed that the high E.M.F. and low resistance necessary for the production of a strong current may be obtained at the expense of constancy; and that the most constant current is not the strongest which can be produced: further, that the acquisition of electrical qualifications may be attended with cost, inconvenience, or mechanical difficulties disproportionate to the purposes for which the battery may be required.

Taking all these points into consideration, the respective merits and demerits of the various batteries described, as relating to the special nature of the work for which they are designed, can be compared. Their resistances, being affected by variety of size, shape, mechanical arrangement, nature of porous vessel or diaphragm, strength of acid solutions; &c., cannot be compared in the same definite terms as their E.M.F., which, for constant batteries, is the same for every combination of the same kind independently of its size or form.[1]

Daniell's Battery.

5. **Daniell's battery** consists of a zinc and copper pair; the zinc, which is the active plate, is immersed in dilute sulphuric acid contained in a porous vessel; the copper or negative plate is placed in an outer jar containing a solution of sulphate of copper, which is kept saturated by the insertion of crystals of the copper sulphate.

In this, as in every form of cell, the outer jar should be made of some insulating and watertight material, such as glazed stoneware, porcelain, guttapercha, &c.[2]

E.M.F. = 1·079 volts.[3]

Chief feature:—*Constancy.*

Polarisation is prevented by surrounding the negative plate with the copper solution.[4]

Advantages:—(1) *Constancy.*
(2) *Inexpensiveness.*

Disadvantage:—Waste of material due to internal action when the battery is not at work, an unpreventable cause of which is the property called '*osmose*.'[5]

Use:—Adapted by its constancy for continual work, and consequently well suited for purposes of telegraphy.

[1] § 2.

[2] Sometimes the outer vessel is made of copper, and so forms the negative plate as well; but this would not do for a telegraph battery, whose cells should always be as well insulated as possible (§ 38).

[3] Defs. 7 and 34.

[4] Def. 19, and § 4.

[5] Def. 28.

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The zinc solution, which by the action of the battery becomes sulphate of zinc,[1] requires daily attention and replenishment with water, to prevent its becoming saturated and forming crystals.[2]

[1] § 12.

[2] § 35.

On the other hand, the copper solution should be kept saturated by replenishment, as required, with crystals of sulphate of copper (Hindustani *tutia*), and any excess of that solution owing to osmose action should be removed by means of a sponge, or, if necessary, a syringe.[3]

[3] § 34.

It may here be mentioned that all the materials used for batteries should be of the purest description obtainable. The use of inferior chemicals is likely to result in setting up action other than that designed, which must result in impairing the electrical and even the mechanical efficiency of the battery.

The water used for replenishing battery cells should always be the softest procurable. Cells should not be too full.

Minotti Battery.

6. In **the Minotti battery** the zinc plate is immersed in water. Its chemical action produces the same results as that of the Daniell; their E.M.F. is, therefore, the same. By the use of water, however, without acid, the original resistance of a Minotti is greater than that of a Daniell cell, so it takes longer to come into working order.[4] Its normal resistance, moreover, is much higher than that of an ordinary Daniell of corresponding size, owing to the nature of its diaphragm, which is of sand or sawdust instead of a porous vessel.

[4] § 21.

With this exception, the Minotti differs only from the Daniell in the mechanical form and arrangement of its materials, by which *simplicity*, *economy*, and *portability* are gained, and the action of *gravity* is utilised and assisted by the horizontal diaphragm, by which the tendency of the liquids to mix is reduced.[5]

[5] § 29.

The construction of this form of battery, which has been found the most suitable for general use in India, will be described in detail hereafter.[6]

[6] § 16 *et seq.*

Leclanché Battery.

7. The battery of **Leclanché** consists of a zinc plate, usually in the form of a cylindrical rod, immersed in a strong solution of salammoniac, which occupies the outer jar; into this is placed a porous vessel containing a plate of carbon surrounded by a mixture of binoxide of manganese and

carbon in coarse grains; these form a compact mass in the porous vessel—

E.M.F. = 1·48 volts.

Chief feature:—No consumption of material when not in work; but when the poles of the battery are joined continuously the action is attended by the deposit of free hydrogen on the carbon plate, and *polarisation* is the result.[1]

Advantages:—(1) Freedom from loss of current by local action.[2]

(2) Of very long duration from the same cause.

Disadvantages:—*Polarisation* and consequent *inconstancy* when used continuously.

Use:—As the bubbles of free hydrogen soon disappear when the poles of the battery are disconnected, the Leclanché is peculiarly adapted for the ringing of bells and all kinds of occasional work; the great length of time it will last when thus employed, without requiring attention, renders this form of battery particularly suitable for dwelling-houses, private telegraph or telephone offices, where incessant communication is not kept up.

The solution of salammoniac (hindustani *nausada*) requires renewal after a time; likewise the zinc plate, which must be kept clean.[3]

Grove's Battery.

8. In **Grove's**, as in all the other forms of battery described herein, the active or positive plate is zinc, which is immersed in dilute sulphuric acid contained in the outer jar; into this is placed a porous vessel containing the negative plate—platinum—immersed in concentrated nitric acid.

E.M.F. = from **1·63 to 1·956 volts,**

being dependent on the strength of the acid solutions.

Chief feature:—*Great strength of current without polarisation*, as the hydrogen given off combines with the oxygen of the nitric acid to form water,[4] and is thus prevented from being deposited on the negative plate.

Advantages:—**High E.M.F.** with **very low resistance**, and consequently a **strong current.**[5]

Disadvantages:—(1) The materials, especially the platinum, are very expensive.

(2) The fumes given off (N_2O_4) are injurious.

[1] Def. 19.

[2] § 33.

[3] A recent and convenient form of this battery is that known as the 'agglomerate block,' in which the porous cell is dispensed with and a conglomerate block of the binoxide of manganese is attached to each of the two faces of the carbon plate; a porcelain or earthenware separator is placed between this block and the zinc rod, the whole being bound together by indiarubber bands and immersed in the solution opalammoniac.

[4] § 12.

[5] § 3.

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(3) The strength of current falls off as the nitric acid is consumed.

(4) Frequent attention is necessary from the above cause.

Use :—From the features of this battery enumerated above, it will be evident that it is greatly superior in point of current strength to any of the forms of battery previously described ; but it is wanting in the lasting power of either the Daniell or Leclanché. It is thus adapted for occasional use where great strength of current is required, being especially valuable for the lecture-room, for laboratory work, the production of the electric light, or for any unprotracted experiments where current strength is the chief desideratum.

It is advisable to dismantle the cells of Grove's battery when not in use, to prevent waste of material. They can be quickly set up again ready for use as required.

As a preventive against local action, the zincs are always amalgamated.[1]

[1] Def. 33.

Bunsen's Battery.

9. **Bunsen's battery** is a modification of Grove's, and in its construction differs from the latter only in the nature of the negative plate, which is of carbon instead of platinum.

E.M.F. = 2 volts (about).

The current elicited from a Bunsen is somewhat less than that of a Grove, owing to the latter having the lower resistance of the two.

The chemical action is the same in both, and consequently the principal disadvantages of the Grove are common to the Bunsen ; the chief advantage of the latter, as compared with the Grove, being its lower prime cost, owing to the substitution of carbon for platinum as the negative plate.

The precautions taken to prevent waste of material in the Grove battery are necessary also in the case of the Bunsen. The solutions removed from these batteries can be used again for recharging them.[2]

[2] They must of course be kept separate.

Bichromate Batteries.

10. Various forms of bichromate batteries are made in which **bichromate of potash,** combined with a powerful acid or agent, is used as the exciting liquid or compound. The most common form is that in which zinc and carbon plates are immersed in a solution composed of bichromate of potash and sulphuric acid, this combination being pro-

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ductive of high E.M.F. and low resistance, thus forming a powerful and comparatively inexpensive battery, and one which is much used for surgical purposes, either for working electro-motors or even for electric lighting on a small scale.

The inconstancy of the ordinary bichromate battery, however, renders it unsuitable for *telegraphic* purposes. The liquid requires to be often stirred or otherwise kept in motion; the plates have to be kept out of the liquid when the battery is not in use, to prevent useless waste of the zincs, which further require to be amalgamated to prevent local action,[1] which would otherwise take place to a very prejudicial extent.

[1] § 33.

The crystals of bichromate of potash are first dissolved in hot water, and the sulphuric acid is not added until the solution is cold.

Fuller's Battery.

11. Fuller has, in his **mercury-bichromate of potash battery**, devised an important modification of the foregoing: the plates are zinc and carbon, the former being always kept amalgamated by the use of mercury in the porous cell, thus remedying one of the evils to which the ordinary bichromate battery is exposed. He further introduces a cylindrical porous vessel in which stands the zinc, which is cast into a shape peculiar to Fuller's form of battery, and consists of a cylindrical rod widening at its base which just fits into the porous vessel. Sufficient mercury is placed in the porous vessel to cover the flattened base of the zinc; a small quantity of sulphuric acid is added, the porous vessel being then filled up with water. The outer jar contains the carbon plate, immersed in a solution of bichromate of potash and sulphuric acid, to which water is added.

This form of battery, also, is liable to polarise when joined through a very low resistance, but is practically constant when the external resistance is considerable, as in the case of an ordinary telegraph line worked on 'open circuit.'[2]

[2] § 179.

The Fuller has been used with advantage in one or two of the chief offices in India for line circuits; and one of these cells when thus used is found to do the work of at least two Minotti. It is, however, neither so portable nor more than one quarter as lasting as the Minotti; neither is it (owing to its greater tendency to polarise) as suitable for low-resistance circuits, such as in the case of earth testing,

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&c.[1] Its cost of maintenance, too, exceeds that of the Minotti.

Both the outer and inner jars of the Fuller are kept replenished with water, and any appearance of blue solution in the porous vessel is at once removed.

When the outer solution becomes blue, more potash is added; or, if it retain its orange colour and the current fails, more sulphuric acid is added, some of the inner solution being at the same time removed, and the porous vessel replenished with water.

If the potash solution is over-saturated, crystals of chrome alum form on the carbon plate; some of the solution should in this case be removed, and a little sulphuric acid and water be added.

Chemical Action.

12. **The chemical action,** which takes place in the above-mentioned batteries when the poles are joined, may be briefly described in chemical symbols as follows:—

DANIELL.

CIRCUIT OPEN (*i.e. poles disconnected*).

Zn Zinc plate	SO_4H_2 Sulphuric acid	DIAPH-	SO_4Cu Sulphate of copper	Cu Copper plate

CIRCUIT CLOSED (*i.e. poles joined*).

$ZnSO_4$ Sulphate of zinc	-RAGM.	H_2SO_4 Sulphuric acid	$CuCu$ Copper deposited on copper plate

LECLANCHÉ.

OPEN.

Zn Zinc plate	$2NH_4Cl$ Salammoniac	DIAPH-	$2MnO_2$ Binoxide of manganese	C Carbon plate

CLOSED.

$Zncl_2$ Chloride of zinc	$2NH_3$ Ammonia	H_2O Water	-RAGM.	Mn_2O_3 Sesquioxide of manganese	C Carbon plate

GROVE.

OPEN.

Zn Zinc plate	H_2SO_4 Sulphuric acid	DIAPH-	N_2O_5 Nitric acid	C Carbon plat

CLOSED.

$ZnSO_4$ Sulphate of zinc	-RAGM.	H_2O Water	N_2O_4 Nitrous acid (gas)	C Carbon plate

1 §§ 336–342.

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BUNSEN.						
OPEN.						
Zn Zinc plate	H_2SO_4 Sulphuric acid	DIAPH-		N_2O_5 Nitric acid		C Carbon plate
CLOSED.						
$ZnSO_4$ Sulphate of zinc		-RAGM.	H_2O Water	N_2O_4 Nitrous acid (gas)		C Carbon plate

Conditions to be fulfilled by Telegraph Batteries.

13. **The design of any battery** is to produce a current with the object of doing certain work, and the stronger the current the more work it will do in a given time. Now, by Ohm's law,[1] we know that the greater the E.M.F. of a battery, and the less its resistance, the stronger the current it will give; so, to get the *strongest possible current*, all we have to do is to make up a battery which shall produce the greatest E.M.F., and offer the lowest resistance possible. We have seen, however, that where everything else is sacrificed to these two attributes—high E.M.F. and low resistance—the current produced, though strong, suffers in other ways, the principal of which are polarisation [2] and falling off in strength as the acid solutions are consumed by the action of the battery.[3]

Both of these causes produce *inconstant currents*,[4] which would never do for telegraph work, for which a steady and continuous current is required; and, as low internal resistance facilitates polarisation, there is a limit to which we can reduce the resistance of batteries without endangering their constancy. Hence, the main points to be aimed at in the construction of a **telegraph battery** are really *maximum* E.M.F. and *constancy*. Cost of materials, chemical simplicity, and freedom from local action [5] also demand consideration.

Daniell's battery combines these qualifications better than any other class of battery yet devised. It stands highest of all in order of constancy, and although its E.M.F. is only half that of a Grove, yet there is no other electro-chemical combination which can produce such a high E.M.F. at so low a cost; and E.M.F. can, in the case of telegraph batteries, be multiplied by increasing the number of cells in series, as will be more fully explained hereafter.[6] Further, copper, zinc, and sulphate of copper are all easily procured, even in India.

1 Law 1, App. A.
2 Def. 19.
3 § 8.
4 Def. 20, and § 15.
5 § 33.
6 §§ 252–254.

The Minotti form of this battery is the most portable and convenient; the zinc or active plate is easily inspected and removed; the diaphragm of sand or sawdust is inexpensive and unbreakable, and forms a convenient means of regulating the resistance of the cell; and the use of water instead of an acid around the zinc, renders the Minotti less liable to local action from surface impurities[1] than the ordinary Daniell, and dispenses with the necessity for amalgamation.[2]

[1] § 33

[2] Def. 33.

E.M.F.: how obtained.

14. The property of electromotive force, being the result of chemical action, causing a difference of potential to be manifested by the respective plates of the battery when immersed in liquid solutions,[3] it becomes necessary to select such a combination as shall produce the greatest possible difference, compatible with constancy, between the potentials of the plates. This is done by immersing them in a solution, or solutions, which shall act vigorously on one (the active) plate, and as little as possible, or not at all, on the other.

[3] § 2.

The combination used in the case of the Minotti battery[4] is productive of *fair* E.M.F., the exciting liquid not being a strong acid, as in the case of the Grove and Bunsen, but merely water which is converted by the action of the battery into sulphate of zinc. This zinc sulphate solution is kept replenished with water, and should never be allowed to become more than semi-saturated, for the following reasons:—

[4] §§ 6 and 16.

1. The semi-saturated condition is that of least resistance to the current.

2. When saturated it becomes more dense than sulphate of copper, so the principle of the gravity battery[5] is no longer retained.

[5] §§ 6 and 29.

3. The crystals formed by saturation are productive of various evils as explained in paragraph 35.

Constancy: how obtained.

15. The great advantage of the Minotti is the *constancy of its E.M.F.*, which remains the same from the time the battery comes into action to the time it is exhausted. It does not depend upon the strength of acid solutions, and the hydrogen generated by the action of the battery, which is the great enemy to constancy when in its *free* or *uncombined* state, by virtue of its polarising effects, is prevented from remaining free by its immediately combining, by

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chemical affinity,[1] with the sulphate of copper solution, and taking the place of a certain amount of copper which it reduces from the solution, depositing it on the copper plate immersed therein, the plate being thus continually supplied with a fresh bright copper coating, so long as the action of the battery continues.

[1] i.e. the natural tendency which certain chemical bodies have to unite with one another.

Description of the Minotti Cell.

16. **The Minotti cell** is constructed as follows :—Into a cylindrical insulated jar (generally of highly glazed stoneware), standing on three projections, which are made with the object of reducing surface-leakage to a minimum,[2] is first placed a circular disc of copper to which a covered leading wire has been previously attached in the following way :—The wire (which is usually Hooper's core) is cut into a length of 15 inches for each cell ; the end which is to be attached to the copper disc is bared for 2½ inches, and well cleaned. Into the disc, which is also well cleaned, are punched three holes—one near the circumference, one at the centre, and one between the two ; each just large enough to receive the bare copper wire, which is then threaded through them until the end of the insulating covering is drawn close down to the disc.

[2] § 38.

The bare end of the wire and the disc are then hammered together so as to secure a good contact between them.

The disc, with its leading wire attached, is then laid flat at the bottom of the jar into which it just fits ; the leading wire (the upper end of which is bared for 1 inch, and subsequently forms the copper or + *pole*[3] of the cell) is led up the side of the jar. Upon the disc is then placed sulphate of copper in powdered crystals, the quantity being determined according to the work required of the cell.[4]

[3] § 1 (note).

[4] § 26.

Over this layer of sulphate of copper is placed a disc of linen, or porous paper, or felt ; then the diaphragm, which consists of a layer of sawdust or sand, on which is placed another disc similar to that below the diaphragm, which is thus kept together by means of these discs.

On this is laid the zinc plate, which consists of a thick circular disc, the upper surface of which has a vertical projection or neck, into which a brass terminal is introduced at the time of casting the disc, and which forms the − pole of the cell. Water is then carefully poured in until it rises just above the level of the flat surface of the zinc, so that the connection between the zinc neck and the brass terminal is above water. Hard water should not be used; but rain water, if possible, as being most free from impurities. The circular zinc and diaphragm discs are each made with a groove or nick in its circumference, through which the leading wire passes.

Use of the Diaphragm.

17. **The diaphragm** is the partition used in two-fluid cells to keep the liquids apart as much as possible,[1] and, at the same time, to allow of the passage of the current through it without offering too great resistance thereto. In most forms of battery the diaphragm consists of a porous, unglazed earthenware vessel: the sand or sawdust diaphragm of the Minotti, however, has special advantages, already referred to.[2]

Sand, if used, should be river, not sea sand, and should not, of course, be so fine as to be rendered imporous. If sawdust is used, it should be of teak or some hard wood. Either should be well washed before use, the water being squeezed out of it before it is placed in the cell. It should be packed in little by little, each layer being flattened down by the hand or with a rammer of wood of similar shape to the zinc disc, the pressure being increased as more is added, especially around the leading wire, which should be kept as rigid as possible.

Respective Merits of Sand and Sawdust diaphragms.

18. **Sawdust** has this advantage over sand for a diaphragm, that, being compressible, it holds the leading wire in a fixed position, whereas with a sand diaphragm the slightest movement of the wire outside the cell is communicated to the inner part too, the result being just the same as if the cell had been shaken,[3] for it causes the copper solution to work up to the zinc, creating local action[4] and possibly destroying the E.M.F. of the cell. The **sand diaphragm**, on the other hand, has this advantage, that it sinks as the sulphate of copper beneath it is consumed, whereas sawdust has been known to form a cake which clings to the sides of the jar, thus creating a space between the diaphragm and the receding sulphate of copper, whereby the resistance of the cell is increased. Further, cells with sand diaphragms last longer than those in which sawdust is used. If, however, the cells require to be moved, there is less danger from shaking when sawdust is used, owing to its forming a more rigid mass than sand.

[1] Def. 28, and § 29.

[2] § 13.

[3] § 29.

[4] § 33.

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New Cells: 'On Short Circuit.' 'In Series.' 'Parallel.'

19. A cell prepared as above offers a very high resistance, and must continue to do so until, by some chemical process, the water, which, as we have shown before, is the worst of liquid conductors, is converted into some solution of less resistance. This is attained by joining together the poles of the cell, and thus allowing the current (however weak at first) to pass between them. Chemical action at once sets in,[1] the water above the diaphragm eventually becoming sulphate of zinc, and that below, sulphate of copper. The diaphragm itself also becomes saturated, the upper part with zinc sulphate and the lower with copper sulphate. As this change goes on so does the internal resistance of the cell decrease, until the zinc solution becomes semi-saturated[2] and the copper solution completely so, the strength of the current increasing accordingly, until the cell comes into working order.[3]

In order that the current may have no unnecessary obstacle in the shape of external resistance, the poles of the cell are joined directly one with the other, in which condition the cell is said to be 'on *short circuit*.'

When cells are joined together to form a battery, with the copper or + pole of one to the zinc or − pole of the next, and so on, they are said to be joined '*in series*.' If, however, all the + poles are joined together to form one electrode,[4] and all the − poles together to form the other, then the cells are said to be joined '*parallel*.'

To bring new cells into working order, each cell is joined on short circuit, so that the current of each has only its own cell's resistance to overcome, and the action of a whole battery is not impeded by any undue resistance which may be exhibited by any individual cell, as would be the case were they all joined in series together.

Salt: its Use and Danger.

20. As the action of a cell reduces its resistance, so inversely, if the resistance of a new cell be reduced by any mechanical means, such as the addition of an acid or salt, its action is accelerated thereby. On this principle, when it is required to hasten the action of a newly prepared cell, it may be done by surrounding the zinc disc with a solution of common salt and by saturating the diaphragm with the same before it is put into the cell. Time would be further saved by adding water to the powdered sulphate of copper before the diaphragm is placed over it. This is a course, however,

1 § 30.
2 § 14.
3 § 30.
4 Def. 26

not to be recommended except under the *most exceptional* circumstances, and when sulphate of zinc is not obtainable;[1] as the use of salt favours local action,[2] prevents the uniform deposit of copper on the copper disc, and interferes with the constancy of the cell.[3]

[1] § 21.
[2] § 33.
[3] Def. 20.

To bring New Cells into Working Order immediately.

21. The *best* way **to bring a new cell into** *immediate* **working order** on an emergency is to pour in enough water to *nearly* cover the powdered sulphate of copper on the copper disc, then to soak the sand or sawdust to be used for a diaphragm in a solution of sulphate of zinc, after inserting which the zinc disc is laid on, as usual, and sufficient water added to cover its surface.

Sulphate of zinc in solution can be obtained by removing the liquid round the zinc discs of working batteries. Any copper which this may contain can be removed by heating the liquid over a slow fire in an earthen vessel with pieces of zinc in it. The liquid should then be evaporated off in shallow earthen dishes, when the crystals of sulphate of zinc which remain can be collected.

Extra Battery Power for Emergencies.

22. To prevent the necessity for resort to such expedients, **reserve cells** are kept ready for use, in case extra battery power may be required, whether it be for the purpose of working through an increased length of line or to compensate for leakage caused by imperfect insulation from atmospheric or other causes.[4]

The reserve cells should be prepared in the ordinary way,[5] brought into working order,[6] reduced to the proper resistance[7] and tested, after which the zinc discs should be removed (to prevent waste through local action),[8] and, having been cleaned and dried, be placed ready for immediate use.

[4] § 289.
[5] §§ 16 and 17.
[6] § 19.
[7] § 46.
[8] § 33.

Diaphragm and its Defects.

23. Sometimes cells do not come into working order owing to the presence of air which is prevented from escaping by the tightness of the diaphragm, and which has the effect of greatly increasing the resistance of the cell.

Bubbles of hydrogen would produce a similar effect, and may be the result of joining the poles of the cell through very low resistance.[9] Should the latter, only, be the case, the bubbles will soon disappear on disconnecting the poles of the cell; if this treatment does not get rid of them, then the diaphragm itself is probably the cause of the mischief, and should be pierced with a sharp fine stick, the bubbles of air or hydrogen gas, as the case may be, will then escape,

[9] Def. 19.

SECTION B.

and the resistance being thus reduced, the cell will come into working order.

The stronger the current and the lower the resistance in its path, the more readily will hydrogen be liberated—sometimes faster than it can be taken up—so that it becomes 'free,'[1] a fault which may thus occur more often in a *local* than in a *line* cell.[2]

[1] Def. 19.
[2] § 26.

Connecting Wires of Battery Cells.

24. Reference has been made[3] to the necessity for drawing the bare end of the leading wire which is connected to the copper disc so far through it that the insulating covering extends quite down to the disc. This is to prevent the bare copper wire being eaten away by the corrosive action within the cell. On the same principle, the insulating covering of the wire should be perfectly free from cracks or defects of any kind.[4]

[3] § 16.
[4] § 37.

Junction of Connecting Wires.

25. The reason why the **junction between the bare wire and the disc** is made by hammering,[5] and not by the help of solder, is that the latter would set up local action in the cell (because it would manifest a potential different from that of the copper), and waste of material would be the result.[6]

[5] § 16.
[6] § 33.

Difference between Line and Local Cells.

26. The consumption of sulphate of copper in properly prepared cells being **in proportion to the strength of current** elicited, which we know by Ohm's law to be *inversely proportional* to the resistance in circuit,[7] the E.M.F. being constant, it follows that those cells which are joined through low resistances, such as that of a '*local circuit*,'[8] which is generally about 50 ohms, would become exhausted more rapidly than those cells which are joined through a telegraph '*line circuit*,'[8] the resistance of which may be several hundreds, or even thousands, of ohms. Twice as much sulphate of copper is therefore used for *local cells* as for *line cells*, the former being made to contain twenty-four ounces and the latter twelve. Notwithstanding this, a line cell should last much longer than a local cell, for it has been proved[9] that the average current passing through a line cell is about one-tenth of that required for working a 'sounder,'[10] the usual resistance of which is about 30 ohms.

[7] Law 1, App. A.
[8] §§ 180, 181.
[9] Schwendler and Brough.
[10] § 58.

Internal Resistance of Cells.

27. Again, **the internal resistance of a battery or cell** *decreases* **with the consumption of material**; any sudden *increase* of resistance, therefore, would show that something was wrong. The defect may be in the diaphragm,[11]

[11] § 23.

or may be due to the formation of some salt in the cell introducing undue resistance. This is the case sometimes when the initial chemical action of the cell deposits the insoluble oxide of zinc upon the zinc disc before the current is sufficient to reduce it to sulphate of zinc.[1] When this is the case, the zinc presents a white appearance, and should be at once replaced by a clean disc.

[1] § 30.

Exhaustion of Cells: Signs of.

28. **The consumption of sulphate of copper is indicated** by the level of the zinc disc; when this has sunk to a depth corresponding to the original thickness of the layer of sulphate of copper with which the cell was charged, it will be found that the cell has become exhausted, and its internal resistance reduced to the saturated diaphragm alone, about 5 ohms.

Mixing of Liquids.

29. One of the advantages claimed for the Minotti is that it is constructed on the principle of a '**gravity battery**,' the object of such being to prevent the *natural* tendency always displayed by the liquids in a two-fluid cell to mix with one another. In view to preventing this, the gravity battery was devised, in which the heavier liquid (or that of greater specific gravity) occupies the lower portion of the jar, and the lighter liquid the upper; porous vessels or partitions are dispensed with, their office being performed by the action of gravity alone. It will be readily understood that the slightest movement of such a battery would be liable to derange it, absolute stillness being necessary to allow of the liquids maintaining their respective levels.

We have this principle in the Minotti in which the saturated solution of sulphate of copper in the lower part of the jar is heavier than the semi-saturated solution of sulphate of zinc in the upper part; these solutions, however, are kept apart, not by gravity alone, but by the porous diaphragm of sand or sawdust. Nevertheless, in this, as in the case of the ordinary gravity battery, the greatest care should be taken to avoid unnecessary movement or shaking of the cells, the result of which would be that the copper solution would be forced up to the zinc disc, on which a salt of copper would be deposited and the E.M.F. of the cell consequently endangered; local action would be set up and material uselessly consumed.

There is never *perfect* separation of the liquids even in the Minotti; so there is always some waste, but this is

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reduced to a minimum by care in the manipulation of the cell. The utility of the diaphragm as a separator is greatly dependent on the care with which it has been prepared.[1]

[1] §§ 17 and 44

To avoid shaking up the solutions, it is advisable to place newly-prepared cells, before the water is added, in the position which they are to occupy permanently.

Processes by which a Cell comes into Working Order.

30. When a cell is prepared in the ordinary way,[2] the water has first to penetrate through the diaphragm down to the sulphate of copper; immediately it has done so, the chemical action of the cell is started, and its E.M.F. established, which, as explained before, remains very constant up to the time the cell is exhausted.

[2] § 16.

Not so, however, the resistance, which at first is very high,[3] but is reduced as chemical action goes on by the formation of sulphate of copper in solution in the lower part of the cell and diaphragm in place of water. As the resistance is thus reduced, so does the force of the current increase, according to Ohm's law, and as the current increases, so does the action which it creates in the short-circuited cell also increase, in virtue of which the solution occupying the upper part of the cell and diaphragm is converted into sulphate of zinc. Thus, when the poles of a newly-prepared cell are joined, the internal resistance continues to fall, and the current strength to increase, until it is fit for use.

[3] § 19.

E.M.F. Constant for Similar Cells.

31. The E.M.F. of a Minotti being a constant quantity so long as there is any action at all in the cell, and being the same for all similar chemical combinations,[4] we can multiply the E.M.F. of a battery by increasing the number of cells joined in series,[5] remembering, however, that each cell carries with it its own resistance, and that the current emitted by a battery or cell, though directly proportional to its E.M.F., is affected at the same time by its internal resistance $(C = \frac{E}{R})$.*

[4] § 2.

[5] § 19.

* Law I, App. A.

C varies with *R*, by Ohm's Law.

32. Hence it follows that when the internal resistance (R) of a battery cell varies (E being constant), the current (C) also varies; and as the current (C) is the property of the cell which produces signals, deflections, &c., it is evident that the larger R becomes, the less working power the cell displays.

Local Action.

33. Ohm's law thus teaches us that when we have high E.M.F. and low resistance, we may expect a strong current. We know also that the strength of current produced by a

battery or cell is proportional to the amount of battery material consumed. To avail ourselves, however, of the full value of the current, it is necessary that it should accumulate at the poles or electrodes of the battery or cell,[1] otherwise it is lost to practical use, and battery material is consumed to no purpose.

This waste is due to what is called **local action,** the effect, often, of impurities (principally iron) in the zinc plate. The iron and the zinc assume different potentials in the exciting acid, and each particle of iron and the zinc surrounding it form the plates of a closed battery, the circuit of which is completed by the solution in which they are immersed, the result being that chemical action is always going on, whether the poles of the battery cell are open or closed, and the zinc, which is the electropositive metal, is consumed to no purpose.[2]

To prevent this cause of local action, battery zincs which have to be immersed in strong acids are amalgamated, with the object of rendering their surface uniform.[3]

This precaution is not necessary in the case of the Minotti battery, in which the zinc is immersed in water, subsequently converted by the action of the current into sulphate of zinc; local action, however, occurs in the Minotti, from the tendency of the liquids to mix, which can never be prevented altogether in any two-fluid battery, though care in the first preparation and in the subsequent handling of the battery will reduce this source of waste of material and loss of current to the lowest possible limit. Amalgamation would, of course, be no remedy for this.

Use of Battery Sponge or Syringe.

34. A battery sponge is useful for removing the water from cells in which it has become impure or saturated.[4]

Syringes may, under certain circumstances, be convenient for this purpose, but if so, they should not be used also for replenishing the cells with fresh water; for there would be a risk of re-inserting impurities, particularly copper solution, which would do as much harm as shaking the cell. A metal vessel should not be used for replenishing cells, unless it be made of *zinc.*

Formation of Zinc Sulphate.

35. White crystals are sometimes seen on the zinc discs as well as on the jars of working cells, caused by the water becoming *saturated* with the sulphate of zinc formed by the chemical action of the cell, the principal danger

[1] § 1.
[2] § 2.
[3] Def. 33.
[4] § 5.

SECTION B.

attending the formation of which is that it is likely to reach the junction between the brass terminal screw and the neck of the zinc disc, and being when dry a very bad conductor, it would introduce a large unnecessary resistance into the circuit.

Secondly, it is liable to form on the sides and edges of the cell, and cause leakage by drawing off the liquid of the cell by capillary action.

Prevention.—(1) As the crystals are caused by saturation, keep the cells replenished with clean water, removing the zinc solution when necessary.

(2) The first fault is prevented by keeping the water below the junction of the zinc disc and brass terminal screw.

(3) The second by keeping the jars dry and clean, but where this is impracticable, by coating their rims with paraffin.[1]

Composition to prevent Corrosion.

(4) A mixture of coal tar and resin (or sealing wax), painted over the junction between the neck and brass terminal of the zinc disc, prevents the formation of sulphate of zinc at this point.

To clean Coppers and Zincs.

36. To clean copper discs.—(1) Keep them from exposure to the air.

(2) On finding them dirty or tarnished, immerse them at once into boiling water with tamarinds in it.

(3) When bright and clean, wash them with fresh water, and leave them under water till required for use.

(4) If the above is not sufficient, the leading wires must be taken off, and the disc must be heated in a charcoal fire and plunged, while hot, into cold water.

To clean zinc discs:

[Zincs which are much eaten away should be re-cast.]

Those which are only slightly worn should be brushed until they assume a bright smooth surface. This can be done either with a battery brush of iron or steel wire, or the surface may be ground smooth on sandstone.

Zincs must **not** *be kept in water.*

Leakage from Cell to Cell.

37. Another point in the conservancy of batteries to be observed, with a view to its prevention, is leakage taking place by capillary action through the wires which connect the cells with one another, inside the insulated covering of the wire, caused by the latter not adhering as closely to the wire as it should.

[1] This is best done by melting the paraffin in a shallow dish, and dipping the inverted battery jar into it, so that the rim becomes covered to a depth of about a quarter of an inch.

This affects the working of the cell seriously, by causing the copper solution of one cell to be conveyed to the zinc solution of the next.

Remedy.—Seal up the ends with wax, guttapercha, paraffin, or Chatterton's compound.

To prevent the same happening through the outer surface of the connecting wires, soak them before use in melted wax.

Insulation of Batteries.

38. *Leakage may be caused by a damp battery stand*, or *by cracked jars*, or *by cells touching one another*, the result being that the cells are partially short circuited; their current is thus shunted,[1] and a portion of it is consequently lost to practical use. The insulation of the battery stand may be effected by standing it on insulators, these being wiped daily.

[1] Defs. 21, 22.

Exhausted Batteries and their Treatment.

39. When a battery is worked out, as shown by the signs of exhaustion referred to in paras. 27 and 28, it should be dismantled and the contents of the cell disposed of as follows:

Copper deposit, when it can be detached from the disc, should be collected, as it is pure metallic copper; when adhering to the disc so firmly that it cannot be hammered off without injuring the disc, clean with tamarind, if necessary,[2] and use again.

[2] § 36.

Sulphate of copper remaining should be washed and used again, its chemical state being unchanged by the action of the battery.

The diaphragm, on the contrary, becomes saturated with mixed solutions which, in the case of a sawdust diaphragm, can never be removed. A sand diaphragm may be cleansed by being thoroughly well washed; in either case, however, it is *safer* not to use an old diaphragm again. If the cell has been carelessly handled metallic copper may be found in the diaphragm.

Dismantled Batteries.

40. **When a cell is dismantled, it can be seen by the state of its contents whether it has been carefully prepared and looked after.**

First, by the regular deposit of metallic copper, which should be evenly distributed over the copper plate.

Second, by the absence of copper in the diaphragm.

Third, by the cleanness of the zinc disc.

Adaptation of Battery Power

41. **Battery power** for line work is regulated as follows:

SECTION B.

to Length and Gauges and Climatic Changes.

RULE Use for every 100 miles of	No.	1 B.W.G.	=50	I.G. Wire,	4	cells in series
	"	3 "	=36	"	5	"
	"	4 "	=30	"	6	"
	"	$5\frac{1}{2}$ "	=24	"	8	"
	"	8 "	=16	"	12	"
	"	$9\frac{1}{2}$ "	=12	"	16	"
	"	$12\frac{1}{2}$ "	= 6	"	13	"

during the dry season ; and during the wet, so many more cells as the state of the line may require.[1]

Arrangement of Cells for Local Circuits.

42. Local batteries are arranged as follows : The average resistance of a departmental sounder[2] being about 30 units, it is worked to the best effect with four local cells joined in series ;[3] if more sounders than one are to be worked, they are grouped in couples, and one local battery of four cells in series and two parallel[4] is connected up with each group according to the diagram shown in fig. 46.[5]

[1] This is discovered by measuring the arriving current, § 290.

[2] § 73.

[3] Law 15, App. A.

[4] § 19.

[5] § 181.

Standard Cell.

43. A **standard cell** is kept in every office as a unit of E.M.F., and the E.M.F. of any battery or cell is estimated relatively to the standard cell which is taken as unity ($E=1$).*

It is prepared like any other cell, *with particular care*, and is never used for any purpose other than testing.

* The result in volts would be $E \times 1{\cdot}079$, as the E.M.F. of a Minotti = 1·079 volts—§ 5.

Summary of Rules for the Preparation of Battery Cells.

44. The following are the most essential points to be regarded in setting it up, and may be considered a summary of rules for guidance in the preparation of any battery cell :

(1) Take care that the jar and all that goes into it are *clean*.

(2) That the leading wire is well insulated.

(3) That the contact between this and the copper plate is clean and firm.

(4) That the zinc terminal screw *bites*.

(5) That leakage is not caused by the wire, allowing of capillary action within the insulated covering.

(6) That the diaphragm is of right consistency, not *too tight* nor *too wet*, and not offering unnecessary resistance in the shape of paper or other discs above and below it ; nor *too loose*, so as to admit of the liquids mixing.

Conservancy.

45. To preserve the standard cell.—(1) *Most carefully avoid shaking it.*

(2) Keep the zinc disc covered with water, but keep this below the brass terminal.

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(3) Remove froth and all dirt from the surface of the water.

(4) Change the zinc whenever it becomes discoloured.

(5) Keep the circuit open, and only use the cell for testing.

Criterion of efficiency of the standard cell:

Its resistance should be about 20 ohms, and its current should give a deflection of not less than 60° through the thin coil of the tangent galvanometer.[1]

[1] § 152.

Rough Standards of Efficiency for 'Line,' 'Local,' 'Testing,' and 'Standard' Cells.

46. The following may be considered **standards of efficiency** (useful, though rough) of the various kinds of batteries used:

	Best resistance	Best deflection (tangent galvanometer)
Standard cells	20 ohms	60° (*not less*) through thin coil, and no resistance.
Line ,,	30 ,,	55° ,, ,,
Local ,,	10 ,,	65° ,, ,,
Testing ,,	20 ,,	60° ,, ,,

Portable Battery.

47. The departmental form of **portable battery** consists of a small box divided into cells by the plates themselves—copper and zinc—which are soldered together in pairs, the rims being covered with pitch to prevent local action between them.[2]

[2] § 33.

It is filled with sand and powdered salammoniac moistened with water (or cotton cloth, in pieces, saturated with a solution of salammoniac).

Zinc is dissolved and chloride of zinc formed.

[NOTE.—For '**Battery Testing**' *see Section* **F**, *Paras.* 267–288.[3]]

[3] The faults to which the battery is liable are described in Sect. E, §§ 216–224.

Section C.

TELEGRAPH INSTRUMENTS

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TELEGRAPH INSTRUMENTS.

PART I.—SIGNALLING INSTRUMENTS.

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Signalling and Testing Instruments.

48. TELEGRAPH instruments may be classed under two heads—viz. '**signalling**' and '**testing**' instruments.

Electro-magnetism.

49. In both cases the property of **electro-magnetism** is mainly made use of—i.e. the desired effect is produced by the operation of a galvanic current upon soft iron or a permanent magnet.

Action of Current on Soft Iron Core.

50. The ordinary Morse sounder[1] is an example of the electro-magnetic action of a current on soft iron.

In the following diagram A B may be considered to represent one of the soft iron cores of the sounder, round which the current circulates in the direction indicated by the arrows.[2] When the current traverses the coil, the soft iron

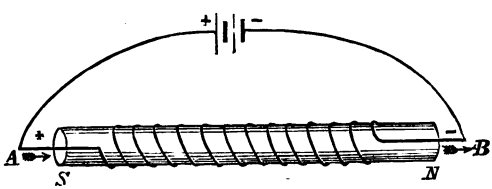

FIG. 1.—RIGHT-HANDED HELIX.

core becomes a magnet with its north pole at B and its south pole at A.

If in the same circuit the battery be reversed,[3] the end of the core, which was before a north pole, becomes a south, and *vice versâ*.

Or if with the same current as in fig. 1, the wire round the coil be wound in the opposite direction, as shown in

[1] § 73.

[2] In speaking of a current, a + current, i.e. copper to line, is always referred to in the absence of remark to the contrary.

[3] § 138.

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fig. 2, then *B*, which was a north pole before, becomes south, and *A* north (see fig. 2). This polarity, according to the direction of the current and the winding of the coil, is determined by Ampère's law,[1] and a means is thus provided of winding the coils of electro-magnets according to the magnetic effect they are required to produce.

[1] Law 13 and § 53, App. A.

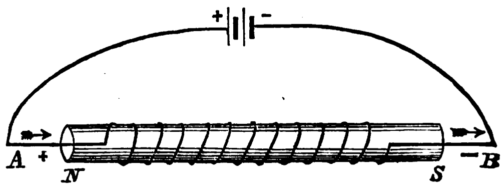

FIG. 2.—LEFT-HANDED HELIX.

Directly the current ceases, the magnetism in the core ceases also, presuming the absence of *coercive force*[2] in soft, i.e. pure untempered iron, a property which renders it of the greatest use in the manufacture of signalling instruments.

[2] Def. 43.

Polarised Instruments.

When the core of an electro-magnet in its normal state is under the influence of a permanent magnet, as in the case of a Siemens' relay,[3] it is said to be **polarised**, and the current exercising its effect on the core either increases or reduces its polarity according to the direction in which the electro-magnet is wound, or reverses the polarity of the core altogether, according to the strength of the permanent magnet.

[3] §§ 59 and 60.

Effect of a Current on a Magnet.

51. The effect of a current on a permanent magnet is illustrated by any galvanoscope or galvanometer needle.[4]

[4] § 142.

The direction in which the needle deflects is determined by the direction of the current.

Oerstedt's Discovery.

52. The simplest case to consider is that of a magnetic needle suspended over a straight wire. Immediately a current is sent through the wire the needle is deflected so as to stand across it.

Ampère's Law.

53. Professor Ampère developed this discovery, and enunciated his famous law by which the direction in which the needle will deflect under the influence of a current is known.

He imagines an observer swimming with the current with his face always turned towards the needle; *the north pole is always deflected to his left.*

Effect of a Current on a Magnet Proportional to Current Strength and Number of Convolutions.

54. The force of the deflection depends principally upon the strength of the current and the distance between the wire and the magnet; and if the wire be bent round the magnet so as to be above as well as below it, the effect of the current is doubled; by an additional turn it is trebled and so on, the action of the current on the magnet being directly multiplied by the number of convolutions round it.

Principles on which Galvanometers are Made.

55. The above facts illustrate the essential principles upon which the construction of galvanoscopes or galvanometers is based.

It is also evident that by multiplying the convolutions of wire round the needle, increased sensitiveness can be obtained.[1]

Other circumstances, however, which will be fully explained in treating of the various forms of galvanometers,[2] come into play, and there is a limit to the multiplying effect of the convolutions, owing to the fact that the extra resistance introduced by the increased number of coils opposes the intensity of the current.[3]

Application of Electro-magnetism to the Construction of Signalling Instruments.

56. To return then to **signalling instruments,** the first matter for consideration is how the property of electro-magnetism is to be applied so as to produce signals, either audible or visible, with the greatest effect.

In either case signals are made by the attraction of a soft iron armature by the core of an electro-magnet under the influence of a current.

Attractive Force of Electro-magnets.

57. A certain force[4] is required to allow of the attraction being sufficient to record signals or produce readable sounds.[5]

Sounders and Relays.

58. The instrument which performs this office is usually called **a sounder,** various forms of which are described in paras. 73–87; but as these require a strength of arriving current seldom obtainable through a long and imperfectly insulated line, a more sensitive instrument, called **a relay,** is placed in the line circuit as the receiver, and is so constructed as to work with the faintest currents, and, in so doing, to complete a local circuit[6] containing the sounder and a local battery, which can be adjusted to any required strength.

[1] Galvanometers are for this reason also called *multipliers.*

[2] §§ 143–165.

[3] Def. 3.

[4] In practice not less than twelve ounces.

[5] This force of attraction depends upon the strength of the current, the number of convolutions round the core, and the size of the core. The larger the core, however, the greater the 'Magnetic Inertia.' See remarks on *Speed of Signalling,* § 121.

[6] § 181.

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Siemens' Relay: Description.

Siemens' polarised relay is the form universally adopted for departmental use.

59. Its essential parts are *a strong permanent* L-*shaped magnet*, *N S* (fig. 3), *two soft iron cores and shoes*, *n*, *n'* (the latter adjustable), *a soft iron tongue*, *S* (delicately pivoted), and working between *two contacts*—one, platinum, *P*, which is adjustable and regulates the play of the tongue; the other, agate, *A*, which is fixed (fig. 4); *a micrometer screw*, *M*, and *the coils*. The frame in which the contacts *P* and *A* are fixed is called the *carriage*, the adjustment of which, by means of the screw *M*, determines the position of the tongue with regard to the shoes *n* and *n'*. In the newest pattern of relay the frame is fixed, and the screw *M*, which is attached to the nut *n'*, serves to increase or decrease

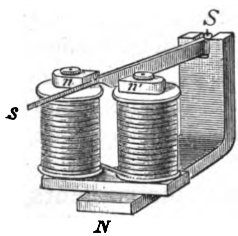

FIG. 3.

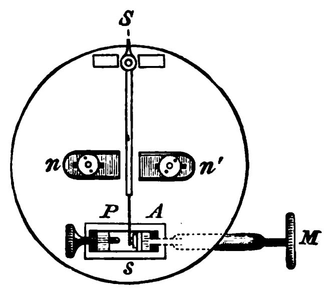

FIG. 4.

SIEMENS' POLARISED RELAY.

the mass of iron acting on the tongue, the result being the same in either case.

A *magnetic indicator*, consisting of a small magnetic needle finely balanced on a vertical pivot, which is supported by a small flat base of brass, is placed on the glass cover of the relay, and acts as a galvanoscope, showing the presence of any current, however faint, passing through the coils.

Electrical Action of Siemens' Relay.

60. By magnetic induction[1] the tongue *S* assumes the same magnetism as the upper or south pole of the permanent magnet, and the cores and shoes, *n*, *n'*, the same as the lower or north pole; so that when no current is flowing *S* is attracted either by *n* or *n'*, whichever is nearer.

[1] Def. 41.

Suppose this to be *n'*, and the tongue to be against the rest contact A (fig. 4), and suppose a current to be sent through the coils, tending to make *n'* a south pole, and, consequently, *n* a north pole, then the original force of *n'* becomes decreased or reversed, and that of *n* correspondingly increased, so that the tongue is drawn over towards *n* (against the platinum contact P), and remains there till the current ceases. When this happens, the soft iron cores resume their original condition, and the tongue falls back to A by reason of the nut *n'* being nearer to it than *n*. Thus the relay works by the polarity of *n* and *n'* produced by the making and ceasing of the current, and hence it is termed **polarised.**

Bias.

61. In order that the tongue may always have a *bias* towards the insulated or rest stop A, it is necessary that the adjustment be so made that the magnetism of the shoe *n* can never exert a stronger force on the tongue than *n'* when no current is flowing; so that on the cessation of the force (called the '*working force*'), which tends to draw the tongue against the working contact P, under the influence of a current, the tongue will readily return to its initial position, against the rest stop A.

Working Force.

Rest Force, and Force of Restitution.

62. The force which holds the tongue, in its position of rest, against A, under the influence of the magnetism of the nearer shoe *n'*, is called the *rest force*, and that which draws it back to that position on the cessation of the *working force* is called the *force of restitution.* Now it is obvious that in any one adjustment of the relay the force of restitution tending to draw the tongue back to A after it has been attracted to P must be smaller than that exerted on the tongue when already against A.

Weak Point of Siemens' Relay.

63. This fact presents an obstacle to sensitiveness in all polarised instruments; a defect which consequently applies to the Siemens' relay, and which is, in fact, the weak point of that instrument.[1]

Play.

64. The effect of this disparity between the rest force and force of restitution is, however, reduced to a minimum by making the *play* of the tongue as small as possible by means of the adjustable contact screw P.

Force of Restitution accelerated by a Reverse Current or E.M. Shunt.

65. From the above it will be clear how the system of *double current working*[2]—in which the force of restitution is no longer effected simply by the bias of the tongue, but by an opposite current drawing it back with a force equal to or

[1] It will be observed also that in one adjustment the force of restitution is the same whatever the strength of the working current may be.

[2] § 191.

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greater than the working force—remedies the above-mentioned defect in the Siemens' relay, rendering it far more sensitive, and reducing the necessity for readjustment.

The same object is effected by the application of an *electro-magnetic shunt*, the action of which is explained in para. 122.

Adjustment.

66. Adjustment of the relay.—The shoes having been securely fixed with their faces parallel and equidistant from the tongue, the more delicate adjustment of the relay is effected as follows.

Sensibility dependent on Play of Tongue.

67. To obtain the greatest sensibility, make the play of the tongue between the metal and agate points as small as possible,[1] provided it is sufficiently large to allow the contact to be opened on the cessation of the current, and not to be jammed by the screwing of the micrometer screw.

This is best done by screwing the local contact screw towards the tongue until a beat on the sounder shows the local circuit to be completed,[2] then gradually unscrew the contact again until the instant when the sounder armature is released.

Use of Micrometer Screw.

Further adjustment to suit variations in the received current is effected by means of the micrometer screw, which alters the relative position of the tongue and the shoes as circumstances require.

Limit to Smallness of Play.

68. There is a limit to the smallness of the play of the tongue, for it is necessary to prevent its being jammed against *both* contacts when its position is altered by the micrometer screw.

Further, the play must be so large that the circuit shall not be closed by the spark produced by the extra current,[3] and so large also that the motion of the tongue shall by its momentum be sufficiently strong to cause a firm contact, and consequently a readable signal on the sounder.

Sticking.

69. The tongue *sticks* when the play is too large, or when it is placed too near the attracting, and too far from the repelling pole, under the influence of a current; in either case this fault is due to the fact that the demagnetisation of the shoe or the reversal of its magnetism caused by the *cessation* of the current does not cause the tongue to return to the position from which it was moved by the current of magnetisation.

Remedy for Sticking.

70. **Sticking** is thus prevented in the first instance by

[1] §§ 62-64.

[2] See fig. 46, § 181.

[3] See §§ 119 and 226 (F).

careful adjustment of the play of the tongue, and further by the adjustment of the micrometer screw.

Efficiency. Range.

71. **The efficiency of a relay** is tested by its **range**; that is, *the extent to which the strength of the working current may be altered without necessitating alteration in the adjustment of the instrument.*

To find this: Adjust the relay with minimum play, with the tongue as far from the metallic stud as regular working will admit of, so that it will work with one cell through a resistance equal to its own; then apply 10 cells without any external resistance: the relay should work without readjustment, thus displaying a range of 20, the minimum range a Siemens' relay should exhibit.[1]

The above results may of course be effected under different conditions of E.M.F. and resistance, as circumstances may suggest.

As a rule, for relays of 1,000 units and under, use 1 and 10 cells; for those of greater resistance, use 2 and 20 cells respectively.

Many of the newer relays exhibit a range of 25 and upwards; any range, however, can be measured and calculated, as shown in para. 344, Sect. **F.**[2]

Sounders inserted in Local Circuit.

72. **Sounders.** It has been mentioned that the attraction of the tongue of the relay against the working contact *P*[3] causes a *sounder* to work.

The circuit in which the sounder is placed and its mode of action being explained in Section **D** on *circuits*,[4] it will be only necessary here to describe the instrument itself.

Siemens' Morse Sounder.

73. The form of sounder most generally used is the **Siemens' Morse,** represented in fig. 5.

Electrical Action of Siemens' Sounder.

74. Like the relay, it works on the principle of electromagnetism, its coils being wound round soft iron cores which become magnetic under the influence of a current. Unlike the relay cores, however, they become altogether demagnetised by the cessation of the current (presuming the iron to be perfectly pure), as the sounder is not a polarised instrument.[5]

The soft iron armature *A* is attracted by the cores whenever a current traverses the coils, imparting its motion to the brass lever *L L* to which it is attached, one extremity of which plays between the contacts *1* and *2*.

In its position of rest, *L L* is held against contact *2* by

1 That the current in the second case is twenty times as strong as in the first is apparent from Ohm's law, as follows:—

Calling the E.M.F. of each cell used e; resistance of relay R; current in first case c; current in second case C. Then, in the second case,

$$C = \frac{10\,e}{R}$$

And, in the first case,

$$c = \frac{1\,e}{2R}$$

$$\therefore \frac{C}{c} = \frac{\frac{10\,e}{R}}{\frac{1\,e}{2R}} = \frac{20\,R}{R} = 20$$

The battery resistance is neglected in the above, being insignificant, in comparison with the external resistances employed.

2 The faults to which the relay is subject are described in § 226.

3 § 59, fig. 4.

4 § 181.

5 § 50.

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means of the spring *s s*, the force of which is adjusted by the screw *c*.[1]

When a current flows through the coils, the magnetism of the cores produced thereby overcomes the force of the spring and attracts the armature *A*, causing the end of the lever to be drawn from contact *2* and pressed against *1*.

[1] Here the action of the sounder, which is a non-polarised instrument, differs from that of the polarised relay, the armature being drawn back by an antagonistic spring, and not by the polarity of a magnet.

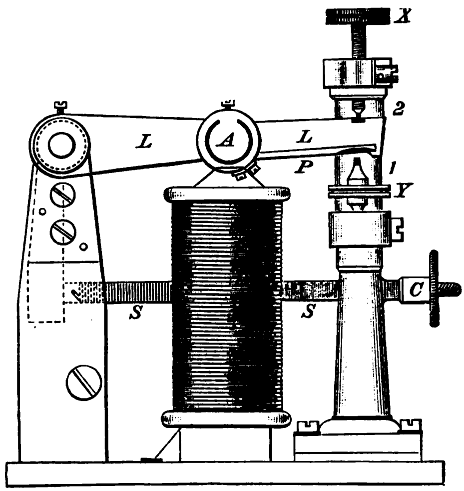

FIG. 5.—SIEMENS' MORSE SOUNDER.

Translation Springs for Prolonging Contacts.

75. The contact between *L* and *1* is prolonged by means of the translation spring *P*, and the screws *X* and *Y* regulate the play of the lever between the contacts *1* and *2*.

Adjustment of the Siemens' Morse Sounder.

76. The adjustable parts of the sounder are as follows :

(1) The two screws *X* and *Y* above and below the armature lever *L L*, which limit its play.

(2) Their clamping screws.

(3) The spiral spring (acting against the current), which draws back the lever into its position of rest.

Rules for adjustment :

(1) Adjust the lower limiting screw *Y* so that the armature (under the influence of a current) does not quite touch the small rivet at the top of the core ; a piece of common note paper should pass between them with slight friction.

When thus adjusted, clamp up this lower screw by its jam nut.

(2) Adjust the upper limiting screw *x*, making the play as small as possible so as to admit of maximum speed and clearness of sound.

(3) Adjust the spiral spring *s s* by the following process: Work the sounder electrically, and tighten the spring until the magnet is unable to attract the armature; *mark the position of the screw on the stem*; now loosen the spring until the armature falls on the electro-magnet by its own weight; *mark the second position on the screw*, then tighten the screw to about midway between the two marks.

N.B.—**Fix all jam nuts securely.**

Efficiency.

77. A Siemens sounder should give a range of *20*.

Electrical Circuit of Siemens Sounder and Relay Combined.

78. Fig. 6 represents, symbolically, the complete circuit of a Siemens' Morse sounder and relay combined.

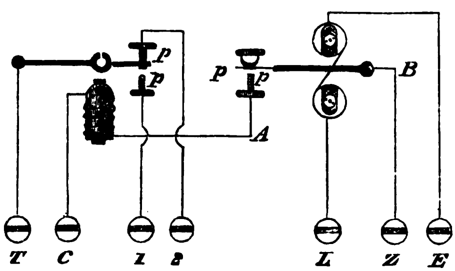

FIG. 6.—SIEMENS SOUNDER AND RELAY.

In the above there are four distinct electrical circuits through the instrument:

(1) That of the arriving line current entering at *L* and leaving at *E*.[1]

(2) That of the local current entering at *C*, traversing the sounder coils and relay tongue, and leaving through *B* and *Z*.[2]

(3) That of the received translating current entering at *T* and leaving at *2*.[3]

(4) That of the sending translation current entering at *1* and leaving at *T*.[3]

Platinum Points and their Use.

79. *p p p p* represent platinum points; these are placed between the tongue and metallic contacts in the relay, because they close the circuit of the local current; and as the

[1] See 'Circuit of S Working,' § 180, Sect. D.

[2] See 'Local Circuit,' § 181, Sect. D.

[3] See 'Translation Circuit,' § 183, Sect. D.

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spark, due to the passage of such strong currents, takes place at these points, a hard metal such as platinum is necessary.

Platinum points are also placed, to ensure conductivity, where the sounder lever makes contact, both with the upper and lower pillar, as both these contacts close the translation circuit.

Douglas State Railway Sounder.

80. Another form of sounder in use in the department is that known as the **Douglas sounder.**

Its electrical principle is precisely the same as that of the Siemens sounder.

In fig. 7 its various parts are lettered so as to agree with

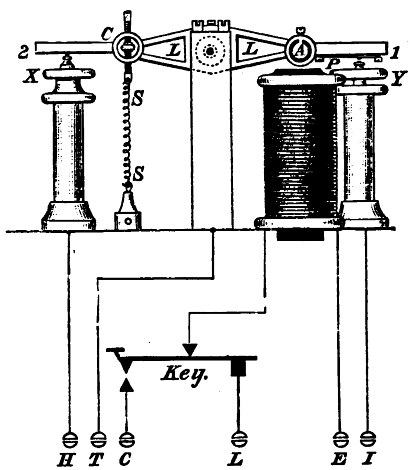

FIG. 7.—DOUGLAS SOUNDER, with Key and connections complete, for direct working on State Railways, &c.

the corresponding parts of the Siemens sounder shown in fig. 6.

The main difference between the two instruments is in the shape of the lever *L L*, the position of the contact screws *1* and *2* and their pillars, as also that of the antagonistic spring *S S*.

The Douglas sounder is now chiefly used for direct working on short circuits, and particularly for State railway working in closed circuit [1] without a relay.

[1] § 189.

Its complete electrical circuit and internal and external connections as a State railway sounder are shown in fig. 7, which includes the key.

Adjustment. Efficiency.

81. The Douglas sounder is adjusted in the same way as the Siemens; its range should be *25*.

It will be observed from figs. 6 and 7 that the armatures of both the Siemens and Douglas sounders are split longitudinally.

This is done with the object of preventing a circuit for extra currents [1] which would be formed by the rapid magnetising and demagnetising of the cores.

[1] § 119.

Dubern Sounder.

82. Fig. 8 represents a **Dubern sounder,** which is

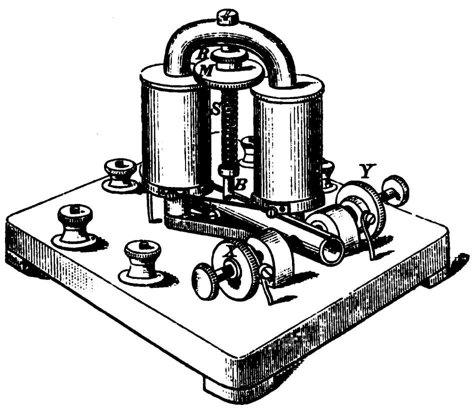

FIG. 8.—DUBERN SOUNDER.

designed either for direct working, or for use, like other sounders, in a local circuit.

Its principle is that of placing the armature in the strongest magnetic field,[2] with which object it is placed across the coils, as shown in fig. 8, and it is relieved of friction as much as possible by means of the spiral spring *S*, inside which is a vertical pin to which the armature is fixed. This pin is pivoted at its lower end below the armature, and at its upper end below the screw *M*.

[2] Def. 40.

The weight of the armature on its lower bearing is regulated by the position of the screw *R* on the pin, by which the spiral screw *S* is tightened or loosened, the bottom end of the spiral being permanently fixed to the small screw *B*; the

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top end is fixed to the circular screw *M*, the adjustment of which imparts a lateral motion to the spiral screw and armature, thus serving to give the latter the necessary bias against the rest stop, and playing the part of the screw *C* (figs. 5 and 7) which regulates the force of the antagonistic spring.

The armature (prolonged) plays between the limiting screws *X* and *Y*.

When the instrument is to be used for direct working, the coils are wound to a resistance of 500 ohms.[1] When used as a local sounder, they are made of the usual resistance of 30 ohms, and the armature is furnished with a translation spring.

Adjustment.

83. The play of the instrument is adjusted by means of the screws *X* and *Y*, in the same way as that of the Siemens and Douglas sounders is done by the screws similarly lettered. See figs. 5 and 7.

Efficiency.

84. A Dubern sounder should have a range of 25.

Portable Sounder.

85. Fig. 9 explains the essential parts of a **portable sounder.**

The whole of the apparatus, including key and connections, is enclosed in a small box; the soft iron tongue, *S*, which produces the sound, is pivoted on the south pole, *S*, of a permanent **L**-shaped magnet, the soft iron cores of the electro-magnet being attached to the north pole (hidden in the figure) of the permanent magnet.

The portable sounder is a *polarised* instrument,[2] and its electrical action is precisely similar to that of the polarised relay explained in paras. 59 and 60, and will be understood by reference thereto, the essential parts, *S*, *s*, *n*, *n'* in fig. 9 corresponding with the similarly lettered parts in fig. 3.

The terminals *Z*, *L*, *C* (fig. 9) are connected outside the instrument to *earth*, *line*, and *copper* respectively.

Inside, *Z* is connected to one end of the coils, *L* to the other end (through the front contact of the key), and *C*[3] to the back contact of the key.

The resistance of the coils is usually about 500 ohms, and the sounder is worked direct by the current from the line.

Adjustment.

86. The play of the tongue is adjusted by means of the screws *X* and *Y*, which are kept in position by their jam nuts.[4]

[1] 250 ohms each.

[2] § 50.

[3] § 105.

[4] The faults to which the various forms of sounders are liable are described in Sect. E, § 227.

Efficiency.

87. The portable sounder should exhibit a range of 20; and should work with a current of 1 milli-oersted.[1]

[1] Defs. 2 and 34, and § 289.

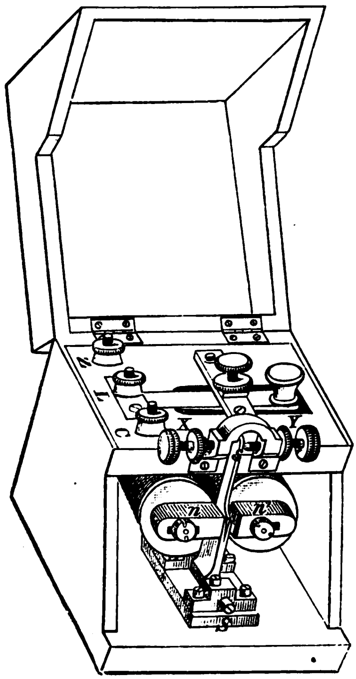

FIG. 9.—PORTABLE SOUNDER.

Morse Characters.

88. The various kinds of sounders described above produce, by the attraction and release of their armatures, audible signals, which are distinguished from one another by their duration.

A short signal, or a long one, or a combination of both, represents a letter of the alphabet.

The length of each signal is determined by the duration of time between the sound caused by the attraction of the armature and that caused by its withdrawal under the influence of the antagonistic spring, when the current ceases.

These signals are separated from one another by pauses, the length of a pause being the duration of time between

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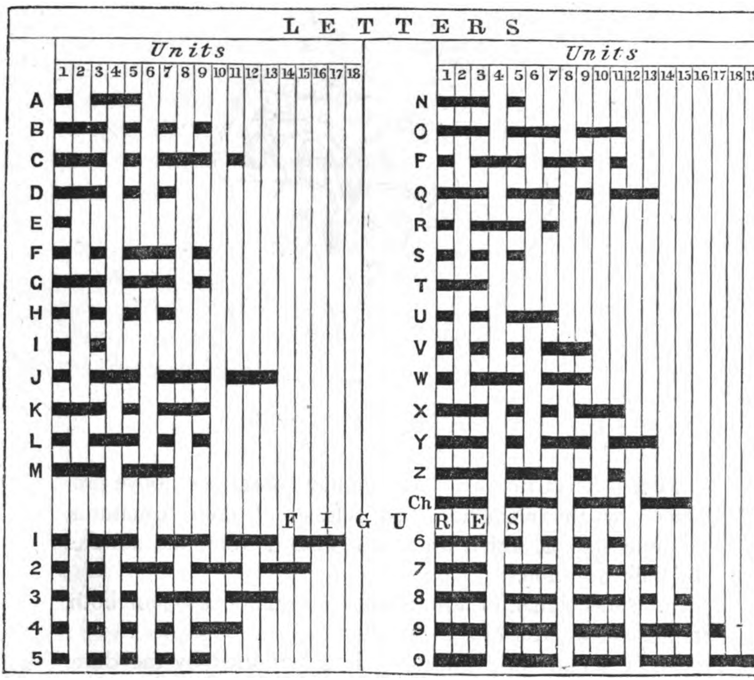
the return of the armature to its position of rest and its next attraction to the cores of the electro-magnet.

The pauses or spaces between the signals are as important as the signals themselves; for their duration indicates whether they separate from one another individual characters, or letters, or words.

The Morse Alphabet.

89. Representing a short signal by a dot (-), and a long one by a dash (—), and combining the two thus (-—), the letter '**a**' is formed, which consists of two signals, viz. a dot and a dash, separated by a space.

Various combinations of the dot with the dash, as shown below, compose the conventional code known as the Morse alphabet.



THE MORSE ALPHABET.

Correct signalling depends mainly upon the accurate duration of signals and spaces.

Rules for Accurate Signalling.

90. The following rules will be found useful as a guide for giving to each signal and space its correct value :

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1. A dot is taken as the unit of time or (when represented on paper) length.

2. A dash is three times the length of a dot, and is thus equal to 3 units.

3. The space between each signal or character forming a letter should be 1 unit, i.e. equal to 1 dot.

4. The space between each letter of a word should be 3 units.

5. That between each word of a sentence 5 units.

It should further be observed that **no letter of the Morse alphabet can contain more than four characters; and that every figure must contain exactly five.** The observance of this fact and of the regular system on which the figure code is arranged, progressing by dots from 1 to 5 and by dashes from 5 to 0; and the check each figure exercises on itself by containing so many dots followed by dashes making up the balance of 5, or *vice versâ*, should render errors in the signalling of the figure code easy of detection and prevention; and it may not be out of place here to add, by way of warning, that the chief, if not the only cause of errors in the signalling of figures (on which, it must be remembered, *the most important issues may depend*), is due to a practice, unfortunately too common, known as '*exaggerating* signals,' by which a letter is given more characters than it really possesses: for example, the letter **h**, a most common victim of this ill-treatment, is, by the addition of an extra dot, mutilated into the figure **5**.

Thus it behoves every telegraphic operator, not only to bear in mind, but to *exercise*, the practical check that no letter can contain more than four characters, and no figure less than five; and positively to desist from taking down any word containing a letter or figure in which a departure from this rule is observed.

Ink-writers. **91.** It has been shown how, by means of various kinds of sounders, the signals representing characters of the Morse alphabet are produced and distinguished by the ear.

In order, however, that these signals should leave some visible trace of their existence, as is necessary in the case of foreign messages, special contrivances are adopted by which the Morse characters are recorded on tape, by the movement of the armature of the sounder.

This is effected by the addition to the armature of a

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light lever, with a small thin brass wheel at the end of it, which is made to revolve by clockwork.

The fulcrum or axis of the lever is between the armature and the wheel.

When the armature is at rest the lower edge of the wheel dips into a vessel of prepared ink : at each attraction of the armature the wheel is raised, and lightly touches a paper tape which is made to pass over small grooved brass rollers revolving at a uniform rate ;[1] each movement of the armature is thus communicated to the tape, on which dots and dashes are printed in ink, resembling the Morse characters shown in the preceding table.

[1] The tape should run at the rate of not less than six feet per minute.

Such a recording instrument is called an **ink-writer**.

It is joined up in the local circuit like any other sounder, the circuit being, as usual, closed by a relay under the influence of a current from the line.

Ink-writers are sometimes fitted up together with a relay, galvanoscope, key and switch, all on one board.

Siemens Ink-writer.

92. Fig. 10 represents such an arrangement.

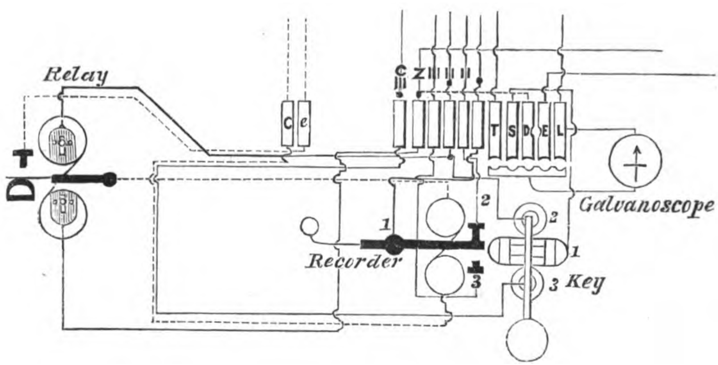

FIG. 10.—SIEMENS INK-WRITER (Relay, &c., combined).

The isolated arrangement first mentioned is preferable ; as, however, the ink-writer with relay combined is sometimes used, and its connections are somewhat complicated, its terminals and the mode of joining them up may, with advantage, be explained, as follows :

Ink-writer Terminals and Connections

93. Ink-writer terminals (from right to left).

Marked	Joined inside instrument to	Joined outside instrument to
L	Galvanoscope	Line
E	By plugs to bar short-circuiting galvanoscope	Earth and K3 of discharger [1]
D		Z of ink-writer
S		K of key (middle)
T or I		(For translation work) to Ị of other ink-writer
Ị	1 of sounder	(For translation work) to T or I of other ink-writer
II	2 of sounder	(For translation work) to IỊ of other ink-writer
IỊ	2 of key (back) and L of relay	E of discharger [1]
III	3 of sounder	(For translation work) to copper of battery of other instrument
Z	ZE of relay	D of ink-writer, and by plug between D, E to earth
Ç	1 of key front contact	L of discharger [1]
e	Metal contact of relay	Zinc of local battery
c	Sounder coils	Copper of local battery

[1] As ink-writers are usually employed on long circuits on which discharging arrangements are necessary, the connections shown in the third column explain how the discharger is joined up with the ink-writer. Fig. 24, § 126, shows a diagram of the discharging instrument.

The faults to which the ink-writer is subject are described in Section **E** (para. 228).

Embossing Recorders.

94. Before the invention of recording the characters in ink was thought of, the tape was marked by means of a sharp style (instead of a wheel) at the end of the lever; such instruments are still in use, and are called '**embossers.**'

Characters thus formed, however, are neither so permanent nor so legible as those recorded in ink. Both ink-writers and embossers are also made for direct working with a resistance of about 500 units, and as such are adapted for use on railway telegraphs.

Needle Instruments.

95. The instrument most commonly used on railways for open circuit working is the needle instrument.[2]

[2] § 190.

Single Needle.

96. The single needle is the simplest form of signalling instrument made, and the most inexpensive.

The receiving part of the instrument is simply a galvanoscope consisting of two coils of wire and a small needle between them with its north end downwards.

Signals are formed by the left and right deflections of the needle under the influence of reverse currents; a left deflection representing a dot, and a right a dash of the Morse alphabet.

The ivory stops *x* and *y* limit the deflections of the needle on either side.

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Fig. 11 represents the circuit of the instrument in its state of rest for receiving.

Its own battery is insulated by the céntre of the handle *H*, which is generally made of ebonite or some hard wood, and the circuit of the line current entering at *B* is completed by the movable metallic springs *L* and *R* and the contact *T* against which they press; thence it traverses the coils, and proceeds through *A* to the earth.

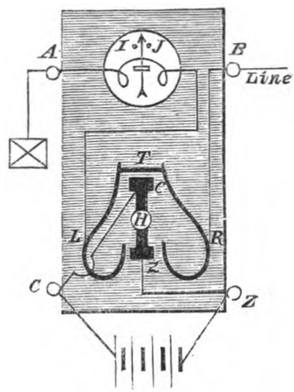

FIG. 11.—SINGLE-NEEDLE INSTRUMENT.

The vertical handle *H* is the sending part of the instrument; its upper and lower parts, *C* and *Z*, being insulated from one another at *H*, and, when it is turned so that *Z* presses against *R*, *C* also presses against *L*, breaking the contact *T*, and sending a zinc current to line.

When turned in the reverse direction a copper current is sent to line.

Any convenient form of battery reverser might take the place of *H* and the springs *L* and *R*.

A newer form of single-needle key is that known as the tapper or pedal, the action of which is explained at paragraph 107, and represented in fig. 15.[1]

Double-needle Instrument.

97. The double-needle instrument is simply the single-needle instrument doubled, having two pairs of coils and two handles.

The electrical action of the two instruments is precisely the same.

[1] The faults to which the needle instrument is subject are described in Sect. E, § 229.

Bells: The Alarum or Trembling Bell.

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98. **Bells** are sometimes used in connection with receiving instruments for the purpose of arresting attention.

The **alarum** or **trembleur** (the form of bell most used in departmental offices) consists of an electro-magnet, *D D*, to the armature *M* of which is connected a flexible steel arm with a small leaden hammer *H* at its extremity, which, under the influence of a current, strikes the bell *E*. A steel spring, *S*, breaks and makes contact with the adjustable screw *F* according as the armature is attracted towards the cores or not.

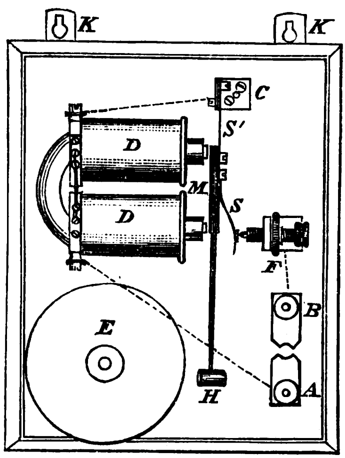

FIG. 12.—ALARUM OR TREMBLING BELL.

Note.—The short-circuiting chattering bell is a modification of this instrument, and is so contrived that each attraction of the armature short-circuits the battery. The current in the coils being thus shunted, the armature is released, which breaks the shunt circuit, causing re-attraction of the armature under the influence of the current, which now follows the direct circuit of the coils, so that attraction and release continue successively.

The instrument can be short circuited by a plug between *A* and *B*.

The electrical circuit of the instrument will be at once understood from fig. 12.

All that it is necessary to remark upon is the spring *S* at which contact is made and broken.

In its position of repose the armature rests against this ng, but immediately a current passes through the coils the armature is drawn away from the spring towards the core of the electro-magnet.

When such occurs, however, it is manifest that the circuit is no longer complete, being broken at *S*; and there-

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fore immediately the current has done its work in causing the attraction of the armature, the circuit is broken; the magnetism of the soft iron core disappears, and the tongue falls back on the spring *s*.[1]

Immediately it does so, however, the circuit is closed again, and so long as a current is flowing, the above action is repeated, and contacts are alternately made and broken in rapid succession, the bell being struck by the hammer at each attraction of the armature.

[1] The defect to which this spring is subject is described in Sect. E, § 230.

Adjustment.

99. **To adjust the instrument,** make the distance between the armature and core as large as possible while yet admitting of its working.

Then reduce this distance to one-half by adjusting the screws at *c* at the back of the armature lever.

Then adjust the spring till contact is made at *s*, and until the best ring of the bell is obtained.

The play, and consequently the speed, of the hammer is regulated by the screw F.

Further, by turning the bell itself round, a position is found when the ring is most regular and clear.

Efficiency.

100. The alarum should exhibit a range of 25.

Single-stroke Bell.

101. **The single-stroke bell,** commonly used in railway offices, consists of an ordinary horse-shoe electro-magnet, with a soft iron armature carrying a wire with a hammer at its extremity, so arranged as to strike the inside of the bell at each attraction of the armature under the influence of a current.

On the cessation of the current, the armature (like that of a sounder) is drawn back by an antagonistic spring, *s*.[2]

[2] § 80, fig. 7.

The instrument is provided with a plug, the removal of which breaks the circuit of the coils, and thus throws the bell out of circuit.

Adjustment.

102. Its play is adjusted by a screw at the back of the hammer furnished with a jam nut, and the bell is turned round till the best ring is ascertained by experiment.

The force of the antagonistic spring is also regulated by an adjusting screw.

Efficiency.

103. The bell should give a range of 25.

Transmitting Apparatus.

104. The foregoing remarks on the subject of instruments have been confined to those parts of the signalling apparatus which indicate received signals; in other words, *receiving instruments*, whether relays, sounders, recorders,

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indicators, or bells; all of which are actuated by the influence of currents on electro-magnets.

The transmitting apparatus is far more simple and less varied; the main object being the contrivance of a simple means of causing a current to flow through a telegraph circuit at given intervals, the duration of which can be so controlled as to indicate the dots and dashes of the Morse alphabet.

Keys or Handles.

105. This is effected by means of the **key** or **handle,** the general simple form of which is represented conventionally in fig. 13.[1]

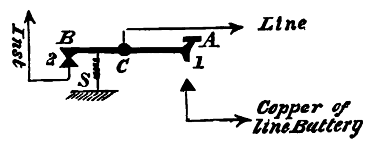

FIG. 13.—SIGNALLING KEY.

A B is a continuous brass lever, working vertically on the pivot *C*, a connection at which keeps the lever always joined to the line; *1* and *2* represent the points at which the lever makes contact with brass studs (all four contact points being platinum-tipped) fixed to an insulated base-board.

The knob at *A* is also made of insulating material.

The spiral spring *S*, joined to the lever and base-board, keeps the end *B* of the lever drawn down, so that the key in its position of rest forms a conducting circuit, through contact *2*, between the line and the receiving instrument.[2]

When *A* is pressed by the hand, however, contact *2* is broken and *1* is closed, allowing a battery current to flow into the line and work the receiving instrument at the distant end, just so long as *A* is held down, the antagonistic spring *S* opening the contact *1* directly the pressure of the hand is withdrawn.

Thus dots and dashes are signalled at will.[3]

Double Current Keys.

106. It will be observed that the above operation only sends a single current—that is to say, a current from the same pole of the battery at each depression of the key, which is all that is desired in the case of non-polarised instruments.[4]

The case of the needle instrument, however, is different,

[1] § 175.

[2] § 180, fig. 45.

[3] The faults to which keys are subject are described in Sect. E, § 232

[4] § 74.

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in which signals are formed by *opposite* deflections of the needle.[1]

[1] § 96.

Fig. 11 shows how the handle of the needle instrument effects this by reversing the current.

In para. 65 it was explained how a reverse current would accelerate the return of the relay tongue to its position of rest; in other words, accelerate its force of restitution.

In order to do this, a key differing from the simple Morse key represented in fig. 13 is necessary.

Keys by which positive and negative currents are sent alternately are called **double current** or **reversing keys.**

Fig. 14 shows a simple arrangement by which this can be done.

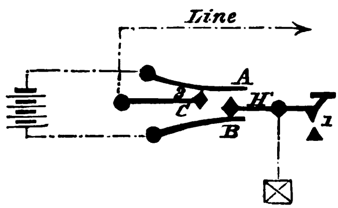

FIG. 14.—PLAN OF REVERSING KEY.

A and *B* are springs, both having a tendency to press towards *C*, a fixed contact.

When the handle *H* is in its position of rest (as in the figure), *A* makes contact with *C*. When the handle is depressed and contact *1* closed, *B* presses against *C*, and *H* against *A*; contact *2* being opened.

Supposing the line and battery connections completed as shown by the dotted lines, it is evident from the diagram that when the key is in a position of rest a zinc current flows to line through *A*; and that every time the handle is depressed a copper current goes to line (through *B*). Further, when the key is released again, the current is at once reversed and a zinc current flows to line (through *A*).

The Tapper or Pedal Key.

107. Various forms of reversing keys are employed.

Fig. 15 represents that known as the **tapper** or **pedal** referred to in para. 96; and which, in the newer forms of needle instrument, takes the place of the upright handle.

L and *E* are the terminals of two springs, which in their position of rest press against the upper bar *C*.

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When either is depressed, it forms metallic contact with the lower bar *z*.

From the diagram it is apparent that when the key is at rest the battery is in open circuit.[1]

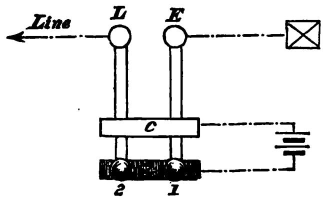

FIG. 15.—THE TAPPER.

When the handle *1* is depressed, a copper current flows to line (zinc to earth); and when *2* is depressed a zinc current flows to line (copper to earth). Thus, copper and zinc currents can be sent in rapid succession, and the former may be employed to indicate the dashes, and the latter the dots composing Morse characters, or *vice versâ*.

Constant Resistance Key.

108. Fig. 16 gives a symbolic representation of a **constant resistance key,** joined up for sending a momentary reverse current after each direct current.

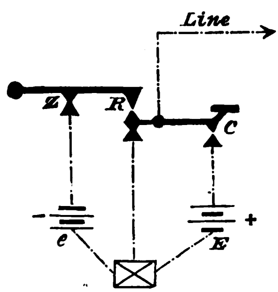

FIG. 16.—CONSTANT RESISTANCE KEY.

When the key is at rest, the line is joined to earth, and contact *z* is closed. The play of contacts *z* and *R* is so adjusted, by means of springs, that when the key is depressed *R* is closed just before *z* is opened, and *z* is opened before *C* is closed; so an instantaneous zinc current from the battery *e* precedes and follows each + signal from the battery *E*.[2]

Charge and Discharge.

109. The above form of key (fig. 16) is commonly used

[1] § 179.

[2] § 196.

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as a *discharging key*, but before describing its action as such, it will be advisable to describe those phenomena observed in telegraph lines and cables known as **charge** and **discharge,** with a view to explaining why discharging instruments are used.

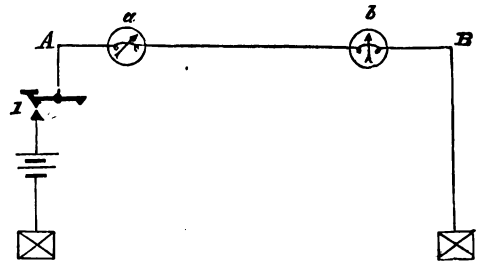

FIG. 17.—PHENOMENA OF 'CHARGE.'

Suppose A B to be a telegraph line with its distant end B to earth. At A is a simple key, by pressing which contact 1 causes a current to flow through the line. *a*, *b*, are galvanometers *of equal sensitiveness* inserted in the line at A and B respectively.

When contact 1 is closed a current flows through the line traversing the galvanometers *a* and *b* *almost* simultaneously.

At the instant of contact, however, the galvanometers, though equally sensitive, manifest very different deflections, *a* being violently deflected to its full extent before *b* shows any movement at all (see fig. 17).

Suppose the key to be still held down, the needle of *a* will be observed to settle down at a point on the scale rather below its first deflection, while *b* will deflect more and more till it reaches the point at which *a* remains steady.[1]

Charge: Variable and Permanent State.

110. This shows that it takes a certain appreciable time before the current arriving at the distant end of a line attains the same strength which it has when leaving the battery, and that during this time, which is termed the **variable state,** the strength of current goes on increasing in the more distant portion of the line until it is the same at all points, when it is said to have assumed the **permanent state.**

Supposing *b* (fig. 17) to be a receiving instrument, it is evident that the speed with which it would indicate signals

[1] It is supposed here that the insulation of the line is perfect, and that the strength of current is the same at every point throughout its length.

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is very much influenced by the time the line takes to receive a charge.

Now the duration of this variable state is in direct proportion to the length of the line, which accounts for the fact that the effects of charge, though often imperceptible on short lines, vastly impede rapid signalling on long ones.

Any increase of resistance in the line, battery, or earth circuits increases the duration of the variable state, as it impedes the circulation of the current through the line.

Leakage has the same effect, by diminishing the potential of the current arriving at the distant end of the line.

The extra currents of electro-magnets in circuit also prolong the duration of the variable state.

The above impediments to rapid signalling are due to the effects of **charge,** by which signals not only take an appreciable time to arrive at the distant end of a line, but are formed by an inconstant current increasing in strength until it arrives at its maximum, or even sufficient strength to work the receiving instrument.

From this it follows that the first evidence of a signal is weak and undefined, owing to the *gradual* appearance of the current, under the influence of the charge (or static charge, as it is called) of the wire.

Discharge.

III. We have also to consider the effects of **discharge,** to illustrate which the diagram represented in fig. 17 is here reproduced (fig. 18), with the addition of a second earth

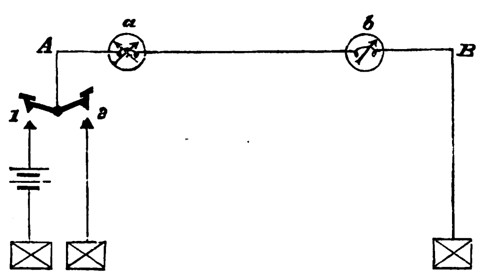

FIG. 18.—PHENOMENA OF DISCHARGE.

connection at the sending end *A*, which can be made by closing contact *2* of the key.

In the above diagram, suppose the handle *1* to be first depressed so that a current flows from *A* to *B*, deflecting the

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galvanometer needles *a* and *b* to the right, as shown by the arrows.

Let contact *1* now be opened and *2* immediately closed, then the needle of *a* will be suddenly deflected to the left, showing that the whole of the charge has not passed to earth through *b*, but that a considerable portion returns through *a* to earth, by way of contact *2*, deflecting the needle in the opposite direction to the *charge* current as shown by the dotted arrow.

The longer and better insulated the line, and the greater the resistance in circuit, the greater will be this **discharge** current, as all the above circumstances tend to impede the flow of the original or direct current of charge to earth at the further end.

Return Current of Discharge.

112. It is evident that if another galvanometer were inserted between *2* and the earth, it would be deflected similarly to *a* by this current of discharge, or **return current,** as it is appropriately called.

Now this is the position that the receiving relay takes in ordinary open circuit (or *S*) working,[1] so that after each signal sent by the closing of contact *1* a return current flows to earth through *2*, causing a momentary beat on the relay.[2]

This return current of discharge must not be confounded with the extra current (described in para. 119) which occurs momentarily at each closing and interruption of the battery circuit, and which is due to the inductive effect of the current on itself.

Induction.

113. Both effects are due to **induction,** but of different kinds and exhibiting different phenomena. In the former case the line has held a charge by virtue of the properties of **electro-static induction.**

The 'extra current' in the second case is the result of **electro-dynamic induction.**[3]

Electro-static Induction.

114. The phenomena of *electro-static induction* may be most simply understood from the action of a **Leyden jar.**

The Leyden Jar.

115. Fig. 19 represents a common form of this instrument.

The glass jar *A* is coated inside and out to the same height with tin-foil, which is not carried up to the top of the jar, for the better insulation of the coatings from one another.

[1] § 180 and fig. 45.

[2] Special instruments used to remedy the effects of discharge are explained in §§ 125–132.

[3] §§ 118–119.

In the mouth of the jar is fixed a stopper of dry wood, or any good insulator, which holds a metal rod, the lower end of which is in connection with the inner coating of the jar, and the upper end terminates in a knob *B* outside. If

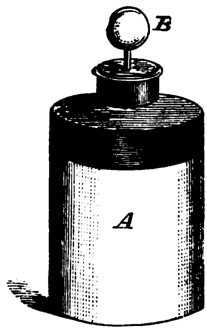

FIG. 19.—THE LEYDEN JAR.

the conductor of an electrical machine in action be placed close to *B*, and the outer coating of the jar be connected with the ground, the inner foil will become charged with positive electricity and the outer with negative, sparks passing from the conductor to the jar till the latter is charged: the greater part of the charge thus communicated to the jar will, if the coatings of foil are well insulated from one another, be retained for many days. To discharge the jar a metallic connection is made between the outer foil and the knob; the opposite electricities which were accumulated on the inner and outer coatings immediately combine with a force infinitely greater than that which charged the jar, as judged by the sparks it emits, or by severe shocks if the body form part of the circuit. After the first discharge, the jar may be found possessed of a *residual charge*, as evidenced by faint sparks on approaching a conductor from the outer foil to the knob *B*.

The above phenomena prove that **the jar is thus capable of receiving and storing up a charge of electricity, and of retaining it for a considerable time.**

The action which takes place to produce this effect is explained on the principle of **static induction,** based on the fact that if a conductor, *A*, connected with the ground,

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be placed near another conductor, *B*, insulated and charged with electricity (fig. 20), a mutual inductive action takes place, by which the charge of *B* is greatly increased.

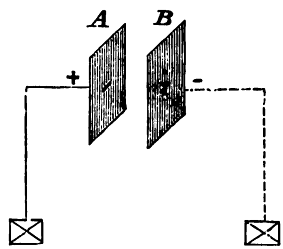

FIG. 20.—PHENOMENA OF STATIC INDUCTION.

To explain this, suppose *B* to be positively electrified. Its charge then induces a certain quantity of — electricity to the side of *A* next to *B*, repelling a corresponding quantity of + electricity from *A* to the earth.

Now suppose *B* also to be connected with the ground, as shown by the dotted line; the — electricity developed in *A* reacts upon *B*, augmenting *B*'s + charge by a certain amount and repelling a corresponding amount of — electricity from *B* to earth.[1]

This reflex action continues indefinitely, causing accumulated charges of electricity to be condensed on *B*.

The Condenser.

116. On this principle **condensers** are made, and are so termed because they are used to condense or store up electricity.

Fig. 21 represents the principle of any form of condenser.

It consists of a number of layers of tin-foil separated from one another by thin sheets of paper saturated with paraffin, or sometimes sheets of mica.

These layers of tin-foil are arranged to form two series, *A* and *B*, which by induction act in a precisely similar way to the inner and outer coatings of a Leyden jar,[2] or to the plates *A* and *B* in fig. 20. The plates of the *A* series (fig. 21) are joined together; likewise those of *B*, but the two series are kept insulated from one another.

Thus a + current entering the *B* series charges these

[1] Electricity developed in this manner, by induction, is called *Bound*, *Dissimulated*, or *Latent*, because it exhibits the remarkable property of not passing off, even when the conductor on which it is condensed is connected to earth. Should the other conductor be removed, however, the electricity of the first no longer remains bound, but passes away to earth. This latter natural condition of electricity is called *Free*.

[2] § 115.

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plates with electricity of the same kind, inducing in the A plates an equal amount of − electricity, and causing a corresponding amount of + electricity to pass through A to earth.

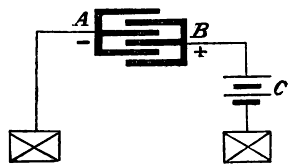

FIG. 21.—THE CONDENSER.

From the above process, which is called *condensation of electricity*, it is easy to understand how a small charge of electricity from the battery C (fig. 21), communicated to the B series (the A series being to earth), can be accumulated in a condenser, and thus be increased to any extent according to the capacity[1] of the condenser.

The quantity of the charge depends upon the number of cells used in the battery, upon the size of the dielectric sheets,[2] their thinness, and the smoothness of their surface.

The use and application of condensers to telegraph work will be explained hereafter.[3]

The object of the foregoing remarks has been to explain how, by virtue of *electro-static induction*, a charge of electricity is communicated to and retained by a Leyden jar or condenser.[4]

Resemblance of a Telegraph Line to a Leyden Jar or Condenser.

117. Now a telegraph line may be regarded in the light of either; the wire itself playing the part of the inner coating of the Leyden jar; the ground and all connected to it, such as posts, &c., representing the outer coating; and the air, the dielectric, acting like the glass jar, and admitting of induction between the wire and the earth.[5]

Electro-static induction, however, is not the only force at work which affects the transmission of signals along a telegraph wire;[6] and in order that the important part played also by **voltaic** or **electro-dynamic induction** may be clearly understood, the phenomena resulting therefrom will be briefly described as follows:

Voltaic or Electro-dynamic Induction.

118. A galvanic current sent through a wire has the power of inducing a momentary current in a neighbouring

[1] Def. 15.

[2] Def. 17.

[3] § 202.

[4] The faults to which the condenser is liable are described in § 231.

[5] Bearing this principle in mind it is obvious that the higher the supports of a telegraph line the less facility is offered to induction, and consequently to 'charge.'

[6] § 110.

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wire, this action being called **induction**; and the momentary current produced, the **induced** or **secondary current**.

The battery current is called the **inducing** or **primary current**.

Suppose the ends of the primary wire A, B (fig. 22) to be joined to a battery and key, and those of the secondary wire *a*, *b* joined to a galvanoscope, it will be observed that in making battery contact 1 the primary current will cause a secondary current in the wire *a*, *b*, as indicated by a movement of the needle; the deflection, however, only lasts an instant, and the needle at once falls back to zero, this induced current being *opposite* in direction to the primary current.

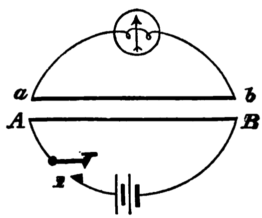

FIG. 22.—PHENOMENA OF VOLTAIC INDUCTION.

When the primary circuit is *broken*, another momentary deflection is observed in the galvanoscope, this time showing the induced current to be the *same* in direction as the battery current.

The action thus observable in single wires is greatly increased when they are wound in coils.

If, when a current is flowing in the primary coil, it be brought nearer to the secondary coil, or if the strength of the primary current be increased, a secondary current will be induced similar in direction to that when contact is *made*; and if the reverse be done, a current will be induced in the same direction as would be caused by *breaking* the primary circuit.

These principles will be found detailed among the laws of induced currents,[1] and a knowledge of them is of great importance.

[1] Laws 20–22, App. A.

If a magnet take the place of the primary current in the above instances, the same effects of induction will be produced;

and this may be readily understood from Ampère's theory, that a magnet is simply a solenoid,[1] *or rather a bundle of solenoids,* i.e. *each molecule of a magnetic substance is traversed by a closed electric current.*

Extra Current.

119. Another phenomenon of induction is that known as an **extra current,** which is caused by the inductive action of a current on itself.

At the moment a current commences to flow through a long coil of an electro-magnet, it induces in it an extra current lasting but an instant, flowing in a reverse direction to that of the battery and opposing it, so that if there were a soft iron core in the coil its magnetisation would be delayed.[2]

On breaking the battery current, an instantaneous *direct* current is induced, which would therefore tend to delay the demagnetisation of the same core.

There are thus two kinds of extra current, viz. the *inverse* caused by *making contact* which opposes the battery, and exists when the magnetism of the iron is *increasing*; and the *direct*, caused by *breaking contact*, and which exists when the magnetism is *decreasing*. Although the E.M.F. of both the extra currents is the same, the effect of the *direct* (caused by breaking contact) is the more observable, as it acts in the same direction as the battery current which it momentarily increases. The spark observed in relays at the moment contact is broken in the local circuit is an illustration of this fact.[3]

It is thus obvious that the extra current in the coils of electro-magnets tends to increase the variable state,[4] and consequently to diminish the speed of signalling.

Extra Current in a pair of Coils neutralised by joining them parallel.

120. To counteract the retarding effects of extra currents in the coils of electro-magnets, they are sometimes wound parallel instead of in series.[5]

The effect of this is to cause the extra current in the coils to be opposite in direction to one another, and thus they neutralise each other instead of combining, as they do when the coils are wound in series, to oppose the primary current at its commencement, and to augment and prolong it at its close.[6]

Summary of Causes affecting the Speed of Signalling: (*a*) Retardation by Electro-

121. Induction is the main cause which diminishes the speed of signalling; first, by accumulating on the surface of the wire a portion of the current which would otherwise pass on to form signals; the quantity accumulated

[1] Def. 25, and Law 25, App. A.

[2] The strength of extra currents is increased by the insertion of a soft iron core into the coil. See Law 22, App. A.

[3] Law 21, App. A.

[4] § 110.

[5] § 162.

[6] It must be remembered that by joining the coils parallel their resistance is reduced (Law 8, App. A), and further, that the magnetic force of the cores is reduced (Law 16, App. A).

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static Induction, 'Charge and Discharge.'

depending upon the length and surface of the wire,[1] upon its proximity to the earth, and upon the insulating medium which separates it from the earth.

For this reason the electro-static capacity[2] of cables is much greater than that of land lines—i.e. they hold a much greater charge.

The greater this electro-static capacity, the less the speed, for it causes the first portion of a sent current to be absorbed or accumulated as shown above, and thus it retards the first appearance of the signal at the distant end.[3]

Again at the cessation of the signal, the accumulated charge takes an appreciable time to discharge, and consequently each signal is prolonged.[4]

Thus '*charge*' *produces retardation, and* '*discharge*' *prolongation.*

This of course necessitates slower signalling to prevent dots from running one into another.

(*b*) Magnetic Inertia.

Again, an electro-magnet cannot be magnetised and demagnetised with infinite rapidity. The core takes time to magnetise and to lose its magnetism;[5] and, moreover, the currents which pass through the coils induce other currents in the same coils which retard their demagnetisation.

(*c*) Extra Currents.

These **extra currents,** as they are called, and which are created in the line as well as in the coils of electro-magnets,[6] influence speed by retarding the commencement of a signal and delaying its termination, and their strength is proportional to the number of turns of wire in the electro-magnet, as well as to the mass of iron in the core.

(*d*) Mechanical Inertia.

The sensitiveness of receiving instruments is an important point affecting the speed of signalling, and the play of the armatures of electro-magnets should for this reason be made as small as possible.

(*e*) Residual Magnetism.

Further, the cores of the electro-magnets should be made of the purest iron possible, in order to allow of their becoming demagnetised immediately on the cessation of the current.[7]

The two last-mentioned causes affecting speed, viz. mechanical inertia and residual magnetism, do not present the obstacles to rapid signalling which the effects of induction do, to remedy which it is necessary to overcome the retarding and prolonging effects of charge and discharge respec-

[1] Law 12, and §§ 114–117.

[2] Def. 15.

[3] §§ 109 and 110.

[4] §§ 111 and 112.

[5] Defs. 44 and 48.

[6] § 119.

[7] Defs. 43 and 44.

tively, and to counteract the influence of extra currents; in the first case by discharging the line as rapidly as possible, and in the second by annihilating the effects of extra currents by counter extra currents more powerful than those from the line.

The Electro-magnetic Shunt and its Action.

122. The latter object is fulfilled by the **electro-magnetic shunt,** which consists of a soft iron core in the shape of a horse-shoe, wound with insulated wire, the ends of which are connected to the two terminals of the receiving relay *R*, as represented in fig. 23.

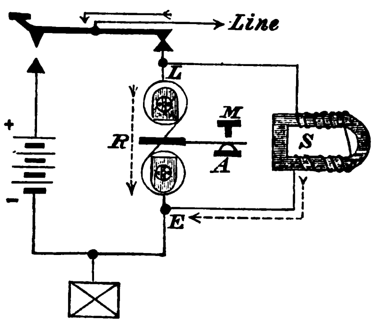

FIG. 23.—RELAY WITH E.M. SHUNT.[1]

From what has been said of extra currents, it will be understood that a momentary extra current of demagnetisation will be formed in the coils of the relay and shunt, in the direction shown by the dotted arrows, at the *termination* of each signal received.[2]

It has also been shown that the strength of the extra currents formed in electro-magnets depends upon the number of turns of wire and the mass of iron in the core, so that it is quite possible to construct the E.M. shunt *S* so that its extra current shall be equal to or greater than that passing through *R*.

It will be observed, by reference to the dotted arrows in the figure, that the extra current of *S* opposes that of *R* at the point *E*; and if the two currents be equal in strength, that of *S* will exactly counteract and neutralise that of *R*.

If, then, the magneto-inductive capacity of the shunt be greater than that of the relay (as it is made in practice), the stronger extra current of *S* will not only counteract that of *R*,

[1] To increase the inductive effect of the core, the two extremities of the horse-shoe are joined by a fixed armature.

[2] §§ 119 and 121 (*c*).

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but overcome it, and will tend to press the tongue against the *insulated* stud *A*, as represented in the figure; preventing its being attracted to *M*, as it otherwise would be under the direct influence of the extra current produced by the inductive action of the working current on itself.

Again, looking at the dotted arrows in the figure, it will be observed that the resultant extra current from the shunt—i.e. what remains after neutralising the opposite extra current of the relay—flows from *E* to *L* in the opposite direction to the working current, thus supplying the relay with a momentary force of restitution, which tends to draw the tongue immediately back to the rest stop *A*.[1]

Thus, the E.M. shunt performs a second and important function in counteracting the prolonging effects of discharge,[2] by exerting a contrary force on the tongue and drawing it back to its rest stop *A* at the termination of each received signal.

It must be distinctly remembered, however, that the E.M. shunt takes no part in discharging the line. This is effected on a different principle altogether—by *discharging instruments*, which are explained in paras. 125–132.[3]

From what has been said in the foregoing paragraphs with regard to the action of the shunt at the termination of each signal, its action at the commencement of each signal will be readily understood.

The extra currents will be in the opposite direction to that shown in the figure, and the superior extra current of the shunt will tend to draw the tongue over to its working contact *M*, aiding the working force, preventing retardation, thus rendering the commencement of signals sharp, and acting in the contrary direction to the 'charge' current of the line.[4]

Results of the E.M. Shunt.

123. The shunt thus fulfils the following important objects:

(1) At the *commencement* of each received signal, it produces an extra current in the *same* direction as, and adding to the force of the initial working current through the coils of the relay.

(2) At the *termination* of every received signal, it produces an extra current in the *opposite* direction to the working current, the effect of which is to hasten the return of the tongue to *A*, thus remedying the defect of Siemens relay, to which reference has been made.[5]

[1] §§ 61–63.

[2] §§ 111, 112, and 121 (*a*).

[3] Observe that shunts are applied in the *Receiving* Circuit, and discharging instruments in the *Sending* Circuit.

[4] §§ 109, 110, and 121 (*a*).

[5] §§ 61–63.

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(3) As its extra current acts in the reverse direction to the charge and discharge of the line, it sharpens received signals by checking the retarding effects of 'charge' at the commencement and the prolonging effects of 'discharge' at the end of each signal.[1]

The resistance of the shunt should be equal to that of the relay with which it is joined.

On the principle of shunts or derived circuits,[2] it is reasonable to conclude that half the working current will be diverted from the relay through the shunt circuit of equal resistance; and this is right so far as the permanent current is concerned. It is necessary, however, to bear in mind the action of the *extra current* of the shunt at the commencement of each received signal, which, traversing the coils of the relay in the same direction as the working current, adds to its strength just at the moment when its force is required to draw the tongue over from the rest stop to the working contact; this done, the strength of the working current in the relay coils, although reduced by the derived circuit of the shunt, is sufficient to hold the tongue over against the rest stop, when it is once there, until the cessation of the signal.

Efficiency.

124. As the object of the shunt is to produce an extra current, its efficiency is tested by the extra current produced in its coils by the minimum working current. The E.M. shunt, when joined up with a relay of the same resistance as its own, should give a flick with a current of three milli-oerstedts.[3]

Discharging Arrangements.

125. In paras. 109–112 it was explained how telegraph lines become electro-statically charged by the battery current; and how, after the release of the front contact (*1*) of the key (fig. 18),[4] after each signal sent, a current of discharge or *return current* rushes back to earth immediately contact (*2*) is closed.

Now the result of this is that the return current causes a momentary beat on the receiving instrument (which is inserted between *2* and earth) after each signal sent; and it is to prevent sent signals thus affecting the instrument of the home station that **discharging instruments** are used, the object of which is to provide a direct circuit to the earth for the return current after each sent signal, and at the same time to permit of the arriving working currents traversing the coils of the receiving instrument.

[1] § 121 (*a*).

[2] Def. 22, and Law 8, App. A.

[3] § 289

[4] § 111.

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Discharging Relay.

126. The **discharging relay,** which consists of an ordinary Siemens relay of low resistance, fulfils this object in the following manner:

It is inserted between the battery and the front contact of the signalling key, as shown in fig. 24. The end of its tongue, *d*, is permanently connected to earth.

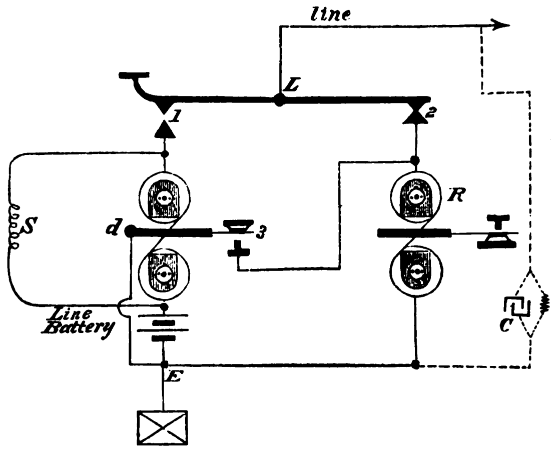

FIG. 24.—DISCHARGING ARRANGEMENT.

Suppose a current to be sent into the line by the depression of the key, contact *1* being thus closed—

The tongue of the discharging relay (*d*) now works and closes contact *3*.

Now suppose the key to be released and contact *1* broken, by which *2* is closed; then *3* is also broken; and if these actions are simultaneous, it is evident that all the discharge of the line would go through the ordinary receiving relay *R*, to earth, causing a beat of the tongue against the working contact.

If, however, contact *3* were prolonged an instant beyond *1*, then it is equally apparent that the discharge would take place through the short circuit to earth afforded by the tongue of the discharging relay *d*.

This object is effected by the shunt *S*, which consists of a coil of insulated wire equal in resistance to the relay coils;

the extra current produced in the shunt coil, on contact *1* being broken, arrests the demagnetisation of the cores of the discharging relay, by reason of which contact *3* is sufficiently prolonged to exist for a moment simultaneously with contact *2*, so that the whole discharge, or at any rate the greatest part of it, has time to pass through contact *3* direct to earth, instead of passing through the receiving relay *R*.[1]

In the newest form of discharging relay the shunt has been dispensed with, and the prolonging effect produced by means of an ordinary translation spring, attached to the tongue, which has been found to be more effectual than the shunt.

Efficiency.

127. The efficiency of the above arrangement to discharge is tested by taking off the line from the key, and by substituting between the points *L* and *E*, as shown by the dotted line (fig. 24), a condenser *C*, containing resistance or joined parallel to a resistance box, and after charging the condenser by closing contact *1* of the key, observing on its sudden release whether the condenser is completely discharged (as it should be) through the tongue of the discharging relay.

If not, the receiving relay *R*, being in the derived circuit, would of course work and tell the tale.

Discharging Key.

128. On the same principle the discharge current of the line can be momentarily short-circuited to earth by means of the **discharging key** described in para. 108.

Referring to fig. 16 (para. 108), and supposing the receiving relay to be inserted between *R* and the earth, and that the terminal *Z* is joined direct to earth (i.e. the − battery *e* removed); then, from the order in which the contacts *R*, *Z*, and *C*, open and close, as explained in para. 108, it is evident that at the cessation of each sent signal the line is discharged through the contact *Z* to earth during the momentary interval when the contacts *Z* and *R* are closed together, before *R* is opened and the line connected with earth through the receiving relay.

The time during which *Z* and *R* are closed together can be prolonged by means of springs, to ensure the complete discharge of the line.

These same springs, however, are a cause of defect, in that they get out of order; and unless their play is very limited they are a serious obstacle to speed.

[1] The action of the discharger is accelerated by the insertion of a battery between the tongue of the discharger and earth, with its copper pole to earth, as in the case of the Zinc Sender described in § 196.

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The discharging key is, therefore, inferior to the dis charging relay described in para. 126.

Discharging Key used as a Zinc Sender.

129. While referring to this form of key, its use as a **zinc sender** may be noticed. Fig. 25 represents it as such ; and it will be observed that the circuit is identical with that described in the foregoing paragraph, explaining the use of the key as a discharging arrangement, with the addition of the second battery *e*.

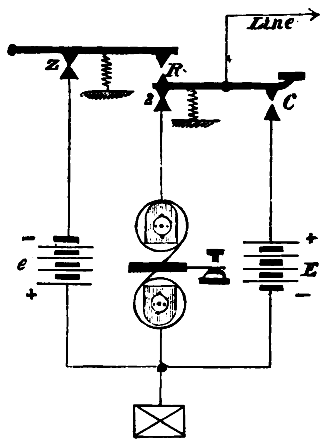

FIG. 25.—CONSTANT RESISTANCE KEY USED AS A ZINC SENDER.

Knowing the operation of the key as a discharger, it will be at once apparent, on reference to the above figure, that at the cessation of each sent signal the line, instead of being discharged *direct* to earth through the contact *z*, is now discharged through the battery *e* ; and further, that this battery, having its copper pole to earth and zinc to line (through *z*), serves to send a momentary zinc or — current into the line after each + signal from the working battery *E*.[1]

Discharge: How effected by d'Arlincourt Relay.

130. Another form of discharger is that adopted in the d'Arlincourt relay, which effects the same object as the discharging relay and key described in paras. 126 and 128 respectively, but on a different system to these instruments.

The Receiver.

131. The d'Arlincourt arrangement is composed of two distinct parts, the '**receiver**' and '**discharger.**' The former consists of an electro-magnet containing a soft iron core in the shape of a horse-shoe, with two projections

[1] The action of the Zinc Sender will be found explained in § 196.

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opposite to one another, one on each arm, at the end nearest the equator[1] (i.e. near the bend of the horse-shoe), between which projections a polarised tongue plays;[2] the electro-magnet is so wound that these projections, under the influence of a current in the coils, form consecutive poles, each being of opposite polarity to the outer extremity of its own arm of the horse-shoe; and being so much nearer the neutral line, the magnetism of these projections is much weaker than that of the extremities.

The process of demagnetisation which takes place at the cessation of each signal, momentarily reverses the polarity of the soft iron projections, by reason of the residual magnetism in the extremities, which is not only stronger and opposite in kind, but, owing to the greater distance between the outer poles, does not disappear so rapidly as the magnetism of the projections; the result being that the tongue is assisted back to its position of rest by this temporary reversal of the magnetism of the projections; speed of signals is gained by the force of restitution thus supplied, and the range of the instrument is made very large by the prevention of the necessity for re-adjustment, the residual magnetism of the core being in proportion to the strength of the working current.[3]

This same property, which, in the case of the receiver, is applied to the important purpose of accelerating the force of restitution, is made use of in the discharger in the following manner, for the purpose of connecting the line momentarily to earth at the end of each sent signal.

The circuit will be understood from the following figure, which also explains the mode of connecting up the instrument.

The Discharger.

132. The discharging part of the arrangement, *D*, is precisely the same in form as the receiver, *R*,[4] but the position of the tongue between the soft iron projections is so adjusted that a current flowing through the coils of the discharger, in the direction of the arrow, presses the tongue harder against its rest stop, *p*.

When the current ceases, however, the momentary reversal of the polarity of the projections between which the tongue lies, as described in the foregoing paragraph, causes the tongue to fly across to the contact *q*, but the magnetic force which causes this action being only momentary, the

[1] Def. 39.

[2] The tongue is polarised by a strong permanent magnet, as in the case of Siemens Relay, §§ 59, 60.

[3] In this singular case residual magnetism supplies a force of restitution instead of being a source of impediment to speed (§ 63).

[4] In fact the tongues of *D* and *R* are pivoted on the same permanent magnet.

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tongue returns again immediately to *p*, by virtue of the bias it is originally given against that stop.

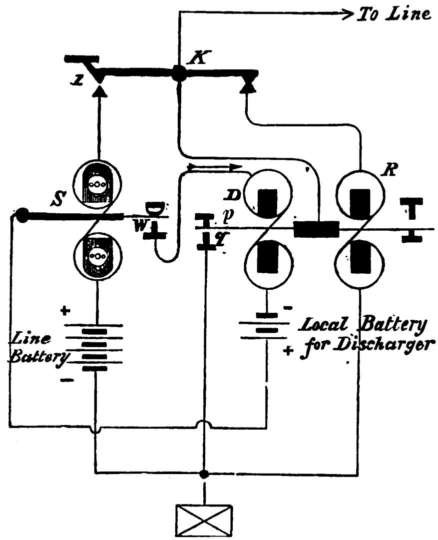

FIG. 26.—THE D'ARLINCOURT ARRANGEMENT.[1]

Examining the figure, it will be observed that every time the key *K* is depressed, the tongue of *S*, which is an ordinary Siemens relay of low resistance, joined in the circuit of the line battery, is attracted to the working contact *W*, and the circuit of the local battery is closed through the coils of the discharger, the tongue of which is thus kept pressed against *p*.

The moment contact *1* of the key is opened, the tongue of the discharger makes an instantaneous contact with *q*, as explained above, thus connecting the line for an instant direct to earth through *K*, the discharger tongue, and contact *q*; by this means effecting the discharge of the line.

Siemens' Lightning Discharger.

133. It is most essential that an efficient means be provided of discharging the line of lightning, which, owing to its high potential, is a source of great danger to instruments; demagnetising or reversing the polarity of magnets, fusing the coils of electro-magnets, and rupturing their insulating covering (or dielectric)[2] in finding for itself a speedy path to the ground.

[1] In this diagram the Sounder and Local Circuit of the Receiving Relay *R* are omitted for clearness' sake

[2] Def. 17.

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This property of high potential, causing it to leave a metallic circuit for a more direct passage to earth through air—a property not exhibited by a galvanic current—is taken advantage of in the various forms of apparatus devised for discharging lightning.

Siemens plate discharger is the departmental form, as represented in fig. 27.

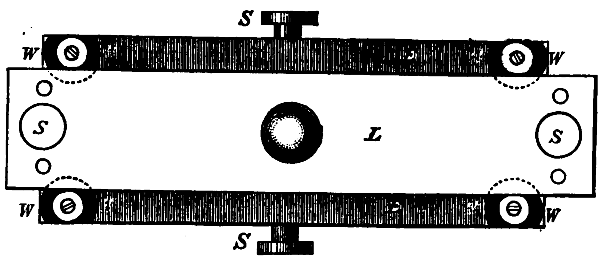

FIG. 27.—SIEMENS' LIGHTNING DISCHARGER (FOR A SINGLE LINE).

It consists of two brass plates, one placed upon the other, but kept from touching one another by very thin ebonite washers, *W*, *W*, *W*, *W*.

The upper plate, *L*, is joined[1] in the circuit of the line outside the instrument, and the lower, *E*, is connected to earth, so that in the case of lightning it is discharged direct to earth, passing in a spark from *L* to *E*, instead of traversing the metallic circuit of the instrument.

The inner surfaces of the plates are grooved, at right angles to one another, on the principle that points facilitate discharge.

Efficiency.

134. The efficiency of the lightning discharger is proved by the perfect conduction of each plate between its terminal screws, *S*, *S*, and by absolute insulation between the plates themselves.[2]

Switches or Commutators.

135. In order to make such changes in circuits as may be found necessary, without the inconvenience of taking off wires or otherwise interfering with fixed connections, **switches** or **commutators** are used, whereby this operation is performed simply by the insertion or withdrawal of metallic plugs or screws.

S.T.D. Switch.

136. The form most commonly used is that known as the **S.T.D. switch,** represented in fig. 28.

[1] Fig. 47, § 182.

[2] The faults to which the Lightning Discharger is liable are described in Sect. E, § 233.

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L, *D*, *S*, *T* are brass blocks insulated from one another by a circular wooden or ebonite base-board, but connected, when necessary, by means of plugs inserted in the circular apertures between them.

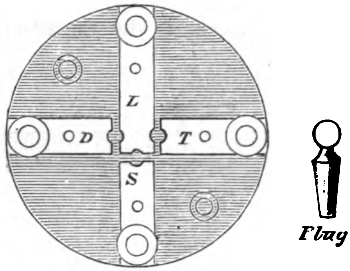

FIG. 28.—S.T.D. SWITCH.

The chief use of this switch is for joining lines either direct, or in translation, or for open circuit working.

The method of connecting it up for these purposes is shown in figs. 47 and 48.[1]

L is joined to line.
S „ instrument.
D „ *D* of neighbouring switch.
T „ *T* „ instrument.

P. Switch.

137. A more complicated form of switch, known as the **P. switch,** is specially designed for connecting lines and

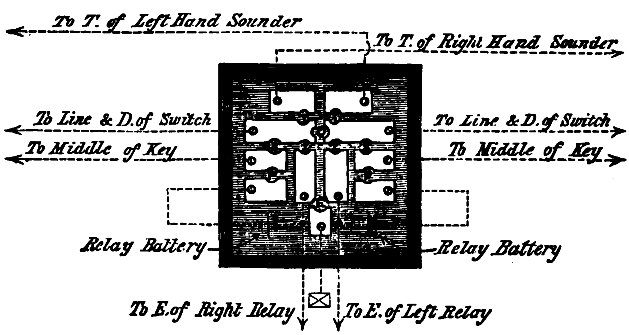

FIG. 29.—P. SWITCH.

instruments for **parallel working,**[2] admitting also of the same changes of connections as are effected by the **S.T.D.** switch described in the foregoing paragraph.

[1] §§ 182 and 183.

[2] § 186.

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The terminals are connected up as shown by the dotted lines in fig. 29,[1] and plugs are inserted for working the various circuits as follows :—

In *D*	for *D*	working	(paragraph	185);
In *S*, *S*, *E*	" *S*	"	("	180);
In *T*, *T*, *E*	" *T*	"	("	183);
In *S*, *S*, *P*, *P*	" *P*	"	("	186);
In *S*, *S*, *Z*, *Z*	" *A*	"	("	187);
In *E*, *Z*	" connecting either line with earth direct.			

[1] See also fig. 51, § 187.

By withdrawing plugs, either or both lines can be insulated.

Current Reversers.

138. Another form of switch is that shown in the following figure.

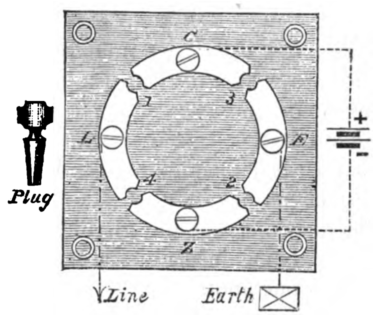

FIG. 30.—CURRENT REVERSER.

This switch can be used for various purposes,[2] but is generally employed for changing the poles of the battery.

[2] In offices into which only two lines are led, this instrument is used as a line commutator (§ 140).

Its connections, when used for this object, are represented in fig. 71, para. 293.

Supposing the terminals *C* and *Z* to be joined to the copper and zinc poles of a battery respectively, and *L* and *E* to line and earth as shown by the dotted lines in fig. 30, then it is evident that when plugs are inserted in *1* and *2* a copper current is sent to line, and the zinc of the battery is joined to earth.

But by changing the plugs to *3* and *4* the current is reversed, zinc being to line, and copper to earth.

Lever Switch.

139. The same object is effected by the **lever switch,** which is represented in fig. 31, this form of switch being sometimes met with as a fixture on the base-board of the

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Wheatstone's bridge or other apparatus, nothing being visible of it except the handle *H* and the two stops *S*, *S* between which it plays.

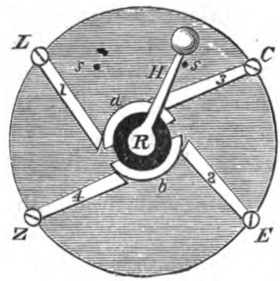

FIG. 31.—LEVER SWITCH OR BATTERY REVERSER.

It will be observed that the terminals correspond with those of the current reverser described in the last paragraph, and are similarly joined up.

With the handle turned to the right, as shown in the above figure, copper is joined to line, and zinc to earth, by means of the steel springs *1*, *2*, *3*, *4*, which press on two semicircular pieces of metal, *a* and *b*, which are fixed to the axis of the handle, being insulated by the ebonite ring *R*, and separated from one another.

When the handle is turned to the left, the springs *2* and *3* press on *b*, and *1* and *4* on *a*, so that copper is then joined to earth, and zinc to line, and the current is thus reversed.

The Commutator.

140. Where the number of lines and instruments in an office exceeds two, the **bar switch** or **commutator** is used.

It consists of two sets of brass bars fixed at right angles to one another, as shown in fig. 32, the upper set being insulated from the lower.

There are, however, holes in all the bars, upper and lower, corresponding with one another so that any *one* upper bar can be connected to any *one* lower bar by means of a brass screw.

Fig. 32 represents a commutator for four lines.

The *L* terminals of the upper series are all joined to the lines,[1] and the *J* terminals of the lower series to the instruments: thus any line can be joined to any instrument, or

1 Through the Lightning Dischargers (§ 182).

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to the spare bar *T* (for testing purposes), or direct to earth, or looped together direct or through a galvanoscope.

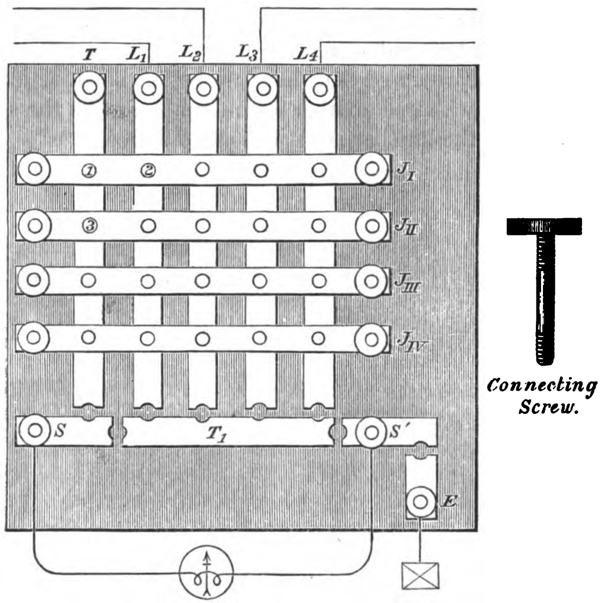

FIG. 32.—THE COMMUTATOR.

The Battery Commutator.

141. On the same principle, and with a slight modification in the number of upper and lower bars to meet the requirements of the case (the lower bars *S*, T_1, *S′*, *E* being dispensed with), a similar instrument is used as a **battery commutator,** enabling the number of cells in any battery to be increased by the insertion of plugs in the commutator.

For suppose the terminal *T* (fig. 32) to be joined to earth, and the zinc pole of a line battery to be joined to J_I so that it can be connected with earth by means of a screw in the hole marked *1*; then, suppose a spare battery to be joined up with its zinc pole to J_{II}, and its copper pole to L_1, it is evident that by taking out the screw from *1* and inserting it at *3*, earth will be taken off the line battery and put on to the zinc pole of the spare battery; and by inserting a second screw in *2*, the line battery zinc will be connected to the spare battery copper, and thus the strength of the latter battery will be added to the former.

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In this way a commutator may be made to provide for any number of line and spare batteries; a lower bar being reserved for the copper pole of each spare battery and one for the earth; and an upper bar for the zinc pole of each battery both line and spare.

It will be observed that the spare batteries can be joined up in series with one another in the same way that the spare is added to the line battery as described above.[1]

[1] The faults to which Switches and Commutators are liable are described in Sect. E, § 234.

PART II.—TESTING INSTRUMENTS.

The Galvanoscope.

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142. Electric currents may be discerned in various ways; the most practically convenient of these being the effect produced on a magnetised needle.

To indicate the presence of an electric current by this means, instruments called **galvanoscopes** or **galvanometers** are used; the principle of which has been already explained under the head of electro-magnetism.[1]

Fig. 33 represents the form of galvanoscope inserted in the line circuit[2] to indicate whether a current is passing.

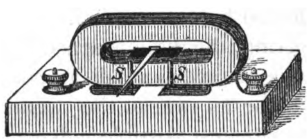

FIG. 33.—GALVANOSCOPE.

It consists of a hollow coil of insulated wire containing a small magnetic needle, rather more than half an inch in length, supported horizontally on a small steel pivot.

A paper pointer or indicator is fixed on the centre of the needle at right angles to its length, the movements of which, under the influence of the current, are limited by the copper stops *s*, *s*, so that, besides affording a means of observing whether a current is passing, short and long beats can be distinguished from one another, and passing signals can thus be read.

If instead of limiting the deflections of this instrument it were provided with a scale, whereby the extent of its deflections could be *measured*, it would be called a **galvanometer**.

Galvanometers.

143. There are many forms of galvanometers, varying in

[1] §§ 51–55.

[2] § 185.

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Aids and Obstacles to Sensitiveness.

sensitiveness and in their mode of construction to suit special requirements.

144. Sensitiveness, that is, the readiness with which the needle moves under the influence of a current, is gained in various ways.

First, by multiplying the number of convolutions or coils of insulated wire around the needle as explained in para. 54.

It must be remembered, however, that a point is arrived at when an increase of the number of convolutions does not increase the deflections in a corresponding ratio, because each layer of coils has to be wound at a greater distance from the needle than the layer next inside it, and thus the effect of the current on the needle becomes less according as the coils are further off, until it is so reduced as to render the addition of convolutions an obstacle (owing to the increased resistance they introduce) rather than a gain to sensitiveness.

Second, by using as small a needle as possible so that it may not be deflected out of the influence of the coils,[1] and yet it should be so long that its poles are sufficiently far apart to be unaffected by one another.

Third, by making the hollow space inside the coil, in which the needle is placed, as small as possible, so that the convolutions shall be as near to the needle as practicable, and thus exert the greatest possible influence upon it.[2]

Fourth, by causing the needle to move with as little friction as possible about its support.[3]

Fifth, by making the needle as light as possible with the above object, and yet making it, or its indicator, so long that the smallest deflection of the needle may be clearly indicated on the scale.[4]

Sixth, by rendering the needle as insensible as possible to the effect of terrestrial magnetism; either by the use of directive magnets,[5] or by weakly magnetising the galvanometer needle. The magnetism of the needle must, however, be sufficiently strong to return to the magnetic meridian on the cessation of the current in the coils.[6]

Seventh, by the use of an astatic pair of needles with the same object.[7]

Terrestrial magnetism must, however, be allowed to exert sufficient force to bring the astatic pair back to zero against the friction of the suspension of the needles.

1 Observed in all delicate galvanometers, the Sine galvanometer excepted, in which special arrangements are devised for keeping the needle under the influence of the coils (§ 150).

2 Specially observed in Thomson's Reflecting Galvanometer and all delicate galvanometers of high resistance.

3 Generally effected by the use of a fine silk or hair fibre, free of torsion.

4 Carried out to perfection in the Thomson Galvanometer, in which the needle and mirror together weigh only 1½ grain, and the indicator, which is a *weightless* ray of light, is 6 feet in length (i.e. twice the distance between the mirror and scale), causing a large traverse on the scale for a faint deflection of the needle (§ 156).

5 See note * next page.

6 See note † next page.

7 See note ‡ next page.

Simple form of Galvanometer.

145. The foregoing remarks will explain how the instrument described in para. 142 may be converted into a galvanometer of required sensitiveness by being furnished with an accurately graduated scale (the movable stops *s*, *s* being removed); by containing a suitable number of convolutions of wire in its coils, according to the measurements to be taken; by delicate suspension of the needle, whose weight and size are reduced to adequate limits; and by suitable protection from the gravitating influence of terrestrial magnetism.

Calibration.

146. With regard to the scale from which the angle of deviation of the needle is read off, it is to be remarked that the same current does not necessarily cause the same number of degrees deflection to be indicated on the scale, even of galvanometers of the same description, owing to the difference in sensitiveness which must exist in various instruments.

It is necessary, then, to find by actual experiment the deflection each galvanometer indicates under the influence of the same E.M.F. through the same resistance.

The Calibrated Galvanoscope.

147. On this principle the instrument, departmentally known as the **calibrated galvanoscope,** is constructed.

It consists of a coil of insulated wire, less than 1 ohm in resistance, so wound as to leave a hollow space inside the coil slightly over 3 inches in length.

In this is pivoted a magnetised needle 3 inches long, the ends of which support a light brass circular ring, marked in divisions of 5° each.

It is observed by experiment through what resistance, in each case, the needle deflects to these various divisions respectively, under the influence of a current of a single Minotti element, the E.M.F. of which has been shown to be a constant quantity, equal in value to about 1 volt.[1]

The various resistances introduced to produce corresponding deflections are noted on a card, and afford a means of determining the approximate value of any unknown resistance (between the limits tabulated on the card) placed in the circuit of the instrument and a Minotti cell, according to the deflection produced; a deflection of or near 15°, for example, representing the inserted resistance as being about the same as that noted on the card opposite the deflection of 15°.[2]

* Directive magnets, either fixed or separate, are generally used with delicate galvanometers, the north pole being placed towards the magnetic north, thus opposing and weakening the influence of the earth's magnetism on the galvanometer.

† And *vice versâ*, the magnetic field must be sufficiently strong to cause the needle to come to rest with a limited number of vibrations.

‡ Def. 32, and § 154.

1 Def. 7, and § 31.

2 It is presumed that the

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horizontal magnetic intensity of the testing station and that of the station where the instrument was calibrated, i.e. where the table was framed on the result of experiments, sufficiently agree (as they do all over India) to render the readings comparable.

As in this instrument the scale moves with the needle, it is necessary that some fixed object should indicate its deflections. This is effected by means of a line scratched on a small circular piece of glass let into the cover of the instrument, through which a portion of the scale is visible, so that the division immediately under the scratch or near it can be read off.

Efficiency.

148. The performance of the instrument is best checked by its agreement with that noted on the card referred to above, which always accompanies the instrument.

On this is also noted the number of oscillations made by the needle before coming to rest (never less than 60), also the number made in two minutes (generally about 35).

Sources of Inaccuracy in Galvanometers.

149. Now in the simple form of galvanometer described in principle, in para. 145, when the needle is deflected, under the influence of a current, it is clear that the greater the angle of deflection the further the poles of the needle are removed from the influence of the coils.

On this account, the deflections observed in such galvanometers are not to be relied upon as being proportional to the current when they exceed 20°.

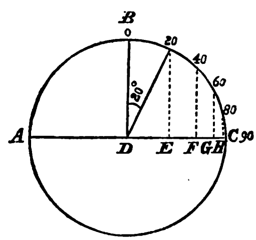

FIG. 34.

The disparity between the Sine and the Arc will be apparent from the following: Supposing the circle *A B C* to represent the graduated scale of a galvanometer, and *D B* the needle, pivoted at the centre *D* (*B* indicating zero); the sine of 20° is represented by the portion of the radius *D E*; and the sine of any other angle would be found by letting fall a perpendicular from the arc to the radius from the number of degrees indicating the angle on the arc, *B C*, which can be graduated into ninety equal divisions of 1° each. By letting fall perpendiculars from any number of degrees up to 20°, it will be observed that the arc and sine agree nearly; but when the deflection extends to multiples of 20°, the values of the sines are not multiplied in the same ratio, but diminish towards 90°, *E F* being less than *D E*, *F G* than *E F*, and *G H* than *F G*. (See Table of Sines, App. B.)

Again, the directive force of the earth's magnetism, which tends to bring the needle to rest in the magnetic meridian,

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is proportional to the sine of the angle of deflection of the needle, and not to the angle itself.[1]

Now between 0° and 20° the degrees on the arc of a circle are fairly proportional to their sines. Above that point, however, the sines differ considerably from the degrees as they increase towards 90°.

[1] For proof of this see Solution IX. App. B.

For this reason, also, deflections above 20° cannot be taken to represent the relative strength of the currents which produce the deflections.

The Sine Galvanometer.

150. To meet these difficulties the **sine galvanometer** was devised, which consists of a circular coil of insulated wire (of high or low resistance according to the purpose for which it is required) in which a magnetised needle is delicately suspended; the coil is made movable in a horizontal plane, so that it can be turned after the needle and kept parallel with it, thus always exerting its full force upon it in any position.

To effect this the needle is surrounded by a circular graduated scale, the scale and coil revolving together; outside this scale is a similar but fixed scale, forming part of the stand of the instrument.

When the galvanometer is used the coil is placed in the magnetic meridian so that the needle points to zero of the inner scale, which is so placed with reference to the outer scale that the zero points of both coincide.

When a current is sent through the coil, the needle is deflected out of the magnetic meridian. The coil is then turned after the needle until the zero point on the inner scale and the needle again coincide. The number of degrees through which the coil is turned, and which obviously represent the angle through which the needle was deviated out of the magnetic meridian, is thus indicated on the outer fixed scale.

When the needle is thus deflected, the directive force of the earth's magnetism tending to draw it back to the magnetic meridian is proportional to the sine of this angle of deflection as stated in para. 149;[2] and the force of the current on the needle being exerted in a direction perpendicular to the plane of the coil,[3] it is evident that **the strengths of currents measured by the sine galvanometer are proportional to the sines of the angles through which the coil is moved after the needle.**

[2] Solution IX. App. B.

[3] Solution VIII. App. B.

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The Tangent Galvanometer.

151. The tangent galvanometer also provides against the inaccuracies referred to in para. 149.

The arrangement for rendering the effect of the current on the needle constant in any position of the needle is simpler than that of the sine galvanometer, this being effected in the tangent galvanometer by the use of a very small needle as compared with the diameter of the coil, so that the electro-magnetic effect of the current on the needle is practically the same, whatever position the latter may take.

The instrument consists of a coil of very thick insulated wire, or sometimes a simple ring of copper, in the centre of which the needle is suspended. The length of the needle should not exceed $\frac{1}{6}$ the diameter of the coil.

A long fine indicator of aluminium is fixed to the centre of the needle at right angles to it, by which the deflections are read on a circular graduated scale, the indicator pointing to zero of the scale when the coil is placed in the magnetic meridian, as it is when used.

The current passing through the coil is proportional to the tangent of the angle of deflection.[1]

This is the principle of the tangent galvanometer.

Owing to its accuracy this form of instrument is much used for electrical measurements. The greater distance of its coils from the needle renders it less delicate than the sine galvanometer, but, on the other hand, admits of a gain in sensitiveness by increasing the number of convolutions in the coil, the increased distance of the outer convolutions from the needle relatively to the inner being slight; and the wire being thick, a considerable number of convolutions may be wound without sensibly increasing its resistance.[2]

It was shown in treating of the sine galvanometer[3] that the value of sines decreases as the number of degrees of the angle increases.

With tangents, however, the reverse is the case, as may be proved by drawing a tangent, *A B*, i.e. a line perpendicular to any radius, *D C*, of a circle (fig. 35): calling the point *C* (at which the tangent touches the circle) zero; and supposing the arc to be graduated from zero (0°) to 90°, a line drawn from the centre of the circle through any degree of the arc till it touches the tangent represents the tangent of that

[1] For proof see Solution VIII. App. B.

[2] § 144.

[3] § 149.

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angle: thus CE represents the tangent of 20°, EF of 40°, FG of 60°.

Now it will be observed that though CE and EF are fairly equal, FG is considerably greater than EF; and for higher angles the tangent will be found to increase in an

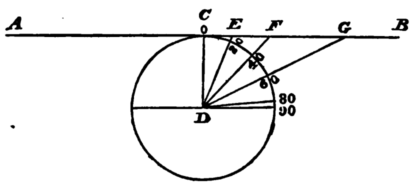

Fig. 35.—Principle of Tangent Galvanometer.

enormous ratio, up to 90° (the tangent of which is infinity), a line drawn through which from the centre would be parallel to the tangent AB, and thus never meet it at all.

This great difference between the arc and its tangent is observed in angles over 45°, on which account observations are likely to be more accurate when the deflections do not exceed 45°, for, as will be seen from the figure, the difference of a degree or two on the scale is a small matter, but the error is much exaggerated on the tangent of the higher angles.[1]

For the same reason, accuracy in reading off the deflections on the scale is of the greatest importance.

In comparing the strengths of currents with this instrument, the deflections are noted, the value of the tangents of the angles of deflection being taken from a table of natural tangents and substituted for the angles themselves.

Departmental Tangent Galvanometer.

152. On the above principle **the departmental tangent galvanometer** is constructed, which contains two coils, one of thick wire, measuring about 1 ohm in resistance, the other of thinner wire measuring about 100 ohms.

The length of the needle is $\frac{1}{6}$ the diameter of the coils.

To render the instrument complete for the measurement of electromotive forces and resistances it is furnished with resistance coils; two, measuring 20 and 200 ohms respectively, being inserted in the circuit of the thick coil; and resistances of 1,000 and 2,000 ohms each are added to the circuit of the thin coil.[2]

[1] The tangents of angles from 0° to 45° only vary between 0 and 1; but between 1 and ∞ for angles between 45° and 90°. See Table of Natural Tangents, App. B.

[2] §§ 260, 261.

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By means of plugs, either coil can be cut off or placed in circuit; the same with the fixed resistances.

Efficiency.

153. (1) The *electrical* efficiency of the instrument is proved by the agreement of the resistance of the various coils with the values marked on the instrument.

(2) The *mechanical* efficiency, by the number of oscillations the needle makes before coming to rest, and by its accurate return to zero.

The number of complete oscillations or vibrations should not be less than 15.[1]

(3) The *magnetic* efficiency, by the number of oscillations of the needle in a given time, under the influence of the earth's magnetism alone.

It should perform not less than 7 oscillations in 10 seconds.

(4) The *sensitiveness* of the galvanometer is proved by the extent of the deflections of the needle under the influence of the E.M.F. of the standard cell through various resistances.

The deflections should be not less than

5°	through thin coil	and	2,000 ohms.
10°	„	„	1,000 „
55°	„	„	nil.
4°	„ thick	„	200 ohms.[2]

Astatic Galvanometer.

154. From the descriptions of the various forms of galvanometer already referred to,[3] it will have been observed that one source of unsensitiveness, common to all, is the directive action of the earth's magnetism, which in causing the needle to take up its position in the magnetic meridian, opposes its deflection under the influence of a current.

The astatic galvanometer provides a remedy for this by the use of an 'astatic pair' of needles.[4]

Two magnetic needles *almost*[5] equal in strength are connected, one above the other, by a light vertical shaft of aluminium, with their poles reversed; i.e. the north pole of the upper is over the south pole of the lower, and *vice versâ*, so that the attractive force of the earth's magnetism on one pole is counteracted by its repulsive force on the other.[6]

The pair thus fixed is delicately suspended, so that the lower needle is inside the coil and the upper one just above it.

[1] Def. 50.

[2] Resistance of cell presumed to be 20 ohms. In the three prior cases the resistance of the cell is immaterial.

[3] §§ 142–153.

[4] Def. 32.

[5] If the needles were *equally* magnetised, then the earth's magnetism would have no directive force at all, and the pair would not return to zero, but would remain in any position.

[6] Law 23, App. A.

Remembering Ampère's law,[1] it is evident that a current passing through the coil causes both the upper and the lower needle to deflect in the same direction, so that the effect is double what it would be on a single needle; and further, the astatic principle on which the needles are joined —with reversed poles, almost nullifying the impeding effects of terrestrial magnetism—renders them free to move with the weakest currents.

To add further to the sensitiveness of the instrument the coils can be wound with as many convolutions as necessary, and should be close to the needle.

The astatic principle can be applied to various forms of galvanometers.

Efficiency.

155. The astatic condition of the pair of needles is measured by the time it occupies in making an oscillation across the magnetic meridian. From five to ten seconds is a fair time for one vibration.[2]

Thomson's Reflecting Galvanometer.

156. In para. 144 it was explained how sensitiveness was gained by the use of a long indicator, the extremity of which would move through a considerable space on the scale for a small deflection of the needle, and which would effect a further advantage in admitting of larger divisions of the scale, thus rendering readings more accurate.

There is, however, this disadvantage in increasing the length of the indicators hitherto described, that their weight is increased according to their length, and an obstacle to sensitiveness is thus introduced.

In **Thomson's reflecting galvanometer** the advantage is gained without the disadvantage attending it, by the use of a ray of light as the indicator.[3]

The needle itself, which is a piece of magnetised watch spring $\frac{3}{8}$ of an inch in length, fixed to a small circular concave mirror, the whole weighing only $1\frac{1}{2}$ grain, is delicately suspended in a coil of fine wire, the resistance of which is generally about 2,000 units or more, the coil being very close round the needle, which is so small as to be always under the influence of the coil in any position.[4]

The needle is generally made astatic, and the instrument is provided with a directing magnet, a glass case for preventing any disturbing effect of the air on the needle, and adjustable feet for levelling the stand.

It is thus extremely sensitive and capable of responding

[1] Law 13, App. A, and § 53.

[2] Def. 50.

[3] § 144, fifth clause (note).

[4] § 144, sixth and seventh clauses.

SECTION C.

to the weakest currents, and is consequently adapted for the measurement of very high resistances.

For observing the deflections of the needle, a horizontal scale on a wooden stand is placed in front of the galvanometer at a convenient distance, found by experiment, generally about three feet from it.

Below the zero point of the scale, which is at its centre, a vertical slit is cut containing a fine wire drawn down the middle of the slit. A lamp is placed behind this so as to shine through the slit on to the mirror of the galvanometer, which reflects back on to the scale a spot of light containing the image of the wire. The instrument is adjusted so that when the needle is at rest this image is upon the zero point of the scale.

A current through the coils deflects the needle and mirror, causing a slight movement of the former to be indicated by a readable deflection of the image on the scale.

As the ray of light moves through an angle double that of the deflection of the needle, it is thus an indicator of about six feet, i.e. twice the length between the mirror and scale.

In taking measurements with this form of galvanometer, it is customary to consider the strength of currents as proportional to the angle of deflection of the needle; which is true when the deflections on the scale do not exceed 5°, for within this limit the values of tangents vary almost equally with their angles; and from the above description of the instrument, it will be seen that the principle of the tangent galvanometer enters into the construction of the Thomson, which contains a small needle in a large coil; but as a deflection of 1° of the needle moves the image more than one inch on the scale when the mirror and scale are three feet apart (so that no reading of the scale can represent a deflection of more than 10° with this instrument), the readings may be accepted as indicating the strength of the current with sufficient accuracy. The deflections of this instrument can be controlled within small limits by means of shunts specially prepared for each instrument.[1]

Shunts.

157. When a current passing through the coils of a galvanometer produces too large a deflection for observation or for accuracy, the terminals of the instrument are connected by means of wire, which forms a **shunt** or **derived circuit,**[2]

[1] The faults to which Galvanometers are liable are described in Sec. E, § 235.

[2] Defs. 21, 22.

the resistance of which bears a known proportion to that of the galvanometer, so that only a fraction of the current passes through the coils to deflect the needle, the rest being led through the derived path of the shunt.[1]

Resistance of Shunts.

158. The relative strength of the current in the galvanometer and shunt circuits depends entirely upon their respective resistance according to the law of derived circuits.[2]

If, for example, their resistances were equal, half the current would go through the galvanometer and half through the shunt.

In practice it is found necessary to make the resistance of the shunt a small proportion of that of the galvanometer, so as to admit of a large portion of the current being diverted by the shunt circuit of low resistance, the small portion traversing the coils being sufficient (owing to the effect of convolutions)[3] to deflect the needle.

It is customary to provide sensitive high resistance galvanometers with shunts containing three coils marked $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$, implying that their respective resistances bear these proportions to that of the galvanometer; or, in other words, that they reduce the deflections of the galvanometer by $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$ respectively; so that in taking a measurement with the galvanometer when it is shunted with the $\frac{1}{9}$ shunt, the value of the deflection must be multiplied by 10; with the $\frac{1}{99}$ shunt by 100; and with the $\frac{1}{999}$ shunt by 1,000.

Thus, the multiplying powers of these shunts are 10, 100, and 1,000 respectively.

In the first case 9 tenths of the current flow through the shunt and 1 tenth through the galvanometer. In the second, 99 hundredths flow through the shunt and 1 hundredth through the galvanometer; and in the third, 999 thousandths flow through the shunt and 1 thousandth through the galvanometer; in each case the resistance of the shunt being

$$\frac{\text{Resistance of galvanometer}}{\text{Multiplying power of shunt} - 1},$$

$$\text{or } S = \frac{G}{n-1} \,*$$

Where S = resistance of shunt;
„ G = „ galvanometer;
„ n = multiplying power of shunt.

[1] On the same principle of derived circuits the terminals of sounders used in the local circuit of a relay are shunted with a wire of high resistance, which forms a path for the extra current of demagnetisation (see § 119, Sec. C), and the spark at the relay contact is prevented.

[2] Law 8, App. A, and Solution I, App. B.

[3] §§ 54 and 144.

* For proof of this formula see Solution V. App. B.

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Multiplying Power of Shunt.

159. By the following formula the multiplying power of any shunt whose resistance and that of the galvanometer are known, may be found :

$$n = \frac{G}{G+S}*$$

* For proof see Solution IV. App. B.

Resistance Coils.

160. It has been already shown[1] that electromotive force is that property of the current which enables it to overcome resistance ; and Ohm's law[2] establishes the fact that the strength of the current, i.e. the property by which it deflects galvanometer needles, &c.,[3] is directly proportional to ts E.M.F., and inversely proportional to its resistance.

Thus, the property of resistance affords a convenient means of uniformly controlling the visible effects of the current ; for example, the current of one Minotti cell through a Thomson's galvanometer with a resistance of 1,000 units in circuit will cause a certain deflection ; by doubling the resistance in circuit the deflection will be halved, and so on.[4]

And conversely, if in the second case an unknown resistance had been inserted, resulting in the deflection being halved, its value would be at once known to be double that which was in circuit in the first case.

For measurement and comparison various standards or units of resistance have been decided upon, the unit most generally adopted being the ohm or B.A. unit.[5]

[1] Def. 5.

[2] Law 1, App. A.

[3] Def. 1.

[4] A Thomson's Galvanometer is mentioned for simplicity, the deflections being considered as proportional to the currents flowing through the coils (§ 156).

[5] Defs. 12 and 34.

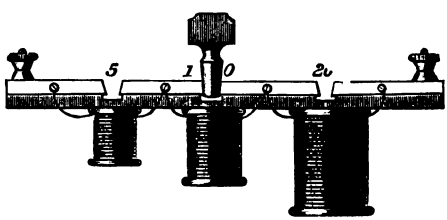

FIG. 36.—RESISTANCE COILS.

Coils of wire varying in resistance from one ohm and upwards and connected so as to form a series, as represented in fig. 36, are called resistance coils.

The resistance of the whole series is generally 10,000 units ; any coil or coils can be short-circuited by means of a plug, as shown in the figure.

The value of each coil is marked opposite the plug hole.

Heating Effect of Currents on Coils.

161. The wire of the coils is made of German silver, the resistance of which does not vary much with change of temperature.[1]

Bifilar Winding of Coils and its Object.

162. Further, instead of winding the coils in one continuous length, the wire of each coil is first doubled and then wound on to the bobbin, as represented in fig. 37, the result of which is that the convolutions of one half of the coil are wound in the opposite direction to those of the other half.

[1] The chief cause of change of temperature is the passage of the current, which flowing through the coils heats the wire. It is therefore advisable not to keep the current flowing longer than necessary.

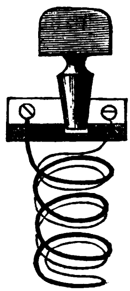

FIG. 37.—SPECIMEN OF BIFILAR WINDING.

It has been already explained[2] that the inductive action of a current upon itself is manifested in a coil of wire by an 'extra current,' the strength of which depends upon the force of the primary current and the number of convolutions in the coil.

[2] §§ 118 and 119, and Laws 20–22, App. A.

The effect of these extra currents, especially in the case of the high resistance coils, would seriously disturb the deflections of the galvanometer which is of necessity in their proximity for testing purposes.

Now the above method of bifilar winding, although it does not prevent the extra current being formed, yet, as will be observed from the figure, it causes the extra current in each convolution to be opposite in direction to that of the adjacent convolution, so that the extra current in one half of the coils is engaged in neutralising that of the other half, and the galvanometer is undisturbed.

Principle of Wheatstone's Bridge.

163. The influence of resistance in controlling the effective strength of the current on a galvanometer, as described in the preceding paragraphs, is in direct agreement with Ohm's law,[3] which states that current strength or potential is immediately proportional to the electromotive force and

[3] Law 1, App. A.

SECTION C.

inversely proportional to the resistance in circuit; from which it follows that with the same E.M.F. the greater the resistance in circuit, the greater the fall of potential of the current.[1]

This law is just as true for a 'divided circuit'[2] as for one composed of a single wire, so that if two precisely similar galvanometers were inserted in each of the paths *p* and *q* of the divided or derived circuit represented in fig. 38, in which a uniform current is flowing in the direction shown by the arrows, they would deflect equally when situated at points in *p* and *q* at which the resistances from *a* were equal.

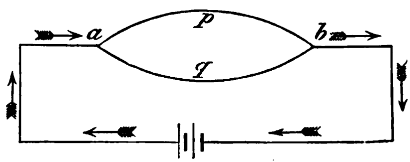

FIG. 38.—DERIVED CIRCUIT.

Conversely, when the galvanometers in *p* and *q* were situated at any points of equal resistance, their similar deflections would show the potential of the current at these points to be the same.

Again, supposing these two points to be connected across by a wire in which a galvanometer was inserted, it is evident that as the potential of the current at each point is the same, and enters the galvanometer in opposite directions, no deflection would be produced.

Thus it can be proved whether the potentials are equal at any two points of a derived circuit by connecting them through a galvanometer, and observing whether there is any deflection manifesting the passage of a current.[3]

The Wheatstone Bridge.

164. Upon this principle the arrangement known as **Wheatstone's bridge** or **balance** is based.

It consists of three sets of resistance coils, A, B, and W, with a sensitive galvanometer, G, joined across the points *p* and *q*, as symbolically represented in fig. 39.

Any unknown resistance (*x*) which it may be required to measure is joined up between the terminals L and L_1.

The battery current enters at *m*, divides between the parallel circuits A, W and B, *x*, and leaves at *n*.

From what has been said in para. 163, it is clear that

[1] Defs. 3 and 4.

[2] Def. 21.

[3] A deflection would of course show a *difference* of potential, resulting in a flow of current. See Defs. 5 and 6.

when the potentials at *p* and *q* are equal, no current will pass through the galvanometer, and the needle will remain unmoved.

This condition of equal potentials at *p* and *q* constitutes '*balance*,' which is obtained by adjusting the resistance of *W*, which consists of a set of resistance coils, adjustable from 1 to 10,000.

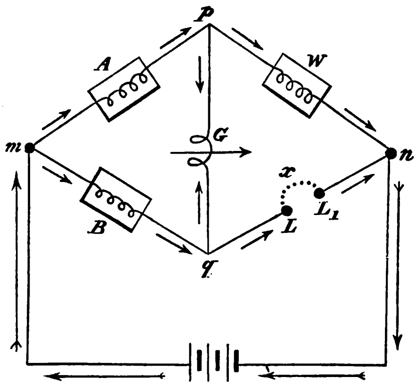

FIG. 39.—WHEATSTONE BRIDGE.

A and *B* each contain three coils of 10, 100, and 1,000 units resistance respectively, and can thus be used for adjusting the ratio of one branch to the other.

When balance is obtained, as shown by the galvanometer needle standing at zero, it follows that the resistance of the circuit *A*, *W* is equal to that of the parallel circuit *B*, *x*; and that if *A* is equal to *B*, *x* must be equal to *W*; or more generally—

$$A : B :: W : x,$$

$$\therefore \frac{x}{W} = \frac{B}{A},$$

$$\text{or } x = \frac{B}{A} W.*$$

This equation is called the condition of permanent balance, and thus affords a means of determining the value of any unknown resistance.[1]

The Differential Galvanometer.

165. On the same principle, viz. the equalisation of potentials, by means of resistance, **the differential galvanometer** is used for the measurement of resistances.

* For proof see Solution VI. App. B.

[1] The modes of testing lines, earths, and various resistances and electromotive forces with this instrument are explained in Sec. F, on 'Testing.'

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The instrument is symbolically represented in fig. 40. It consists of two distinct coils of equal resistance, and equal in their effect on the needle, the two wires being wound together on to the same bobbin, but in such a way that a current sent through the instrument shall traverse the coils in opposite directions; thus, if the copper pole of a battery were connected to the terminal *c*, to which the inner extremities of both the coils are joined; and the zinc pole to *A* and *B*, the outer terminals of the coils, the current would divide at *c*, circulating from *c* to *A*, and from *c* to *B* in contrary directions and the needle would stand at zero.

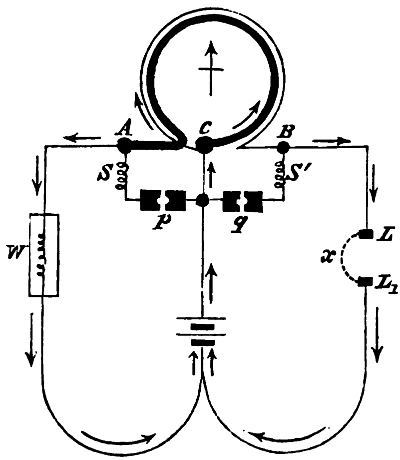

FIG. 40.—DIFFERENTIAL GALVANOMETER.

Further, if equal resistances were inserted between each of the terminals and the battery, the needle would still remain at zero.

Any difference, however, in the resistance of either circuit would cause a difference of potential between the currents in either coil, and thus the needle would be deflected.

S and *S'* are shunts of equal resistance (generally $\frac{1}{99}$ that of the galvanometer; thus having a multiplying power of 100).[1] *W* is a box of resistance coils adjustable from 1 to 10,000; *x*, the unknown resistance to be measured, is inserted between *L* and L_1.

[1] See §§ 158, 159.

SECTION C.

When $w = x$ the needle stands at zero, and thus the resistance of x is known.

The condition of balance for this instrument is therefore represented by the equation

$$x = w.*$$

If the shunt s is placed in circuit, then

$$x = 100\ w.$$

Or if the shunt s' be placed in circuit, then

$$x = \frac{w}{100}.†$$

* For proof of this equation see Solution VII. App. B.

† See Law 9, App. A, and § 159.

PART III.

MAGNETO-ELECTRIC INSTRUMENTS.

SECTION C.

Magneto-electric Induction.

166. In para. 118[1] it was explained how, by induction, a current flowing through a coil of wire produces a momentary extra current, in a neighbouring wire, opposite in direction to the primary current when the latter commences, increases, or is brought nearer to the secondary coil; and that another momentary extra current is formed, in the same direction as the original current, whenever the latter ceases, decreases, or is moved away from the secondary coil.

[1] See also Laws 20–22, App. A.

It was shown in para. 119 that the above effects were also produced in a coil by the inductive action of a current upon itself, the strength of the extra currents being increased by the insertion of an iron core in the interior of the coil; and supposing a current to be sent through such an electro-magnetic coil, the *inverse* extra current (caused by commencing or increasing the direct current) would retard the *magnetisation* of the core; the direct extra current tending to delay its *demagnetisation*.

Further, in para. 118 the converse also was shown to be the case, viz. that if the pole of a permanent magnet, instead of a battery current, were approached towards and withdrawn from a coil of wire, it would produce extra currents in the coil in precisely the same way that the galvanic current does; that is to say, any alteration of the magnetic field in the neighbourhood of the coil would create an extra current therein, just as any alteration of the battery current was shown to affect the magnetism of the core of an electro-magnet.

Principle of Magneto-electric Machines.

167. Thus, if an ordinary electro-magnet, consisting of a pair of coils containing soft iron cores, be so placed in the field of a permanent magnet as to be capable of altering their relative position, so that the coils may be under the influence of either pole of the magnet successively, extra currents in reverse directions will be formed in the coils for each change of polarity produced in their cores.

The number of currents thus produced in a certain time will of course depend upon the rapidity with which these reversals are effected, and by means of a commutator, to be explained hereafter,[1] the extra currents may be made to act all in one direction, causing a continuous flow of current, the force of this current depending also upon the strength of the magnetic field.[2]

[1] § 169.

[2] Def. 40.

The Magneto-electric Machine.

168. Instruments made on this principle are called **magneto-** or **dynamo-electric machines.**

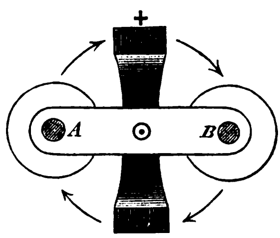

FIG. 41.—MAGNETO- OR DYNAMO-ELECTRIC MACHINE.

Fig. 41 explains the principle on which they act, in which, for simplicity, the arrangement is confined to one permanent magnet, in the form of a horse-shoe with its poles at *N* and *S*, and a pair of coils whose soft iron cores *A* and *B* are connected to a cross-bar of soft iron, capable of motion round the axis *O* in the direction shown by the arrows, and so pivoted (by means of a shaft running through *O*) that the lower ends of the cores *A* and *B* rotate over the poles *N* and *S*, close to, but not touching them.

The above figure represents the axis of the coils as lying across that of the permanent magnet, the cores *A* and *B* being equidistant from the poles *N* and *S*, so that the latter have no influence on the former.

Now suppose the pair of coils to be turned to the right till *A* is over *N*, when *B* must also be over *S*.

During this quarter-revolution magnetism is induced in both the cores *A* and *B*, which goes on increasing until they stand over the poles, when their magnetism is at its maximum.

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This increase of magnetism in the cores forms an extra current in the coils which surround them.

Again, continuing the motion in the direction of the arrows, and observing the action of the core *A* (that of *B* is precisely similar), as *A* recedes from *N* the magnetism of the core decreases until it becomes *nil* again when midway between *N* and *S*; continuing the motion towards *S*, however, the magnetism of *A* begins to increase again till it stands over *S*, but as the magnetism it now acquires is opposite in kind to that with which it started from *N*, its effect corresponds to a decrease of its original magnetism from maximum + to maximum −, thus acting in one direction; its motion, therefore, from *N* to *S* produces an extra current in the coils without any reversal, but opposite in direction to the extra current formed by the rotation of the coil in the direction from *S* to *N*, viz. from − to +.

Thus, for every complete revolution of the pair of coils two currents are formed, opposite in direction; one while the magnetism of the coils is increasing, i.e. while they are approaching the poles of the permanent magnet, the other while their magnetism is decreasing, i.e. while they are receding from the poles.

The Commutator.

169. The commutator consists of two metal pieces *m* and *n*, fitted round the shaft on which the coils revolve, as represented in section in fig. 42; these pieces being insulated from one another by pieces of ebonite, *e*, *e'*, and from the shaft by an ebonite ring between it and them. The extremities of the coils are joined to *m* and *n* respectively.

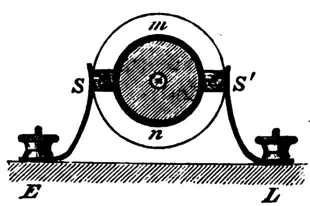

FIG. 42.—THE COMMUTATOR.

The above figure represents the position of the commutator when the coils lie in the position of *no current* as they are shown in fig. 41.

In this position it will be observed that the two steel springs *S S'* which are connected with the fixed terminals

L and E of the instrument press against the ebonite pieces *e* and *e'*, the ends of the coils being thus insulated.

When the coils are turned from N to S in the direction of the arrows (fig. 41), i.e. when the magnetism of the core is *increasing*, *m* is connected to L, and *n* to E (fig. 42); but by the other half-revolution, when the magnetism is *decreasing*, *n* is connected to L, and *m* to E; but as these two half-revolutions produce two currents in opposite directions, it is evident that by their alternate connection to the terminals L and E their effect on the circuit outside these terminals is that of a current in one direction.

Magneto-electric Currents of High Potential.

170. By means of the magneto-electric machine currents of very high potential[1] can be produced.

Its magnetic field can be made very powerful by the use of a large number of strong compound magnets; and the rotatory speed of the coils can be rendered extremely rapid by the use of steam power.

As such it is employed for generating powerful currents for the production of the electric light and various purposes.

Insulator and Joint Detector.

171. A small and portable form of magneto-electric machine, turned by hand, is applied to great practical use in Schwendler's **insulator and joint detector.**

The current, which is produced by even slow rotation of the handle, is sufficient to produce severe shocks.

It is also such that when passed through a line insulator offering some millions of ohms' resistance, it can be detected by the shock the tester receives when placed himself in the circuit. A key, which is fitted up as part of the connections of the instrument, and which when closed forms part of the conducting circuit, affords him the means of doing this.

The key has two platinum-tipped knobs, one fixed, the other movable.

By placing a finger on each knob, and pressing the movable one, the key circuit is broken, and the current passes through the fingers of the tester.

It is estimated that the resistance of an insulator which would allow of a current being thus felt is less than a megohm; but that if the finger on the fixed knob be replaced by the tongue, the current can be detected, by taste, through resistances up to 8 megohms.[2]

To test the conductivity of a joint, the portion of the circuit in which the insulator is placed is bridged over by a

[1] Def. 3.

[2] The standard of minimum resistance for a single insulator is 2,000 megohms.

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direct circuit, by means of a plug, this direct circuit being broken by the key as before.

The terminals of the coil are, however, also connected, by insulated wires, to each end of the joint to be tested, which thus forms a shunt or derived circuit;[1] so that if the joint is perfect, i.e. offers no resistance, no appreciable current passes through the direct path.

[1] Def. 2, and § 157.

If the resistance of the joint is over 5 ohms, the current in the direct path is strong enough to be tasted on opening the key contact; and if over 200 ohms, the current can be felt by the fingers.

Wheatstone's A B C Instrument.

172. In the electro-magnetic machine described in para. 170, the coils are represented as movable round the poles of the permanent magnet; it is evident, however, that if each pair of coils with its cores be fixed to a pole of the permanent magnet, an alteration of the magnetism of the cores and the consequent production of extra currents in the coils can be effected by causing a soft iron armature to rotate instead of the coils themselves, with the gain of reducing the friction and simplifying the connections between the wires and the terminals of the instrument.

This plan is adopted in **Wheatstone's A B C instrument,** in which the reversed currents thus produced are applied to telegraph purposes, each reversal being made to cause the armature of an electro-magnet at the distant end of the line to vibrate, thus turning an escapement wheel with an index needle attached.

It is found that the extra currents induced in a pair of coils when the armature *approaches* the cores are not so strong as those induced when it *recedes* from them; this inequality is remedied in Wheatstone's instrument by the use of two pairs of coils, the ends of the armature thus being made to approach one pole while it recedes from the one opposite to it.

The breadth of the armature covers the space between two neighbouring cores. Four reversals are effected by each revolution of the armature.

The Wheatstone's A B C instrument consists of two essential parts, the transmitter and the receiver.[2]

[2] Fig. 57, § 197.

The *transmitter*, which is inclosed in a wooden case, consists of a magneto-electric machine, as described above, *but without a commutator*, currents being formed by uniformly turning a handle which is in connection with the axis of the armature.

Connected to the same axis is a metal pointer, which revolves outside the upper surface of the box, on which is fixed a circular dial, divided into 30 parts, containing the 26 letters of the alphabet, 3 signs of punctuation, and an asterisk; one of which divisions is passed over by the metal pointer for each current produced, i.e. at each quarter-revolution of the armature.[1]

Round the dial are 30 metal keys, the depression of any one of which stops the pointer at the letter or sign opposite the depressed key, and at the same time cuts off the currents immediately the pointer arrives at that spot, where it remains until another key is depressed.

Underneath the circular row of keys is an endless chain, which is forced out into a loop by a projection under the key which is depressed; the depression of any other key, however, at another point in the chain tightens it and pushes up the key which was put down previously, and the pointer moves on to the key last depressed.

The receiver also carries a dial marked to correspond with that of the transmitter, and a fine pointer which rotates over the dial; its axis being that of a small escapement wheel, moved by the backward and forward attractions of the tongue of an electro-magnet under the influence of each current sent by the transmitter.

Thus, if the pointers of both transmitter and receiver be at the asterisk, which represents the zero of the dials, one revolution of the handle which, as explained before, produces four currents will turn the pointer through four letters, e.g. to the letter '*d*.'

Suppose this to be the case, or, which is the same thing, that the key opposite *d* is depressed, by which the currents are cut off from the line terminal on the arrival of the pointer at *d*; and suppose the terminals of the electro-magnet of the receiver to be at the same time joined to the terminals of the transmitter, the four currents which caused the pointer of the transmitter to traverse four divisions of the dial (up to the letter *d*) will also produce four attractions of the armature of the receiver, causing its pointer also to move through four spaces on the dial, stopping at the letter *d*.

Thus the depression of any key of the transmitter causes

[1] Fig. 57, § 197.

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the pointer of the receiver to stand at the corresponding letter or sign, affording a means of telegraphing words and sentences.

The receiver is provided with a switch, by means of which the circuit of an alarum can be added to that of the receiver when required for calling attention.

The mode of connecting up these instruments is shown in para. 197, Sec. **D**, on 'circuits.'

The Telephone.

172 (*a*). A description of the instruments in use in the Indian Telegraph Department would be incomplete without mention of the telephone and the apparatus connected therewith.

The telephone itself is an instrument by which sounds are reproduced, on the principle that *sound is the result of vibration*; also the converse, viz. that just as the pitch of any note is dependent on the number of vibrations which take place in a given time (the greater the number of vibrations the higher the note, and *vice versâ*), so also, by causing the same frequency of vibration the identical note will be the result.[1]

The instrument consists of a small electro-magnet *e* (fig. 42 *a*), the soft iron core of which is connected with the end of a steel permanent magnet *N S*.

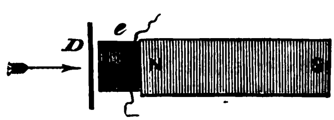

FIG. 42 (*a*).

A thin circular disc, *D*, of soft iron, is placed opposite the end of the core of the electro-magnet, being held in this position by means of the shoulder of a mouthpiece, as referred to below, so as to be capable of vibrating under the influence of any pressure of the air in the direction of the arrow.

The instrument, as described in principle in the above figure, is inclosed in a light cylindrical case of ebonite or wood, as represented by dotted lines in fig. 42 (*b*), terminating in a mouthpiece, the object of which is to concentrate upon the disc *D* any sound directed against it. At the other end of the case are two terminal screws, *S*, *S*, to which the ends of the coil are led.

[1] The *intensity* or *loudness* of the sound is determined by the *amplitude* of the vibrations; the *timbre* or *character* by the harmonics produced, these being notes, the frequency of vibration of which are exact multiples of the frequency of vibration of the fundamental note.

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To explain the principle of the instrument, its action both as a transmitter and receiver of sound will be here described, though, for reasons explained hereafter, its use is almost entirely confined to receiving.

First, as a sending instrument. In its position of rest the soft iron core of the electro-magnet is magnetised by induction from the permanent magnet *N S*, and itself induces magnetism in the soft iron disc *D*. Every vibration of the air caused by speaking in front of *D* is communicated to the disc itself, each movement of which, in the direction of the arrow (fig. 42, *a*), increases the magnetism of the core, and each return of the disc to its position of rest, by reason of its own elasticity, causes a corresponding decrease in the magnetism of the core.

Now it has been already explained[1] that every alteration in the magnetism of the core of an electro-magnet is attended by a current in the coil which surrounds it, the direction of which is reversed according as the magnetism of the core is increased or decreased, its E.M.F. being proportional to the variations of magnetic force, and consequently to the variations of pressure against the disc *D*.

[1] § 166.

Thus every vibration of the disc creates a current in the coil, the strength of which is proportional to the intensity of the vibration. Now suppose the two ends of the coil *e* to be connected with the terminals of another similar telephone, which *in this case is made the receiving instrument*, it is evident that every current produced in the coil *e*, corresponding to the vibrations of the disc *D*, is communicated to the coil of the *receiving* telephone, the currents in which react upon the magnetism of the core of the electro-magnet of the receiver, causing movements of the disc (corresponding to the vibrations of the sending disc *D*), which again vibrate the air in front of the receiving disc, reproducing the sounds which originally actuated *D*.

This instrument is extremely sensitive as a receiver, revealing sounds which the ear, unaided, is not capable of detecting; the electromotive forces produced in the coil, however, under the influence of the small vibrating disc, are so small that it lacks the power required for perfect sending.

The Microphone.

172 (*b*). This desideratum in the telephone as a transmitter led to the employment of special sending instruments termed **microphones,** in which increase of E.M.F. is gained

SECTION C.

by applying a permanent galvanic current to the circuit, the resistance of which, being made to vary with each vibration of the sending disc, a corresponding variation in the strength of the battery current in the coils of the receiver is effected, which thus causes the variations of the receiving telephone to correspond with those of the transmitter.

Fig. 42 (*b*) represents in its simplest form the general principle on which a microphone, *M*, is used as a transmitter with a telephone, *T*, as the receiver.

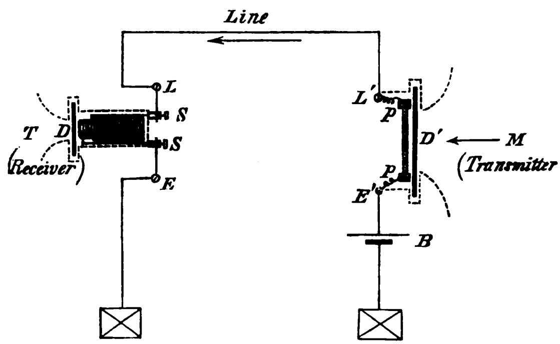

FIG. 42 (*b*).

B is the microphone battery, which sends a permanent current through the circuit including the line and the coils of the receiving telephone *T*, causing the disc *D* to be attracted to the core with a certain force, which is constant so long as the strength of the current remains the same.

That part of the microphone circuit, however, between the points *L'* and *E'* is so constituted that with every vibration of the disc *D'* the strength of the battery current is altered. This is effected by the insertion of one or more carbon pencils, the pointed ends of which, *p*, *p*, rest loosely in sockets fixed to the back of the thin disc *D'*, which is made of some light resonant wood,[1] against which the voice or sound to be transmitted is directed, this being concentrated upon the disc by means of a mouthpiece.

Every vibration of the air in front of the disc *D'* is thus communicated to the carbon conductors, the resistance of which varies in proportion to the intensity of each vibration, which again, in accordance with Ohm's law, produces a corresponding change in the strength of current in the coils of

[1] Deal is the best, this wood being chosen for the sounding boards of pianos &c. on account of the readiness with which it responds to vibrations.

the receiving telephone, reacting upon the disc of that instrument and causing it to vibrate the air in front of the disc *D*, and to reproduce the sounds which originally vibrated the transmitting disc *D*′.

In some forms of transmitter, such as the 'Gower' and 'Crossley,' an induction coil is inserted in the microphone circuit; the battery poles being closed through the primary coil and carbon conductor; the secondary coil being joined up between the line and earth, the telephone being included in the latter circuit.

Any change in the strength of the current which, in this case, flows through the primary coil instead of through the line, produces an extra current in the secondary coil,[1] traversing the line and coils of the receiver which thus responds to the vibrations of the transmitter as explained above.

[1] § 118, and Law 20, App. A.

In Johnston's form of transmitter a direct current is used; but the microphone *M* (fig. 42, *c*), instead of forming

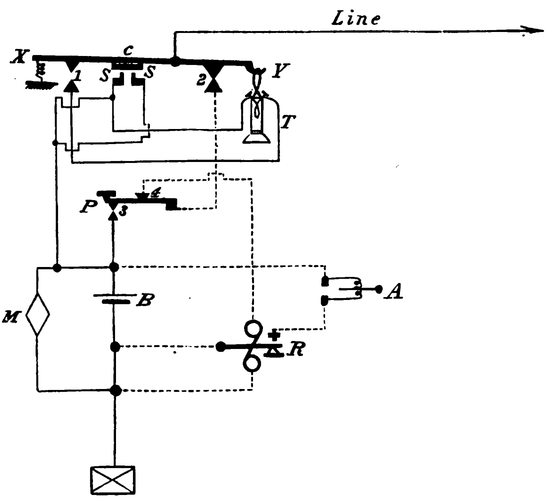

FIG. 42 (*c*).

Outgoing Microphone Circuit . . .		Contacts 2 and 3 open; 1 and 4 closed and *s*, *s* connected through *c*.
Incoming Telephone	,,	Ditto.
Incoming Bell	,,	1, 3 and *s*, *s* open; 2 and 4 closed.
Outgoing Bell	,,	1, 4 and *s*, *s* open; 3 and 2 closed.

[Bell Circuits dotted.]

part of the line circuit, is inserted as a shunt to the transmitting battery *B*, the poles of which are respectively con-

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nected to either end of the carbons; so that when the instrument is at rest nearly the whole of the battery current is short-circuited through the low resistance of the carbon transmitter; but when the latter, under the influence of the voice, vibrates with the disc (to which it is attached), corresponding variations occur in the strength of the current flowing out through the line, these being greater by reason of the microphone being in a derived circuit, than they would be if it were in the direct circuit of the line.

An alarum *A* or other form of electric bell is generally used in connection with the telephone *T* for calling attention when the talking apparatus is not being used. By means of a switch *X Y* either the telephone or the bell is placed in circuit, the outer arm of the switch *Y* being arranged as a receptacle for the telephone, which, when not in use, is always placed in it. The weight of the telephone draws down the arm, thereby closing contact *2*, which places the bell in circuit, in a position to call attention when required. When the telephone is removed from the hook, contact *2* is opened and *1* is closed, and at the same time the two springs *S*, *S* are connected to one another by the metallic contact *C*, which is insulated from the lever of the switch

A separate line battery (either galvanic or magneto-electric) for ringing the bell can be applied to the line circuit by means of a key, usually in the form of a push button *P* fitted up as part of the transmitting apparatus.

In Johnston's arrangement the *same* battery (generally six Minotti cells in series for short lines) is used for the microphone and the alarum, the latter being included in a local circuit[1] and worked by a relay *R*, as shown by the dotted line (fig. 42, *c*). In most arrangements Bell's telephone is used as the receiving instrument.

For exchanging communication between two stations connected by a telegraph line, *each* station is fitted with the complete apparatus referred to above.

[1] § 181.

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TELEGRAPHIC CIRCUITS

TELEGRAPHIC CIRCUITS.

Battery Circuit.

173. A circuit has been described [1] as consisting of a battery and everything between its two poles which takes a part in conducting the current, as represented in the following figure, in which the direction of the current is shown by arrows : SECTION D.

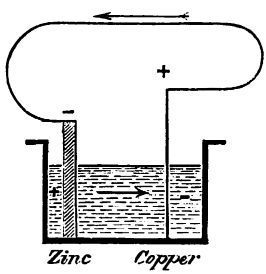

FIG. 43.—ELECTRICAL CIRCUIT.

It will be observed that the current starts from the generating or + plate,[2] whence it is conducted by the liquid to the negative plate ; thence to the + pole, from which it is conducted by a wire to the − pole, which is the outer extremity of the + plate from which the current started, thus traversing a complete round or *circuit* as it is called.

Internal and External Circuit and Resistance.

174. That portion of the circuit which is between the plates is called the **internal circuit,** and its resistance the **internal resistance of the battery** ; the portion between the poles is called the **external circuit,** and its resistance the **external resistance** of the circuit.

Conventional Symbols for the various portions of Telegraphic Circuits.

175. The following paragraphs describe various forms of telegraphic circuits, the component parts of which are, for the sake of simplicity, represented symbolically.

As conventional symbols are universally adopted, their

[1] Def. 13.

[2] § 1 (note).

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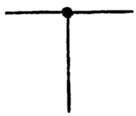
use is recommended in taking down diagrams of any circuits whatever.

The following explanations will render them intelligible :

Wire Connection.

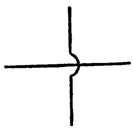
(1) A straight (or curved) line represents a wire connecting two points of a circuit.

Branch Connections.



(2) The point at which any branch connection is made is indicated by a dot.

Cross Wires.



(3) In order to trace wires which cross one another, one of them is looped at the point where they cross.

Direction of Current.

(4) The direction of currents is shown by arrows.

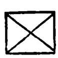
Resistance Coils.

(5) A sinuous line denotes resistance coils[1] inserted in the circuit.

Battery Cell.

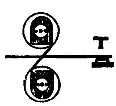
(6) Represents a battery cell, its + and − poles[2] being indicated. Any number of such cells can be drawn in series or parallel[3] to represent batteries so connected.

Earth Plate.



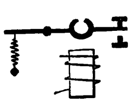
(7) Represents an earth plate.

Polarised Relay.



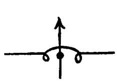
(8) A polarised relay.[4] In rough diagrams the nuts and shoes can be omitted.

Sounder (Non-polarised).



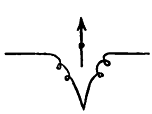
(9) Represents a sounder. The spring shown in the figure explains that the sounder indicated must be a non-polarised one.[5]

Galvanoscope or Galvanometer.



(10) Represents any form of galvanoscope or galvanometer.[6]

Differential Galvanometer.



(11) A differential galvanometer.[7]

1 § 160.

2 § 1 (note).

3 Fig. 46, § 181.

4 § 59.

5 §§ 73–84.

6 §§ 142–156.

7 § 165.

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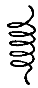
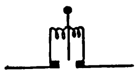
Coils representing Shunts, &c.



(12) Represents any coil of wire; its use, whether as a shunt, a magneto-induction coil, or any other purpose, being expressed by a referring letter.[1]

Electric Bell or Alarum.



(13) Represents an electric bell.[2]

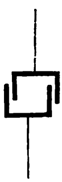
Signalling Key.

(14) Signifies an ordinary single current signalling key.[3]

Constant Resistance Key.

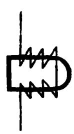
(15) A constant resistance key.[4]

Condenser.



(16) A condenser.[5]

E.M. Shunt.



(17) An electro-magnetic shunt.[6]

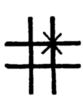
Lightning Discharger.

(18) A Siemens' lightning discharger, the upper plate forming part of the line circuit, the lower being joined to earth.[7]

Switch.

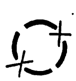
(19) Represents the S. T. D. switch, the insertion of a plug being indicated by a cross, as in the figure.[8]

Commutator.



(20) Represents the bar commutator, in which the cross signifies the point at which the upper and lower bars are joined by the connecting screw. Only so many bars as are necessary for the circuit under description need be shown.[9]

Current Reverser.



(21) Represents a current reverser, crosses indicating the insertion of plugs.[10]

Current Strength the same at all points of a Direct Circuit.

176. The external part of the circuit represented in fig. 43[11] may be supposed to be composed of a telegraph line, one end of which is connected to the + pole of the

1 §§ 157 and 168.
2 §§ 98–103.
3 § 105.
4 § 108.
5 § 116.
6 § 122.
7 § 133.
8 § 136.
9 § 140.
10 § 138.
11 § 173.

SECTION D.

battery, the other end being brought back to the − pole, the flow of current through the line in the direction of the arrow being caused by the completion of a conducting circuit.

If, however, this circuit were broken at any point, the current would cease to flow, and the + and − electricities of the battery, being deprived of a conducting medium through which to unite, would accumulate at their respective poles.

When the poles are joined by a conductor these electricities reunite, resulting in the flow of a current from the + to the − pole, the strength of which is the same in every point of such a circuit, independently of its resistance, provided the insulation of the circuit is uniform.

Earth Circuit.

177. **The earth,** being a conductor of electricity, may form part of the circuit between the battery poles, as represented in fig. 44.

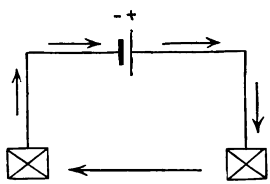


FIG. 44.—EARTH CIRCUIT.

This fact is of the greatest importance in telegraphy, as it renders it unnecessary to connect both ends of a telegraph wire to the battery poles to form a circuit, as in fig. 43, the current being afforded a means of returning to the − pole of the battery through the ground, in the direction shown by the arrows in fig. 44.

Earth Plates.

178. Connection with the ground is made by means of **earth plates,** which consist of sheets of copper $\frac{1}{8}$ of an inch in thickness, and measuring about 4 × 3 feet, which are buried *vertically* in moist ground.

Although the specific resistance of earth is much greater than that of iron, its actual resistance can be reduced to almost nothing by the use of large plates, thus making the sectional area of the earth circuit very great;[1] for it may be considered as a column of earth, of which the plates at each end represent the section.

[1] See Law II (*b*), App. A.

The action of the earth in thus taking the place of a return wire effects the important result of reducing the resistance of the complete circuit to about one-half what it would be if it were all of wire.

It is, of course, necessary that the plates should make as good connection with the ground as possible, which is effected by using a metal whose surface keeps clean.

Conducting wires are soldered to the plate; they are of insulated wire, to prevent electrolytic action at points of leakage and consequent corrosion of the wire.[1]

[1] Def. 26, and § 239 (*c*).

The conducting nature of the soil itself affects the readiness with which the current is diffused; and when it is necessary to lay an earth plate in badly conducting soil, it is advisable to lead the conducting wires underground a few yards from the building, and there to sink the earth plate vertically in a pit filled with charcoal and old scrap iron up to the edge of the plate, measures being taken to keep the soil above it always moist, and to lead, if possible, all surface drainage and discharge from water-pipes to it.

Open and Closed Circuit.

179. The circuit represented in fig. 44 is called a **closed circuit,** as the poles of the battery are closed through a conductor, the result of which is that a continuous current is caused to flow in the direction shown by the arrows.

A circuit in which the poles of a battery are not thus permanently connected, but closed by means of a key to form signals, is called an **open circuit.**

Telegraph circuits are worked on both the open and closed principles, as explained in the following paragraphs.

Open Circuit or *S* Working.

180. The **open circuit** system is that generally adopted in departmental offices.

Fig. 45 represents the essential parts of the circuit necessary to explain its working.

The figure represents two stations, *A* and *B*, with their keys in the position of rest, the circuit thus being open.

Suppose *A* to send a signal to *B* by closing contact *1* of his key. Contact *2* is opened, and *A*'s battery circuit is closed through the line—contact *2* of *B*'s key—relay, and earth; and the current flows in the direction shown by the arrows, forming a signal on *B*'s relay at each depression of *A*'s key.

Thus signals are exchanged, and stations as far apart as

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800 miles and upwards are able to communicate with one another.

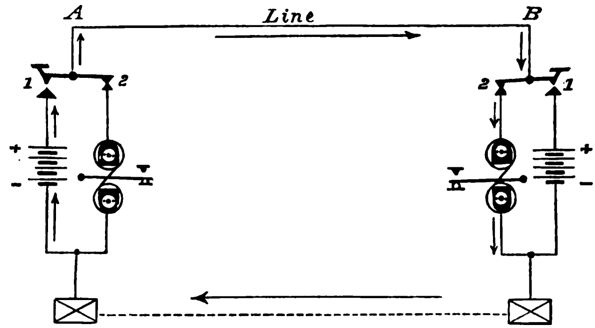

FIG. 45.—MORSE OPEN CIRCUIT WORKING WITH RELAYS.

Local Circuit.

181. These signals, however, are not read off the relays, for reasons already explained ;[1] the sounder, which performs this office, being joined up with the relay and a local battery in what is called the **local circuit,** as *separately* shown for clearness' sake in fig. 46, which represents two relays and sounders joined up in the circuit of one local battery, consisting of two series of four cells each, joined parallel.[2]

[1] §§ 57 and 58.

[2] § 42.

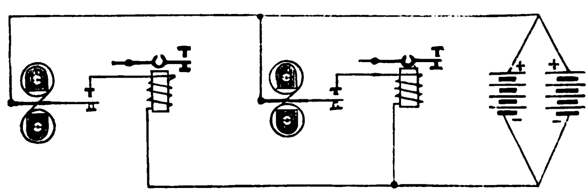

FIG. 46.—LOCAL CIRCUIT.

It will be seen from the above that every attraction of the relay tongue against its metal working-contact, under the influence of a current from the line, closes the circuit of the local battery, which can be adjusted to any required strength in order to work the sounder, which the current, arriving through a long line, reduced in strength by the resistance and leakage thereof, would fail to do.

The sounder terminals can be shunted by a coil of wire to prevent a spark being formed at the opening of the relay contacts.[3]

[3] § 157, and marginal note.

Office Circuit between Line and Signalling Instruments.

182. The apparatus included in that portion of the office circuit which is between the line and the signalling key, not directly affecting the principle of open circuit or *s* working and the mode of connecting it up, is, for the sake of clearness, separately represented in fig. 47, and it is important that the same order with regard to the relative position of the various instruments be followed in all cases in joining them up.

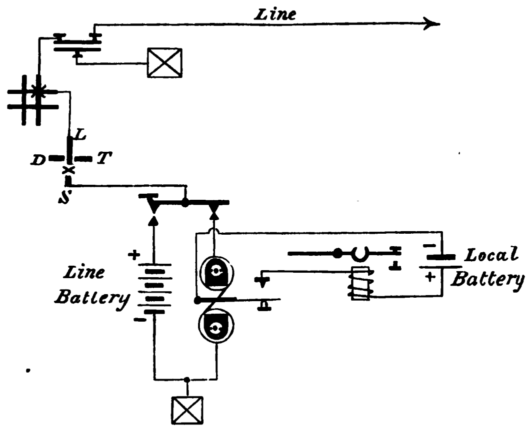

FIG. 47.—*S* OFFICE CONNECTIONS.

The lightning discharger is placed next the line in order to protect *all* the apparatus from the effects of lightning;[1] and it will be observed that the lower plate of the discharger is connected to a special earth plate of its own, distinct from the battery and instrument earth.

[1] § 133.

Translation Circuit.

183. It was shown in para. 180 that there is a limit to the length of line through which two stations can communicate with each other direct, owing to the reduction of the strength of the original current by the resistance opposed to it, as well as through leakage at all the points of support, for which the addition of battery power fails to compensate.

It then becomes necessary that intermediate stations should either repeat—i.e. receive the distant signals in open circuit,[2] which is called 'opening out,' and re-transmit them by hand towards their destination—or *translate* them by an

[2] See fig. 45.

arrangement which shall cause received signals to be automatically repeated by the instruments themselves.

The latter object is effected by means of switches in the intermediate office, plugs being inserted between the *L* and *T* terminals of the switches attached to the lines to be joined.

Lines thus connected are said to be joined in *T*.

Fig. 48 illustrates the circuit of the intermediate *T* office and the course of the incoming and outgoing currents ; and it will be observed that the incoming current from station *A*, in working the relay, causes each attraction of its tongue to be the means of picking up a fresh battery current and automatically sending it on to *B* by means of the sounder in its local circuit, which acts as a key.

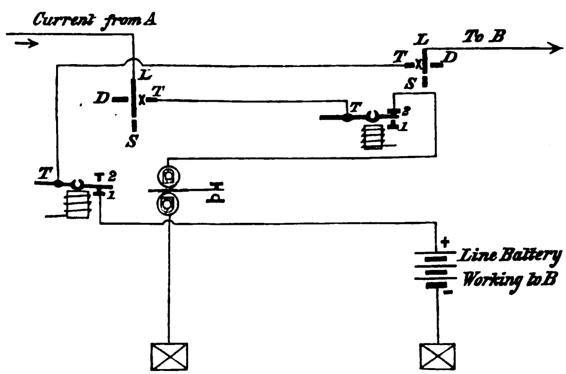

FIG. 48.—TRANSLATION CIRCUIT (of an Intermediate Station joined in T).

To render the Translation Circuit as clear as possible, only those Connections are shown which are traversed by the Line Currents.

The relay and sounder on the *A* side are represented above as actually working under the influence of a current from *A*, which enters through *T* of the left-hand switch into the *T* pillar of the right-hand sounder (at rest), thence through the lever and pillar *2* to *L* of the left-hand relay, the coils of which it traverses and goes to earth.

In doing so, however, it works the left-hand sounder, the lower pillar (*1*) of which is connected to the copper pole of the right-hand battery, whose current therefore passes through *1* into the attracted lever, thence into the pillar *T*, which is joined to *T* of the right-hand switch, and thus proceeds through the line to station *B*.

To secure a good contact between the lever and battery pillar (*1*) of a translating sounder, both are tipped with platinum, and the former is provided with a spring which prolongs the contact.

Circuit of *T* working with Discharging Arrangements.

184. Fig. 49 explains how discharging arrangements may be connected up in the circuit of translation working.

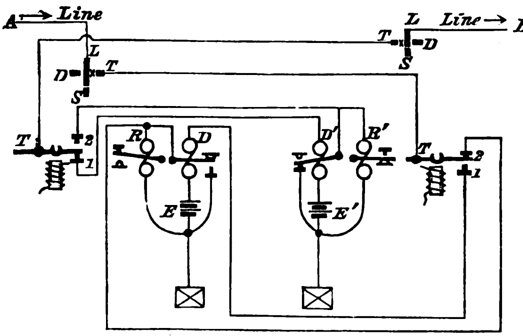

FIG. 49.—TRANSLATION WITH DISCHARGING ARRANGEMENTS.

R and R′ are Receiving Relays.
D ,, D′ ,, Discharging Relays.
E ,, E′ ,, Line Batteries.

In this figure, as in fig. 48, the Local Batteries &c. are not shown, for the sake of clearness.

The line current from *A* is shown in the above (as in fig. 48) to be actually working the left-hand relay and sounder, causing contact *1* of the latter to be closed, and thus placing the line to *B* in connection with its own battery.

It will now be observed that the coils of the discharging relay *D′* are inserted in this battery circuit, the current of which causes the tongue of discharger *D′* to be drawn against its working contact, thus connecting the line (on the *B* side) to earth for a moment through contact *2*, after each sent signal, and discharging it direct instead of through the coils of the receiving relay R_1.[1]

[1] § 126.

D and *G* Working Circuits.

185. The intermediate office, whose translation circuit is represented in figs. 48 and 49, may be joined over *direct*, or *in D*, as it is called, by connecting the lines to *A* and *B* directly with one another.

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This is done by means of the switches shown in the diagrams, the D terminals of which may be joined to each other by a short length of covered wire.

By removing the plugs from T and inserting them between L and D of both switches, the office is *joined in* D.

A galvanoscope[1] may be inserted in this wire for the purpose of observing passing signals, in which case the office is said to be *joined in* G.

[1] § 142.

G galvanoscopes are always provided with a short circuit plug, so that their resistance is only introduced into the circuit when they are being used.

P Working Circuit.

186. To obviate the necessity for the continuous and close watching required to observe and attend to passing signals when indicated only by a galvanoscope needle, the system of **parallel relay (or P)** working, as it is called, has been introduced, by which such signals can be read *by sound.*

Fig. 50 represents the circuit of an intermed ate station joined in P, from which it will be observed that the E

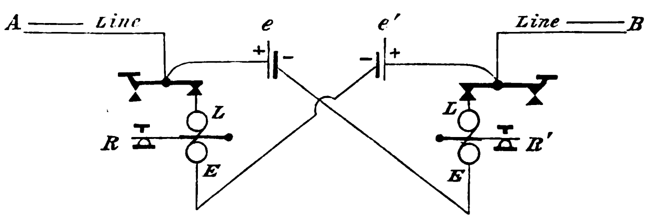

FIG. 50.—PARALLEL POLARISED RELAY OR *P* WORKING.

The *P* Switch described in para. 137 affords the means of joining from *S* to *P*. It is omitted from this diagram in order that the actual *P* circuit may be more clearly understood.

terminal of the left-hand relay R is connected to the L terminal of the right R[1], and *vice versâ*, so that a current entering from either line passes through a divided circuit[2] between the middle contacts of the two keys; but from the mode of joining up the relays, a current from A works R only, pressing the tongue of R[1] harder against its rest stop. Similarly a current from B works R[1] only; thus each relay responds to the current of its own line.

[2] Def. 21.

According to the law of derived circuits[3] the strength of current in each path is inversely proportional to the resist-

[3] Law 8, App. A.

ance of each branch; hence the two relays should be of equal resistance, in order that one may not divert more of the current than the other.

Another important result of using relays of equal resistance is that the extra currents formed in their coils will be equal, and thus counteract one another.[1]

To obviate the necessity for readjustment on changing from *S* to *P* work, by which the resistance of the circuit is considerably altered (the working current being manifestly stronger in the former than in the latter circuit), equating batteries *e* and *e'* are inserted in the derived circuits, so as to add the necessary strength for *P* working to the received current from whichever side it comes, these batteries being so placed that their current is in the same direction as the working current in either branch; but, being equal in strength (generally one cell each), and opposed to one another in direction, each cancels the other's influence on the line.

To facilitate adjustment a horse-shoe directing magnet is placed on each relay cover, by turning which the tongue can be delicately adjusted as near to the neutral line between the shoes as possible, so that the force required to drive the tongue back to its rest stop may be so small as to be produced by the cessation even of the weakest line current; so that 'sticking,' a common fault in *P* working, resulting from weakness of the line current and inefficient adjustment, may be avoided. It is obvious, therefore, that the strength of the received current should never be less than three milli-oerstedts.[2]

Circuit of *A* Working.

187. In fig. 51 the same circuit as that shown in fig. 50 is reproduced with the addition of a *P* switch, illustrating how the lines are changed from open circuit to *P* circuit working and *vice versâ*; the local circuit (in dotted lines) is also added, in which it will be observed an alarum is introduced.

By inserting plugs in *S S E* both relays are placed in open circuit, as already explained,[3] the left-hand instrument communicating with station *A* and the right with *B*.

By removing the plug from *E*, and having plugs in *S*, *S*, *P*, *P*, the instruments are joined for *parallel* or *P* working.

An alarum *a* is shown in the local circuit of the left-hand

[1] § 119, and Laws 21 and 22, App. A.

[2] § 289.

[3] § 137.

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instrument, by means of which the intermediate office thus joined over can be called in when closed for traffic.

During working hours the alarum is short-circuited by means of a plug, signals passing in *P* being audible and sufficient of themselves to arrest attention.

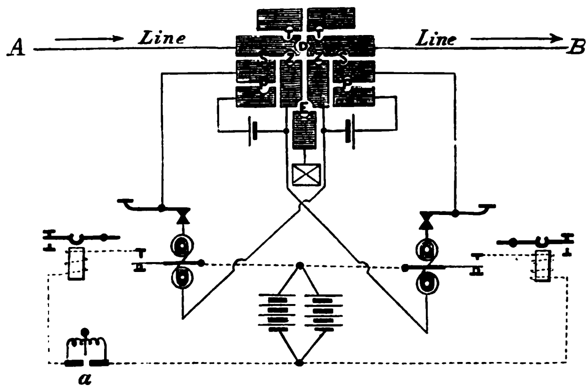

FIG. 51.—CIRCUIT OF *A* WORKING.

T and *D* and Line Battery Connections are not shown in figs. 50 and 51, in order that the *A* and *P* Circuits may be more distinctly traced.

When, however, the *P* office closes, the short circuit plug is removed from *a*, so that the bell rings every time a current from station *A* causes the local circuit to be closed.

In order that ordinary signals passing through the *P* circuit may not do this, the intermediate office adjusts the parallel relays just so *unsensitively* that the ordinary working currents between *A* and *B* do not affect them.

The equating batteries are therefore thrown out of circuit by removing the plugs from *P*, *P* and inserting them in *Z*, *Z*; the office is then said to be **joined in A** (plugs in *S*, *S*, *Z*, *Z*); and whenever it is necessary that it should be called in, this is done by means of an increased current sufficiently strong to work the relay on the *A* side.

A effects this by causing *B* to reverse his battery[1] and himself giving a beat; the left-hand relay of the intermediate office works, closes the local circuit, and rings the alarum.

[1] This is best done by a Current Reverser (see § 138) inserted between the Battery and Key.

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In practice any terminal office, observing that an intermediate '*A office*' is being called, immediately reverses his battery and gives a beat.

Looped Open Circuit (Morse).

188. Railway stations close to one another are often connected in loops by the '*train*' or '*block wire*'—i.e. the special wire used for blocking trains from station to station, and worked in open circuit.

Fig. 52 represents such an arrangement—*A* and *B* are the terminal stations of a train wire connected by a loop containing the intermediate station *C*.

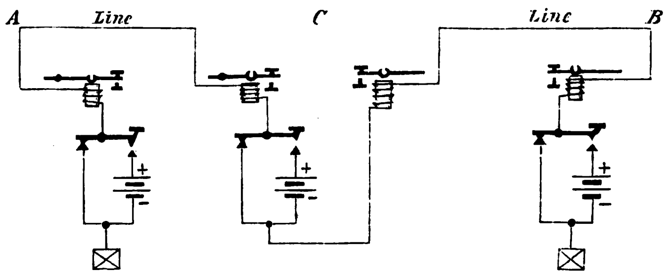

FIG. 52.—LOOPED OPEN CIRCUIT (MORSE).

It will be observed that when the key of any one of these stations is depressed, the instruments of all the stations in the loop are worked, each station containing one battery of which the copper pole is to line.

The number of stations which may be joined together in such a loop is limited to five, each of the intermediate stations being joined up similarly to *C*.

They may, however, be provided with a means of joining the zinc battery pole to earth in case of interruption on either side.

Closed Circuit (Morse).

189. The same three stations are represented in fig. 53 as joined up in **closed circuit.**[1]

It will be observed here that only the terminal stations are provided with batteries, that of *A* being joined with its copper pole to line, and that of *B* with zinc to line and copper to earth; thus a continuous current flows from *A* to *B*, attracting the sounder armatures in each station when all the keys are at rest, as they are shown in the figure. The interruption of this current, by depressing any one of the keys in the circuit, causes all the armatures to be released,

[1] § 179.

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signals being read from the upward or reversed beats of the levers.

The '*main*' or '*talking wire*'—that is, the wire by which paid messages are sent—on State railway lines is usually worked in closed circuit, as many as five stations being joined in one loop.

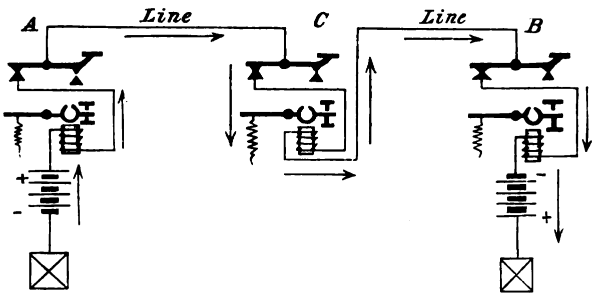

FIG. 53.—CLOSED CIRCUIT (MORSE).

The State Railway Sounder used for both the Circuits described in paras. 188 and 189 will be found illustrated in fig. 7, para. 80, which explains its connections.

The advantages this system has over the looped open circuit, described in the foregoing paragraph, are as follows :

(1) The instrument being worked with *no current*, the necessity for readjustment to suit the strength of various received currents is avoided.

(2) By dispensing with batteries at the intermediate stations, the supervision and conservancy of batteries is centralised at the terminal stations.

(3) The number of battery cells required is reduced to $\frac{1}{3}$ of what is necessary for open circuit working in a loop containing three instruments, $\frac{1}{4}$ for four instruments, and $\frac{1}{5}$ for five.

On the other hand, the disadvantages of closed circuit working are :

(1) That the batteries are always at work, thus becoming more rapidly exhausted than if used intermittently.

(2) The continuous action of the current tends to injure the covered wires in circuit.

(3) Translation in closed circuit is complicated.

To the practical reader cases will doubtless suggest themselves in which the advantages will outweigh the disadvantages, rendering the adoption of the closed circuit system desirable.

Looped Open Circuit (Needle Instruments).

190. Another form of circuit, which, on account of its simplicity and inexpensiveness, has been extensively adopted on railways for working 'station to station' or 'train' wires, is the **needle circuit,** in which a large number of stations can be looped together in open circuit; there being, however, a limit to this number, as the battery of each station must be strong enough to work the instruments of all the other stations in the loop.

Fig. 54 represents three stations—*X*, *Y*, and *Z*—so joined, with needle instruments, the action of which is described in paras. 96 and 97.

Each station is provided with one battery, which, in the case of intermediate stations such as *Y*, serves to work in both directions.

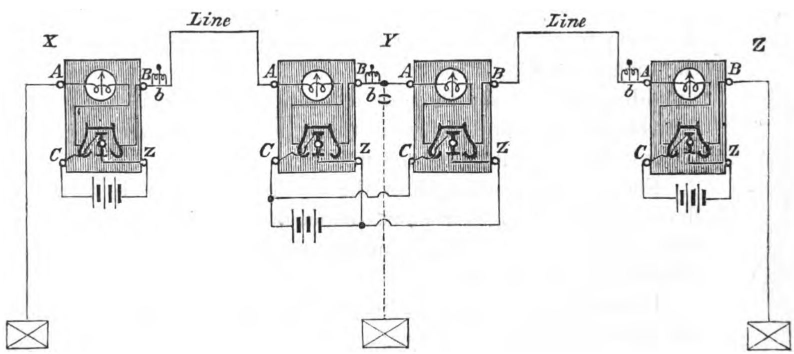

FIG. 54.—LOOPED OPEN CIRCUIT (NEEDLE INSTRUMENTS).

The line circuit is completed through the coils and handles of all the instruments in the loop, as shown by fig. 54, signalling currents being switched on to the lines by means of the handles, as explained in para. 97.

Intermediate stations are provided with a separate instrument for each station with which they are in communication, and further, with a means of joining to earth (as shown by the dotted line, fig. 54), which, in the case of interruption between *Y* and *Z*, enables *Y* still to communicate with *X* (disconnecting the *Z* line meanwhile).

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A single-stroke bell, *b*,[1] is placed in the circuit of each office for calling attention.

[1] § 101.

As the needle instrument works by reversals of the battery current, a copper current deflecting the needle in one direction, and a zinc current in the other, it can only be used for open circuit working.

Reverse Current Working.

191. The system of **reverse current** or **double current working** can be adopted on short lines in which Siemens' relays or other polarised instruments are joined up in open circuit, with the effect of increasing the speed of signals, by rendering the receiving instruments more sensitive than when influenced by a single current only.

It has been already explained[1] why it is necessary that the tongue of the Siemens' relay should be given a bias towards the rest stop, to give it a 'force of restitution' after each attraction by the current, thus introducing an obstacle to the sensitiveness of the instrument.

[1] §§ 61–64.

It has been also shown[2] how a current, opposite in direction to the working current, may be employed to draw the tongue back to its position of rest after each signal, thus providing an *external* force of restitution, and rendering it possible to adjust the tongue in the neutral line between the shoes—that is, in its most sensitive position.

[2] § 65.

Further, as the strength of the working current may and does undergo changes in consequence of the variation of the state of the line, it is desirable that the force of restitution should vary accordingly.

By using an opposite current as the force of restitution, this is to a certain extent the case;[3] whereas, in the case of single current working, however much the current from the line may vary, the force of restitution, which depends upon the bias of the tongue, remains the same, rendering readjustment necessary—another defect, against which double current working provides a remedy.

Fig. 55 describes the essential parts of the circuit of an office connected up for reverse or double current sending and receiving.[4]

It will be observed that when the plug is inserted at *3* for sending, the zinc pole of the battery is connected directly with the line; but when signals are transmitted by the depression of the key, copper currents are sent through the

[3] This may be considered the case for short well-insulated lines, but not for long and defective ones. See § 194.

[4] The figure represents the operation as performed with an ordinary key and two batteries. One battery, however, may be made to suffice, by the use of a 'Double Current Key,' as described in §§ 106 and 107.

line, followed by a zinc current each time the key is released.

These zinc currents, acting on the relay of the distant station in the reverse direction to the working currents, tend to draw back the relay tongue against its rest contact, thus terminating each signal sharply.

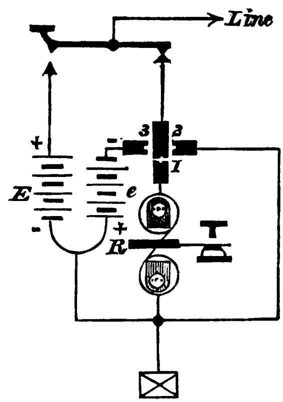

FIG. 55.

For Sending	. . . .	Plug 3.
,, Receiving	. . . .	,, 1.
,, Putting Line to Earth	. . . .	,, 2.

Advantages of Reverse Current Working.

192. Reverse current working thus presents the following advantages :

(1) It remedies a defect in Siemens' relay by supplying a force of restitution varying with the working force, which increases the sensitiveness of the instrument and reduces the necessity for readjustments.

(2) It improves communication by admitting of finer adjustment than in single current working, and thus renders receiving instruments susceptible to weaker currents.

(3) It counteracts the effects of residual magnetism in the cores of receiving relays.

(4) During the pauses between signals the reverse current renders the relay less sensitive to the disturbing effects of earth currents, contact beats, &c.

Disadvantages.

193. On the other hand, the system is attended with the following disadvantages :

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(1) It is necessary to alter the circuit by means of a switch, as shown in fig. 55, so that either the battery may be joined to the line for sending (plug in *3*), or the instrument to the line for receiving (plug in *1*); but as this necessitates the sending signaller's instrument being cut out of circuit, and the receiver's battery cut off, the latter is deprived of the means of stopping the former or of sending acknowledging signals, and no corrections can be called for until the receiver switches his instrument off and his battery on, to send, and the sender alters his circuit to receive.

(2) Translation with double currents is difficult, and requires somewhat complicated apparatus: nevertheless the principal *duplex* circuits in India are now worked on the double current differential system with an intermediate station in translation.

Though its advantages are great, the system has not hitherto been adopted on the Indian single circuits; the E.M. shunt[1] having been found to effect (by its extra current) the principal object of double current working, viz. the acquisition of a force of restitution for the tongue of the polarised receiving instrument, admitting of its being adjusted in its most sensitive position.

[1] § 122.

(3) Further, on long and imperfectly insulated lines the reverse currents do not exert equal force on the receiving instrument, which is one of the theoretical advantages claimed in favour of double current working [para. 192 (1)].

Circuits worked with Positive Currents.

194. This is to be accounted for by the fact that *electrolytic action*[2] takes place at any and every point where the insulation is so imperfect as to admit of the passage of a current to the ground; a copper current causing a deposit of chloride of copper and oxygen to take place at the point of leakage, a zinc current causing a deposit of salt and hydrogen; the former deposit is of an insulating nature, the latter the reverse; hence the zinc current makes for itself a way of escape.

[2] Def. 26.

The above fact explains the reason why it is customary to work the departmental circuits with copper currents, i.e. copper to line and zinc to earth.

Circuits worked with Negative Currents.

195. When the telegraph circuit, however, consists of covered wire, as in the case of a submarine cable, the effects of this electrolytic action are manifested in a way which renders it desirable that zinc currents should be used for signalling (i.e. zinc to line and copper to earth), for the copper deposit, alluded to above, which is formed at any point where the dielectric[1] is not perfect, although it has the effect of sealing up the fault by its insulating nature, nevertheless corrodes the copper conductor, gradually eating it away until it breaks altogether.[2]

The zinc current, on the other hand, though it decreases the insulation of the cable, has the effect of breaking down a fault of insulation, rendering its discovery practicable while the conductor is intact and communication is maintained.

Circuit of Zinc Sender.

196. It is necessary that the system of double current working should not be confounded with that of the **zinc sender,** whereby a *momentary* reverse current is sent after each signal with the object of counteracting the prolonging effects caused by the charge of the line, or in other words, its incomplete discharge through the receiving instrument of the distant station.[3]

It has been shown already (paras. 125–128) how the effects of this prolongation are reduced by means of discharging arrangements at the sending end, connecting the line instantaneously to earth with the object of reducing its potential to zero after each sent signal.[4]

It is evident, however, that the potential of the line would be lowered still more (viz. below zero) if it were connected to the zinc pole of the sending battery instead of direct to earth; and that thus its discharge would be accelerated.

This is effected in the following manner by the 'zinc sender' depicted in fig. 56:

The zinc sender, *d*, is a Siemens' relay of low resistance, placed between the line battery *E* and the front contact of the signalling key.

The tongue of *d* plays between two metal contacts *3* and *4*, the former of which is joined to the *L* terminal of the receiving relay *R*, the other to the zinc pole of a reverse battery *e*, whose copper pole is joined to earth.

When signals are sent by the depression of the key, the battery circuit is closed through contact *1* of the key and the coils of the zinc sender *d*, causing its tongue to be attracted to contact *4*.

At the same time contact *2* of the key is opened.

The shunt *b*, attached to the terminals of the zinc sender,

[1] Def. 26.

[2] The same result is observed in the covered wires of office connections, especially the leading wires connected to the copper pole of strong batteries.

[3] §§ 111, 112, and 121.

[4] Def. 3.

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causes contact 4 to remain closed a moment after the current ceases in the coils of the relay *d*.[1]

[1] The action of the Shunt is fully explained in § 126.

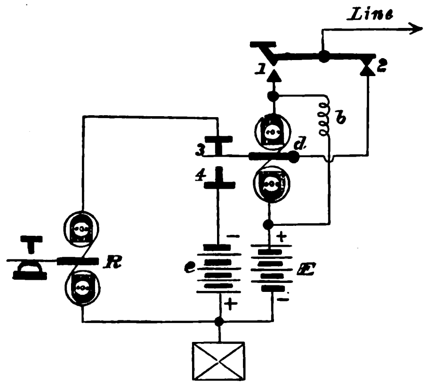

FIG. 56.—ZINC SENDER.

Thus, at the cessation of each signal, when the key is released and contact *1* broken, *2* being simultaneously closed, the line is discharged through contact *2*, the tongue *d*, contact *4*, and the zinc battery *e*, before the tongue (*d*) falls back against its rest contact *3*, connecting the line to the receiving relay *R*.

Circuit of A B C Instruments.

197. Fig. 57 represents the circuit of a line worked by Wheatstone's A B C instruments.[2]

[2] § 172.

e, *e′* represent the coils of the electro-magnets in the receivers, *m*, *m′* the magneto-electric coils of the transmitters.

Supposing *X* to be sending to *Y*, currents are generated in the coils of *m* by turning the handle (*h*) of that transmitter; these currents passing out through *e* to line, and thence through *e′* to earth at *Y*, cause the indicators of these three instruments to work together, stopping when they arrive at that letter on the dial at which the key of *m* is depressed.

When the pointer of the transmitter reaches this depressed key the connection between the coil *m* and the line is broken, as explained in para. 172, and no further current can flow out to the line until the key is raised by the depression of another key, when all three needles travel on to the letter on the dial corresponding to the last depression, and so on.

s, *s'* are the ends of brass levers, by turning either of which to the left a clockwork alarum is switched on to the circuit of the receiver for calling attention.

When the instrument is in use for telegraphing, the switches are turned to the right, as shown in the figure, in which position they cut the alarum out of circuit.

Lightning dischargers, *d* and *d'*, are inserted in the line circuit, as it is most important that the instruments should be protected from the effects of lightning, which would readily demagnetise the delicate polarised electro-magnets of the receivers.

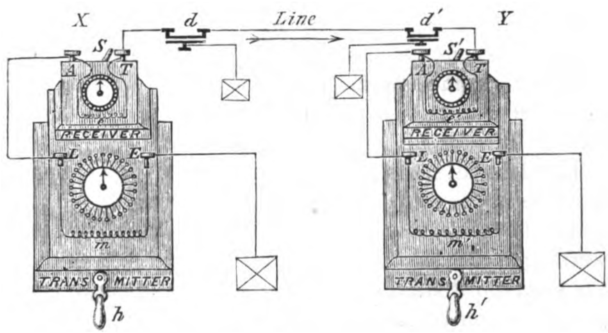

FIG. 57.—A B C CIRCUIT.

If the needles of all the instruments in circuit do not work in unison, the line and earth wires should be temporarily replaced by a short piece of wire connecting the *T* and *E* terminals of the instrument.

If, on turning the handle of the transmitter, it be found that the pointers of the transmitter and receiver thus joined together in short circuit still fail to correspond, reverse the connecting wires, joining the terminal *A* to *E* and *L* to *T*.

If this remedies the failure the line should be joined up accordingly (i.e. *A* joined to *E* instead of to *L*, and *L* joined to earth); but if not, and the needle of the receiver loses letters, i.e. falls behind the pointer of the transmitter, the springs between which the escapement wheel plays require tightening; if the reverse be the case, i.e. that the receiver gains letters, the springs require loosening.

If, however, the receiver agrees with the transmitter when they are joined on short circuit as above, but fails

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when connected through a line with another instrument, as represented in fig. 57, it is probable that the line is in fault.

It is important that lines worked with magneto-electric currents should be well insulated, especially in the case of circuits in which Wheatstone's A B C instruments are used, as the failure of a single reversal would be liable to destroy the sense of a whole word.

In order to bring the needle of the receiver to the same letter as the pointer of the transmitter, the former is provided with a small handle, by which the tongue of the electro-magnet is moved backwards and forwards by the hand in the same way as it is actuated by the magneto-electric currents.

Duplex Telegraphy.

198. The circuits described in the foregoing paragraphs have been confined to those which admit of single working, that is, of transmission in one direction only on the same wire.

Duplex telegraphy admits of transmission in opposite directions at the same time on the same wire.

To effect this, it is evidently necessary that the circuit be so arranged that signals formed by the depression of the key at one station shall work the receiving instrument of another station without affecting that of the sending station; and further, that the transmitting and receiving apparatus at both ends be always in circuit, so that either or both stations be in a position to send and receive.

Various modes of accomplishing this object have been devised, the most practical of which may be divided into two classes: the one including those methods which are based on the principle of the Wheatstone bridge,[1] in which outgoing currents have no effect on the receiving instrument of the same station by placing the latter in a null branch, similarly to the bridge galvanometer; the other on the principle of the differential galvanometer,[2] in which the effect of the outgoing currents on the home receiving instruments are nullified by dividing the coils of the latter into two separate circuits of equal resistance, so that the outgoing current dividing between them exercises an equal and opposite magnetic effect on the cores.

[1] § 163.

[2] §§ 163, 164.

Duplex Circuit. Bridge Method.

199. The first of these systems is known as **the bridge method,** the circuit of which is illustrated by fig. 58.

A and *B* are two stations so connected that *A* can both transmit to and receive from B at the same time, or *vice versâ.*

Examining the arrangements at station A (those of B are precisely similar), the circuit of the Wheatstone's bridge (fig. 39)[1] will be at once recognised; the line circuit[2] taking the place of the x branch, and the relay R that of the galvanometer, the branch resistances a and b, and the adjustable resistance W, corresponding with those similarly lettered in fig. 39.

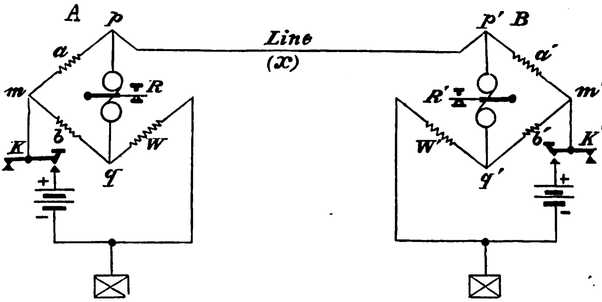

FIG. 58.—BRIDGE DUPLEX.

Thus, when the condition of balance is fulfilled, i.e. when

$$a : b :: W : x;$$

or, in other words,

$$a\,x = b\,W,$$

a current made to enter the system at the point m, by the depression of the key K, will have no effect on the relay R, the potentials at the points p and q being equal.

Thus (in the 1st case) the signalling current does not affect the relay of the home station, when the resistances are adjusted according to the above condition, in which the system is said to be in a state of *permanent balance.*

Tracing A's current from the point m, where it divides between two circuits of equal resistance, viz. through b and W to earth, and through the line and receiving apparatus of station B to earth, the latter portion, which may be called the signalling current, enters B at the point p', at which it again divides, one portion traversing and working the relay R', and completing the circuit to earth through W', the

[1] § 164.

[2] I.e. the resistance of the line together with that portion of the derived circuit comprising the receiving apparatus at the distant end.

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other portion passing through the branch resistances a' and b', which form a shunt circuit to the relay.

Thus (in the 2nd case) A's signals work B's relay.

In precisely the same manner B's signals would not affect the home relay R', but would work A's relay R.

Now, suppose that while A's key is depressed, B also sends a signal by the depression of K'; B's current divides at the point m', one portion flowing to earth through b' w', the other through a' to line; but, as explained before, without altering the potentials at p' and q', so that the effect of A's current on B's relay R' is not disturbed.

B's current, however, on arriving at A alters the potential at the point p, making it greater than that at q, so that a current flows from p to q, causing A's relay R to work.

Thus (in the 3rd case), when both keys are depressed, the relays respond to the signals from the distant end, being unaffected by those of the home station, and duplex work is maintained.

Signals formed by the depression of both keys simultaneously are called *duplex signals*; those formed by the depression of one key only being called *single signals*; and, as in the course of communication words or even letters may be made up of both duplex and single signals, it is evident that the receiving relay should be equally influenced by both.

Now this is the case when balance is maintained at the time when both keys are depressed, as will be understood from the above remarks explaining the course of the duplex current in '*the 3rd case*;' for, under these circumstances, the receiving relay is worked by the difference of current in the opposite branches—viz. the line and the W branch—which balance one another; the incoming current from station A (for example) reducing the strength of the outgoing current from B at the point p' by an amount equal to its own strength, i.e. the strength of the current which forms single signals.

The same, of course, holds good for signals received at A.

Adjustable Resistance.

200. It has been stated above that W and W', the resistances which balance that of the line, are adjustable. If the resistance of the line never altered, this would not be necessary, as, balance once obtained, the condition

$$a\,x = b\,W$$

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would remain a fixed quantity; but, as the effects of climate on the insulation of lines cause great changes in their resistance, it is necessary that the artificial resistance *W*, used to balance that of the line *x*, should be made to vary with it; *W* is therefore made to possess a range sufficiently great that it may be increased or decreased to the limits between which the resistance of the line varies, and usually consists of a fixed coil approximating the minimum resistance of the line, joined in series with a circular set of resistance coils, which are added to or removed from the circuit as required by means of a switch turned by a handle.

When the resistance of the *W* branch exactly equals that of the line branch—i.e. when $a x = b W$—the system is said to be in *permanent balance.*

To obtain Permanent Balance.

201. Now, it has been shown that the results of permanent balance are:

(1) That the currents forming duplex and single signals are equal in strength.

(2) That outgoing currents have no effect on the receiving instrument of the home station.

Permanent balance is therefore tested prior to commencing duplex working, in the following way:

Station *A*, desiring to obtain balance, gives the signal '*balance*' to *B*. *B* gives attacks, and *A* adjusts his relay to receive *B*'s *single signals.* *A* then depresses his key, continuing to receive attacks from *B*, whose signals are now *duplex signals*, as both keys are down. If *A*'s relay works equally well with duplex as with single signals, balance is perfect; but if not, the resistance of *W* is adjusted till it does. If received signals *miss*, it is evident that too much current passes to earth through *W*, and too little through the relay; the resistance of *W* is therefore increased; if, however, signals *stick*, then the reverse is the case, and the resistance of *W* is decreased.

After thus altering the resistance of *W*, *A* releases his key again, observing whether his relay still responds perfectly to *B*'s single signals.

Minor adjustments are made by means of the micrometer screw. *A* then gives '*RT*,' and *B* repeats the operation.

Either station tests the effect of his outgoing current by observing the magnetic indicator on his relay, which, of

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Duplex Condensers.

course, remains unaffected when permanent balance is perfect.

202. Permanent balance, however, is not the only adjustment necessary in the case of long and well-insulated lines ; for, although the *w* branch may compensate for the *resistance* of the line, it does not balance the effects of its *capacity.*

It has been explained [1] how, by virtue of the latter property, momentary currents of charge and discharge are formed when the battery contact is closed and opened ; and, as the receiving relays are always in circuit, they would be affected by these induced currents, which would thus interfere with ordinary signals.

It is, therefore, necessary that the artificial line *w*, which balances the resistance of the real line, should also be made to balance its capacity.

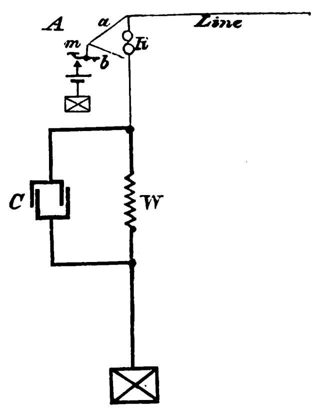

FIG. 59.—DUPLEX CONDENSERS.

This is done by means of condensers joined parallel to the resistance coils of *w*, as shown in fig. 59, the action of which may be explained as follows :

Considering the resistance *w* to occupy its proper position in the duplex circuit as represented in fig. 58, it is evident that every time *A* depresses his key to send a signal to *B*, the current which goes to charge the line splits at the point *m*, dividing between the line circuit (through *a*) and the *w* circuit (through *b*).

Now if the capacity of the condenser *c*,[2] the outer and

[1] §§ 109–112.

[2] § 116 and Def. 15.

inner plates of which are respectively joined to the line and earth terminals of *W*, be equal to the capacity of the line, the amount of charge held by the condenser will be exactly equal to that of the line, so that when *A*'s key is released, the current of discharge rushing out from the line in the direction from *p* to *q* will be met by the equal and opposite current of discharge from the condenser, in the direction *q* to *p*, thus counteracting the effects of the charge of the line on the relay *R*.

The capacity of the condenser is made adjustable, like the resistance of the branch *W*, to correspond with variations in the capacity of the line.

There is an important point, however, in which the action of the line and a single condenser of equal capacity differ, and that is in the time they take to discharge.

A long well-insulated line takes a considerable time to discharge, as explained in para. 111, owing to the resistance it offers *at every point* to the passage of the current. In order, therefore, to produce a corresponding retardation in the discharge of condensers, resistance is inserted between each pair of plates.

When the condenser capacity of the branch *W* is equal to the capacity of the line the system is said to be in a state of *transient balance*.

To obtain Transient Balance.

203. As the effects of inductive capacity are manifested by extra currents of momentary duration, the absence of induction beats on the relay indicator of the sending station is a proof that transient balance is perfect.

After permanent balance is obtained, as described in para. 201, the capacity of the condenser is adjusted for transient balance, as follows :

A depresses his key and releases it sharply ; any movement of the relay indicator, manifesting a return current from the line, shows that its capacity is not balanced.

If the *depression* of *A*'s key causes a sudden deflection of the indicator needle the condenser capacity is too small.

If, on the other hand, *A*'s condenser capacity be too large, it can be discovered by causing *B* to give a continuous beat, during which the depression of *A*'s key will cause a momentary interruption of *B*'s signal ; *A* therefore reduces capacity until the depression of his key has no effect on *B*'s signal.

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Respective Advantages and Disadvantages of the Bridge and Differential Methods of Duplex.

204. The bridge method of duplex working presents this advantage, that as the receiving instruments are placed in a null circuit, between the points *p* and *q* (fig. 58), no special form of receiving apparatus is necessary, as is the case in the differential system described in the following paragraph.

It has, on the other hand, a great disadvantage, detracting from its efficacy on long lines, viz. loss of working force, owing to the battery current being split up by means of the various derived circuits offered to its course by the bridge apparatus.

The result of this is that the bridge system of duplex telegraphy requires four times the battery power used for working the same line single or simplex.

Differential duplex is accomplished with 2½ times the battery power used for single working.

Differential Duplex Working.

205. In the **differential system of duplex working** the effect of outgoing currents on the home instrument is nullified, on a similar principle to that of the differential galvanometer,[1] viz. that *equal currents passing through equal coils produce equal magnetisation in the cores thereof.*

[1] § 165.

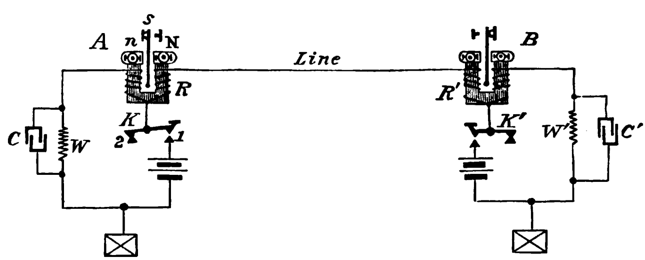

FIG. 60.—DIFFERENTIAL DUPLEX.

Fig. 60 represents two differential (Siemens') relays, *R* and *R'*, each with two equal coils wound on the above principle; the permanent magnets of the instruments are shown in the figure, in order that their action may be more clearly understood.

With no current, the tongue *S* (see station *A*) is a south pole by induction, and the two shoes *N*, *n*, north poles, as explained in para. 60.

When *A* sends a signal by the depression of his key, the current splits at the point *K*, dividing itself equally between the two coils which, besides being equal themselves, are placed in circuits of equal resistance (the resistance of *W* being made equal to that of the line, the front coil and the derived circuit of the back coil, artificial line and battery of the distant station); the effect of the home current in both coils is to decrease equally the north polarity of the shoes *N*, *n*, which thus exert an equal magnetic force on the tongue *S*, from opposite directions, so that the relay does not work under the influence of outgoing currents.

An incoming current, however, acts differently. Entering by the right coil (in the opposite direction to the outgoing current), it increases the north polarity of the shoe *N*, and thence proceeding through the left coil and *W* to earth, it *decreases* or *reverses* the polarity of *n*, so that both coils act in the same direction, their tendency being to cause the tongue *S* to be attracted towards *N*.

Constant Resistance Keys for Differential Duplex.

206. In the case of long and well-insulated lines, when condensers are not available, constant resistance keys may be used, as described in para. 128, with the object of discharging the line of return currents

Permanent and Transient Balance.

207. The condition of permanent balance in differential duplex working is that the resistance of *W* be equal to that of the line circuit, which comprises the line wire and the circuit of the distant station; transient balance is obtained by making the condenser capacity *C*[1] equal to that of the line.

The mode of adjusting permanent and transient balance is precisely similar to that described for obtaining balance for working bridge duplex.[2]

The above conditions of balance being fulfilled, it will be seen that the strength of single and duplex signals is the same, and that the depression of either key is responded to by the distant relay, the instrument of the home station remaining unaffected by outgoing currents.

For, suppose a signal to be sent from *A* to *B* by the depression of the key *K*; the battery current divides at the point *K*, half traversing the line circuit, the other half the derived circuit to earth through *W*; but as these equal currents traverse the relay *R* in opposite directions, the tongue *S* does not move. *Thus (in the first case) the signalling current does not affect the relay of the home station.*

The portion of *A*'s current traversing the line circuit,

[1] § 202.

[2] §§ 201 and 203.

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however, flows to earth at station *B* through the coils of the relay *R′* and *W* (fig. 60), causing *R′* to work, as described in para. 205. *Thus (in the second case) A's signals work B's relay.*

Similarly, *B*'s signals do not affect the home relay *R′*, but are responded to by relay *R* at station *A*.

Next, suppose that while *A*'s current is working *B*'s relay, *B* depresses his key, *K′*. As explained before, *R′* is unaffected by the home current of *B*, but is responded to by *R*, the distant relay at *A*; for the front portion of *A*'s current which flows out to the line is opposed by the received current from *B* so long as *B*'s key is depressed, the result being that the opposite current from *B* neutralises the current flowing out to line through *A*'s front coil,[1] so that *R* works under the influence of the current in its back coil, which renders *n* a south pole, so that the tongue *S* is drawn towards *N* by each depression of *B*'s key (*K′*).

Similarly, *B*'s relay would respond to *A*'s signals when both were sending, the magnetic effects of the currents, in each case, on the distant relay being the same as that produced by the currents which form single signals. *Thus (in the third case), when both keys are depressed, the relays respond to distant signals, but are unaffected by those of the home station.*

[1] The *front* coil in each case is that which is joined to the line; and the *back* that which is joined to the artificial line *W* or *W′*.

Double Current Differential Duplex.

208. Differential duplex is sometimes worked by double currents,[2] with the object of accelerating the action of the relays and thus increasing the speed of signals.

[2] § 191.

Fig. 61 represents such an arrangement, in which **Gerrit Smith's battery reverser** is used to transmit reverse currents.

The battery reverser consists of an electro-magnet *m*, the coils of which are joined in circuit with a local battery *e* and an ordinary key *k*. Each depression of the key *k* causes the armature *a* to be attracted.

The armature *a* is permanently connected to earth, and its two continuations *C*, *C′* are so arranged that one or other of them is in contact with one of the steel springs *S*, *S′*, both of which have a tendency to press against *p*, which is a fixed pillar permanently connected with the line and artificial line through the differential relay *R*.

One of the steel springs, *S*, is permanently connected to the copper pole of the line battery *E*, the other *S′* to the zinc pole.

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When the armature *a* is at rest, as it is shown in the figure, the zinc pole of the line battery is connected to the line through the spring *s′* and pillar *p*, the other spring *s* being pressed away from *p* by the lever *c*, which further connects the copper pole of the line battery with earth.

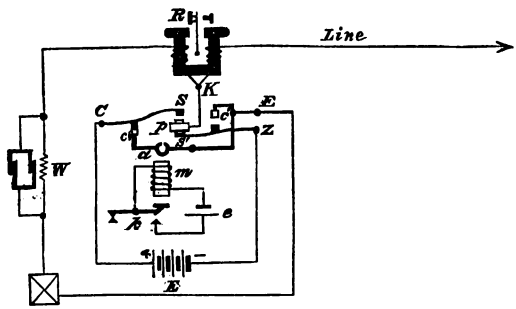

FIG. 61.—DOUBLE CURRENT DIFFERENTIAL DUPLEX.

When, however, the key *k* is depressed, the armature *a* is attracted towards *m*, drawing down the end *c* of the lever, which permits the spring *s* to press against *p*, connecting copper to line, zinc being joined to earth through *s′* by means of the end *c′* of the lever, which at the same time presses *s′* away from *p*.

Thus each depression of the ordinary key *k* causes the electro-magnet to send a copper current into the line, a continuous zinc current flowing to line during the pauses between the signals.

The play of the springs *s*, *s′* should be so carefully adjusted that contact with the pillar *p* is made by one just before it is broken by the other, the point K being thus always in connection either with the line or battery.[1]

Split Battery Duplex.

209. Another system of duplex working is that known as **split battery duplex,** which has the advantage possessed by the bridge system, in that a special form of receiving instrument is not required, provided, however, that the instrument be a polarised one;[2] and there is no necessity for any special form of transmitting key; further, the '*split battery*' is superior to the '*bridge*' method in that the arriving current in the former system is not reduced to the same extent by derived circuits, as in the bridge method.

[1] By using two batteries, one with its −, the other with its + pole to earth, this special apparatus can be dispensed with, the simple key *k′* being used, its middle point *k* joined direct to K, its front and back contacts being joined to the poles of the + and − batteries respectively. This plan is found the simpler, and is generally adopted.

[2] §§ 50, 59, and 60.

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The same amount of battery power is required for split battery duplex as for the system described in para. 205 as differential duplex, there being a similarity between these two methods in that they are both differential;[1] the batteries being in the former case differentiated, and in the latter the instruments—a difference in favour of the latter. [1] Def. 30.

Fig. 62 represents the circuit of two stations, *A* and *B*, connected for split battery duplex working.

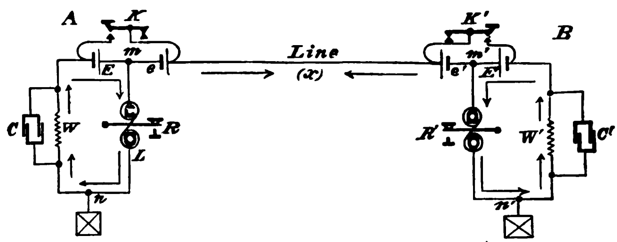

FIG. 62.—SPLIT BATTERY DUPLEX.

Examining the circuit of station *A* (that of *B* is precisely similar), *m* represents the middle point of the signalling battery, the back and front halves *E*, *e* of which are composed of an equal number of cells of equal resistance.

K is the signalling key, the depression of which short-circuits the whole of the line battery, the copper pole of which is joined to the line and the zinc pole to earth through the adjustable resistance *W*, which is made equal to that of the line and the derived circuit of the distant station; the condenser *C* being adjusted to balance the capacity of the line, as explained in para. 202.

The middle point *m* of the battery is joined to earth through the receiving relay *R*, which is an ordinary Siemens' polarised relay connected up in reverse direction, i.e. with its *L* terminal to earth, so that a copper current entering the relay from the line will cause the tongue to be attracted towards its insulated stud, as shown in the figure, instead of towards the metal working contact, as would be the case if joined up in the usual way.

When employed in the split battery duplex circuit, however, the tongue is adjusted with a bias[2] against the metal contact, so that when no current flows through the relay [2] § 61.

the local battery circuit is closed, causing the sounder to work.

Now referring to fig. 62, it will be observed that when no signals are being sent, i.e. both keys *K*, *K'* at rest with their contacts open, the battery currents flow in the directions shown by the arrows, the *front* half *e* of *A*'s battery being opposed by the *front* half *e'* of *B*'s battery, which thus counteract and neutralise one another; a continuous current from the *back* half *E* of either battery thus flows through the relay of its own station, causing the tongue to be held against its insulated stop, as represented in the figure.

The principle of closed circuit working[1] will be here recognised, signals being formed by the interruption of the permanent current flowing through the coils of the receiving instrument.

[1] § 189, and fig. 53.

Single and duplex signals[2] are both formed by the absence of current in the receiving relay; in the former case by nullifying the continuous current by an equal current opposite in direction, and in the latter by cutting off the current altogether.

[2] § 199 (last clause).

How this is effected by the transmitting station without influencing the home station will be understood from the following paragraph.

Permanent and Transient Balance.

210. The condition of permanent balance in this system (with batteries split at their middle point, as described above) is that *W*, the resistance of the artificial line, and *x*, that of the real line and the derived circuit of the distant station, be equal.

Transient balance is obtained by making the capacity of the condenser *C* equal to that of the line.[3]

[3] § 202.

The mode of adjusting permanent and transient balance is precisely similar to that described for obtaining balance for working both the bridge and differential systems of duplex.[4]

[4] §§ 201 and 203.

Supposing balance to be thus adjusted, and that *A* depresses his key to send a signal to *B* (*K'* open), *A*'s battery is then short-circuited; its front half *e* is no longer free to oppose the front half *e'* of *B*'s battery, the current from which therefore flows to *A*, dividing between the derived circuit of *R* and *W* to earth, thus keeping the tongue of *R* still held against its insulated stop.

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Thus (in the first case) the signalling current does not affect the relay of the home station.

It does, however, affect that of the distant station in the following manner:

Tracing the current from e' (the *front* half of *B*'s battery), which, as described above, on the depression of *A*'s key, flows through *R* and *W*, thence through the point *n* to earth and back to the zinc pole of its own battery *viâ* n', R', and the point m', the course of this current through *B*'s relay R' is opposed by the copper current of E' (the *back* half of *B*'s battery); and these two opposite currents being equal (because $W' = x$), they counteract one another, causing *no current* to flow through the coils of R', the tongue of which consequently falls back against its metal contact, producing a signal on the sounder so long as *A*'s key is depressed.

Thus (in the second case) A's signals work B's relay.

Similarly, *B*'s signals do not affect the home relay R', but work *A*'s relay *R*.

Next, considering the case in which both *A* and *B* depress their keys together.

The act of doing so short-circuits both their batteries so that the currents are entirely cut off both from the line and instruments; the tongue of R' therefore falls back, as explained in case 2, producing a signal so long as the key *K* is depressed, and *vice versâ*; relay *R* responds to the signals of K', the strength of duplex and single signals being obviously the same, since both are produced by 'no current.'

Thus (in the third case), when both keys are simultaneously depressed, the distant relays work, those of the home station being unaffected.

Circuits containing Covered Wires.

211. The circuits described in the foregoing paragraphs of this section embrace such systems of working as are adopted in India.

Those portions of the circuit included between the line and earth, termed **'office connections,'** are invariably composed of covered copper wires, the insulating material employed being a specially prepared form of indiarubber, known as Hooper's core, which bears exposure to high temperature better than guttapercha or any other kind of insulating covering.

Guttapercha not only cracks by exposure to heat as well as light, but becomes plastic, allowing the position of the

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conductor inside to shift; and its resistance decreases with rise of temperature. At a given temperature, the resistance of guttapercha is far below that of indiarubber.[1]

The superiority of indiarubber for office, or earth, or aërial connections is thus obvious; and, besides possessing the advantage of higher insulation, its specific inductive capacity is lower than that of guttapercha,[2] an important point in considering its merits as regards use for circuits including long submarine wires, by virtue of which property retardation is reduced and speed enhanced.[3]

The following, however, can be said in favour of guttapercha:

(1) Guttapercha never perishes under water, and insulates sufficiently well at low temperatures, its resistance increasing with pressure.[4]

(2) Indiarubber, on the contrary, suffers decomposition under water, or under any circumstances whereby air is excluded.

(3) Guttapercha is more easily jointed than indiarubber.

(4) Faults in indiarubber (accidents excepted) are generally extended over a considerable length, occurring through a general deterioration of material; those in guttapercha are usually confined to a single spot: hence the greater ease with which the latter may be localised.

Joints in Covered Wires.

212. In making **joints in the insulating covering,** or '**core**' of wires used for circuits laid under water—as, for example, submarine cables—special apparatus is used, and great care and experience are necessary in order to insure the insulation of the joint being not less perfect than that of the cable at any other point.

For office connections, however, the following will be found a simple and effectual form of joint:

Unwind the felt tape which forms the outer surface of the core for about two inches from the ends of the wires to be jointed, allowing the tape to hang down, as shown in fig. 63.

Next, pare off the indiarubber from the copper wire for the same distance, tapering the ends as shown in the figure.

Thoroughly clean the ends of the copper wires, thus stripped, with sandpaper; for the presence of the least portion of dirt will endanger the continuity of the joint and render soldering difficult.

[1] At 75° Fahr. the resistance of Hooper's Core is sixteen times as great as that of guttapercha.

[2] The specific inductive capacity of air being = 1; that of guttapercha = 4·2; Hooper's Core = 3·1; pure indiarubber = 2·8.

[3] § 121 (*a*).

[4] The temperature of the sea below 1,200 fathoms is supposed to be everywhere about 40° Fahr. Pressure, of course, increases with depth.

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Then firmly twist the wires round one another, as shown below.

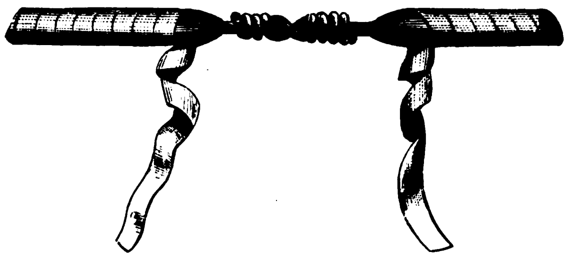

FIG. 63.—JOINT IN OFFICE CONNECTIONS.

Bind a piece of damp rag round each end of the core to prevent its being melted by the heat of the soldering bolt. Apply the solder, removing the bolt immediately the solder is seen to run through the joint, so that the wire may not be unnecessarily heated.

After wiping the joint with a dry cloth it should be covered with Chatterton's compound (a prepared mixture of Stockholm tar, resin, and guttapercha) until the covering is rather thicker than the ordinary core ; the tape ends should then be tightly wound round this and neatly fastened ; the joint is then complete, but should be allowed to become perfectly cool before any strain is put upon the wire.

Connections between Wires and Terminal Screws.

213. *Every joint* connecting office wires should be soldered, except, of course, in cases where such connections are made by means of terminal or binding screws, when perfect continuity should be secured by keeping the contacts scrupulously clean.

Further, the wire should be looped closely round the terminal screw in the same direction as the screw turns—that is, almost invariably to the right—so that the tendency of the loop is to close round the screw when the latter commences to 'bite,' instead of opening out from it, as the tendency would be if the wire were looped in the contrary direction.

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FAULTS IN TELEGRAPHIC APPARATUS

AND THEIR REMEDY

FAULTS IN TELEGRAPHIC CIRCUITS AND THEIR REMEDY.

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First Causes of Faults.

214. The telegraphic circuit may be considered as comprising four different parts, viz. the *battery*, the *instruments*, the *office connections* (including that with the *earth*), and the *line.*

The failure of any of these parts to perform their required functions results in the interruption of the circuit.

Each class of apparatus is subject to faults peculiar to itself. The line is most exposed to the weather and to accidents, whereby it may be broken or displaced from the insulators which support it.

In offices, faults generally result from less obvious causes, being often so gradual in their development as to lead to waste of battery power or reduction of sensitiveness in the instruments, or complete eating away of the connecting wires for a long-continued period, before making their presence felt by actual interruption or even imperfect communication.

At the same time evidences of the existence of such faults are not wanting to those who know where to look for them; it therefore becomes a matter of great importance that the earliest signs indicating incipient failure of any part of the circuit should be understood, and further, that they should be acted upon immediately they are observed, so that prevention may obviate the necessity for cure.

Injurious Effects of Dust and Dirt.

215. Before proceeding to describe the various kinds of faults peculiar to the different parts of the circuit it may be well to draw attention to the great importance attaching to *cleanliness* in all matters relating to telegraphy. **Dirt** is a semi-conductor; its presence, therefore, in a conducting circuit, e.g. between contact points or between terminal screws, must introduce unnecessary resistance into the circuit.

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Being a semi-conductor, it must also be a semi-insulator; its effect, therefore, on the surface of an insulating body must be to reduce its insulation, and to cause an unnecessary loss of current.

Its exclusion, therefore, from instruments, keys, switches, lightning dischargers, and all metallic contacts cannot be too scrupulously attended to.

In the line circuit its presence in joints is detrimental to conduction; on the surface of insulators it impairs the insulation of the line.

In the battery circuit its adherence to the surface of the jars tends to leakage, and its presence on the battery plates or screws adds to the resistance of the circuit.

Faults in Working Batteries, and their Indications.

216. The faults most likely to occur in **telegraph batteries** are detailed in the following paragraphs, it being understood that the battery cells have been carefully prepared and set up in the first instance.

Mixing of Liquids.

217. Mixing of the copper and zinc solutions in one or more of the cells, whereby a copper salt is deposited on the zinc disc and the E.M.F. of the cell is destroyed.

Indication.—The zinc disc becomes discoloured.

Cause and remedy.—This fault is generally the result of the cell having been suddenly shaken, in which case the discoloured disc should be replaced by a clean one.

It may be due to the imperfect preparation of the cell, in which case the disc will soon become discoloured again; the cell should then be removed altogether and dismantled.

Local Action.

218. Local action within the cell.[1]

[1] § 33.

Indication.—Loss of effective current, frequently attended with frothiness of the surface.

Cause and remedy.—The presence of dirt or other impurities in the cell is the general cause of this fault; the froth and all impurities therein should be removed from the surface of the water immediately on its appearance. In view of *prevention*, the sand or sawdust is well washed previous to use.

Leakage.

219. Leakage, by imperfect insulation from the ground, resulting in continuous loss of current.

Indication.—Dampness of the battery stand or of the outer surface of the battery jars, or the deposition of crystals thereon.

Cause and remedy.—The first two indications are likely to be due either to moisture of the air or carelessness in replenishing the cells with water. The jars and the battery stand should be wiped dry, and care taken that the latter is not resting against a damp wall, nor in fact against any object whatever.

The crystals formed on the sides of the jars also act like a syphon, and draw off the liquid over the edges of the jar.

They should be wiped off immediately they appear, but as their formation is due to saturation of the zinc solution, it should be prevented by keeping the zinc disc always covered with *clean* water.[1]

Cross Leakage.

220. Cells short-circuited or shunted, resulting in the whole or part of the current of one or more cells being lost, by the completion of a circuit within the poles of the battery.

Indications.—In the case of a complete short circuit, it will probably be found that the leading wires between the copper and zinc poles of two or more cells are in metallic contact with one another.

A partial short circuit may be indicated by the insulated covering of the leading wire between two cells being either cracked, or loose, or covered with crystals of sulphate of zinc, or by the surface being damp, or by a drop of liquid being visible at the end of the wire which is fastened to the zinc terminal, or by discoloration of the zinc disc.

Cause and remedy.—The cause in both cases is to be found in the insulating covering of the leading wire. If it is loose and allows of the liquid percolating between the core and the wire, the end should be sealed up with Chatterton's compound.

The conduction of the liquid over the outer surface of the wires is prevented by soaking the covered wires, before use, in melted wax.

Disconnection.

221. Cells disconnected wholly or partially, by which the resistance of the battery is increased and the current weakened.

Indication.—Deposition of white crystals of zinc sulphate on the terminal screws of the zinc plate or discoloration of the disc ; or the appearance of dirty froth thereon.

Causes and remedy.—The action of the cell causes the formation of zinc sulphate at the zinc plate, which crystallises

[1] The Zinc Solution is removed by means of a sponge. See § 34.

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when the water becomes saturated with the salt; hence the necessity for frequently changing the water, as this sulphate when dry offers a high resistance.[1]

If the zinc is discoloured, it should be removed. If the liquid is only frothy, the froth should be removed.

The appearance of the above indications together in the cells of a battery would indicate neglect.

If disconnection in a battery be manifested, without any of the above appearances, and the cells are clean, it is probable that one of the terminal screws has become loosened by accident. If this is not the case, then probably the remedy will be found by piercing the diaphragm.[2]

Such a fault occurring through the looseness of a terminal screw may be intermittent in its nature, causing the cell to emit a current of varying strength.

Rise in Resistance.

222. **Increase of internal resistance** of a cell, whereby the current is weakened.

Indication.—The only sure indication in this case is that afforded by actual measurement; the cell often presents a clean and passive appearance, but this is not an infallible criterion.

Cause and remedy.—If there are no external evidences of corrosion, or dirt or neglect, this fault is probably due to polarisation of the copper plate,[3] which even in a constant battery may take place when strong currents are generated through low resistance.

The free hydrogen, collecting in the form of bubbles at the copper plate, may, however, be liberated by piercing the diaphragm with a pointed piece of wood or bone or non-metallic substance.

If the above remedy fails to reduce the resistance and increase the current, and the terminals are clean and firmly connected, the fault is probably due to a dirty plate, and the zinc should be changed.

Fall in Resistance.

223. **Decrease of internal resistance** of a cell signifies consumption of material, and is therefore to be expected to attend the working out of the battery.

Indication and cause.—The zinc disc sinks in the jar as the sulphate of copper becomes consumed by the action of the cell.

When it has sunk to a depth corresponding to the original depth of the sulphate of copper, there is no more

[1] To prevent the formation of crystals at the zinc terminal *a* composition is applied to the neck of the disc (§ 35).

[2] § 222.

[3] Def. 19, and § 15.

to consume, the action of the cell may be expected to cease.

The resistance of an exhausted Minotti is about five ohms.

Battery Faults indicated by Regular Tests.

224. It will be observed that the faults enumerated above all affect more or less the internal resistance of the battery; regular testing, therefore, as will be explained hereafter,[1] affords an accurate and valuable means of detecting the first traces of falling off, the symptoms of such being directly indicated by the deflections of the testing galvanometer.

Instrument Faults.

225. The efficiency of **telegraph instruments** is practically tested by their sensitiveness under the influence of working currents.

The principal defects to which instruments are liable may be stated in general terms as follows:

(i.) **Mechanical faults,** due to friction, imperfect springs, contacts working loose, &c.

(ii.) **Electrical faults,** due to defective insulation of covered wires in coils or connections, causing contacts or derived circuits or leakage, through uninsulated parts of the instrument; also to imperfect contacts through dust, or dirt, or oxidation; also to discontinuity, caused by the fusion of a coil by lightning, or by corrosion, or accidental breakage of any part of the instrument connections. The *end* of a coil is frequently found to be the spot at which such a defect occurs.

(iii.) **Faults of magnetisation,** whereby permanent magnets lose their magnetism through exposure to heat; or their polarity is reversed from the same cause or by the effects of lightning; also when the iron cores of electro-magnets retain their magnetism after the cessation of the current.

(iv.) **Faults of adjustment,** whereby the current is employed in overcoming unnecessary mechanical inertia; as, for instance, when the play of tongues or levers is too great,[2] or antagonistic springs are too strong; or where extra currents produce unnecessarily large sparks in consequence of too great play, impairing the points thereby; or by want of judicious adaptation of battery power to the resistance in circuit.

Faults in the Relay.

226. The relay is subject to the following defects:[3]

(*a*) *Loose carriage.*—In those relays in which the micrometer screw effects adjustment by moving a traverse, con-

[1] §§ 267–288.

[2] §§ 64 and 121 (*d*).

[3] For description of the instrument, see § 59.

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taining the limiting points between which the tongue plays, this traverse or 'carriage,' after long use, or through rough handling of the micrometer screw, becomes loose. This is a serious fault, for the instrument is thrown out of adjustment by the working of the tongue under the influence of the current, which alters the position of the carriage, and consequently the play of the tongue.

Immediately such a fault shows itself, the instrument should be sent for repair.

(*b*) *Unequal coils.*—This fault occurs when, from accident or other cause, the insulating covering of the wire in either coil becomes imperfect, admitting of contact between several convolutions of wire.

Such a defect shows itself by the unequal magnetic effect exerted by the two cores on the tongue, and is further proved by testing the resistance of each coil separately.

Coils in which such a defect is manifested must be rewound.

(*c*) *Imperfect insulation of working contact.*

The metal working contact is itself insulated from the body of the relay, and is further connected by insulated wire, through the sounder coils, to the copper pole of the local battery. The zinc pole is joined to the relay tongue; and, as this is not insulated from the rest of the instrument, any defect in the insulation of the working contact or of the wire connected with it would short-circuit the local battery through the tongue, a fault which would make itself known by causing a permanent beat on the sounder.

(*d*) *Demagnetisation of permanent magnet.*

This may be the result of exposure to heat or the effects of lightning.

The failure of the relay to act, under the influence of a current, as a polarised instrument, as displayed by the attraction of the tongue by either core indifferently, would at once indicate such a fault.

Remagnetisation, by means of a powerful permanent or electro-magnet, would be necessary.

(*e*) *Residual magnetism in cores or shoes.*—This fault arises from impurity of the iron, which may have become hard in course of use. It is rendered apparent by the sluggish movement of the tongue, the result of magnetic inertia,[1] and is remedied by annealing the iron; the more

[1] § 121 (*b*).

gradually the iron is allowed to cool the more effectually will the process of annealing be accomplished.[1]

(*f*) *Oxidation of platinum contacts.*—The platinum points between the tongue and the working contact become fused by the sparks caused by the extra currents, which are formed on the making and breaking of the local circuit,[2] a black oxide being deposited upon the points, which introduces considerable resistance into the local circuit, thus affecting the strength of signals on the sounder.

The oxide is removed by the application of chalk and oil, and the spark is prevented or reduced by connecting the terminals of the sounder coils through a comparatively high resistance, and thus forming a derived circuit or shunt through which the extra currents pass instead of discharging in a spark through the air.

The strength of these extra currents is dependent on the strength of the current of the local battery; hence, again, the necessity for regulating the battery power according to the resistance of the local circuit.[3]

(*g*) *Mechanical inertia of the tongue.*

The delicacy of suspension of the tongue between its bearings is sometimes impaired by their becoming dirty or rusty, in which case they should be cleaned with chalk and oil. The smallest drop of best watchmaker's oil will serve to connect the tongue with the bearings as well as to keep them clean.

The friction between the tongue and its bearings should be so small that when the shoes are removed, and the tongue is made to move under the influence of a small magnet held above the middle of the iron part of it, it should swing rapidly, and should only come to rest after a great many oscillations.

(*h*) *Imperfect adjustment.*

The sensitiveness of the instrument is greatly dependent upon its accurate adjustment, which should be carried out in accordance with the processes already described.[4]

(*i*) *A broken coil* of course interrupts the circuit altogether, being indicated by the failure of the tongue to work, or the magnetic indicator to deflect, under the influence of a received current.

Faults in the Sounder.

227. (*a*) **The various forms of sounder** described in Section C[5] are, in common with the relay, subject to the

1 § 238 (*f*).

2 § 119.

3 §§ 42 and 181.

4 §§ 66–70.

5 §§ 73–87.

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defects described in clauses (*b*), (*e*), (*h*), and (*i*) of the foregoing paragraph, and the remedies therein prescribed apply equally to the case of the sounder.

Dirt and dust must be prevented from collecting on contact points, this precaution being specially necessary when the instruments are used for translation.[1]

(*b*) *Imperfect insulation of the pillars* from the base plate and from one another, or of the coils or connecting wires from the base plate, would give rise to serious faults in translation working, creating metallic contacts between these parts of the instrument, which would cause a permanent beat on the sounder with which it is joined up in translation.

(*c*) *The spiral antagonistic spring* is liable to lose its power by long-continued use, thus failing to exert the required force of restitution, the result of which is that the armature '*sticks*,' in spite of careful adjustment.

When this is the case a new spiral spring should be fitted.[2]

Faults in the Ink-writer.

228. (*a*) **The ink-writer**[3] is liable to the same faults as the sounder, and besides these, is subject to defects in its clockwork machinery and inking arrangements, the result of accident or long-continued use.

(*b*) *Broken spring.*—The steel spring which sets the machinery in motion may be broken by over-winding, an accident which should be prevented by care; and as a further precaution against which the clockwork should never be allowed to run down completely.

(*c*) *Dust and rust* seriously affect the springs and all the steel and iron part of the machinery, and are excluded as much as possible by inclosing the clockwork in an air-tight case.

The wheels and bearings become clogged from the same cause, in which case the latter should be lubricated with pure watchmaker's oil.

The bearings of the wheels rest in countersunk holes in the sides of the brass case, and are covered by thin, closely fitting brass plates, which should only be opened for the purpose of oiling the bearings.

(*d*) *Friction of the paper wheel*, i.e. the wheel which holds the tape, may impede the action of the clockwork, in which case the axle should be oiled; or the sides of the wheel may be screwed up too tightly against the roll of tape; or

[1] § 183, and fig. 48.

[2] The rules for adjusting various forms of Sounders will be found in §§ 76, 81, 83, and 86.

[3] § 93.

the tape itself may offer friction by the adhesion of the different layers to one another.

In this case, without taking off the wheel, unroll the tape by hand and roll it up again, so that when unwound by the clockwork it may be relieved of the strain necessary to separate the layers.

(*e*) *Failure of the inking-wheel to mark.*

The adjustment of the ink-writer is effected in a precisely similar manner to the ordinary sounder; it sometimes occurs, however, that when the lever is correctly adjusted for indicating audible signals clearly, the inking-wheel fails to press against the tape and thus record the signals. This is remedied by means of a small adjusting screw near the point where the lever of the armature is joined to the arm which carries the inking-wheel.

This arm acts as a spring, the tendency of which is to press the wheel upwards towards the tape; the tightening of the screw resists the pressure of the spring; by loosening the screw the spring or arm is enabled to press the wheel as close to the tape as may be desired.

The inking-wheel may sometimes fail to mark anything but dots, in consequence of its having worked loose on its axle through use.

It is tightened by turning it round the axle.

The bearings of this wheel sometimes become clogged with ink, which can be remedied by the application of a few drops of olive oil; the wheel can be slipped off the axle for cleaning.

To prevent the ink from being spilt and entering the bearings of the instrument and clogging the wheels, the vessel which holds the ink should be carefully filled, but not too full, and its cover should always be kept closed, not only with the object of preventing the ink being spilt on the apparatus, but in order to exclude dust, which would render the ink thick and blotchy.

The inking-wheel should not dip deeper than one sixteenth of an inch into the ink.

Faults in the Needle Instrument.

229. (*a*) **The needle instrument**[1] is liable to the rupture or imperfect insulation of its coils or connections, or to the demagnetisation of the needle, defects which, with their respective remedies, are described in para. 226 (clauses *b* and *i*) and para. 238 (*d*).

[1] § 96.

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(*b*) *Imperfect continuity* of the sending or receiving circuit of the instrument, or both, may be caused by the accumulation of rust or dirt on the steel springs which press against the contact *T* (fig. 11), and between which the handle makes battery contact.

This is indicated by a falling off in the strength of the deflections of the needle under the influence of the sent or received current, or both.

If the application of chalk and oil does not remove the dust or rust, the springs should be cleaned with kerosine oil, rubbed on with brown paper; if this fails, fine emery powder may be used.

The same fault would result from weak springs, in which case they would require to be re-tempered or renewed.

Such a fault in the sending circuit can be at once discovered by short-circuiting the instrument with a piece of wire connecting the terminals *A* and *B* (fig. 11).[1] On turning the handle the needle should deflect violently.

The receiving portion of the circuit is tested by connecting the battery poles direct with the terminals *A* and *B*, leaving the handle at rest, when the same deflections should be observed.

(*c*) *The permanent deflection of the needle* out of the perpendicular is sometimes the result of terrestrial magnetism or of earth currents, in which case the disc is turned round until the needle hangs midway between its limiting studs.

The roughness of these studs sometimes causes the needle to cling to them. Rubbing them with a black-lead pencil is a remedy against this.

Faults in Electric Bells, Electro-magnetic Shunts, and Discharging Relays.

230. **Electric bells,**[2] **electro-magnetic shunts,**[3] and **discharging relays**[4] are subject to the faults general to electro-magnets, as described in paras. 226 and 227, the only special source of defect to which attention is necessary being in the steel spring of the alarum, which is likely to lose its power.

Cleaning the spring with oil, and thus keeping it free from rust, is the best prevention against this fault.

Faults in the Condenser.

231. **The condenser**[5] only suffers from two defects, viz.:

(1) Deterioration of the dielectric.

(2) Surface leakage between the terminals.

Both these faults produce the same effect, viz. that of

[1] § 96.
[2] §§ 98–103.
[3] § 122.
[4] § 126.
[5] § 116.

impairing the inductive capacity of the condenser by creating a *conductive* circuit between its terminals.

In the first case, which is the most serious, a path of more or less resistance is opened to the current between two adjacent plates through the injured dielectric; this fault is generally the result of exposure to heat or light, and when once developed there is no remedy for it short of re-insulating the plates; hence it becomes most important to take measures to prevent the occurrence of this fault. With this object, the boxes of condensers should be inclosed in air-tight cases or cupboards, always kept closed, these cases being a further protection against the settlement of dust or damp on the surface of the condenser boxes.

The terminals are usually, for the sake of insulation, fitted into sockets of ebonite, the surface of which should be kept dry and clean.

Faults in Keys.

232. The key[1] is so simple in its mechanism that it is not liable to many faults.

(*a*) *Dirty contacts* are the chief cause of defect, which should be carefully guarded against by exercising the precautions recommended in para. 226 (*f*).

The unnecessary resistance introduced by dirt or dust between the *front* contacts would reduce the strength of sent currents; and received signals would be weakened by the presence of dirt between the *back* contacts.

(*b*) *Weak antagonistic spring.*—Imperfect continuity of the received circuit is sometimes caused by the steel spiral antagonistic spring becoming weak and failing to effect a firm back contact when the handle is released by the hand.

(*c*) *Large play* is to be avoided, as besides being an impediment to speed, and causing unnecessary noise, it is likely to cause the platinum facings of the contact points to be worn away unevenly, resulting in their failing to make perfect contact.

(*d*) *Electrolytic action*[2] is liable to take place at the copper terminal of the key, especially when connected with a strong battery, the result being that the terminal becomes oxidised, and the connection between it and the battery wire is rendered imperfect.

In view to preventing this action the insulating covering of the wire should reach close up to the key terminal, which

[1] § 105.

[2] Def. 26.

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should itself be well insulated. The base-boards of keys should therefore be kept dry and clean.

(*e*) **Constant resistance keys** [1] are liable to the same faults as ordinary keys, and in addition are open to the defects arising from the use of the steel springs which prolong the contacts (see para. 230).

[1] § 108.

Faults in the Lightning Discharger.

233. (*a*) The faults peculiar to the **lightning discharger** [2] are *contacts* either between the upper and lower plates or between the upper plates themselves.

[2] § 133.

Both are usually the result of dust collecting between the plates or on the surface of the ebonite washers which separate them,[3] causing either loss of current by leakage to the ground, or forming a partial contact between two or more lines, by which the currents sent through one affect the receiving instruments of the others.

[3] Fig. 27, § 133.

Lightning dischargers are provided with glass cases; and as a further protection from dust, the holes through which connecting wires are passed should be closed up with wax, and any spare holes should be plugged up with wooden pegs.

The dischargers should be frequently examined and the slightest appearance of dust on the ebonite washers removed; the plates themselves being cleaned when necessary with a dry rough cloth or with the interior of the husk of the cocoa-nut when dry.

(*b*) *Imperfect connections* through dirty or loose terminals are, of course, to be avoided; and to prevent the liability to this fault in the case of the thick stranded wire from the earth plate, which is joined to the lower discharger plate, a circular copper washer may be soldered to the end of the wire, the washer being fitted on to the terminal screw of the discharger plate.

Faults in Switches or Commutators.

234. (*a*) **Switches or commutators** [4] are liable to the same faults as the lightning discharger, resulting from the effects of dust, or dirt, or imperfect connections.

[4] §§ 136–141.

(*b*) *The plugs* used for connecting the various parts of the switch or commutator are liable to *corrosion*, which is assisted by the action of the current. They become coated with a greasy green oxide, which introduces considerable resistance into the circuit.

It is important, therefore, that the formation of this oxide in any quantity should be prevented by wiping all plugs daily with a dry cloth or chamois leather.

If corrosion has taken place to such an extent as not to be removed by rubbing, boiling water is the only remedy short of scraping, which latter is to be avoided if possible.

(*c*) *The conductivity of the bars* of the commutator or switch is sometimes rendered imperfect by a portion of the lacquer with which their surface is varnished having entered the plug holes.

It is necessary to carefully remove this with a penknife.

The bars themselves may occasionally work loose, and open out on the insertion of a plug between them, thus failing to make perfect contact, in which case the screws which fix them to the base-board require tightening.

Faults in Galvanoscopes or Galvanometers.

235. (*a*) **Galvanoscopes or galvanometers**[1] are, in common with all electro-magnets, subject to the disorders resulting from a broken coil or the imperfect insulation thereof, as described in para. 226 (*b*) and (*i*).

[1] 142-156.

(*b*) A more common fault, however, is demagnetisation of the needle by being subjected to strong currents, or through exposure to heat, which defect is discovered by its failing to perform the usual number of oscillations in a given time.

This fault is remedied by remagnetising the needle as described in para. 238 (*d*) or (*e*).

(*c*) *Defective suspension* is another fault seriously affecting the sensitiveness of a galvanometer, reducing the deflections thereof, and further showing itself by the number of times the needle swings before coming to rest. The greater the friction caused by its suspension, the less, of course, will be the number of oscillations.

If the needle be supported on a pivot, the defect will be probably found to be due to the pivot having become dirty or rusty, in which case it should be cleaned with chalk and oil, and rubbed with leather—*on no account sandpaper*; if the pivot be at all bent, it should be carefully straightened: or, if blunt, it may be sharpened with a very fine file.

The socket in which the pivot is placed may be dirty, in which case it can be cleaned with a sharply pointed piece of soft wood, great care being taken not to scratch the inside of the socket.

In those galvanometers which admit of it, the needle should always be raised off its pivot; or, in the case of a

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fibre suspension, the fibre should be relieved of the weight of the needle when the instrument is not in use.

When the latter form of suspension becomes defective, it is necessary to renew it altogether.

Faults in Resistance Coils.

236. The only fault peculiar to **resistance coils**,[1] to which attention need here be drawn, is that which arises from the fact that the passage of a strong current through a fine wire heats it considerably, and the resistance of wire is *affected by temperature*; thus the standard by which electrical measurements are made is itself subject to variation under the influence of the current.

To reduce the effect of this source of inaccuracy to a minimum, the coils of resistance boxes are usually made of German silver wire, which is less affected by temperature than copper wire.

As a further precaution, the currents should be kept on as short a time as possible.

Faults in the A B C Instrument.

237. **The A B C instrument**[2] suffers chiefly from *mechanical faults*, due to continued or rough usage, resulting in the handle of the transmitter being jammed so that it will not turn. This may be due to broken or loose bearings, or to wheels becoming clogged with oil.

To prevent this, only the best watchmaker's oil should be used.[3]

Sometimes, on depressing one of the keys round the dial of the transmitter, the key previously depressed fails to rise; when this is the case, the chain which encircles the keys has become too loose, and requires tightening by means of the screw which effects that purpose, and which also admits of the chain being loosened in the event of its being so tight that any one key cannot be properly depressed.

The receiver is liable to the defects which are common to electro-magnets generally, as described in para. 226 (*b*), (*d*), (*f*), and (*i*).

General Remedies for Instrument Faults.

238. The following are **general remedies for the faults most frequently met with in telegraph instruments.**

To remedy Dirty or Fused Contacts.

(*a*) *Imperfect contacts* resulting from the settlement of dirt or dust, or from oxidation at points of contact, such as the platinum points of relays, sounders, or keys, resulting from the action of strong currents at these points, are best remedied by *daily* or more frequently passing a piece of

[1] § 160.

[2] § 172. See § 197.

[3] § 228 (*c*).

smooth paper between such contacts until no trace of dirt is observed on the paper.

Sandpaper should never be used, as, besides wearing away the facing of platinum, it renders the surfaces rough and uneven, and the efficacy of the points to secure good contact when closed is impaired.

If paper fails to remove the oxide and to produce a bright surface, the points should be cleaned with chalk and oil and rubbed with chamois leather.

If it is found that the surface is at all eaten away, it should be smoothed with a *very fine* file, and then burnished and cleaned as above.

To preserve Steel Springs from Rust.

(*b*) *Failure of springs.*—If this is the result of loss of temper, the springs must of course be re-tempered.

The prime cause, however, is often rust, from the action of the climate. This is effectually prevented by the application of a little kerosine oil on all exposed steel springs.

To secure Pivots from unnecessary Friction.

(*c*) *Friction of pivots*, the result of dust or rust. Clean with chalk and oil, and rub with chamois leather, *avoiding the use of sandpaper*, and subsequently apply the smallest quantity of pure watchmaker's oil.

Sufficient oil for application will be obtained by dipping the point of a needle into the oil.

The sockets in which pivots are balanced are best cleaned with a sharp-pointed piece of soft wood.

To Magnetise Needles.

(*d*) *Demagnetisation of needles*, under the influence of strong currents or lightning; or the result of exposure to heat.

Galvanometer needles, and those used as magnetic indicators on the covers of relays, can be re-magnetised either by placing them across the poles of a permanent horse-shoe magnet, or across the cores of an electro-magnet, such as a sounder (the armature of which is removed), the needle being at the same time rubbed two or three times *across* the poles of the permanent or electro-magnet, as the case may be.[1]

A needle may be considered sufficiently magnetised when it can support its own weight of soft iron on either pole.

To Magnetise an Astatic Pair.

(*e*) *Demagnetisation of an astatic pair*,[2] due to strong currents passing through the coils, to heat, or lightning, resulting in loss of sensitiveness.

[1] The end of the needle which is to be a North Pole is, of course, placed on the South Pole of the permanent magnet or electro-magnet and *vice versâ*.

[2] Def. 32, and § 154.

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Each of the needles is separately magnetised as above, with reverse poles facing one another. Then suspend the pair by a thread without torsion; if the system will remain in a position at right angles to the magnetic meridian, it is perfectly astatic; if not, the magnetism of one needle must be stronger than that of the other. First try to add magnetism to the weaker magnet; if, however, this be magnetised to saturation,[1] then magnetism must be abstracted from the stronger till both become nearly equal.

[1] Def. 47.

This must be effected by stroking the needle in the reverse direction to that by which it would be magnetised, but with a very feeble magnet, such as a magnetised sewing needle or penknife.

To render Iron soft.

(*f*) *Residual magnetism* owing to the impurity of the iron used for electro-magnetic cores.

Anneal the iron by heating it in a charcoal fire and allowing it to cool gradually.

To protect Instruments from the Effects of Lightning.

(*g*) *Lightning faults*, such as the fusion of coils, the rupture of their insulating covering, or the demagnetisation of permanent magnets, are prevented or mitigated by protecting them by means of the lightning discharger, as described in para. 133.

The discharger is inserted in the circuit at the point where the line enters the office, so that the whole apparatus may be protected.

The inductive effects of lightning, commonly called 'lightning beats,' are often indicated by receiving instruments in spite of the discharger, owing to the potential of these currents not being sufficiently great to effect discharge between the plates of the discharger. It is therefore important that the instrument itself should not present a better means of discharge than the discharger. The iron cores of electro-magnets should, for this reason, never be connected with the earth, as discharge might take place to the ground through the covering of the coils.

To secure firm Connections at Terminal Screws.

(*h*) *Imperfect connections* between wires and terminal screws may be the result of oxidation or dirt, as explained in the case of contact points in clause (*a*) of this paragraph, where the remedy is also given.

Loose connections are, however, a not unfrequent cause of imperfection, which, though sometimes the result of careless dusting or wiping, are more often originated by neglect of the precautions given in para. 213 for forming the loops of connecting wires.

The wire loop should always close round the terminal in the same direction as the screw.

Faults in Office Connections.

239. (*a*) The **covered wires** used for office connections invariably *deteriorate*, not only from the effects of exposure to heat and light, but from the action of the currents which pass through them, which causes them to crack and perish.

(*b*) *Leakage* is the result of this, by which the effective strength of the current is reduced.

(*c*) *Electrolytic action* taking place at these points causes the copper conductor to corrode, under the influence of copper currents, resulting in its being eaten completely through, when sudden interruption ensues.

The practice of fastening office wires with metal staples is thus a most dangerous one. Leather straps or wooden battens are to be preferred.

When office wires show signs of perishing, the only remedy is to renew them throughout.

The leading wire joined to the copper pole of the signalling battery is likely to be the first to become defective.

Faults in Earth Connections.

240. (*a*) **Earth connections,**[1] besides being liable to the defects described in the foregoing paragraph, may become defective from the following causes :

(*b*) *Corrosion of plate.*—The resistance of copper earth plates is often found to increase after long use, in consequence of the formation of a green greasy oxide on their surface similar to that described in the case of commutator plugs.[2] On the first indication of this fault the plate should be thoroughly cleaned, as the longer oxidation goes on, the more difficult its removal becomes.

(*c*) *Polarisation* may result from such a fault as the above, or from any cause whereby electrical contact between the plate and the ground is rendered imperfect, the consequence of which is that the plate fails to diffuse the current into the earth and becomes charged or *polarised*, as it is called, discharging its current back through the line circuit in the opposite direction to the working current.

Faults in Telegraph Lines.

241. **Faults in the line circuit** may be due to either of the following causes :

[1] § 178.

[2] § 234 (*a*).

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(*a*) *Total disconnection*, caused by breakage of the line through accident, a bad joint, or rusty wire.

(*b*) *Partial disconnection* is almost invariably the result of an imperfectly soldered joint which has not actually given way. This fault is often intermittent in its nature.

(*c*) *Total or 'dead' earth* is caused by the line wire forming connection with damp ground, either directly or by touching an iron post or stay, or a wet tree, whereby a perfect contact is formed with the ground, the resistance of the fault in this case being *nil.*

(*d*) *Partial earth* is due to similar causes, which do not, however, cause perfect connection with the ground.[1]

(*e*) *Contacts* are caused by two or more wires being twisted together or connected by a piece of wire thrown upon them, by which they are placed in *metallic* contact, the resistance of such a fault being generally *nil*, when the contact is called *perfect*; or by kite-strings, dead snakes, leaves of trees, or other imperfect conductors, whereby the contact itself offers resistance, in which case it is called a *partial contact.*[2]

Disconnections, *earths*, and *contacts* may occur together; for example, in the case where a line is broken and the ends on the ground and touching other wires.

Sec. **F**, on 'Testing,' includes a description of the mode of localising the various faults which occur in telegraph lines.

Natural Causes obstructing Communication.

242. Communication through telegraph lines is subject to disturbances due to what are termed **natural currents,** such being attributable to any of the following causes:

(1) Atmospheric electricity.
(2) Earth currents.
(3) Thermo-electric currents.
(4) Moisture.

Atmospheric Electricity.

(*a*) *Atmospheric currents* are generated by the electricity of the air or clouds, either by induction or by direct discharge; any change of state in the air or clouds producing a current in the line.

Lightning dischargers[3] are the only protection against disturbances of this kind; and when they fail, it becomes necessary to stop work and put the line direct to earth, until the atmospheric electricity is sufficiently discharged to allow of communication being resumed.

[1] A troublesome and not uncommon cause of earth faults is the persistent building of crows' nests on the telegraph posts. These nests contain bits of wire, such as ends of binding or jointing wire, which may have been left on the ground, and form a conducting circuit between the line and the iron post. Hence the necessity for requiring the workmen to gather up and bury all useless scraps of wire.

[2] Snakes are not unfrequently dropped across the wires by birds.

[3] § 133.

These currents must be clearly distinguished from 'earth currents,' the causes of which are as follows :

Earth Currents.

(*b*) *Earth currents* simply appear to be caused by currents flowing from one part of the earth to another (owing to a difference of potential between these points) through the line, which is placed in metallic contact with the ground by means of the earth plates. These currents must not, however, be confused with the currents produced by polarisation of earth plates,[1] though they exhibit the same features.

[1] § 240 (*c*).

Earth currents are intimately connected with magnetic storms. They are observed to be strongest in lines running N.E. and S.W., and are variable in strength and direction. When they are so strong as to interfere with communication their effect can be nullified by throwing off earth and using a spare line, when there is one, as a return wire.

Thermo-electric Currents.

(*c*) *Thermo-electric currents* are generated between different points of the line, varying in temperature. These currents, however, are rarely, if ever, sufficiently strong to interfere with the working current.

Moisture.

(*d*) *Moisture*, such as rain, or dew, or sea air, has the effect of producing polarisation currents at points of defective insulation.

Such faults are felt least when working with a copper current,[2] but when the strength of the polarisation currents, due to electrolytic action, is such as to obstruct communication, their direction may be reversed by sending a zinc current through the line for a short time.

[2] Def. 26, and § 239 (*c*).

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TESTING

243-266. MEASUREMENT OF ORDINARY RESISTANCES BY VARIOUS METHODS, WITH RULES FOR THE SELECTION OF SUITABLE TESTING BATTERIES AND INSTRUMENTS

267-278. MEASUREMENT OF BATTERY RESISTANCES (OR ANY RESISTANCES CONTAINING E.M.F.), BY VARIOUS METHODS

279-287. MEASUREMENT OF ELECTROMOTIVE FORCE (VARIOUS METHODS)

288. REGULAR TESTS OF BATTERIES

289-291. MEASUREMENT OF ARRIVING CURRENTS

292-318. TESTING OF LINES (REGULAR TESTS)

319-333. DITTO (FAULT TESTS)

334. MEASUREMENT OF CAPACITIES

335-343. 'EARTH' AND 'LIGHTNING CONDUCTOR' TESTING (VARIOUS METHODS)

344. TESTS OF INSTRUMENTS AND CONNECTIONS

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Object of Testing.

243. Electrical testing has two objects: first, that of examining the normal conditions of batteries, lines, and earths, which is the purpose of *regular testing*; any sudden or unaccountable change from the regular readings recorded thus affording a means of detecting and remedying faults before they affect communication or otherwise show themselves; the second object, which is accomplished by *fault testing* (and which is confined to the *lines*), being that of ascertaining the locality of a fault immediately its presence is manifested.

To measure ordinary Resistances.

244. The simplest electrical measurement which can be made is that of a resistance not containing an electromotive force: for example, a piece of wire or a coil, such being called a 'dead resistance.'

A resistance of this kind may be measured in various ways.

Resistances measured by the Wheatstone Bridge.

245. By the Wheatstone bridge, described in para. 164 (see fig. 39). The unknown resistance, which we may call x, is joined up between the terminals L and L' of the bridge, and, as explained in the above-mentioned paragraph,

$$x = \frac{B}{A} W. *$$

* For proof of this formula, see Solution VI. App. B.

By this means resistances from 0·01 unit up to one million units can be measured.

As the measurement of x depends upon the '*balance*' of the bridge, which is adjusted by the resistance of the various branches, it is necessary that this should be tested, which is done as follows.

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To test the Branches of the Bridge.

246. To test the bridge for conduction.

First, make $x = 0$, $W = 0$, $A = 10$, $B = 10$	Opposite branches being equal, the potentials at p and q should be equal, and therefore there should be no deflection of the galvanometer, indicating balance to be perfect.
Second, make $W = 1$, x, A, and B remaining as before	A strong deflection of the needle should result, indicating that W is too large.
Third, now make x infinity	A stronger deflection of the needle, in the opposite direction, should show x too large.
Fourth, make W also infinity, A and B being each $= 1000$	Opposite branches being again equal, balance should be restored, as indicated by no deflection of the needle.

In testing with equal branches A and B their resistance should be determined by that under measurement.

If x be between 1 and 100 units, A and B should be $= 10$.
" " 100 " 1000 " A and B should be $= 100$.
" " 1000 " 10000 " A and B should be $= 1000$.

To test the Insulation of the Bridge.

247. To test the bridge for insulation.

As the limit of measurement (by balance) with the bridge is one million units, it is only possible to test whether its insulation resistance is above that standard. This is done by making

$$A = 10$$
$$B = 1000$$
$$W = 10000$$
$$x = \text{infinity}.$$

The deflection of the needle should show x greater than $\frac{B}{A}W$, i.e. greater than one million.

Resistances measured by the Differential Galvanometer.

248. The differential galvanometer, described in para. 165,[1] affords another means of measuring x.

When neither shunt is used,

$$x = W$$

[1] See fig. 40.

With the shunt s in circuit,

$$x = 100\ W.^*$$

And with the shunt s',

$$x = \tfrac{1}{100}\ W.^*$$

* For proof, see Solution VII. App. B.

The differential galvanometer, like the bridge, has a range of measurement from 0·01 to 1,000,000 units; the bridge, however, is the more accurate measurer of the two, in consequence of the difficulty experienced in winding both coils of the differential galvanometer alike.

Rules for testing the Accuracy of the Differential Galvanometer.

249. The accuracy of the differential galvanometer is tested as follows:

For conduction.

First, make $x = 0$, $W = 0$; or make $x = \infty$, $W = \infty$	with or without shunts	Balance should be indicated by no deflection.
Second, make $x = \infty$, $W = 0$; then make $x = 0$, $W = \infty$	"	The needle should in both cases be deflected strongly, but in opposite directions.
Third, make $x = 0$, $W = 1$; then make $x = 1$, $W = 0$	"	The needle should be deflected in opposite directions, but less strongly than in the second case.

For insulation.

Make $x = \infty$, $W = 10000$	with the shunt s	The deflection should show x greater than 100 W, i.e. greater than one million.

Resistances measured by the Deflection of a Galvanometer.

250. By deflections, on the principle that the angle of deflection of a galvanometer needle (or, in the case of sine and tangent galvanometers,[1] the sine or tangent respectively of the angle of deflection) is proportional to the strength of the current, which is itself inversely proportional to the resistance in circuit;[2] that is to say, if a certain resistance, w, be joined up in the circuit of a battery and galvanometer, a certain deflection of the needle will be the result. Suppose, now, that w is replaced by some other resistance, x. Then, if x be equal to w, the deflection of the needle will be the

[1] §§ 150 and 151.

[2] Law 1, App. A.

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same as before; or, if x be one *half* of w, then the deflection will be *double* what it was before; or, if x be *twice* as great as w, the deflection will be *half* what it was before. In other words, with the same electromotive force, the strength of current, as shown by the deflection of the galvanometer, is inversely proportional to the resistance in circuit—i.e.

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

* This follows directly from Ohm's Law $C=\frac{E}{R}$ from which $\frac{R}{E}=\frac{1}{C}$ $\therefore R=\frac{E}{C}$.

R being the resistance in circuit;

E the electromotive force, as represented by the number of cells in series;

C the strength of current, as denoted by the angle of deflection of the galvanometer.

Now if, in the circuit above described, R (the known resistance) be replaced by x, an unknown resistance which it is desired to measure—E remaining the same—it follows that

$$x = \frac{E}{C'}$$

C' representing the deflection of the galvanometer when the unknown resistance x is in circuit.

Now if $C = C'$—that is, if the deflection is the same with x in circuit as it was when R was in circuit—it follows that

$$x = R.$$

If not, however, then

$$x : R :: \frac{E}{C'} : \frac{E}{C}$$

$$\text{or, } \frac{x}{R} = \frac{\frac{E}{C'}}{\frac{E}{C}}.$$

And, E being the same in both cases,

$$\frac{x}{R} = \frac{C}{C'};$$

$$\therefore x = \frac{C\,R}{C'}$$

that is, the unknown resistance x is equal to the known resistance R, multiplied by the ratio between the angles of deflection in the first and second cases respectively.[1]

[1] It is presumed here, for the sake of simplicity, that the Galvanometer used is one in which the deflections are proportional to the strength of current (§ 149).

Effect of altering the E.M.F. of the Testing Battery.

251. It may often occur that, although the angle of deflection C in the first case with the resistance R in circuit, may be a readable deflection, x, the unknown resistance, may be so much greater than R that when x is in circuit the needle may scarcely be deflected a single degree on the scale, with the same battery. Hence it becomes desirable to increase the electromotive force of the testing battery, so that in the second case with the large resistance x in circuit the strength of the current may be increased sufficiently to produce a readable deflection, C', of the needle for comparison with the deflection C, obtained in the first case with the smaller electromotive force E through the smaller resistance R.

Calling the increased E.M.F., when x is in circuit, E', we have

$$x : R :: \frac{E'}{C'} : \frac{E}{C}$$

$$\text{or, } \frac{x}{R} = \frac{\frac{E'}{C'}}{\frac{E}{C}};$$

$$\therefore \frac{x}{R} = \frac{E'\,C}{E\,C'}$$

$$\text{and } x = \frac{E'\,C}{E\,C'}\,R.$$

Battery Resistance when taken into account.

252. It will be observed that the only resistances taken into account in the above circuit are those *external* to the testing battery.

It must be remembered, however, that the batteries themselves contain resistance, and under certain circumstances the battery resistance may form an important part of that of the whole circuit.

For example, in the case when a single cell whose resistance is 20 ohms[1] is joined in circuit with a very low resistance, say 2 ohms, it is obvious that if another cell be added to the first (in series), although the E.M.F. will be doubled, the strength of the current as indicated by the deflection of the galvanometer will *not* also be doubled.

[1] § 46.

This is because the resistance introduced by the second cell (20 ohms) is so great in comparison with the external resistance (2 ohms) that the increased E.M.F. does not increase the strength of the current accordingly, on account of the resistance introduced along with it, which acts on the strength of current in the inverse or opposite way to E.M.F. —that is to say, by adding *E.M.F.*, the strength of the current C is *increased*; but, by adding *resistance*, C is *decreased*; thus it may happen that adding cells to a battery may have no effect whatever upon the deflections of a galvanometer in circuit, the strength or *quantity* of the current (not its E.M.F. simply) being the property of the current which does work, i.e. deflects needles, decomposes water, heats wires, &c.[1]

[1] Def. 1.

This may be very simply explained by Ohm's law as follows:

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

Now, in the first case described above, viz. when the circuit is composed of one cell of 20 ohms, and an external resistance of 2 ohms,

$$C = \frac{1}{20+2} = \frac{1}{22}.$$

In the second case, when another cell is added,

$$C' = \frac{2}{20+20+2} = \frac{2}{42} = \frac{1}{21};$$

that is to say, the strength of the current (and consequently the deflection) is almost precisely the same with two cells as with one.

If, however, the external resistance be very large compared with that of the battery—for example, say 5000 ohms —then, with one cell,

$$C = \frac{1}{20+5000} = \frac{1}{5020},$$

and with two cells,

$$C' = \frac{2}{20+20+5000} = \frac{2}{5040} = \frac{1}{2520};$$

$$\therefore C' : C :: 5020 : 2520,$$

$$\text{or } \frac{C'}{C} = \frac{5020}{2520} = 2 \text{ nearly};$$

that is to say, the current is twice as strong with two cells as with one.

Rule for calculating the Strength of Current in reference to arrangement of battery power.

253. This enables us to make a rule which shall be a guide in calculating the effect of the current in all cases of testing by deflections, according to the number of cells used, under various conditions of resistance.

This rule may be stated as follows :

If the resistance to be tested is so great that the battery resistance is insignificant in comparison with it, then, by multiplying the E.M.F. of the battery, the deflections will be multiplied accordingly.

That is to say, if one cell causes the needle to deflect 10°, two cells will produce a deflection of 20°, and so on (in instruments whose deflections are proportional to the strength of the current).

Testing Batteries joined for Tension or Quantity.

254. The definition of E.M.F.[1] accounts for this fact, for, being that property of the current which overcomes resistance, it follows that when the external circuit is such that the work of the testing current is that of overcoming high resistance the battery should be given high E.M.F., which is effected by joining its cells in series, or for '*tension*' as it is sometimes called.

It is obvious, on the other hand, that if the resistance of the circuit to be measured is so small that the current has practically nothing to overcome, then the property of high E.M.F. is not required, and no increase of deflection would result from joining the cells in series.

In this case, doubling the *quantity* of the current would double the deflections.

Now as the quantity of the current depends upon the quantity of material consumed, it is evident that by doubling the surface of the plates of a cell—or, which is the same thing, joining two cells parallel to one another[2]—the quantity of the current (and consequently the deflections) will be doubled in those cases where the external resistance is insignificant compared with that of the battery. Hence joining cells parallel is called '*joining for quantity.*'

Measurement of Low Resistances.

255. The fact of doubling the surface, by joining the plates of the cells parallel, reduces their combined resistance to one half that of a single cell, according to the law of derived circuits, their joint resistance being the product of the resistance of each cell divided by their sum.[3] For example, the parallel resistance of two cells, each measuring 20 units, is

[1] Defs. 5 and 6.

[2] § 19.

[3] Law 8, App. A.

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$$\frac{20 \times 20}{20+20} = \frac{400}{40} = 10,$$

or half the resistance of one cell.

Thus, in testing low resistances, when it is desired to reduce the battery resistance to less than that of one cell, it can be effected by joining cells parallel.

Adjustment of Battery Power according to work to be done.

256. It will be observed that the effects of joining batteries for tension or for quantity respectively are in agreement with the law for obtaining the maximum effects from electro-magnets, viz. that the greatest magnetic force is obtained when the internal resistance of the battery is equal to the resistance of the coils of the electro-magnet.[1]

These rules, regulating the adjustment of battery power, are useful, not only in the case of testing currents, but in the adaptation of working batteries to suit the circuits in which they are placed.

[1] Law 15, App. A.

Deflections controlled by Adjustment of E.M.F. and by Galvanometer Shunts.

257. From the above remarks[2] it will be understood how the addition of E.M.F. in the testing battery increases the range of measurements which may be tested by deflections, in those cases where the unknown resistance x (para. 251) is so much greater than the known resistance R, as to render the deflection of the galvanometer, when x is in circuit, too small for comparison with its deflection when R was in circuit, the E.M.F. in both cases being the same.

[2] § 251 *et seq.*

On the other hand, it may occur that x may be so much smaller than R that the deflection with x in circuit may be so much *greater* than with R in circuit (the E.M.F. being the same), that the needle may deflect to its full extent on the scale, and readings be thus again incomparable.

Here it would be necessary to *reduce* E.M.F., so as to reduce the deflections in a corresponding ratio until brought within readable limits.

Under certain circumstances, however, the E.M.F. of the battery may be already so small as not to admit of further reduction, as, for example, in the case when one cell only is used.

Other means must therefore be employed for reducing the deflections within readable bounds, this being most conveniently done by shunting the galvanometer, so that a known fraction of the current only shall pass through the coils to deflect the needle; these deflections being multiplied again by the coefficient known as '*the multiplying power of*

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the shunt'[1] in calculating the effective strength of the current.

Resistances measured with the Thomson Galvanometer.

258. The **Thomson galvanometer,**[2] which, by its extreme sensitiveness, indicates the weakest currents passing through its coils, is used in accordance with the above principles for the measurement of very high resistances.

Fig. 64 represents the instrument joined in circuit with the testing battery E, and an unknown resistance x. S represents the shunt.[3]

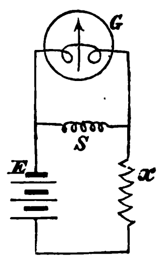

FIG. 64.—MEASUREMENTS WITH REFLECTING GALVANOMETER.

Now, considering the deflections of the needle as directly proportional to the strength of the current flowing through the coils,[4] it follows from Ohm's simple law that

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

$$\text{or } x = \frac{E}{C}$$

E representing the number of cells employed, C the deflection produced thereby through the unknown resistance x.

Now supposing E and x in the above circuit to be replaced by a different electromotive force e, and a *known* resistance R, and calling the deflection in this case C'

Then, by the same law,

$$C' = \frac{e}{R}$$

$$\text{or } R = \frac{e}{C'}.$$

And comparing the two circuits, we have

$$x : R :: \frac{E}{C} : \frac{e}{C'}$$

1 §§ 157–159.

2 For description of the instrument, see § 156.

3 § 157.

4 § 149.

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$$\text{or, } \frac{x}{R} = \frac{\frac{E}{C}}{\frac{e}{C'}};$$

$$\therefore x = \frac{\frac{E}{C}}{\frac{e}{C'}} R = \frac{E\,C'}{e\,C} R$$

the above being a general formula which is applicable to any E.M. forces and resistances which may be in circuit.

Adjustment of Circuit.

259. Now the deflection C' produced by the known E.M. force e, through the known resistance R, may be adjusted to any value most convenient consistent with readable deflections.

For example, supposing C' to be produced by the current of one cell through a resistance of 10,000 ohms, the galvanometer being shunted with the $\frac{1}{999}$ shunt—i.e. the shunt which allows $\frac{1}{1000}$ part of the current to go through the galvanometer—or, in other words, has the effect of multiplying the value of the resistance in circuit by 1,000;

$$\text{then} \qquad C' = \frac{1}{10000 \times 1000} = \frac{1}{1 \text{ million}}.$$

Now, supposing the unknown resistance x to be a very large one, and, in order to produce a readable deflection C when x is in circuit, we increase the number of cells to 100, and take off the shunt so as to give the galvanometer its full deflecting power; then, in this case,

$$C = \frac{100}{x};$$

and, comparing this with the preceding equation,

$$C' : C :: \frac{1}{1 \text{ million}} : \frac{100}{x},$$

$$\text{or, } \frac{C'}{C} = \frac{\frac{1}{1 \text{ million}}}{\frac{100}{x}};$$

$$\therefore \frac{C'}{C} = \frac{x}{100 \text{ millions}} \text{ (or megohms)},$$

$$\text{and } x = \frac{C'}{C}\, 100 \text{ (megohms)}.$$

To measure Resistances with the Tangent Galvanometer.

260. To measure resistances with the tangent galvanometer.

Having selected a suitable testing battery of known resistance, f, join up between its poles the resistance to be measured, x, and the galvanometer, whose resistance may be called G.

Then observe the deflection indicated by the galvanometer, which we may call $a°$.

Now replace the unknown resistance x by a known resistance W, the rest of the circuit remaining the same, and observe the deflection in the second case, which we may call $a'°$. Then

$$x = \frac{\tan a'°}{\tan a°}\left(W + G + f\right) - \left(G + f\right)^{*}$$

* For proof of this formula, see Solution X. App. B.

Use of thick and thin Coil.

261. In measuring low resistances with strong currents, it is desirable to use a galvanometer of low resistance, because, in this case, the sensitiveness gained by increasing the number of convolutions in the coil would be counteracted by the resistance they introduce into the circuit.[1]

[1] § 54.

The case is different, however, in measuring high resistances when the resistance of the galvanometer bears but a small proportion to the external resistance to be measured. In this case a high resistance galvanometer should be used, not that its resistance is of any advantage, but because it implies a large number of convolutions in the coils, the whole of the multiplying power of which is brought to bear (as their resistance can be neglected) to render the needle sensitive to the currents, enfeebled as they may be, in consequence of the high external resistances they have to traverse.

Thus, in the departmental tangent galvanometer,[2] which has two separate coils—one of high, and the other of low resistance—it is advisable to use the thick coil for measuring low resistances (i.e. up to 350 units), and for higher resistances the thin.

[2] § 152.

Reduction Coefficient of the Coils.

262. As a rule, the various observations made in the same test should be taken through the same coil of the instrument; it is possible, however, that the battery and *known* resistance making up one of the circuits may allow of a very readable deflection through one coil, when the deflection obtained through the same coil with the *unknown*

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resistance in circuit may be either too small or too large for comparison; hence it becomes necessary to take the reading, in the case of the second circuit, through the other coil.

Now this shows that there is a certain property in different coils, depending on their respective resistance, form, or construction, whereby the deflections of each differ, although actuated by the same current through the same external resistance. This property, peculiar to each coil, which may be represented by the letter K, is called **the coefficient of the coil**; and as the value of the coefficient K varies for each, so, in the same proportion, will the deflections of various coils (or in the case of tangent galvanometers, the *tangents* of their deflections) differ.

For example, supposing it to be possible to find two *exactly* similar coils, whose coefficients may be called K and K', respectively, and that two equal currents C, C' are sent through these coils, then in this particular case, as the value of the coefficients K, K' is the same for both coils, their deflections a° and a'° through the thick and thin coils, respectively, will be equal.

Supposing K and K', however, to be different; and, for example, that C represent the current in the thick coil, and C' that in the thin, produced by the same battery, through no external resistance in either case;

Then (by the principle of the tangent galvanometer)

$$C = K \tan a^\circ$$

and

$$C' = K' \tan a'^\circ$$

$$\therefore \frac{C}{C'} = \frac{K \tan a^\circ}{K' \tan a'^\circ};$$

whence

$$\frac{C\,K'}{C'\,K} = \frac{\tan a}{\tan a'}$$

$$\therefore \frac{K'}{K} = \frac{C' \tan a^\circ}{C \tan a'^\circ} = \mathbf{n}.$$

This ratio (represented above by the letter **n**) may be found once for all for any pair of coils; and to reduce their deflections to the same terms, the readings through the thin coil must be multiplied by **n**, or those through the thick coil divided by **n**, as is obvious from the above equation; hence **n** is called *the reduction coefficient of the coils.*

To measure Resistances using both coils of the Tangent Galvanometer.

263. In those cases in which the readings of the galvanometer cannot be controlled by the alteration of the E.M.F. of the testing battery[1]—such, for example, as the measurement of earths of very low resistance, when increased E.M.F. would give rise to polarisation,[2] and to variations in the resistance in circuit—the use of two coils becomes necessary.

[1] § 251.

[2] § 222.

In this case the natural current between the earths is used as the testing battery, and the resistance (x) to be measured is first placed in the circuit of the thick coil of the galvanometer of resistance g whose coefficient is K.

Calling the deflection produced in the above circuit $a°$,

then

$$K \tan a° = \frac{e}{g + x}$$

Now, replacing the thick coil g in the above circuit by the thin coil g', whose coefficient is K', and noting the deflection $a'°$,

then, in the second case,

$$K' \tan a'° = \frac{e}{g' + x};$$

from which,

$$x = \frac{ng' - \frac{\tan a°}{\tan a'°} g}{\frac{\tan a°}{\tan a'°} - n} *$$

* For proof, see Solution XI. App. B.

Rules for Testing with the Tangent Galvanometer.

264. The following will be found useful rules to be remembered when testing with the tangent galvanometer.

Efficiency.

(1) The tester should satisfy himself as to the perfect **efficiency of the instrument** electrically, magnetically, and mechanically.[3]

[3] For tests of efficiency, see § 153.

Accuracy of Observations.

(2) **Errors of observation** cannot be totally avoided, but to reduce them to a minimum the deflections should be controlled so as not to exceed 45°, and to be as near that angle as possible.[4]

[4] The reasons for this are explained in § 151. See fig. 35.

To control Deflections.

(3) **The position of the needle on the scale** is controlled by the use of suitable resistances and electromotive forces in the circuit;[5] and it should be remembered that the most accurate results are obtained when the known resistance inserted (W) is equal to (x), the resistance to be measured.

[5] §§ 251 and 257.

Instrument placed out of the field of

(4) **The deflections** of the needle being **influenced by neighbouring magnets** or magnetic bodies, great

SECTION F.

neighbouring Magnets.

care is necessary that such be removed to a distance (found by experiment), where their movement to and fro does not affect the galvanometer needle.

Compensation for Errors of Zero Point.

(5) **Errors of zero point,** observed by the needle not returning to zero, in the course of testing, must be overcome by using reversed currents for each observation, and taking the mean of + and − readings.

Earth currents may sometimes cause this, when the earth forms part of the circuit.

Adjustment of E.M.F. and Resistance of Testing Battery.

(6) On the principle that the **maximum effect is obtained when the internal resistance of the battery is equal to the resistance external to it,**[1] a battery of high resistance, i.e. containing a number of cells in series, should be used for measuring high resistances; but for the measurement of low resistances, the battery resistance should be as low as possible, so as to reduce errors in its computation to a minimum, but yet large enough to maintain its constancy, for in batteries of low resistance polarisation takes place, causing variation, both in their resistance and electromotive force.[2]

To reduce the Resistance of the Testing Battery.

(7) **To reduce the resistance of a testing battery** to less than the normal resistance of one cell, when necessary, increase the surface by joining the number of cells '*parallel*,'[3] and calculate their joint resistance $\left(\frac{\text{product}}{\text{sum}}\right)$,[4] having carefully found the individual resistance of each.

This *calculated* value will be more correct than the measured resistance of a number of cells thus joined up; for the measurement of such a circuit, closed as it is through a very small resistance, is liable to be rendered inaccurate by virtue of polarisation, creating a false resistance.

In testing electromotive forces also, calculations are likely to be more correct than measurements, the E.M.F. of a Minotti cell being a constant quantity;[5] and, further, the *measurement* of its E.M.F. is dependent on its resistance,[6] and all measurements are liable to errors of observation.

Testing Battery the same throughout one test.

(8) For the various observations taken in the measurement of one quantity, **the same testing battery should be used,** unless absolutely impracticable, as in the case when a very high resistance is to be measured.[7]

[1] Law 15, App. A.

[2] § 222.

[3] § 254.

[4] Law 8, App. A.

[5] § 31.

[6] § 264 (2).

[7] § 251.

Choice of Galvanometer Resistance.

(9) In testing resistances up to 350 units the thick coil is used, and above that the thin, for reasons explained in para. 261.

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Both Coils only used when absolutely necessary.

(10) **The same coil** should be used for the various observations in measuring the same quantity when practicable, as explained in para. 262.

Battery tested before and after Measurements.

(11) When great accuracy is required, the resistance of the testing battery should be measured both before and after the tests.

Measurements made rapidly.

(12) **All measurements should be made as quickly as possible,** as the resistance of standard coils may vary under the influence of continued currents;[1] and also in cases when the earth forms part of the circuit, in order that the earth plates may not become polarised, and thus render results inaccurate.[2]

[1] §§ 161 and 236.

[2] § 240.

Resistances measured with the Sine Galvanometer.

265. To measure a resistance with the sine galvanometer, the same process is adopted as that described in para. 260, for measurements with the tangent galvanometer, the same formula holding true; but with this modification that the *sines* instead of the tangents of the angles of deflection are used; thus:

$$x = \frac{\sin a'^{\circ}}{\sin a^{\circ}}\left(W + G + f\right) - \left(G + f\right).$$

It must be remembered in this case that the deflections of the needle on the scale are not read off direct, but are ascertained by turning the coil after the needle, so that the zero point of the movable scale stands under the needle; in which case the number of degrees through which the coil was turned, as indicated by the outer fixed scale, represents the angle of deflection.[3]

[3] § 150.

On account of this operation, it takes longer to execute measurements with the sine, than with the tangent galvanometer.

Bridge used in Measurement of high Resistance.

266. The Wheatstone bridge may be used for the measurement of a high resistance, in connection with a sensitive galvanometer; for, although when used as a '*balance*,' it is only capable of measuring resistances up to one million,[4] it can be made to form part of the circuit for testing **by deflections** so that its branch resistances *A* and *B* act as shunts to the galvanometer; the adjustable resistance *W* being used as described in para. 259.

[4] § 245.

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Fig. 65 represents such an arrangement, in which the A branch of the bridge is used as a shunt, whose resistance is adjustable by 10, 100, or 1,000 units. B is plugged up so that its resistance=0, and the terminals L and L′ are insulated.

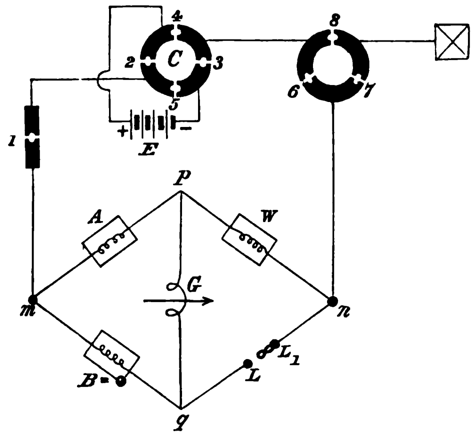

FIG. 65.

To find the deflection with the known resistance W in circuit, insert plugs in 1 and 6, the current reverser C being plugged at 2 and 3 for a copper current, and at 4 and 5 for a zinc current.

Observe the deflection $a°$ of the needle, with 1 cell through the resistance W, allowing for the multiplying power of the shunt A.[1]

According to the law of shunts[2] the resistance in circuit would be represented by the expression

$$W\left(1 + \frac{G}{A}\right) + G$$

(G being the resistance of the galvanometer), and it is easy to adjust the resistances of W and A, so that the above expression may be made equal to 1 million.

Then,

Join x, the resistance to be measured, between L and L′

making $A = 0$
$B = \infty$
$W = \infty$

[1] § 159

[2] Law 9, App. A.

Increase the electromotive force to n cells, and call the deflection in this case $b°$.

Then, if the instrument in use is a reflecting galvanometer it follows that

$$x = \frac{a°}{b°} \cdot n\,E^* \left(\textit{millions} \right);$$

* § 259.

or, if a sine galvanometer,

$$x = \frac{\sin a°}{\sin b°} \cdot n\,E \left(\textit{millions} \right).$$

To measure Resistances containing Electromotive Force.

267. In treating of the measurement of resistances in the foregoing paras. (244–266), the property of resistance alone has been considered, with reference to the quantity x to be measured.

It often occurs, however, that x may contain an electromotive force, as in the case of battery cells (the object of which is to generate electromotive force),[1] or in the case of lines in which natural currents may be flowing,[2] or between earth plates, the result either of polarisation,[3] or of the difference of potential of the plates;[4] and it is obvious that the effect of this electromotive force, when opposed to that of the testing battery, is to create an apparent *increase* of resistance in circuit; or when acting in the *same direction* as that of the testing battery, to indicate a corresponding *decrease* of resistance.

[1] § 2.
[2] § 242.
[3] § 240 (*c*).
[4] § 242 (*b*).

For this reason it is necessary to take all measurements of x both with + and − currents, so that the apparent error in one case is counteracted by the error in the opposite direction, in the other case.

Further, it is sometimes found convenient to use the electromotive force contained in x as its own testing battery.

Measurement of Battery Resistance.

268. Batteries are tested both for *Resistance* and *Electromotive Force.*

As **the internal resistance of the battery** often forms an important part of the testing circuit in the measurement of an electrical resistance or electromotive force;[5] and further, as any alteration in the resistance of a working battery is a sign either of exhaustion or of some specific fault;[6] it is obviously important that this property of the battery should be accurately ascertained.

[5] § 252.
[6] § 27.

The internal resistance of a battery may be measured by

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any of the following methods, which describe various processes of measurement, with various instruments, one or more of which will be found to apply to the case of any telegraph office.

First Method, with the Tangent Galvanometer.

269. *First Method.* **To measure the resistance of a battery with the departmental tangent galvanometer.**

As the battery contains an electromotive force (E) of its own, it is used to supply its own testing current.

First, the battery and galvanometer are joined in circuit; and the deflection produced, which may be called $a°$, is noted.[1]

Second, a known resistance w (adjusted so as to produce a readable deflection $a'°$) is inserted in the above circuit. Then, denoting by f the battery resistance to be measured, and by g the resistance of the galvanometer,

$$f = \frac{\tan a'°}{\tan a° - \tan a'°} w - g^{*}$$

[1] For a single cell the thin coil may be used, but for a battery producing too large deflections through the thin coil to be read, the thick coil is used.

* For proof of this formula, see Solution XII. App. B.

Second Method (Poggendorff's), with the Wheatstone Bridge.

270. *Second Method.* **To measure the resistance of a battery with the Wheatstone bridge** (Poggendorff).

The standard cell is inserted between L and L'; and the branch B is made infinity.

The battery, whose resistance f is to be measured, is joined up to the points m and n, as shown in the following figure:

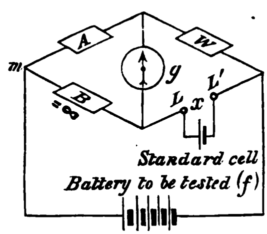

FIG. 66.

First, make $A = 1110$, and adjust W till balance is obtained.

Second, make $A = 10$, and call this value A', and the resistance unplugged in this case—to obtain balance—W'; then—

$$f = \frac{A W' - A' W}{W - W'} \dagger$$

† For proof of this formula, see Solution XIII. App. B.

Third Method (Sir William Thomson's).

271. *Third Method.* **To measure the resistance of the testing battery of the Wheatstone bridge.** (Sir William Thomson.)

The battery to be tested is first joined in circuit with the galvanometer, g, and a resistance, W, its poles being shunted by a resistance, A. W and A are adjusted so as to produce a convenient deflection ($a°$).

The shunt is then taken off, and the resistance of W increased until the same deflection ($a°$) is reproduced.

Calling the new resistance W', and that of the battery to be tested, f,

$$f = A\,\frac{W' - W}{W + g};$$

or, if the shunt A be made equal to $W+g$,

$$f = W' - W.$$

The Wheatstone bridge itself supplies the necessary apparatus. The positions of the battery and galvanometer are interchanged;[1] the A branch forms the shunt to the battery, and its resistance is made $=10$, 100, or $1{,}000$, so as to produce a suitable deflection ($a°$).

[1] Fig. 66, § 270.

$$B = 0.$$
$$W = \text{any suitable resistance}.$$
$$x = \infty.$$

After noting the deflection ($a°$), the shunt is taken off by making $A=\infty$, which, of course, increases the deflection; plugs are then withdrawn from W until the original deflection ($a°$) is reproduced through the new resistance, W'.

Fourth Method, with the Sine Galvanometer.

272. *Fourth Method.* **To measure the resistance of a battery with the sine galvanometer.**

Join the poles of the battery to be tested to the terminals of a sine galvanometer; note the deflection ($a°$) produced, and find the sine of this angle.

Then insert resistance W until the deflection is reduced to the angle whose sine is half that of the first deflection; then

$$f = W - g.*$$

* For in the first circuit the current is indicated by $\text{Sin } a° = \frac{E}{f+g}$ and in the second, by $\text{Sin } \frac{a°}{2} = \frac{E}{f+g+W}$, whence $\frac{f+g+W}{f+g} = 2$, $\therefore 2f+2g = f+g+W$ $\therefore f = W-g$.

Fifth Method, the same with the Tangent Galvanometer.

273. *Fifth Method.* **To measure the resistance of a battery with any tangent galvanometer.**

The process is precisely similar to that prescribed in the

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preceding para. for measurements with the sine galvanometer, the only difference being that the *tangents* instead of the sines of the angles of deflection are read; and, by the same reasoning,

$$f = W - g.$$

Sixth Method, with the Differential Galvanometer.

274. *Sixth Method.* **To measure the resistance of a battery with a differential galvanometer.**[1]

First join the battery to be tested in circuit with one coil only of the galvanometer, and note the deflection produced.

Then through both coils, in series, by which the deflection will be increased; because, by doubling the convolutions, sensitiveness is also doubled.[2] The resistance of the added coil, however, has to be considered; if the addition of this in the second case exactly doubled the total resistance in circuit, then the deflections in the first and second cases would be the same. It will be found in practice, however, that the deflection in the second case is greater than in the first. This is due to the fact that f is not doubled at the same time that the resistance of the galvanometer coils is. If, then, in the third case resistance w be inserted, until the first deflection is reproduced, it follows that w is equal to f, the resistance of the battery; thus,

$$f = W.$$

[1] § 165.

[2] § 144.

Seventh Method, with a reflecting Galvanometer.

275. *Seventh Method.* **To measure the resistance of a battery with Thomson's reflecting galvanometer,** or any galvanometer whose deflections are proportional to the current traversing the coils.

Join up the battery, f, and galvanometer, g, in circuit with a resistance, w, and note the deflection, $a°$. Increase the resistance to w', and note the corresponding deflection, $b°$.

Then, from Ohm's law, and according to the principle of the instrument, the current in the first case may be expressed thus:

$$a° = \frac{E}{W+g+f};$$

and, similarly, in the second case:

$$b° = \frac{E}{W'+g+f};$$

$$\therefore \frac{a°}{b°} = \frac{(W'+g)+f}{(W+g)+f};$$

$$\therefore fa + a\,(W+g) = fb + b\,(W'+g)\,;$$

$$\therefore f\,(a-b) = b\,(W'+g) - a\,(W+g),$$

$$\text{and } f = \frac{\{b^\circ\,(W'+g)\} - \{a^\circ\,(W+g)\}}{b^\circ - a^\circ}$$

Eighth Method, Mance's Bridge Method.

276. *Eighth Method.* **Mance's bridge method of testing the resistance of a battery.**

Place the battery whose resistance f is to be measured in the x branch of the bridge.

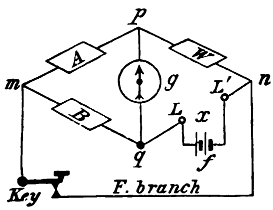

FIG. 67.

As the resistance to be measured possesses an electromotive force of its own, it is used to supply its own testing current, and the usual testing battery is removed and replaced by a key in a circuit known as the F branch of the bridge.

By depressing the key, the resistance of the F branch is made *nil*, and, by opening it, infinity.

Adjust the resistance of the branches A, B, and W until the deflection of the galvanometer is the same whether the key be open or closed.

Now, as this can only occur when the condition of balance is obtained,[1] i.e. when

$$Ax = BW,$$

it follows that

$$x = \frac{B}{A}W$$

or, in this case, as the battery forms the x branch,

$$f = \frac{B}{A}W.$$

[1] § 164.

Ninth Method, (Mance's) by opposing E.M.F.

277. *Ninth Method* (Mance's). **To measure the resistance f of a battery by opposing electromotive force.**

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Join the poles of the battery to be tested to a galvanometer, and into this circuit introduce a smaller battery (generally 1 cell) with its poles reversed so as to oppose the battery under test.

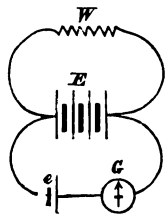

FIG. 68.

Shunt the poles of the battery whose resistance f is to be measured through a variable resistance W, and adjust this resistance until the galvanometer needle stands at zero.

Calling the number of cells in the battery under test . E

And that of the opposing battery . . . . . . e

Then

$$f = W\frac{E}{e} - W.^{*}$$

* For proof of this formula, see Solution XIV. App. B.

Tenth Method, with a Calibrated Galvanoscope or Galvanometer.

278. *Tenth Method.* **To measure the resistance of a battery with a calibrated galvanometer.**[1]

The battery to be tested is joined up in circuit with the galvanometer, and the deflection noted.

Look up the corresponding deflection on the card issued with the instrument, and note the resistance marked opposite to it.

This represents the average resistance *per cell* of the battery under test, for reasons explained in para. 252, and when multiplied by the number of cells in series represents the resistance of the whole battery.

[1] For description of the instrument and its mode of use, see § 147.

Measurement of Electromotive Force.

279. The unit of **electromotive force** is termed a Volt,[2] and as the E.M.F. of a Minotti or any form of Daniell's cell is almost identical with the volt, it is found convenient to measure the electromotive force of working batteries in terms of a standard Minotti cell.[3]

[2] Def. 7.

[3] § 43.

First Method, with the Tangent Galvanometer.

280. *First Method.* **To measure the electromotive force, E, of a battery, with the tangent galvanometer.**[4]

Calling the E.M.F. of the battery under test E, and its

[4] For description of the instrument and its use, see § 151.

resistance f; and the corresponding properties of the standard cell used for comparison E' and f';

First, observe the deflection a'°, produced by the standard cell through the galvanometer alone, the resistance of which is g. If the departmental tangent galvanometer be the instrument employed, use the thin coil.

Second. Observe the deflection a°, produced by the battery under test, through the same coil and a suitable external resistance W.[1]

Then—

$$E = \frac{\tan a^{\circ}}{\tan a'^{\circ}} \cdot \frac{f + g + W}{f' + g} E'.*$$

[1] With the Departmental Tangent Galvanometer, W may = 2,000 ohms.

* For proof of this formula, see Solution XV. App. B.

Second Method, with the Wheatstone Bridge.

281. *Second Method.* **To measure the electromotive force, E, of a battery, with the Wheatstone bridge** (Poggendorff).

The circuit is arranged in precisely the same way as that represented in fig. 66, para. 270.

When balance is obtained, no current flows through the branches x and g of the bridge, but follows the circuit composed of A, W, and f. From the same observations which are made to measure the resistance of the battery, its electromotive force is calculated by the following formula:

$$E = \frac{A - A'}{W - W'} + 1.\dagger$$

† For proof of this formula, see Solution XVI. App. B.

Third Method, with any Galvanometer.

282. *Third Method.* **To measure E, the electromotive force of a battery, in terms of that of the standard cell, e, with any galvanometer.**

First join the battery to be tested in circuit with the galvanometer, g, and a certain resistance, W; and note the deflection produced.

Then replace the battery by the standard cell and adjust the resistance until a value, W', is found, when the same deflection is obtained.

Then, by Ohm's law—

$$\frac{E}{e} = \frac{g + f + W}{g + f' + W'}$$

(f and f' being the resistances of the battery and standard cell respectively).

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$$\therefore E = \frac{g + f + W}{g + f' + W'} e;$$

Or, as e is the standard of unity—

$$E = \frac{g + f + W}{g + f' + W'}*$$

The above simple plan has the merit of being practicable when only a galvanoscope is available.

* Where g and W are very large compared with f, the latter may be neglected.

Fourth Method, the same with a Shunt.

283. *Fourth Method.* **The same when a shunt is necessary** to bring the deflection produced by the stronger battery within readable limits.

In this case, the expression g in the first circuit described in the preceding para. becomes $\frac{g\,s}{g+s}$ (s representing the resistance of the shunt), according to the law of derived circuits,[1] and the value of the deflection is multiplied by $\frac{g+s}{s}$, the multiplying power of the shunt.[2]

Thus :

$$E = \frac{\frac{g\,s}{g+s} + f + W}{g + f' + W'} \times \frac{g+s}{s}$$

[1] Law 8, App. A.

[2] § 159.

Fifth Method (Wheatstone's).

284. *Fifth Method.* **To measure the electromotive force of a battery by Wheatstone's system.**

The battery, whose electromotive force E is to be measured, is joined up with a galvanometer; resistance being inserted, if necessary, to produce a convenient deflection, say $a°$, which is noted.

Resistance (W) is then added until the deflection is reduced to $b°$, which reading is also noted.

Now replace E by e (the electromotive force of the standard cell), and adjust the resistance in circuit so as to reproduce the first deflection ($a°$).

Then add resistance (W') until the second deflection ($b°$) is reproduced.

From Ohm's law it is obvious that—

$$\frac{E}{e} = \frac{W}{W'}$$

Or, as e is taken as unity, being the standard of comparison—

$$E = \frac{W}{W'}.$$

Sixth Method, by opposing equal Electromotive Forces.

285. *Sixth Method.* **To measure the electromotive force of a battery by opposing to it a battery of equal electromotive force.**

Connect the poles of the battery to be tested with the terminals of a galvanometer.

Then into this circuit insert cells of known electromotive force, with their poles in the opposite direction to those of the battery under comparison, adjusting their number until the deflection of the galvanometer is reduced to zero.

Then, obviously, the electromotive force of the battery under test is equal to that of the cells inserted.

Seventh Method (Poggendorff's).

286. *Seventh Method* (Poggendorff's). **To measure the electromotive force E of a battery by opposing e, that of a standard cell or cells.**

Join the poles of the battery to be tested (E) to an adjustable resistance W.

To the terminals of W connect also another circuit, consisting of a galvanometer, G, and a battery of smaller electromotive force e (generally 1 cell), with its poles reversed to those of E, as shown in the following figure :

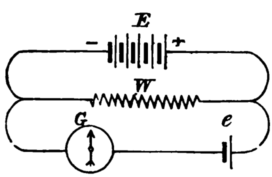

FIG. 69.

Now, the direction of the currents of both batteries is the same through W, but opposite through G. W forms a shunt, by adjusting which the amount of current from E, flowing through G, can be regulated. By increasing W, therefore, the deflecting current of E can be reduced to that of e, when the needle will stand at zero ; in which case—

$$\frac{E}{F+\frac{(g+f)}{W+g+f}}$$

(the strength of current from E, whose resistance is F) is equal to—

SECTION F.

$$\frac{e}{f+g+\frac{FW}{F+W}}$$

(the current strength of e, whose resistance is f, the resistance of the galvanometer being g).

Whence—

$$E \cdot \frac{fF+fW+gF+gW+FW}{F+W} = e \cdot \frac{FW+gF+fF+gW+fW}{W+g+f}$$

$$\therefore\ E = e \cdot \frac{F+W}{W+g+f}.$$

Eighth Method, with a Reflecting Galvanometer.

287. *Eighth Method.* **To measure the electromotive force, E, of a battery by means of a reflecting galvanometer.**

First join the standard cell e in circuit with the galvanometer g and a certain resistance W, adjusted so as to cause a readable deflection, $a°$.

Then replace the standard cell by the battery E, and observe the deflection produced, $b°$.

Now, from the principle of the reflecting galvanometer,[1] the deflections $a°$ and $b°$ are proportional to the strength of current in the first and second circuits respectively, i.e.

$$\frac{e}{g+W+f} = a° \ \& \ \frac{E}{g+W+F} = b°$$

$$\therefore\ \frac{E}{e} \cdot \frac{g+W+f}{g+W+F} = \frac{b}{a}.$$

$$\text{And } E = e \cdot \frac{g+W+F}{g+W+f} \cdot \frac{b}{a}.$$

Or if, as is probable, it be necessary to shunt the galvanometer in the second case (with the larger battery E), to keep the deflections within readable limits,

The expression g in the numerator becomes $\frac{gs}{g+s}$, and the value of the deflection $b°$ is multiplied by the coefficient of the shunt $\frac{g+s}{s}$.*

[1] § 156.

* § 159.

Regular Tests of Batteries.

288. Batteries are tested daily. When first set up, each cell is tested in the battery room, both for resistance and electromotive force, by one or other of the methods described in the preceding paragraphs, according to the apparatus available.

As the electromotive force of the Minotti reaches its full extent immediately chemical action takes place in the cell and remains constant, it becomes necessary to measure the resistance only in taking the regular daily tests of working batteries.

When the cells have been short-circuited[1] a sufficient time to have reduced their resistance to the standard required for the purpose to which they are to be applied, they are joined up together and the whole battery is tested in the battery room.

The operation is then repeated in the instrument room, and if the additional resistance of the leading wires makes no appreciable difference (as it should not, these wires being always as short as possible), further tests are continued at the commutator.

In order that they may be made as expeditiously as possible, and that the whole of the office connections may be included in the circuit, it is generally arranged as follows :

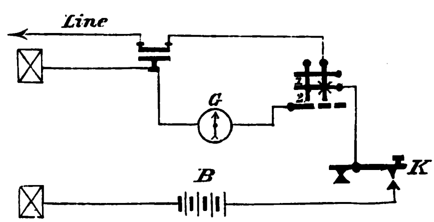

FIG. 70.

The galvanometer *G* is joined up between the testing bar of the commutator and the lower plate of the lightning discharger, by which it is connected with the earth.

B and *K* represent any line battery and signalling key joined up in the ordinary circuit for *S* working.[2]

In order to close the circuit of the line battery *B*, it is only necessary to throw off the line by removing the commutator screw in *X* and replacing it in *1*.

Then insert a plug in *2*.

On depressing the key *K*, the battery current traverses the leading wires, key, commutator, galvanometer, and

[1] § 19.

[2] § 180.

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lightning discharger earth, thence returning through the battery earth to the zinc pole of the battery *B*.

As the natural tendency of working batteries is to fall in resistance according to the consumption which goes on, any sudden rise in resistance should be at once checked by a test in the battery room, with a view to discovering whether the increased resistance is due to an imperfect contact, or to a defect in one of the leading wires.

If to neither, it will probably be traceable to one of the causes mentioned in paras. 221, 222 (sec. **E**).

Strength of Current arriving at distant Station.

289. The design of a line battery being the production of a current which shall work a receiving instrument at the distant end of a telegraph line, it is of obvious importance that the strength of the *arriving* current should be known, for as the insulation of no line can be absolutely perfect, the loss of current along it, due to leakage, must always render the received current less than that which leaves the battery at the transmitting end.

The unit current, that is, the standard by which currents are measured, has been already described as the *Ampère* or *Oerstedt*,[1] such being the current produced by 1 volt (the unit of E.M.F.) through 1 ohm (the unit of resistance).

As signalling currents, however, never exceed more than a few thousandths of an oerstedt in strength, it is more convenient to express them in thousandths or millioerstedts (moe).[2]

It is found in practice that Siemens' relays work best with a current of from 3 to 5 moe.

The minimum arriving current is thus fixed at 3 moe; and when found to be less than that strength the sending station is instructed to increase battery power, or if this fails to bring the current up to 3 moe, an intermediate station is called in to translate or repeat.

4 moe is considered **the average**, and **5 moe** the **maximum arriving current.**

If a current is received stronger than the maximum, the sending battery is reduced until the current arriving falls to about 4 moe, the average.

Measurement of received Currents.

290. The process by which these values of the strength of received currents is determined may be described as follows :

[1] Def. 2.

[2] Def. 2 and 34.

Remembering that the current produced by 1 volt through 1 ohm is called an oerstedt; that is

$$\frac{1\ volt}{1\ ohm} = 1\ oerstedt;$$

and that the E.M.F. of a Minotti cell is so nearly equal to 1 volt that it is always taken as such;[1] it follows that—

[1] § 43.

$$\frac{No.\ of\ cells}{Res.\ in\ circuit} = strength\ of\ current\ in\ oerstedts;$$

Or—

$$\frac{No.\ of\ cells}{Res.\ in\ circuit} \times 1{,}000 = \quad do. \quad in\ millioerstedts.$$

For example, the current from 1 cell through 300 ohms, i.e.:

$$\frac{1\ volt}{300\ ohms} = 0{\cdot}0033\ oerstedts$$

or 3·3 *millioerstedts.*

The current c arriving through any line is measured as follows, by means of the departmental tangent galvanometer:

First, to form a standard of comparison, the current c' of the standard cell is measured through the amount of resistance, w, necessary to produce, through the galvanometer, g (thin coil), a deflection of 45°, whose tangent is unity.

$$\text{Supposing } W = 300$$
$$g = 100$$
$$f = 20\ (res.\ of\ cell)$$

$$\text{Then } C' = \frac{1}{420} = 0{\cdot}0023\dot{8}\ oerstedts$$
$$= 2{\cdot}3\dot{8}\ moe,$$

which may be called the constant of the galvanometer; and this fixed value of c' representing the strength of the constant current, in moe, has only to be multiplied by the tangent of the deflection ($a°$), produced (in the same instrument, of course) by any arriving current, to determine c, the strength of that current in moe.

For, on the principle of the tangent galvanometer—

$$\frac{C}{C'} = \frac{tan\ a°}{tan\ 45°} = \frac{tan\ a°}{1}$$

$$\therefore\ C = C'\ tan\ a°.$$

Now suppose, for example, the deflection $a°$ in the above case to be 50°.

Then c (the strength of the arriving current producing this deflection),

$$= C' \tan 50°$$
$$= 2{\cdot}38 \times 1{\cdot}192 \text{ moe}$$
$$= 2{\cdot}94 \text{ moe.}$$

Thus, the value of any arriving current is at once calculated from its deflection on the tangent galvanometer.

Again:

The constant value of c' for any galvanometer being determined, it is easy to calculate the deflections which will correspond to any given strength of arriving current in moe.

For as

$$\frac{C}{C'} = \frac{\tan a°}{1}$$

it follows that in *the case of a current of* 3 *moe*,

$$\frac{3}{2{\cdot}38} = \tan a°$$

$$\therefore \tan a° = 1{\cdot}26,$$

which will be found from a table of tangents to represent an angle of 52° (nearly).

Similarly for a current of 4 *moe*,

$$\frac{4}{2{\cdot}38} = \tan a°$$

$$\therefore \tan a° = 1{\cdot}68,$$

which is the tangent of 59° (about).

And for a current of 5 *moe*,

$$\frac{5}{2{\cdot}38} = \tan a°$$

$$\therefore \tan a° = 2{\cdot}1,$$

which is the tangent of 65° (nearly).

Thus the galvanometer whose constant is 2·38 moe, as described above, would indicate an arriving current of

3 moe	*by a deflection*	*of*	*52°*
4 moe	,,	,,	*59°*
5 moe	,,	,,	*65°*

In taking these measurements, the galvanometer is inserted between the receiving instrument and the earth.

Line testing by Strength of received Currents.

291. The system of measuring received currents is extensively adopted in England, where it is used as a means of estimating the insulation of the various lines.

The resistance of each line, and the E.M.F. of the battery used to work through it, being known, the maximum current which can possibly be received is at once ascertained by dividing the latter by the former: e.g. suppose a battery of 10 cells to be used to work a circuit of 1,000 ohms; here—

$$C = \frac{10}{1,000} = 0\cdot01 \text{ oerstedts}$$

Or *10 millioerstedts*

which may be called the standard current of that circuit, i.e. the current arriving when the insulation of the line is absolutely perfect; and any falling off from the standard current (provided the battery is in order) must be due to leakage along the line—the greater the leakage, the greater being the falling off of the strength of the arriving current from the standard value; thus the ratio between the arriving current and the standard forms a comparative measure of the state of insulation of the line.

Regular Testing of Lines.

292. In India, however, where a more perfect knowledge of the electrical state of the lines is required, to afford data whereby faults occurring in long sections may be localised electrically, **regular tests** of the actual conduction and insulation resistance of the lines are periodically made and recorded; whereby also the normal condition of the line is constantly under observation, and a means is thus afforded of often detecting irregularities before they develop themselves into faults which would interrupt communication.

Bridge used for Testing.

293. The instrument universally used for regular testing is the Wheatstone's bridge, described in para. 164.

The following figure represents the apparatus with the connections and switches used for line testing.

1 is a key by means of which the testing current can be made to enter the bridge at *m*.

U is a battery reverser, by plugging *2* and *3* of which,

SECTION F.

the copper pole of the testing battery *E* is connected to *m* of the bridge.

A zinc current is applied by changing the plugs to *4* and *5*.

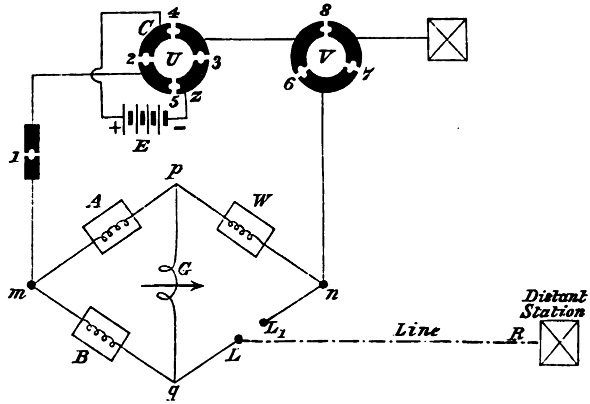

FIG. 71.

V is a switch by means of which the point *n* of the bridge is connected either to the earth (plug in *7*), or to the battery (plug in *6*), or to both battery and earth (plugs in *7* and *8*).

Adjustment of Testing Battery.

294. Another switch *S* (shown separately in fig. 72) is often inserted between the block (*Z*) of the battery reverser *U*, and various zinc poles of the testing battery (e.g. the 1st,

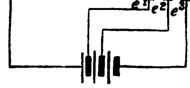

FIG. 72.

10th, and 30th), so that by inserting a plug in e^3 the E.M.F. of the whole battery of 30 cells is applied, as required for measurement of lines and other high resistances.

By changing the plug to e^2 the testing battery is reduced to 20 cells, for the measurement of lower resistances.

When the plug is changed to *e'*, then only one cell is in circuit, forming a suitable battery for measuring very low resistances.

Mode of connecting Lines to be tested with the Bridge.

295. It has been explained in para. 245 how any ordinary metallic resistance x, joined up between the terminals L and L' of the bridge, can be measured.

The resistance of a telegraph line is measured in precisely the same way.

The end of the line at the testing station is joined to L of the bridge: the farther end, although it cannot be brought back direct to the L' terminal, is practically joined thereto by using the earth as a return wire.

This is effected by connecting the distant end to the earth, as shown in fig. 71, the return circuit to L' being completed through the earth at the testing station joined to the switch V, thence through the plug *7* to n and L' of the bridge; a plug being inserted in either *8* or *6* to connect the testing battery with the earth.

The Conduction Test.

296. Thus in the above circuit the resistance between the points L and L' (to be measured) is that of the line alone, the earth resistance being so small in comparison that its value may be neglected.[1]

The above measurement constitutes what is called the **Conduction Test**, denoted by the letter $\mathfrak{w}$.

Thus when balance is obtained—

$$\mathfrak{w} = \frac{B}{A} W.$$

[1] §§ 177 and 178.

The Circuit Test.

297. If the distant station inserts a relay between the line and the earth at the point R (fig. 71), the resistance under measurement between the points L and L' comprises that of the line and relay, the measurement of which constitutes the **circuit test**, denoted by the letter $\mathfrak{W}$.

The Insulation Test.

298. If, however, the distant station throws off earth by insulating the end of the line, then the return circuit to L' is altered, being no longer completed simply through the resistance of the line wire and the insignificant resistance between the earth-plates, but through each point of leakage of the line to the testing office earth.

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The measurement in this case is that of the resistance of the *insulators*, that of the wire being comparatively insignificant in the case of a short well-insulated line.

This measurement, which is called the **insulation test**, is denoted by the letter $\mathfrak{I}$.

Objects of the Circuit Test.

299. Thus:

$\mathfrak{w}$ shows the *measured* conductor resistance of the line.

$\mathfrak{I}$ the *measured* insulation.

$\mathfrak{CW}$ represents the *measured* resistance of the line and distant relay together; and by the difference, $\mathfrak{CW}-\mathfrak{w}$, affords a measure of the resistance of the relay itself.

Measured Relay Resistance an indication of the state of Insulation of the Line.

300. This, however, is not the only object of the circuit test, its most important use being that the measured value of the relay *R*, as shown by the difference between $\mathfrak{CW}$ and $\mathfrak{w}$, forms a valuable criterion as to whether the measured values of $\mathfrak{w}$ and $\mathfrak{I}$ are correct.

For if $\mathfrak{CW}-\mathfrak{w}$, as found by the difference between the measured values of the circuit and conduction tests, be exactly equal to the known resistance of the relay inserted at the distant end, then it follows that $\mathfrak{w}$ represents the correct conductor resistance of the line.

This, however, is only the case when the insulation of the line is very high. When the reverse is the case, the testing current is shunted by the derived circuits formed at each point of leakage, so that only a portion of it arrives at the distant end; the greater this leakage, the more nearly will the value of $\mathfrak{w}$ correspond with that of $\mathfrak{CW}$; in other words, the smaller will be the measured resistance of the relay.

Thus it is that the measured value of the relay affords an indication as to whether the measured resistance $\mathfrak{w}$ represents the real conductor resistance of the wire, or that of a derived circuit made up of the wire and the paths of leakage.

In the same way, the measured value of $\mathfrak{CW}-\mathfrak{w}$ is a check on the correctness of $\mathfrak{I}$, the measured insulation of the line; for if the measured resistance of the relay is much less than its actual known resistance, it shows that the difference is due to escape of the current along the line, and this may be so great that $\mathfrak{I}$ may not be a measure of the insulation merely, as it should be, but that the actual resistance of the wire may be so considerable in comparison with the insulation that it cannot be neglected.

Correction of the measured Values rendered necessary by defective Insulation.

301. In the above cases the values of $\mathfrak{I}$ and $\mathfrak{w}$ both require *correction*: and the measured relay $\mathfrak{CR} - \mathfrak{w}$ not only points out when this is necessary, as explained above, but, by the proportion it bears to the actual known value of the relay, forms the basis on which the formulæ for corrected values are calculated, as described in paras. 311–315.

Order of Observations made in regular Testing.

302. The regular tests of lines embrace the three measurements described above, which are made in the following order:

I.	Circuit. . . .	$\mathfrak{CR}$
II.	Conduction . . .	$\mathfrak{w}$
III.	Insulation . . .	$\mathfrak{I}$

Adjustment of Branch Resistances of Bridge.

303. In taking the measurements of the circuit and conduction tests, equal branches are used in the bridge, *A* and *B* being usually made 1,000 each, as the resistance of telegraph lines under test is generally between 1,000 and 10,000 units.

For the insulation test, however, where the absolute insulation resistance of the line is often greater than 10,000 (the maximum resistance of the comparison coil *W*), it is necessary to adjust the branches *A* and *B*, so as to gain a multiplying power; *B* being made 1,000 and *A* 100, when the absolute insulation resistance of the line is between 10,000 and 100,000 units, in which case the resistance unplugged in *W* is multiplied by 10; or, when the resistance to be measured is greater than 100,000, $\frac{B}{A}$ is made $\frac{1{,}000}{10}$, in which case the resistance unplugged in *W* is multiplied by 100.

Routine of Testing.

304. The testing officer, before taking the circuit test, informs the distant station by the signal '*circuit*,' which is replied to by the *resistance marked on the relay in circuit.*

Before the conduction test is taken, the signal '*Conduction—minutes*' is sent, which is acknowledged by *the readings of the wet and dry bulb thermometer.*

The signal '*Insulation—minutes*' is then given, and acknowledged by *the state of the weather* at the distant station.

Relay Resistance.

305. The importance of knowing the actual resistance of the relay included in the circuit test, for comparison with the measured value $\mathfrak{CR} - \mathfrak{w}$, has already been explained in para. 300.

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Reduction of Resistances to corresponding Units.

306. If the resistance given by the distant station be expressed in B.A. units, and the comparison coil used for measurement be composed of resistances in Siemens units (as is the case with most, if not all, of the bridges used in the department), it is necessary to reduce the B.A.U. to S.U. by multiplying the former by 1·0456, as 1 ohm or B.A. unit = 1·0456 S.U.[1]

Reduction of Resistances to corresponding Temperatures.

307. The resistances marked on telegraph instruments represent their value at 80° Fahrenheit, and as copper wire increases in resistance about ·21 per cent. with each degree of temperature (Fahrenheit), it is necessary when accuracy is required to reduce the marked resistances to their corresponding value at the actual time of test.

This is done by the following formula :

$$R_t' = \left\{ \frac{1 + (t' - 32)\,a}{1 + (t - 32)\,a} \right\} R_t *.$$

In the above :

R_t' = Resistance at temperature t'.
R_t = „ „ t.
a = ·0021, the coefficient of increase of resistance of copper for each degree (F.) of temperature.

Positive and Negative Readings differ owing to Natural Currents.

308. The three measurements, viz. 𝔚𝔚, 𝔴, and 𝔍, from which the electrical condition of the line is known, are all taken with positive and negative currents, the difference between the + and − readings representing a measure of the strength of the natural currents existing in the line.[2]

Calculation of measured Resistances allowing for the Effect of Natural Currents.

309. Expressing by w' the resistance unplugged in the comparison coil w to obtain balance when testing with a positive current, and w'' the resistance unplugged when a negative current is used, if the difference between w' and w'' is small their mean is taken, i.e. :

$$x = \frac{B}{A} \cdot \frac{w'' + w'}{2}$$

and e, the electromotive force of the natural current, is considered *nil.*

Rule.—The difference between w' and w'' is considered small when less than 20% for resistances under 1,000 units,

or less than 15% for resistances under 5,000 units
„ , 10% „ „ over 5,000 „

[1] Appendix VIII. Vol. I. Testing Instructions, contains a useful table in which the operation is already performed for corresponding values between 1 and 100 units.

* For proof of this formula, see Solution XXXVII. App. B.

[2] § 267 and Def. 29.

When the difference is greater than stated above, and e is sufficiently large to be a multiple (N) of E, the electromotive force of the testing battery $e = NE$, and the following formula is used for the calculation of x, the resistance to be measured:

$$x = \frac{w'' + w'}{2} - N\frac{w'' - w'}{2} \; *$$

the value of N being as under:

$$N = \frac{w'' - w'}{w'' + w' + 2(A + 2f)}. \dagger$$

* In this formula the branches A and B are supposed to be equal.

† f being the resistance of the battery. For proof of these formulæ, see Solution XVII. App. B.

Electromotive Force of the Natural Current.

310. When the strength of the natural current is considerable, as in the last case, its electromotive force e is calculated in terms of the testing battery E, and expressed by the following formula:

$$e = \frac{w'' - w'}{w'' + w' + 2(A + 2f)} E. \ddagger$$

‡ For proof of this formula, see Solution XVIII. App. B.

The above calculations are only made in the case of the *circuit* and *conduction* tests.

The simple mean of positive and negative readings is always taken in the case of the insulation measurements, for, as the distant end of the line is disconnected from the earth, the difference between w' and w'' is likely to be the result more of electrolytic action [1] than of natural currents.

Correction of measured Values.

311. It has been explained, in para. 300, that in the case of *perfect* insulation, $\mathfrak{W} - \mathfrak{w}$ (the difference between the measured circuit and conduction resistances) is equal to R, the actual resistance of the relay in circuit, in which case the measured values may be accepted as correct, but in proportion to the leakage of the line, so does $\mathfrak{W} - \mathfrak{w}$ become less than R.[2]

To discover, therefore, whether corrections are necessary, the first thing to do is to compare $\mathfrak{W} - \mathfrak{w}$ with R, the actual resistance of the distant relay.[3]

If $\mathfrak{W} - \mathfrak{w} = R$, or very nearly, and at the same time the insulation is so great that the conduction resistance can be neglected against it, that is, in practice, say when $\frac{\mathfrak{J}}{\mathfrak{W}} > 36$, the measured values suffice, and no corrections are necessary.

[1] § 242 (*d*).

[2] By an error of observation, $\mathfrak{W} - \mathfrak{w}$ may be greater than R by a few units in the case of high insulation; but if under other circumstances, or if greater by many units, the test should be rejected.

[3] Reduced to temperature of test; see § 307.

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Corrected Relay Resistance a Test of Uniformity of Line.

312. When the above, however, is not the case, g, the corrected value of the measured relay resistance, is calculated by the following formula:

$$g = \frac{\mathfrak{I}(\mathfrak{CW} - \mathfrak{w})}{\mathfrak{I} - \mathfrak{CW}}.^{*}$$

* For proof of this formula, see Solution XIX. App. B.

As the above formula is based on the supposition that the electrical condition of the line is uniform throughout its length, it becomes, conversely, by its approximation to R (the actual value of the relay), a criterion of the uniformity of the line.

Thus, if the value found for g agree within 15% of R (at temperature of test), the line may be considered uniform, and the resultant fault, consequently, at the centre of conduction, i.e. $l = l'$ (l and l' representing the conduction resistance from testing station to resultant fault, and from resultant fault to distant station respectively), as explained in Solution XIX. App. B.

Correction of measured Values of 'Conduction' and 'Insulation' in the case of a uniform Line.

313. In this case, the **actual corrected insulation resistance** of the line (i) is found by the following formula:

$$i = \sqrt{\mathfrak{I}\,(\mathfrak{I} - \mathfrak{w})}\ \dagger$$

and $\qquad iM = j$ (the corrected insulation per mile)

† For proof of this formula, see Solution XXI. App. B (footnote).

and the **corrected conductor resistance** (L) of the same line, by the following:

$$L = 2\{\mathfrak{I} - \sqrt{\mathfrak{I}\,(\mathfrak{I} - \mathfrak{w})}\}\ \dagger$$

and

$$K = \frac{L}{M}.$$

Resistance per Mile expressed in reduced Length.

314. Or, expressing the same in terms of **reduced length**, the convenience of which will be understood from the remarks which follow:

$$rm = KM = L,$$

Whence

$$r = \frac{L}{m};$$

m representing the reduced length in miles
r " " " per mile
K " average conduction resistance per mile
M " actual length in miles;

and, denoting by q the ratio $\frac{M}{m}$, i.e. the **average gauge** of the wire of which the line is composed,

$$K=\frac{r}{q}.$$

The plan of expressing the average conduction resistance per mile of the whole line in reduced length—i.e. in terms of No. 1 wire (Indian Iron Wire Gauge)—is most convenient for comparing the results of regular tests when a knowledge of the average only is required, but is not a sufficient record from which to calculate the distance of faults, unless it so happen (which is rarely, if ever, the case) that the whole line is composed of wire of the same gauge.

For the localisation of faults it is necessary to know the reduced length of *each* gauge, which is found by dividing its length by its I.W. gauge.

Thus the reduced length of a section containing two miles of No. 1 wire I.W.G. would be $\frac{2}{1}=2$; and to find M, the reduced length, of a line containing various gauges, a', a'', a''', &c. (expressed by their numbers according to the I.W.G.), of lengths l', l'', l''', &c. respectively,

$$M=\frac{l'}{a'}+\frac{l''}{a''}+\frac{l'''}{a'''}+\text{\&c.}$$

It is most important that the various lengths and gauges of wire in every line that is tested should be accurately known; which with their corresponding reduced length should be recorded.

The following will be found a convenient form :

LINE NO. —— FROM —— TO ——.

Order of sections and gauge of wire (I.W.G.) (a)	Actual length of section (l)	Actual distance to end of section (λ)	Reduced length of section ($m=\frac{l}{a}$)	Reduced distance to end of section (μ)
50	177·666	177·666	3·5533	3·5533
24	9·250	186·916	0·3854	3·9387
6	6·048	192·964	1·0080	4·9467

This table shows at once in case of a fault (the conduction resistance to which (L) has been found) in what section the fault lies, for

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$$r\left\{\begin{matrix}\text{reduced distance}\\ \text{to the fault}\end{matrix}\right\}=\frac{L}{M}$$

from which n (the actual distance) is calculated, by the formula explained in para. 323 on 'Fault Testing.'[1]

Measured Values, how corrected in the case of a line not uniform in Insulation and Conduction.

315. If the value found for g (para. 312) is not within 15 per cent. of R, it proves that the line is ***not uniform*** in

[1] To find r, the *actual* resistance per mile, of any particular section of wire, of length l, and diameter d, in a line made up of various lengths, l, l', and diameters d, d', from x, the measured absolute conduction resistance of the whole line,

$$r=\frac{\frac{x}{d^2}}{\frac{l}{d^2}+\frac{l'}{d'^2}}.$$

For, as the resistance of any wire is inversely proportional to the square of its diameter [App. A, Law 11 (ii)], the resistance of any section

$$l=\frac{\frac{l}{d^2}}{\frac{l}{d^2}+\frac{l'}{d'^2}}.x;$$

whence, the per-mile resistance of the same section

$$r=\frac{\frac{l}{d^2}}{\frac{l}{d^2}+\frac{l'}{d'^2}}.\frac{x}{l};$$

$$\therefore r=\frac{\frac{lx}{d^2}}{\left(\frac{l}{d^2}+\frac{l'}{d'^2}\right)l};$$

$$\therefore r=\frac{\frac{x}{d^2}}{\frac{l}{d^2}+\frac{l'}{d'^2}}.$$

Similarly, for any other length l', of diameter d',

$$r'=\frac{\frac{x}{d'^2}}{\frac{l}{d^2}+\frac{l'}{d'^2}};$$

or, in a line composed of any number of sections of wire, of diameters

d, d', d'' . . . . . . &c.

of lengths

l, l', l'' . . . . . . &c.

to find the per-mile resistance of any particular gauge, it is only necessary to divide x by the product of d^2 (the square of the diameter of that particular gauge), and a constant C (C being the sum of all the lengths divided by the squares of their respective diameters), i.e.

$$C=\frac{l}{d^2}+\frac{l'}{d'^2}+\frac{l''}{d''^2}+\ .\ .\ .\ .\ \&c.$$

insulation and conduction, the measured values for which are therefore corrected by the following general formula, in which want of uniformity is taken into account :

$$i = \sqrt{\frac{(\mathfrak{J} - \mathfrak{W})(\mathfrak{J} - \mathfrak{w})R}{\mathfrak{W} - \mathfrak{w}}}\ *$$

* For proof of this formula, see Solution XX. App. B.

and j (the insulation per mile) is found by multiplying i (the absolute insulation) by M (the actual length of the line),

And
$$L = \mathfrak{J} + \frac{(\mathfrak{J} - \mathfrak{W})R}{\mathfrak{W} - \mathfrak{w}} - 2i.\dagger$$

† For proof of this formula, see Solution XXI. App. B.

K being found by dividing L (the absolute conduction resistance) by m (the *reduced* length of the line).[1]

[1] Def. 38.

Displacement of resultant Fault.

316. If the value of the corrected relay g (para. 312) be *greater* than R, the resultant fault is *beyond* the centre of conduction ; if g be *less* than R, the resultant fault is *nearer* (towards the testing station) than the centre of conduction.

Localisation of resultant Fault.

317. The real conduction resistance (l) of the line, from the testing station to the resultant fault, is found by the following formula :

$$l = \mathfrak{J} - i\ \ddagger$$

‡ For proof of this formula, see Solution XIX. App. B.

$\frac{l}{K}$ representing its distance in miles.

Or, calculated from the measured values,

$$l = \mathfrak{J} - \sqrt{\frac{(\mathfrak{J} - \mathfrak{W})(\mathfrak{J} - \mathfrak{w})R}{\mathfrak{W} - \mathfrak{w}}}.\S$$

§ See Equation (3), Solution XIX.; also Solution XX. App. B.

Further, the position l and the resistance z of the resultant fault can be found by the following formulæ :

$$l = \frac{\Sigma\left(\frac{r}{y}\right)}{\Sigma\left(\frac{1}{y}\right)}\ \|$$

$$z = \frac{1}{\Sigma\left(\frac{1}{y}\right)}\ \|$$

‖ For proof of these formulæ, see Solution XXII App. B.

y representing the resistance of any fault ;

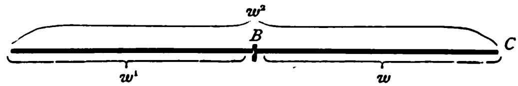
r being the conduction resistance from the testing station to the fault.

Section Tests.

318. The conduction and insulation of separate sections of the same line may be calculated from measurements

SECTION F.

made at one end of the whole line by the following formulæ :



In the above figure *A C* represents a line consisting of two sections *A B* and *B C*.

Let $\mathfrak{I}_1$ and $\mathfrak{w}_1$ represent the measured insulation and conduction respectively of the section *A B*;

and $\mathfrak{I}_2$ and $\mathfrak{w}_2$ the same for the whole line, joined direct at *B* ;

and $\mathfrak{I}$ and $\mathfrak{w}$ the required corresponding values for the distant section *B C*.

Then, in the case of an imperfectly insulated line, the measured values of which require correction,

$$\mathfrak{w} = \frac{\mathfrak{I}_1 (\mathfrak{w}_2 - \mathfrak{w}_1)}{\mathfrak{I}_1 - \mathfrak{w}_2} *$$

$$\mathfrak{I} = \frac{\mathfrak{I}_1 (\mathfrak{I}_2 - \mathfrak{w}_1)}{\mathfrak{I}_1 - \mathfrak{I}_2} *$$

* For proof of these formulæ, see Solution XXIV. App. B.

Or when the measured values suffice,

$$\mathfrak{w} = \mathfrak{w}_2 - \mathfrak{w}_1 \dagger$$

And

$$\mathfrak{I} = \frac{\mathfrak{I}_1 \mathfrak{I}_2}{\mathfrak{I}_1 - \mathfrak{I}_2} \dagger$$

† For proof of these formulæ, see Solution XXIII. App. B.

Fault Testing.

319. The **faults** to which the line circuit is liable[1]—viz. 'disconnections,' 'earths,' and contacts, total or partial, are also common to the circuit of the office, including batteries, instruments, earths, or connecting wires ; the *first step* to be taken, therefore, on the existence of a fault becoming known, is to ascertain whether it is in any part of the office circuit, i.e. in the *batteries*, *instruments*, *connecting wires*, or *earth plates*, or whether it is on *the line*, i.e. that part of the circuit exterior to the terminal post of the office.

[1] § 241.

To discover whether Fault is in Office.

320. To ascertain this : *First.* Close the front contacts of the signalling key by means of a lead pencil or the blade of a penknife, without depressing the handle ; so that contacts

1 and *2* of the key are both closed together.[1] If the sounder works, it shows that there is no fault in the back contact of the key, nor in the relay coils, nor in the circuit in which they are joined, and that the relay contacts and every part of the local circuit are in order.[2]

Second. Take a regular test of the line battery at the commutator, as explained in para. 288. If the deflection agrees with the regular readings recorded, it proves that there is no fault in the battery, earth-plates, key, switch, or contacts *1* and *2* of the commutator, nor in any of the wires connecting them.[3]

Third. Replace the commutator screw as usual, for working; disconnect the wire between the testing bar of the commutator and the galvanometer, and join that terminal of the galvanometer by a direct wire to the line at the terminal post.[4]

Then depress the key; if the deflection now observed agrees with the former reading, it proves that the continuity of the working bars of the commutator and that of the upper plate of the lightning discharger, and of the leading wire therefrom to the terminal post, is perfect, and that there is no fault in any part of the office circuit between the earth-plate and the terminal post.[5]

Nature of Line Faults and their distinguishing Features.

321. The line must therefore be tested for *earth*,[6] *contact*,[6] or *discontinuity*,[6] as the case may be.

Any or all of these classes of faults may occur together; for example, a line may be broken, its ends to earth, and the wire in contact with a working line. It must, therefore, first be decided which class of fault to test for.

The case of a *contact*, when the signals of one line are shown upon another, is sufficiently clear to distinguish it from *earth* or *disconnection.*

The tester should, however, be sure that the duplicate signals are due to contact and not to induction, which can be ascertained at once by depressing the key on one line; if the signal produced on the instrument of the other line continues so long as the key is depressed, there is contact; but if the signal is only a transient one, observed at the instant of depressing and releasing the key, then induction is the cause.[7]

A *discontinuity*, however, in the case when both ends of the broken wire rest on the ground, is liable to be mistaken

1 Fig. 45, § 180.

2 Fig. 46, § 181.

3 Fig. 70, § 288.

4 The other terminal of the galvanometer remains joined to earth through the lower plate of the lightning discharger, as before.

5 Where a good line enters the office, as well as the faulty line, the first step taken may be simply that of looping the two wires at the terminal post. If perfect signals can be exchanged between the instruments of these lines, the complete office circuit must be in order, and the fault is on the line. If the contrary be the case, the fault is *most probably* in the office, and should be traced by the processes described above. If not actually in the office, it will be found close to it.

6 See § 241, Section E.

7 § 118.

SECTION F.

for an *earth* fault, for the result may be that the measured conduction resistance to the fault is even less than the normal value of the whole line, instead of being greater, as would be the natural result of a more or less insulated break.

It then becomes necessary to loop the faulty wire with a good line at the distant station, and to measure the resistance of the loop without any earth on the bridge.

If the resistance of the loop be higher than the normal conduction resistance of the wires, then the fault must be *discontinuity with earth*; but if it agree with the normal resistance, the fault is probably *earth* alone.

The latter result, however, might occur in the case of a broken wire, the ends of which made *perfect*, i.e. *dead earth* at the fault, which in this case would itself offer no resistance.

It would, however, give rise to a strong natural current of polarisation, which would distinguish it from earth on an unbroken wire.[1]

General principle on which Faults are localised: (1) In a Line of uniform Gauge.

322. **To find the distance,** n, **of a fault** from the testing station, it is necessary first to measure the absolute conduction resistance, x, of the line up to the fault; and in the case of a line of uniform gauge simply to divide this by K, the average resistance per mile;

Thus:
$$n = \frac{x}{K} \text{ miles.}$$

(2) In a Line composed of Wires of various Gauges.

323. In the case of a **line composed of various gauges,** however, the *reduced length* to the fault must be found by dividing x by r, the *reduced* conduction resistance per mile.[2]

This reduced length is then compared with the last column of the table (explained in para. 314), prepared for the particular line under test, from which it is seen up to what section the reduced length, thus found, extends.

Calling λ the actual } length up to the farther
and μ the reduced } end of the section

then
$$n = \Sigma\lambda + a\left\{\frac{x}{r} - \Sigma\mu\right\}^{*}$$

(a representing the number [I.W.G.] of the wire in which the fault occurs).

[1] In testing faults in which natural currents exist, the testing currents should be made as small as possible, and the readings should be taken as quickly as possible, so as not to polarise the fault more than can be avoided.

[2] §§ 314, 315.

* For proof of this formula, see Solution XXV. App. B.

Dead Earth on a single Wire.

324. To localise a dead earth it is sufficient to take a simple conduction test, x (mean of + and − readings), and if the line be of one gauge,

$$n = \frac{x}{K};$$

Or if composed of various gauges,

$$n = \Sigma\ \lambda + a \left\{ \frac{x}{r} - \Sigma\mu \right\} *$$

as explained in para. 323.

* For proof of this formula, see Solution XXV. App. B.

Partial Earth on a single Wire.

325. When the fault offers resistance, however, in which case it is called **partial earth**, the above value for x would obviously be too high.

In such a case, the resistance of the fault itself is an important and often a varying element.

Further, it is subject to variation owing to polarisation, caused by the testing currents.

To reduce the effects of this to a minimum, a testing battery as small as possible is used, and + and − readings are taken, as explained in paras. 267 and 337.

Further, the reverse currents should be applied as follows:

First, a +, or copper current, should be kept on so long as the resistance of the circuit is observed to increase;[1] when approximately constant, note the + readings, and apply the − or zinc current, which will dissolve the copper salt formed at the surface of the fault by electrolytic action, and will gradually reduce its resistance until the metallic surface becomes bare, when the resistance will of course be at its minimum, and the − reading should be noted at this moment.[2]

As a *partial earth* admits of communication with the distant station, the *insulation* I of the line is first measured, and then the conduction resistance w.

In this case, the resistance to the fault,

$$x = w - \sqrt{(L-w)\,(I-w)}\ \dagger$$

L being the normal conduction resistance of the line, taken from regular tests under corresponding conditions of climate, &c.

x may be still more accurately determined by taking a circuit test W in addition to the above,

[1] Def. 26 and § 195.

[2] There will be no difficulty in knowing when to take the reading, as after the minimum is reached the resistance of the fault begins to rise again, owing to polarisation by the − current, hydrogen being formed at the surface of the fault.

† For proof of this formula, see Solution XXVI. App. B.

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When $x = I - \sqrt{\frac{(I-W)(I-w)R}{W-w}}$ *

* For proof of this formula, see Solution XXVI. App. B.

R denoting the resistance of the relay inserted, reduced to the temperature at which the test was taken.[1]

[1] § 307.

n (the distance of the fault in miles) is found as explained in para. 322, if the line be of uniform gauge; or, as in para. 323, in the case of different gauges.

Earth on a multiple line. The Loop Test.

326. An earth *dead* or *partial* should, when a second good line is available, always be tested by **the loop method**; for, as the following figure explains, the testing current enters the fault at *z*, by both branches of the bridge, in opposite directions; its resistance, therefore, or any natural current in it, can exercise no influence on the test.

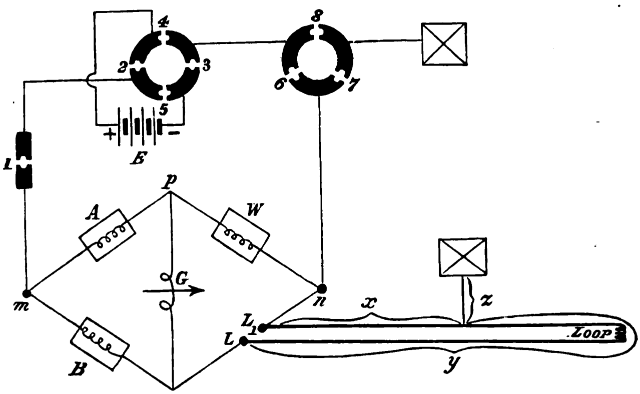

FIG. 73.

In the above figure, *x* represents the conduction resistance to the fault through the faulty wire; and *y* that of the whole of the good line and the section of the faulty line beyond the fault.

The two lines are looped at the distant end, care being taken that the loop is perfectly insulated from the ground, and the two near ends are brought to the bridge; the faulty wire to L_1, and the good wire to L, so that *x* (which must always be less than *y*, in the case of similar lines) may be in the same branch as the comparison coil W. The branches of the bridge must be always made equal. The resistance of the comparison coil, W, is now adjusted till balance is obtained, *with the testing battery to earth*: plugs in

$$\left\{\begin{matrix} 1, 2, 3, 8 \text{ for } + \text{ current} \\ 1, 4, 5, 8 \text{ ,, } - \text{ ,, } \end{matrix}\right\}.$$

The resistance of the looped lines, L, is next measured, *with no earth on the testing battery*: plugs in

$$\left\{\begin{matrix} 1, 2, 3, 6 \text{ for } + \text{ current} \\ 1, 4, 5, 6 \text{ ,, } - \text{ ,, } \end{matrix}\right\}.$$

The resistance up to the fault is at once found by the following formula:

$$x = \frac{L - W}{2} *$$

And n, the distance in miles, is calculated by the formula either in para. 322 or 323, according as the line is made up of wire of one or more gauges.

* For proof of this formula, see Solution XXVII. App. B.

Contact on a double line. First Method.

327. **To localise a contact** between two wires (*when a third wire is not available for a loop*), it is necessary to connect one of the two wires in contact to L of the bridge, the other to L', and to take two measurements of their resistance, the first (W) when their distant ends are insulated, and apart;

The second (w) when their distant ends are insulated, but *looped together.*

Let L' and L'' represent the real conduction resistance of these lines, respectively, to the distant station,

and x' and x'' the conduction resistance, to the fault, of the corresponding wires,

z the resistance of the contact itself.

Then if $z = o$ (i.e. perfect contact),

$$W = w$$

And $x' + x'' = W$;

Or expressing $(x' + x'')$ as X, which thus represents the conduction resistance of the two wires between the testing station and the contact,

$$X = W;$$

Q

SECTION F.

and if the lines are of uniform gauge, of resistances K and K' per mile respectively,

$$n \text{ (the distance of the fault)} = \frac{W}{K' + K''} \text{ (miles).}$$

Or, if K' and K'' are equal,

$$n = \frac{W}{2K}.$$

In the above, the lines in contact have been considered as being of equal length; but if, in consequence of a diversion, one be longer than the other; for example, suppose the wire whose resistance to the fault is expressed by x'' to be longer than x' by, say, d miles, then

$$X = x' + x'' = nK + (n + d) K''$$

$$\text{and } n = \frac{X - dK''}{K' + K''}.$$

And when the lines are composed of various gauges,

$$n = \Sigma\lambda + a\left\{\frac{X - \delta r''}{r' + r''} - \lambda\mu\right\}$$

δ being the reduced length of the diversion, the other letters of the formula corresponding with those explained in para. 323.

We have now to consider the case in which the contact itself offers resistance, as indicated by the measurement W being greater than w.

In this case,

$$X = w - \sqrt{(R - w)(W - w)}\text{*}$$

R being the sum of the resistances $L' + L''$.

n (the distance to the fault) is found precisely as in the preceding cases explained in this paragraph.

* For proof of this formula, see Solution XXVIII. App. B.

Correction for Leakage.

328. When the resistance of the contact (z) is not zero, and the insulation of the lines in contact is imperfect, a second fault (i)—viz. earth due to leakage—is introduced, the magnitude of which depends upon the ratio $\frac{z}{i}$.

When this is considerable, the value obtained for x, by the formula in the preceding paragraph, requires correction as follows:

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Expressing by e the ratio $\frac{z}{i}$

and by i' the corrected absolute insulation of one line,[1]

" i'' that of the other,[1]

" l' the resistance of the first line up to the resultant fault due to leakage,[1]

" l'' the same for the second line,[1]

" l the sum of $l' + l''$.

Then $$i = i' + i'',$$

and the combined resistance (z') of the two faults i and z becomes

$$z' = \frac{iz}{i+z} \; *$$

whence

$$e = \frac{z'}{i-z}$$

and the corrected value for x becomes

$$X = \{w - \sqrt{(R-w)(W-w)}\}(i+e) - el.$$

[1] Known from record of previous tests.

* Law 8, App. A.

Second Method: Contact on a two-wire line localised by the Loop Method.

329. A contact may be localised on the principle of the loop test as follows :

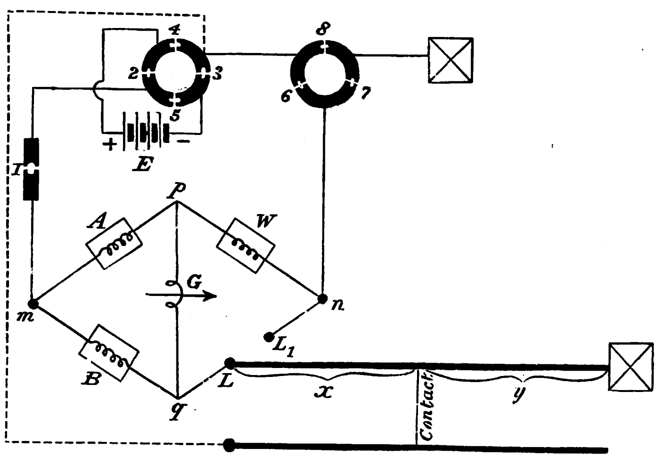

FIG. 74.

The end of one of the wires in contact is brought to L of the bridge.

SECTION F.

The distant end of the same wire is *joined to earth.*

The distant end of the other wire is *insulated*, the home end being connected to the testing battery (through the battery reverser), as shown by the dotted line.

L' of the bridge is joined to earth through plug 7. Then, when balance is obtained (branches A and B being equal, as they are always made in the loop test), the testing current enters the contact from the A branch through W and y, and from the B branch through x, so that $x = W + y$,

$$\therefore\ x - y = W^{*} \quad . \quad . \quad . \quad (1)$$

Then disconnecting the second wire from the battery (both ends insulated), and taking an ordinary conduction test of the wire connected to L, and calling the resistance unplugged to obtain balance in this case W'

$$x + y = W' . \quad . \quad . \quad . \quad (2)$$

But, from equation (1), $x - y = W.$

Whence, by adding (1) and (2),

$$x = \frac{W + W'}{2} = \text{resistance to fault,}$$

and $$n = \frac{x}{K} \text{ miles.}\dagger$$

Or, in the case of a line of different gauges,

$$n = \Sigma\lambda + a\left\{\frac{x}{r} - \Sigma\mu\right\}.\ddagger$$

* If balance is not obtainable, with line to L, and earth to L', reverse the connections. But if balance is obtainable in both cases, the best value of x is obtained by taking the measurement first with line to L and earth to L', and then *vice versâ*, W being taken as the mean of the two measurements.

† § 322.

‡ § 323.

Third Method: Contact localised by the Loop Method when a third good wire is available.

330. When a third good wire is available the following connections are made:

The good wire and one of the faulty wires are joined to L and L' of the bridge respectively, their other ends being looped at the distant station.

The second faulty wire is joined to the testing battery, its distant end being insulated. Then, at balance (A and B being equal), $x + W = y$;

$$\therefore\ y - x = W . \quad . \quad . \quad . \quad (1)$$

Then, disconnecting the second faulty wire from the battery reverser and leaving both ends insulated, we have the circuit of the loop test, and

$$y + x = L \quad . \quad . \quad . \quad . \quad (2)$$

Subtracting (1) from (2)

$$x = \frac{L - W}{2}.\ *$$

* § 326.

Whence n, the distance in miles, is found as described in the preceding case (para. 329).

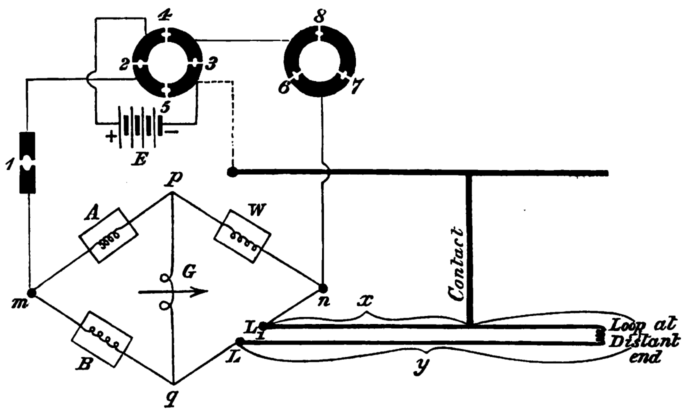

FIG. 75.

Discon-nection. Localisation by Insulation Test.

331. A perfectly insulated break can be localised by an ordinary insulation test, on the principle that the length of line to the fault (n) is to the length of whole line (N) as the absolute insulation of the whole line (I)[1] is to the absolute insulation of the section up to the fault, i.e.

$$\frac{n}{N} = \frac{I}{i}$$

$$\therefore \quad n = \frac{NI}{i}.$$

It is assumed in the above case that the insulation of the line is uniform throughout its length.

[1] Known from regular tests taken under similar condition of weather and time of day; or if there be a second good wire by comparison with tests of that, at the time of fault test.

Localisation by Capacity Test.

332. In the case of a break in a single wire the method of localisation by the insulation test is open to the objection that, owing to the great changes which the normal insulation of lines undergoes, it is very difficult to decide what value of

SECTION F.

l to select from the regular tests as most likely to correspond with the state of insulation of the line when the fault test is taken.

In such a case **the capacity test** is of great advantage as a check on the results obtained by the insulation tests.

It is based upon the principle that the length of line up to the fault (n) is to N the length of the whole line as the inductive capacity of the line up to the fault (s) is to that of the whole line (S),[1] i.e.

[1] § 334.

$$\frac{n}{N} = \frac{s}{S}$$

$$\therefore \quad n = \frac{s}{S}N.$$

s being known by regular capacity tests recorded in terms of a standard condenser.

Imperfectly Insulated Break.

333. In the case of a break, when the end of the wire is not perfectly insulated from the ground, correct localisation from the testing station is impossible, as there is no means of ascertaining what proportion of the measured insulation is due to the fault itself and what to the line; thus, a distant fault offering considerable resistance may be mistaken for a near fault offering infinite resistance (i.e. an insulated break).

Here, again, the capacity test forms a useful criterion, for a near disconnection is generally characterised by high insulation and low capacity, and a distant disconnection by low insulation and high capacity.

Measurement of Capacities.

334. The capacity of a line is proportional to the quantity of current (Q) with which it can be charged by a given electromotive force.

The amount of this current is proportional to the transient deflection or *throw* of the needle of a galvanometer placed in its circuit. This first swing is, of course, its maximum deflection, which we may call $a°$.

Again, the force which produces this deflection (i.e. the current of charge or discharge) is proportional to the sine of half the angle of deflection.[2]

Whence,

$$Q = sin\ \tfrac{1}{2}\ a°.$$

Thus the capacity S, of a line or condenser, can be measured

[2] This follows the law relating to a force actuating a pendulum, to which the momentary current of charge or discharge deflecting the needle to its full extent may be compared. It is assumed that the motion of the needle is not sensibly impeded by friction, or by the resistance of the air.

either by the current of *charge* or *discharge*. The following figures will sufficiently explain the circuit in either case :

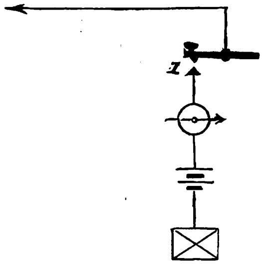

FIG. 76.—CHARGE.

Make *momentary* contact (1) and observe the throw of the needle $a°$.

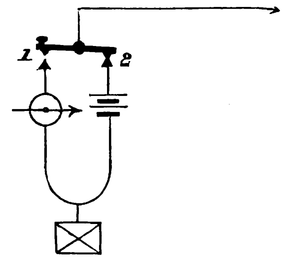

FIG. 77.—DISCHARGE.

With key at rest, the current is charging the line (through 2). Allowing time for the line to be fully charged, make *momentary* contact (1) and observe $a°$.

Then, in either case, as explained above,

$$Q = sin\ \tfrac{1}{2}\ a°.$$

Suppose the above to represent the charge of a condenser of capacity C, with which it is desired to compare the unknown capacity, S, of a line, and supposing $a'°$ to represent the throw of the needle in the case of the line (the distant end of which is of course insulated), the current being denoted by Q'.

Then
$$\frac{S}{C} = \frac{Q'}{Q} = \frac{sin\ \frac{1}{2}\ a'}{sin\ \frac{1}{2}\ a}$$

and
$$S = \frac{sin\ \frac{1}{2}\ a'}{sin\ \frac{1}{2}\ a}\ C,$$

or, with unequal electromotive forces, E and E', in the first and second cases respectively,

$$\frac{Q'}{Q} = \frac{E'}{E}$$

$$\therefore \frac{S}{C} = \frac{EQ'}{E'Q} = \frac{E\ sin\ \frac{1}{2}\ a'}{E'\ sin\ \frac{1}{2}\ a}$$

$$\therefore S = \frac{E\ sin\ \frac{1}{2}\ a'}{E'\ sin\ \frac{1}{2}\ a}\ C.$$

It is presumed that the above readings, $a°$ and $a'°$, are taken at the same time and with the same galvanometer, so that the constant of the instrument is the same in both cases.

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The state of insulation of the line under test has an important influence on the results of capacity tests, for leakage obviously tends to *increase* the deflection when the current of *charge* is applied, and to *decrease* it in the case of the *discharge* current; hence, to reduce this source of error to a minimum, it is advisable to take both *charge* and *discharge* tests and to take the mean of a series of successive deflections of both, alternately.

Earth Testing.

335. The importance of a *good earth* has been already remarked upon (para. 178).

The maximum resistance a telegraph earth should offer is 10 units.

As every office is provided with two earths,[1] it is easy to test whether they fulfil the above condition by measuring their total resistance by any of the simple methods described in the preceding paragraphs,[2] their two leading wires forming the terminals of the circuit $(x + y)$ to be measured. Call this w'.

[1] § 182.

[2] 243–266.

Then, if w' be less than 10 units, of course the resistance of either of the two earths x or y alone must be within the required limit.

This result does not, however, show how much of the resistance measured is due to one earth and how much to the other.

In order to ascertain this, it is necessary to use a third earth (z) for comparison, so that by measuring each pair of earths together we obtain the following equations:

$$x + y = w'$$

$$x + z = w''$$

$$y + z = w'''.$$

Care must be taken that there is no *metallic* connection between one earth and another, for the object of the test, which is to measure the resistance offered by the *surface of the soil* to the diffusion of the current from each plate, would then of course be defeated.

The absence of natural currents between any two earth plates at once indicates that the plates are in metallic contact, unless the measurement proves the resistance between them to be so great as to account for the natural current not being observed.

The resistance of the leading wires is, of course, always as small as possible.

First Method: with Tangent Galvanometer and no Battery.

336. When the E.M.F. of the natural current between each pair of earth plates is sufficiently strong, it is used as its own testing battery, whereby the polarisation likely to result from the use of a galvanic cell is avoided, together with the inaccuracy attendant thereon.[1]

[1] § 325.

To measure earth resistance when the natural current between each pair of earths is sufficiently strong to produce readable deflections (say not less than 10°) with the tangent galvanometer.

Note the mean of + and − readings, obtained from each pair of earths, both through the thick and thin coils of the galvanometer.

a° representing deflections through the thick coil
a'° " " " thin "

in the case of each couple. Then, as explained in para. 263, the resistance of each pair of earths

$$w' \text{ or } w'' \text{ or } w''' = \frac{ng' - \dfrac{\tan a^\circ}{\tan a'^\circ}g}{\dfrac{\tan a^\circ}{\tan a'^\circ} - n}.*$$

* For proof of this formula, see Solution XI. App. B.

From which the separate values of x, y, and z are found, as follows:

$$x = \frac{w' + w'' - w'''}{2}\dagger$$

$$y = \frac{w' + w''' - w''}{2}\dagger$$

$$z = \frac{w'' + w''' - w'}{2}.\dagger$$

† For proof of these equations, see Solution XXIX, App. B.

Second Method: with the Tangent Galvanometer and a Testing Battery.

337. In the case **when the natural current between each pair of earth plates is not sufficiently strong to produce readable deflections** through the thin coil, it becomes necessary to use a testing battery.

This should be as small as possible, in order that polarisation of the plates may be avoided,[2] and, with the same object, the tests should be executed as rapidly as possible.

[2] § 240.

The standard cell, of resistance f, will, as a rule, suffice, and the readings should be taken through the thick coil (resistance g), with no external resistance.

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Call the deflection resulting from the above circuit, $c°$, which should be measured before and after the earth circuits.

Then insert each pair of earths (w), and note the mean of the deflections in each case, with opposite currents $\left(\frac{a° + b°}{2}\right)$.*

Then

$$w' \text{ or } w'' \text{ or } w''' = \left(\frac{\tan C°}{\frac{\tan a° + \tan b°}{2}} - 1\right)(f + g).\dagger$$

From which the separate values of x, y, and z are found, as explained in para. 336.

* Each pair of earths should be inserted, first with one to the + and the other to the − pole of the testing cell, and then *vice versâ*.

† For proof of this formula, see Solution XXX. App. B.

Third Method: with the Calibrated Galvanoscope.

338. To measure the resistance of earths with the calibrated galvanoscope, first join up the instrument in circuit with the standard cell and the two leading wires to be used, and by comparing the deflections (mean of + and − readings) with the calibration table,[1] note the resistance (r) due to the battery, leading wires, and galvanometer, which make up this circuit, and deduct it from the subsequent value obtained in measuring each pair of earth plates.

[1] § 147.

Then separate the two ends of the leading wires, which are joined to each other, connecting the free end of one to one earth plate (x, say) and the other to y.

Then observe the decreased deflection (mean of + and − readings), and, comparing it again with the table, note the increased resistance due to the addition of the pair of earths (w'), remembering to exclude the value noted for r.

Repeat the same operation for each pair, viz. w'' and w''', and from these measurements find the value of x, y, and z, as explained in para. 336.

Fourth Method: with the Wheatstone's Bridge and no Testing Battery.

339. When a Wheatstone's bridge is available, and the natural current between each pair of earths is sufficiently strong to render a testing battery unnecessary, **Mance's method,** described in para. 276, is the simplest and most accurate.

Each pair of earths is successively joined up between the terminals L and L′ of the bridge; and

$$w' \text{ or } w'' \text{ or } w''' = \frac{B}{A} W$$

w being the mean of + and − readings; and the separate values for x, y, and z are found as explained in para. 336.

Fifth Method: with the Differential Galvanometer and no Testing Battery.

340. **The differential galvanometer may be used for the above test**, in which case

$$w' \text{ or } w'' \text{ or } w''' = W.*$$

* § 248.

Sixth Method: with the Wheatstone's Bridge and a Testing Battery.

341. **In measuring the resistance of earths with a Wheatstone's bridge in the case when a testing battery is necessary**, it is reduced to one cell,[1] and each pair of earths is successively joined up between the terminals L and L' of the bridge, and measured with + and − currents like any ordinary resistance; and

$$w' \text{ or } w'' \text{ or } w''' = \frac{B}{A} W \dagger$$

x, y, and z being found as explained in para. 336.

[1] If this is not sufficient to overcome the natural current opposing either measurement of the battery current, two or more cells may be joined parallel, so as to keep the resistance of the battery down.

† § 245.

Seventh Method: with the Differential Galvanometer and a Testing Battery.

342. The same measurements may be made with the **differential galvanometer**, in which case

$$w' \text{ or } w'' \text{ or } w''' = W, \ddagger$$

x, y, and z being found as before.

‡ § 248.

To Test Lightning Conductors.

343. The principal object of a lightning conductor being to afford a path of least resistance to the discharge (either disruptive or silent) of the electricity of the clouds to the earth, it is obvious that the conductor should be continuous, and that it should make as perfect a connection with the earth as possible.

The foregoing rules for earth testing apply, therefore, to **the measurement of the resistance of lightning conductors.**

Looking upon the conducting rod and its earth (x) as one, a leading wire should be first connected with the point, so as to include the whole of the rod in the circuit, and another leading wire to each of two separate earths, y and z, successively.

If the resistance be found unduly high, then disconnect the leading wire from the upper extremity, and join it to the rod just above the level of the ground, and repeat the test; if the resistance in circuit be now reduced, there is a fault in the rod; if, however, it be found the same as before, the rod is perfect, and the fault is underground, being probably due to imperfect earth.

SECTION F.

Faults in the rod are likely to be due to **bad joints**; hence the necessity for carefully testing them when the rod is first constructed, and if possible before erection, when it should be ascertained that **every joint is soldered.**

The points attached to the upper part of the rod, the object of which is to facilitate the combination of the opposite potentials of the clouds and the ground by silent discharge, should also be **in perfect contact with the rod,** and should be kept **free from corrosion.**

In testing the efficacy of lightning conductors it should be ascertained that they are **perfectly connected with all masses of metal** about the building, such as iron pipes, gutters, and other lightning rods, if more than one is used.

In the case of the earth connection being found defective, the precautions recommended with regard to a telegraph earth may be observed with advantage.[1]

[1] § 278.

Tests of Instruments and Connections.

344. **The electrical resistance of instruments and connections** can be measured, according to the apparatus available, by either of the methods described in paras. 245, 248, 250, 258, 260, 265, by which also the efficiency of the **insulation** of those parts which are purposely kept free of contact with one another may be tested.

The range of instruments is ascertained by the processes described in para. 71.

The resistance (w) to be added in order to give any range (n) may be calculated by the following formula:

$$w = \left(\frac{qn}{p} - 1\right)R + (n - 1)\,qf\,^*$$

* For proof of this formula, see Solution XXXI. App. B.

p representing the number of cells used (without external resistance) to produce the strong current C;[2]

q the number of cells used (with external resistance w) to produce the weak current c;[2]

[2] § 71.

R the resistance of the instrument;

f the average resistance per cell (which may be neglected when R is large).

In the case when only one fixed resistance w is available, it becomes necessary to adjust the ratio $\frac{p}{q}$, i.e. the relative battery power used in the two circuits, to find n, the required range.

Here $$p = \frac{nqR}{R + w - (n-1)qf}.*$$

* For proof of this formula, see Solution XXXII. App. B.

Usually $q = 1$ for instruments whose resistance is under 1,000 units, and 2 for greater resistances.

Capacity is ascertained by the mode explained in para. 334, and the prolonging effects of **extra currents** as described in para. 124.

Appendix A.

LAWS AND PRINCIPLES

1– 7. LAWS OF CURRENTS

8–12. LAWS OF CIRCUITS

13–19. LAWS OF ELECTRO-MAGNETISM

20–22. LAWS OF INDUCTION

23–26. LAWS OF MAGNETISM

LAWS AND PRINCIPLES.

LAWS OF CURRENTS.

1. Ohm's Law. (i.) THE strength or intensity of a current C is equal to the electromotive force E divided by the total resistance in circuit R: APPENDIX A.

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

(ii.) Or, letting r represent the external resistance and f the internal resistance of each battery cell joined in series, and expressing by n the number of cells (of resistance f),

$$C = \frac{nE}{nf + r}.$$

(iii.) If the n cells are joined parallel,

$$C = \frac{nE}{nr + f}.*$$

* Because in this case

$$C = \frac{E}{\frac{f}{n} + r} = \frac{E}{\frac{nr+f}{n}} = \frac{nE}{nr+f}$$

2. Kirchhoff's Laws. (i.) The sum of the current strengths in all those wires which meet in a point is equal to nothing. In other words, the sum of all the currents approaching the point is equal to the sum of those going away from it.

(ii.) In any inclosed figure the sum of all the products of the currents into the resistances of the wires conveying them is equal to the sum of all the electromotive forces in the circuit.

3. Bosscha's Laws, or Corollaries to Kirchhoff's Laws. (i.) If in any system of circuits containing any electromotive forces there is a conductor in which the current = o, the currents in the remaining circuits are not altered if the circuit of the conductor in question is taken away, together with the electromotive force contained in it.

(ii.) If the conductor in question contains no electromotive force it may be removed, and the points between which it previously existed may be connected directly with

R

APPENDIX A.

each other without affecting the currents in any part of the circuit. If, on the other hand, it contain an electromotive force, an equivalent electromotive force must be inserted between the points before they can be joined again.

(iii.) In a system of linear conductors containing electromotive force, the current set up in any conductor *a* by an electromotive force contained in any other conductor *b* will be identically the same as that which would be set up in *b* by an equal electromotive force in *a*.

(iv.) If in a system of linear conductors there are two of them, *a* and *b*, in which an electromotive force in *a* produces no current in *b*, then *a* may be divided or removed without altering the current in *b*, and likewise *b* may be divided or removed without altering the current in *a*.

4. Laws of Mutual Action of Currents.

(i.) Two parallel wires in which currents flow in the same direction attract one another; or, more simply, '*Parallel currents in the same direction attract one another.*'

(ii.) '*Parallel currents in opposite directions repel one another.*'

(iii.) When the wires are straight, but not parallel, they (i.e. the currents in them) attract one another, if both currents flow towards or away from the point of convergence;

(iv.) But repel one another if one current flows towards and the other from the point of convergence.

Thus, it is obvious that the tendency of angular currents is to become straight, so that, in the following figure, the points *a* and *c* would tend to coincide; likewise *b* and *d*.

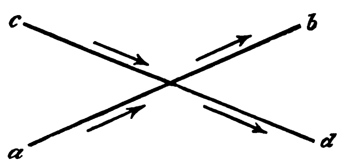

FIG. 78.

[If two wires conveying currents be coiled, the above effects are multiplied in proportion to the number of convolutions; and if one coil be large enough to embrace the other, the larger will, if the currents are flowing in the same direction in both, draw the latter into it; but if the currents are flowing in contrary directions through the coils, repulsion will take place between them.

A magnet presented to the interior of the larger coil will behave similarly to the smaller coil, bearing out the resemblance between magnets and solenoids.] [1]

[1] Def. 25.

5. Maximum Current of a Battery. In a telegraphic circuit the best effect is obtained from the battery when the internal resistance of the battery approximates most nearly that of the circuit exterior to it.

6. Laws of Current Strength in Derived Circuits. (i.) The sum of the currents in the derived parts of a circuit is equal to the strength of the main current.

(ii.) The strength of current in each branch of a derived circuit is inversely as the resistance of the branch.

7. Laws of Electrolytic Decomposition. (i.) The quantity of any particular electrolyte decomposed in a given time is proportional to the strength of the electrolysing current.[1]

(ii.) With the same current the quantities decomposed of various electrolytes are proportional to their chemical equivalents.

[1] Def. 26.

LAWS OF CIRCUITS.

8. Combined Resistance of a Derived Circuit or Multiple Arc. (i.) The joint resistance R of any two branches of a derived circuit[2] of resistances x and y respectively is equal to the product of the two resistances divided by their sum, i.e.

$$R = \frac{xy}{x+y}.^{*}$$

[2] Defs. 21, 22.

* For proof, see Solution I. App. B.

(ii.) Denoting by R the joint resistance of any three circuits, x, y, and z,

$$R = \frac{xyz}{xy + yz + xz},^{\dagger}$$

† For proof, see Solution II. App. B.

i.e. their product divided by the sum of the products of each pair.

(iii.) The joint resistance of any number of resistances in derived circuit is found by dividing unity by the sum of their reciprocals :

$$R = \frac{1}{\frac{1}{x} + \frac{1}{y} + \frac{1}{z}}.^{\ddagger}$$

‡ For proof, see Solution III. App. B.

[The reciprocal of any number is 1 divided by that number.]

[Conductivity is the reciprocal or converse of resistance, and *vice versâ* ; thus, if x = the resistance of a circuit, $\frac{1}{x}$ = its conductivity or conduction.]

9. Multiplying Power of Shunts. The multiplying power of any shunt of resistance S on a galvanometer of resistance G is represented by the following expression :

$$\frac{G+S}{S}.\S$$

§ For proof of this formula, see Solution IV. App. B.

APPENDIX A.

10. Resistance of Shunts. To prepare a galvanometer shunt having a multiplying power *n*, the resistance of the shunt must be

$$\frac{G}{n-1}.*$$

* For proof, see Solution V. App. B.

11. Resistance of Telegraph Wire. (i.) The resistance of any wire of one quality is directly proportional to its length.

(ii.) It is inversely proportional to its weight per mile, and also inversely proportional to the square of its diameter.

12. Laws which govern Speed of Signalling. (i.) In cables (or well-insulated land lines) of similar make, the speed of signalling in each, s and s', is inversely proportional to the squares of their respective lengths; thus

$$\frac{S}{S'} = \frac{l'^2}{l^2}.$$

(ii.) If the lengths are the same, the speed is proportional to the expression

$$d^2 \times \log \frac{D}{d}.$$

Where d represents the diameter of the conductor, and D that of the insulator or dielectric. Thus, for two cables of equal lengths but of different diameters,

$$\frac{S}{S'} = \frac{d^2 \log \frac{D}{d}}{d'^2 \log \frac{D'}{d'}}.$$

(iii.) If their lengths differ as well as their diameters,

$$\frac{S}{S'} = \frac{l'^2 d^2 \log \frac{D}{d}}{l^2 d'^2 \log \frac{D'}{d'}}.$$

LAWS OF ELECTRO-MAGNETISM.

13. Action of Currents on Magnets (Oerstedt's discovery). A suspended magnet brought within the influence of a current will take up a position across it.

Ampère's rule for the direction of the magnet in such a case is as follows:

Ampère's Rule. '*Imagine an observer swimming with the current, with his face always turned towards the needle, the north pole is always deflected to his left.*'

APPENDIX A.

14. Polarity of Electro-Magnets. In electro-magnets the south pole is always found at that end where the positive current enters a right-handed helix.[1]

15. Best Resistance for Electro-Magnetic Coils. The maximum force is obtained from an electro-magnet, when the resistance of the coils is equal to the resistance of the battery.

16. Laws of the Magnetic Intensity of Electro-Magnets. The magnetic force developed in the soft iron core of an electro-magnet is proportional to the strength of the battery current and to the number of turns of the wire.[2]

17. Principle of Tangent Galvanometer. A circular current flowing in the plane of the magnetic meridian deflects a needle, which is infinitely short in comparison with the radius of the current, so that *the tangent of the angle of deflection is proportional to the strength of the current.*[3]

18. Deflection of Galvanometer Needle. The angle of deflection is not determined in any way by the strength of the magnetism in a single needle.

19. Principle of Sine Galvanometer. If the circular conductor or coil be turned after the deflected needle until the latter lies again parallel with the coil, *the current strength is proportional to the sine of the angle through which the conductor is turned.*[4]

[1] § 50.

[2] It must be remembered that this law treats only of the *force of magnetic attraction* in an electro-magnet, irrespective of its efficiency for use as a signalling instrument in the matter of speed, where other conditions, such as extra currents, magnetic inertia, residual magnetism, &c., come into effect and must be considered.

[3] § 151.

[4] § 150.

LAWS OF INDUCTION.

20. Laws and Principles of Induced Currents. (i.) A current at the moment of the circuit being *closed* produces in a neighbouring conductor an *inverse* induced current.[5]

(ii.) A current at the moment it *ceases* produces a *direct* induced current.

(iii.) A current which is *removed*, or which *diminishes* in strength, gives rise to a *direct* induced current.

(iv.) A current which is *approached*, or which *increases* in strength, gives rise to an *inverse* induced current.

(v.) A continuous and constant current does not induce any current.

(vi.) The strength of induced currents is proportional to that of the inducing currents.

21. Laws of Extra Currents. (i.) With the same strength of primary currents, the extra currents obtained on opening and closing the circuit have the same electromotive force.

(ii.) The E.M.F. of the extra current is proportional to the strength of the primary current.

22. Laws of Extra Currents in Coils of Electro-Magnets. The strength of the extra currents induced in the coils of electro-magnets, by the working currents which pass through them, is proportional to the number of convolutions in the electro-magnet and to the mass of iron in the core.

[5] In the case of an electro-magnet, the inverse current exists during the time the magnetism is increasing; the direct, while it is decreasing.

APPENDIX A.

LAWS OF MAGNETISM.

23. Mutual Action of Magnets.

Like poles repel and unlike poles attract one another.

24. Law of Magnetic Attractions and Repulsions.

Magnetic attractions and repulsions are inversely as the square of the distances between the bodies exerting their influence on one another.

25. Law of the Direction of the Ampèrian Currents in Magnets.

At the *north* pole of a magnet the direction of the Ampèrian currents [1] is *opposite* to that of the movement of the hands of a watch; but at the *south* pole the direction is the *same* as that of the movement of the hands of a watch.

26. Law of Portative Force of a Magnet.

The portative force P [2] of a saturated horse-shoe magnet [3] is proportional to its own weight p and to a coefficient a, depending upon the coercive force of the steel. [4]

This is expressed mathematically by Hacker's formula—

$$P = a\sqrt[3]{p^2}.$$

[1] § 118 (last clause).

[2] Def. 45.

[3] Def. 47.

[4] Def. 43.

APPENDIX B.

FORMULÆ

AND THEIR SOLUTIONS

FORMULÆ.

To those who do not possess the knowledge of mathematics necessary for the comprehension of algebraic formulæ, the study of electrical science is likely to be rendered difficult by reason of the unintelligible symbols which are often introduced into the thread of explanations—such as may relate to the working of instruments, the action of currents, the testing of batteries, lines, or earths; in fact, the most ordinary electrical matters. Moreover, the fact of not understanding these formulæ renders such explanations unattractive, and too often induces the reader at the sight of them to give up all attempt to follow the reasoning any further.

This is a mistake which is usually the result of a wrong impression as to what formulæ really are; and it is the object of the following remarks and proofs to show that, by the exercise of a little intelligence and perseverance, the reader who will take the pains to master even the very rudiments of arithmetic and algebra may follow and understand many of the electrical truths and principles algebraically expressed which were at first quite incomprehensible to him.

He will then discover that the real object of mathematical formulæ is not intricacy, but *simplicity* and *brevity*, and that each letter represents some distinctive electrical feature, such as a resistance, electromotive force, deflection, &c., which, when combined with arithmetical or algebraical signs, represents some electrical law in a much more concise and intelligible form than could be expressed in a great number of words.

The sight of letters of the Greek alphabet, which are frequently met with in formulæ, need create no alarm, for they are employed in precisely the same manner as English letters, i.e. simply as conventional signs representing certain quantities, to avoid the necessity for writing these quantities in full; for example, the English letters L and l may have

APPENDIX B.

been used to denote the lengths of two conductors under certain conditions; then, to express the lengths of the same conductors under different conditions, it may be obviously convenient to employ the corresponding Greek letters Λ and λ.

As all formulæ are based upon laws and principles, it is essential that the fundamental laws which govern the action of electrical currents &c. should be thoroughly understood, and with this object they are included in the preceding appendix (A).

It will be found that the laws of currents and circuits (Nos. 1 to 12, App. A) comprise the principles on which testing formulæ generally are based, two of which, in particular, are of the greatest use and importance, viz.

No. 1, Ohm's Law, and **No. 8, On the joint resistance of derived circuits.**

The first is expressed by the simple formula

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

* Law 1, App. A.

the truth of which is confirmed by experiment, as manifested by the deflections of a galvanometer needle under various conditions of electromotive force and resistance. (For examples see paras. 250 and 290, sec. **F.**)[1]

The laws for the joint resistance of derived circuits admit of such simple mathematical proof as to be readily understood by the beginner, and their development will form a suitable introduction to the solution of electrical formulæ generally.

Ohm's Law *mathematically* proved.

1 See Appendix II. Testing Instructions.

SOLUTION I.

Joint Resistance of Derived Circuits.

The joint resistance R of two conductors x and y, forming a derived circuit, is equal to the product of the resistances of each conductor divided by their sum.

$$R = \frac{xy}{x+y}.$$

Let x and y represent the resistances of the two branches of the derived circuit between the points a and b.[1]

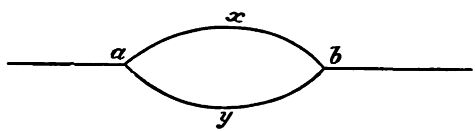

FIG. 79.

Let X be the sum of the two resistances x and y, i.e.

$$X = x + y.$$

Then

$$\frac{1}{X} = \frac{1}{x} + \frac{1}{y} = \frac{y+x}{xy}$$

i.e. $\frac{y+x}{xy}$ = the joint *conductivity* of the derived circuit (conductivity being the reciprocal of resistance).[2]

And, for the same reason, the joint resistance R will be the reciprocal of this, or

$$R = \frac{xy}{x+y},$$

i.e. the product of x and y divided by their sum.

[1] Defs. 21, 22.

[2] Law 8, App. A.

APPENDIX B.

SOLUTION II.

The joint resistance R of any number of conductors in derived circuit is equal to the product of their resistances divided by the sum of each resistance multiplied into each of the other resistances.

Thus, in the circuit represented below,

$$R = \frac{xyz}{xy + yz + xz}.$$

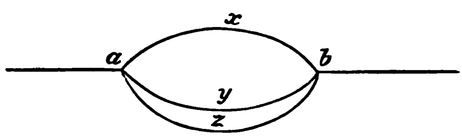

FIG. 80.

It will be observed that the above figure represents the circuit described in the preceding proof, with the addition of a third wire of resistance z.

It was shown by Solution I. that the expression for the joint resistance of x and y is

$$\frac{xy}{x + y}.$$

Its joint resistance, therefore, with that of z is found, as explained in the preceding case, by dividing their product by their sum, i.e.

$$R = \frac{\frac{xy}{x + y} \times z}{\frac{xy}{x + y} + z}$$

whence

$$R = \frac{\frac{xyz}{x + y}}{\frac{xy + xz + yz}{x + y}}$$

$$\therefore \quad R = \frac{xyz}{xy + yz + xz}.$$

SOLUTION III.

The joint resistance R of any number of resistances in derived circuit is found by dividing unity by the sum of their reciprocals.[1]

Thus, in the preceding case,

$$R = \frac{1}{\frac{1}{x} + \frac{1}{y} + \frac{1}{z}}.$$

For the sum of the above resistances would be

$$x + y + z.$$

Therefore the sum of their conductivities would be

$$\frac{1}{x} + \frac{1}{y} + \frac{1}{z}$$

(resistance and conductivity being reciprocals of one another).

For the same reason,

$$R = \frac{1}{\frac{1}{x} + \frac{1}{y} + \frac{1}{z}}.$$

[1] Law 8, App. A.

APPENDIX B.

SOLUTION IV.

To find n the multiplying power of a shunt of resistance S on a galvanometer of resistance G.

$$n = \frac{G+S}{S}.^*$$

* Law 9, App. A, and §§ 158, 159.

A galvanometer and its shunt form a derived circuit containing two branches of resistances G and S respectively. A current C of E.M.F. E flowing through this circuit will, therefore, divide between these branches into two currents, c_1, c_2, the strength of which may, in accordance with Ohm's Law,[1] be expressed as follows :

[1] Law 1, App. A.

$$c_1 = \frac{E}{G} = \text{current in } G \text{ branch;}$$

$$c_2 = \frac{E}{S} = \text{ ,, ,, } S \text{ ,,}$$

$$\therefore \frac{c_1}{c_2} = \frac{S}{G}$$

$$\therefore c_2 = \frac{S}{G} c_1.$$

But $$C = c_1 + c_2$$

$\therefore$ (substituting the above value for c_2)

$$C = c_1 + \frac{G}{S} c_1$$

$$= \frac{c_1 S + c_1 G}{S}$$

$$= c_1 \frac{S+G}{S}.$$

That is, the value of the whole current C is found by multiplying the current in the galvanometer (as shown by the deflection) by

$$\frac{G+S}{S}.$$

Hence, $\frac{G+S}{S}$ is called the multiplying power of the shunt.

APPENDIX B.

SOLUTION V.

To find *s* the required resistance for a shunt in order to produce a given multiplying power *n* on a galvanometer of known resistance *G*.

$$S = \frac{G}{n-1}.*$$

* § 158.

The above formula follows from the general rule that

$$n = \frac{G+S}{S}$$

as proved by the preceding solution. Whence

$$Sn = G + S$$

$$\therefore \quad Sn - S = G$$

$$\therefore \quad S(n-1) = G$$

and $$S = \frac{G}{n-1}.$$

APPENDIX B.

SOLUTION VI.

Proof of the theory of the Wheatstone bridge.

$$x = \frac{B}{A} W.*$$

* § 245.

PROOF.

The principle of the bridge is based upon the equalisation of the potentials at the points p and q by adjusting the relative resistances of the branches A, B, W, and x.

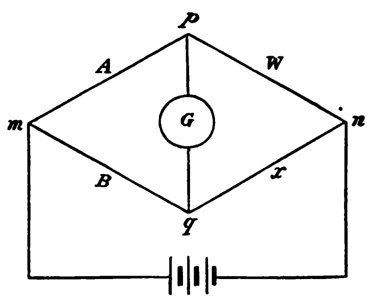

FIG. 81.

Now, in the derived circuit between the points m and n, made up of the two branches $(A + W)$ and $(B + x)$ the potential of the current at any point in either circuit falls in direct proportion to the resistance up to that point from m.[1]

[1] § 163.

First, let us consider the upper branch $(A + W)$, which may be represented by the straight line mpn, as under; V, U, and V' denoting the potential at the points m, p, and n (the line $V\,U\,V'$ thus showing the fall of the potential from m to n):

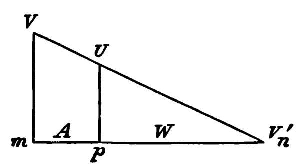

FIG. 82.

Then, in the similar triangles $V\,m\,V'$ and $U\,p\,V'$,

$$Vm : mV' :: Up : pV'$$

$$\therefore \quad \frac{Vm}{mV'} = \frac{Up}{pV'}.$$

Now, the vertical lines in the above figure represent potentials, and the horizontal ones resistances.

Thus Vm represents the difference between the potential at the points m and n, i.e.

$$Vm = V - V',$$

and, similarly, $$Up = U - V'.$$

mV' represents the resistance ($A + W$) and pV' represents the resistance W.

Thus, substituting these values in the above equation,

$$\frac{V - V'}{A + W} = \frac{U - V'}{W}.$$

$$V - V' = \frac{U - V'}{W} . A + W.$$

Now, considering the lower branch of the bridge made up of the resistances B and x, it may be proved in precisely the same way that

$$\frac{V - V'}{B + x} = \frac{U - V'}{x}$$

whence

$$V - V' = \frac{U - V'}{x} . B + x.$$

But, in the first case,

$$V - V' = \frac{U - V'}{W} . A + W$$

$$\therefore \quad \frac{U - V'}{x} . B + x = \frac{U - V'}{W} . A + W$$

$$\therefore \quad \frac{B + x}{x} = \frac{A + W}{W}$$

$$\therefore \quad Ax + Wx = BW + Wx$$

$$\therefore \quad Ax = BW$$

and $$x = \frac{B}{A} W.*$$

* Formula I. Testing Instructions.

APPENDIX B.

SOLUTION VII.

Proof of the theory of the differential galvanometer.

$$x = W.^{*}$$ * § 248.

PROOF.

The principle of the differential galvanometer is also based upon the equalisation of potentials by the equalisation of the external resistances x and w.

For, it follows from Ohm's Law and the construction of the instrument [1] that, in the case of c^1, the portion of current passing through one coil r^1 and the resistance x external to it, [1] § 165.

$$C^1 = \frac{E}{r^1 + x}.$$

And in the case of the current c^2, through the other coil r^2 and external resistance w, that

$$C^2 = \frac{E}{r^2 + W}.$$

But, as c^1 and c^2 are equal when balance is obtained, i.e. when the needle stands at zero, and E is the same in both cases,

$$r^1 + x = r^2 + W$$

$$\therefore \quad x = W + r^2 - r^1.$$

But as $$r^2 = r^1$$

$$\therefore \quad x = W.$$

SOLUTION VIII.

Proof of the theory of the tangent galvanometer.

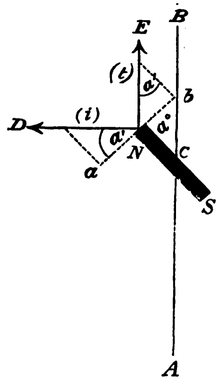

FIG. 83.

Let AB represent the plane of the coil in the magnetic meridian,[1] and NS the needle (suspended at C) which is deflected by a current in the coil, so as to form the angle $a°$ with the magnetic meridian.

In this position the needle is held in equilibrium by two forces:[2] one, the horizontal component of the earth's magnetism, represented by the line NE parallel to the magnetic meridian, the other the resultant of the forces exercised on the needle by the current in the circular coil, which, owing to the breadth of the coil and the shortness of the needle, acts practically at right angles to the magnetic meridian, and is thus represented by the line ND.

Now, denoting by t the directive force of the earth's magnetism on the pole N, as represented by the line NE, and by i the force of the current as represented by ND, and resolving t into the two forces bE (parallel to the plane of the deflected needle) and Nb (at right angles to it), and similarly the force i into the components aD and aN, then, as the components aD and bE act parallel to the needle, they exercise no influence on its deflection; the only remaining forces therefore acting on the pole N are the two opposite forces Na, tending to increase the angle $a°$, and Nb, tending to diminish it.

[1] § 151.

[2] *Note.*—Attention is here confined to the action of the forces on one pole, *N*, of the needle; the same reasoning of course applies to the action of the pole *S*.

APPENDIX B.

But, when the needle is in equilibrium,

$$Na = Nb.$$

Now $$Na = i \,.\, \cos a^{\circ}*$$

and $$Nb = t \,.\, \sin a^{\circ}*$$

$$\therefore \quad i \cos a^{\circ} = t \,.\, \sin a^{\circ}$$

$$\therefore \quad \frac{i}{t} = \frac{\sin a^{\circ}}{\cos a^{\circ}} = \tan a^{\circ}$$

$$\therefore \quad i = t \,.\, \tan a^{\circ}.$$

That is, **the tangent of the angle of deflection is proportional to the strength of the current in the coil.**

* The angles *NCB*, *Nab*, *aND*, are by construction equal, and thus $= a^{\circ}$.

SOLUTION IX.

Proof of the theory of the sine galvanometer.

In the preceding proof it has been shown that

$$Nb = t \sin a^\circ$$

and that

$$Nb = Na.$$

Each of the forces therefore acting on the deflected needle and holding it in equilibrium may be denoted by the expression

$$t \sin a^\circ.$$

Now suppose the coils of the sine galvanometer to be turned after the needle.[1]

The current in the coils will cause the needle to be deflected still farther from the magnetic meridian until a point is reached where the needle lies parallel to the coils, in which position they are shown in the following figure, a° representing the angle through which the needle and coils have been turned out of the magnetic meridian.

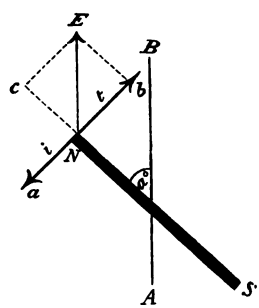

FIG. 84.

The deflecting force *i*, represented by the line *NA*, thus acts at right angles to the needle as well as to its own plane, viz. that of the coils.

NA being counteracted by the equal and opposite force *t* represented by the line *Nb*, tending to draw the needle back to the magnetic meridian *AB*.

[1] § 150.

APPENDIX B.

But it has been shown above that

$$Nb = t \sin a^\circ$$

$$\therefore \quad Na = t \sin a^\circ$$

$$\text{i.e.} \quad i = t \sin a^\circ.$$

And it may be similarly shown that, for any other strength of current i', requiring the coils to be turned after the needle through an angle a'°, that

$$i' = t \sin a'^\circ$$

and

$$\therefore \quad \frac{i}{i'} = \frac{\sin a^\circ}{\sin a'^\circ}.$$

That is, **the currents are proportional to the sines of the angles through which the coils are turned after the needle.**

SOLUTION X.

To measure a resistance x by the deflections of a tangent galvanometer.

$$x = \frac{\tan a'^\circ}{\tan a^\circ}(W+G+f)-(G+f).*$$

* § 260.

PROOF.

In the first circuit, described in para. 260, it follows from Ohm's Law that

$$\tan a^\circ = \frac{E}{x+G+f}$$

and in the second circuit that

$$\tan a'^\circ = \frac{E}{W+G+f}.$$

Thus

$$\frac{\tan a^\circ}{\tan a'^\circ} = \frac{\dfrac{E}{x+G+f}}{\dfrac{E}{W+G+f}}$$

$$\therefore \quad \frac{\tan a^\circ}{\tan a'^\circ} = \frac{W+G+f}{x+G+f}.$$

Whence

$$x(\tan a^\circ)+(G+f)\tan a^\circ = (W+G+f)\tan a'^\circ$$

$$\therefore\ x(\tan a^\circ) = (W+G+f)\tan a'^\circ-(G+f)\tan a^\circ$$

$$\therefore \quad x = \frac{(W+G+f)\tan a'^\circ}{\tan a^\circ}-(G+f)\frac{\tan a^\circ}{\tan a^\circ}$$

$$x = \frac{\tan a'^\circ}{\tan a^\circ}(W+G+f)-(G+f).\dagger$$

† Formula LXIX. Testing Instructions.

APPENDIX B.

SOLUTION XI.

To measure a resistance x using both coils of the tangent galvanometer.

$$x = \frac{\mathbf{n}g' - \dfrac{\tan a^\circ}{\tan a'^\circ} g}{\dfrac{\tan a^\circ}{\tan a'^\circ} - \mathbf{n}}.\text{*}$$

* § 263.

Proof.

It has been shown in the case of the first circuit described in para. 263 that

$$K \tan a^\circ = \frac{e}{g + x}$$

and in the second circuit that

$$K' \tan a'^\circ = \frac{e}{g' + x}$$

$$\therefore \quad \frac{K \tan a^\circ}{K' \tan a'^\circ} = \frac{g' + x}{g + x}$$

$$\therefore \quad \frac{\tan a^\circ}{\tan a'^\circ} = \frac{g' + x}{g + x} \cdot \frac{K'}{K}$$

and as

$$\frac{K'}{K} = \mathbf{n} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(see para. 262)}$$

$$\therefore \quad \frac{\tan a^\circ}{\tan a'^\circ} = \mathbf{n} \, \frac{g' + x}{g + x}$$

$$\therefore \; g + x \left(\frac{\tan a^\circ}{\tan a'^\circ}\right) = \mathbf{n}g' + \mathbf{n}x,$$

whence

$$x \left(\frac{\tan a^\circ}{\tan a'^\circ}\right) - \mathbf{n}x = \mathbf{n}g' - g \left(\frac{\tan a^\circ}{\tan a'^\circ}\right)$$

$$\therefore \quad x = \frac{\mathbf{n}g' - \dfrac{\tan a^\circ}{\tan a'^\circ} g}{\dfrac{\tan a^\circ}{\tan a'^\circ} - \mathbf{n}}.\dagger$$

† Formula LXXIV. Testing Instructions.

APPENDIX B.

SOLUTION XII.

To measure f the internal resistance of a battery with the departmental tangent galvanometer.

$$f = \frac{tan\ a'^{\circ}}{tan\ a^{\circ} - tan\ a'^{\circ}} \cdot w - g.*$$

* § 269.

PROOF.

In the case of the first circuit described in para. 269, it follows from Ohm's Law that

$$C = \frac{E}{f+g}$$

and, in the second circuit,

$$C' = \frac{E}{f+g+w}$$

$$\therefore \quad \frac{C}{C'} = \frac{\frac{E}{f+g}}{\frac{E}{f+g+w}} = \frac{f+g+w}{f+g}$$

But as, according to the principle of the tangent galvanometer,[1]

$$\frac{C}{C'} = \frac{tan\ a^{\circ}}{tan\ a'^{\circ}}$$

then by substituting the latter expression for the former

$$\frac{tan\ a^{\circ}}{tan\ a'^{\circ}} = \frac{f+g+w}{f+g}$$

$$\therefore \quad (tan\ a^{\circ})\,f + (tan\ a^{\circ})\,g = (tan\ a'^{\circ})\,(f+g+w)$$

$$\therefore\ f\,(tan\ a^{\circ} - tan\ a'^{\circ}) = w\,(tan\ a'^{\circ}) - g\,(tan\ a^{\circ} - tan\ a'^{\circ})$$

$$\therefore \quad f = \frac{(tan\ a'^{\circ})\,w}{(tan\ a^{\circ} - tan\ a'^{\circ})} - \frac{g\,(tan\ a^{\circ} - tan\ a'^{\circ})}{(tan\ a^{\circ} - tan\ a'^{\circ})}$$

$$\therefore \quad f = \frac{tan\ a'^{\circ}}{tan\ a^{\circ} - tan\ a'^{\circ}} \cdot w - g.\dagger$$

[1] § 151.

† Formula LXV. Testing Instructions.

APPENDIX B.

SOLUTION XIII.

To measure f the resistance of a battery with the Wheatstone's bridge (Poggendorff).

$$f = \frac{AW' - A'W}{W - W'}.\text{*}$$

* § 270.

PROOF.

By reference to fig. 66, para. 270, it will be observed that when balance is obtained no current flows through the x and g branches of the bridge, but is closed through the circuit composed of A, W, and f.

Now, by Kirchhoff's second law,[1] which states that the total electromotive force in any circuit is equal to the sum of all the resistances multiplied by the sum of all the current strengths (c) in the same circuit, it follows that, in the first circuit described in para. 270,

$$E = C(A + f + W),\dagger$$

and for the same reason, in the closed circuit made up of W, x, and g, as no current flows in x and g,

$$e = CW,$$

whence
$$\frac{E}{e} = \frac{A + f + W}{W};$$

and similarly in the second case described in para. 270,

$$\frac{E'}{e'} = \frac{A' + f + W'}{W'}$$

and as
$$\frac{E}{e} = \frac{E'}{e'}$$

$$\frac{A' + f + W'}{W'} = \frac{A + f + W}{W}$$

$$\therefore\ A'W + fW + WW' = AW' + fW' + WW'$$

$$\therefore\ fW - fW' = AW' - A'W$$

$$\therefore\ f(W - W') = AW' - A'W$$

$$\text{and } f = \frac{AW' - A'W}{W - W'}.\ddagger$$

[1] Law 2 (ii), App. A.

† E and E' represent the electromotive forces in the first and second observations respectively of the battery whose resistance is to be measured; e, e' the same for the standard cell in the x branch.

‡ Formula IX. Testing Instructions.

SOLUTION XIV.

To measure f the resistance of a battery by Mance's method of opposing E.M.F.

$$f = W\frac{E}{e} - W.^{*}$$

* § 277.

PROOF.

Referring to fig. 68 (para. 277), it is obvious that when the galvanometer needle stands at zero, C (the current strength of the battery E on the needle) must be equal to c (the effective strength of the battery e).

Now

$$C = \frac{E}{f + \frac{GW}{G+W}} \times \frac{W}{W+G}$$

$\left(\frac{W}{W+G}\right.$ being the multiplying power of the shunt w on the galvanometer G),

and

$$c = \frac{e}{G + \frac{fW}{f+W}}$$

$$\therefore \quad \frac{E}{f + \frac{GW}{G+W}} \times \frac{W}{W+G} = \frac{e}{G + \frac{fW}{f+W}}$$

whence

$$\frac{EW}{\frac{f(G+W)+GW}{\cancel{W+G}} \times \cancel{G+W}} = \frac{e}{\frac{G(f+W)+fW}{f+W}}$$

$$\therefore \quad \frac{EW}{fG+fW+GW} = \frac{e(f+W)}{Gf+GW+fW}$$

$$\therefore \quad f + W = \frac{EW}{e}$$

and

$$f = W\frac{E}{e} - W.$$

APPENDIX B.

SOLUTION XV.

To measure E the electromotive force of a battery in terms of the standard cell with the tangent galvanometer.

$$E = \frac{tan\ a^\circ}{tan\ a'^\circ} \cdot \frac{f+g+W}{f'+g} \cdot E'.*$$

* § 280.

PROOF.

Calling C' the current strength of the standard cell in the first circuit described in para. 280, and C the current strength of the battery under test in the second circuit, it follows from Ohm's Law[1] that

$$C = \frac{E}{f+g+W}$$

and that

$$C' = \frac{E'}{f'+g}.$$

And, from the principle of the tangent galvanometer,[2] that

$$\frac{C}{C'} = \frac{tan\ a^\circ}{tan\ a'^\circ}$$

$$\therefore \quad \frac{tan\ a^\circ}{tan\ a'^\circ} = \frac{\frac{E}{f+g+W}}{\frac{E'}{f'+g}}.$$

Hence

$$\frac{tan\ a^\circ}{tan\ a'^\circ} = \frac{E}{E'} \cdot \frac{f'+g}{f+g+W}$$

$$\therefore \quad \frac{E}{E'} = \frac{tan\ a^\circ}{tan\ a'^\circ} \cdot \frac{f+g+W}{f'+g}$$

and

$$E = \frac{tan\ a^\circ}{tan\ a'^\circ} \cdot \frac{f+g+W}{f'+g} \cdot E'.\dagger$$

[1] Law 1, App. A.

[2] § 151.

† Formula LXVII. Testing Instructions.

SOLUTION XVI.

To measure E **the electromotive force of a battery with the Wheatstone bridge** (Poggendorff).

$$E = \frac{A - A'}{W - W'} + 1.^*$$

* § 281.

PROOF.

The circuit is described in fig. 66, para. 270.[1]

In the first case described in para. 270 it follows from Kirchhoff's second law [2] that

$$E = C(A + f + W)$$

and

$$e = CW$$

(E and e representing the electromotive forces of the battery under test and of the standard cell respectively)

$$\therefore \quad \frac{E}{e} = \frac{A + f + W}{W}$$

and

$$E = \left(\frac{A + W + f}{W}\right)e.$$

Now, by the formula in para. 270, proved by Solution XIII.

$$f = \frac{AW' - A'W}{W - W'}.$$

$\therefore$ Substituting the above value of f,

$$E = \left\{\frac{A + W}{W} + \frac{AW' - A'W}{W(W - W')}\right\}e.$$

Hence (e, the standard, being taken as unity)

$$E = \frac{A + W}{W} + \frac{AW' - A'W}{W(W - W')}$$

$$= \frac{(A + W)(W - W') + AW' - A'W}{W(W - W')}$$

$$= \frac{AW + WW - AW' - WW' + AW' - A'W}{W(W - W')}$$

[1] See also § 281.

[2] Law 2 (ii), App. A.

APPENDIX B.

$$= \frac{AW - A'W + WW - WW'}{W(W - W')}$$

$$= \frac{W(A - A') + W(W - W')}{W(W - W')}$$

$$= \frac{W(A - A')}{W(W - W')} + \frac{W(W - W')}{W(W - W')}$$

$$\therefore \; E = \frac{A - A'}{W - W'} + 1.^{*}$$

* Formula VIII. Testing Instructions.

SOLUTION XVII.

To find x the corrected resistance of a conductor influenced by natural currents.

$$x = \frac{w'' + w'}{2} - N\frac{w'' - w'}{2}.*$$

* § 309.

PROOF.

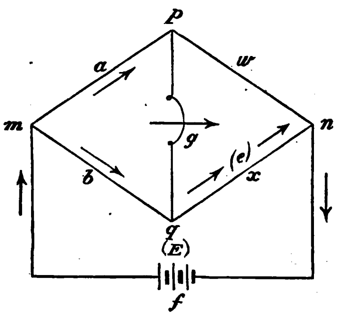

FIG. 85.

Denoting by the letters A, B, W, G, X, and F the currents which flow through the corresponding resistances a, b, w,[1] g, x, and f respectively in the figure represented above, we have, when balance is established (i.e. $G = o$), the following equations of current strength according to Kirchhoff's first law.[2]

Considering the

$$\text{point } p \; .\;.\;.\;.\; A = W \; .\;.\;.\;.\; (a) \;\therefore\; A - W = o$$
$$\text{,, } q \; .\;.\;.\;.\; B = X \; .\;.\;.\;.\; (b) \;\therefore\; X - B = o$$
$$\text{,, } m \; .\;.\;.\;.\; F = A + B \; .\;.\; (c) \;\therefore\; F - A - B = o$$

Suppose the natural current (e) to be in the same direction as the testing current (E), as shown by the arrows, then by Kirchhoff's second law[3] we have the following three equations :

In the closed figure $mpqm$ . . . . $aA - bB = o$ . . (1)

No E.M.F. in a or b. $aA = bB$.

[1] w' expressing the value of w when measured with a + current, and w'' its value with a − current.

[2] Law 2 (i), App. A.

[3] Law 2 (ii), App. A.

APPENDIX B.

In the closed figure $npqn$ . . . . $xX - w'W = e$. (2)
(e) the E.M.F. in x being the only E.M.F. in the circuit.

In the closed figure $\left\{\begin{array}{c} mpqn \text{ and} \\ \text{testing} \\ \text{battery} \end{array}\right\} fF + aA + xX = E + e$ (3)

E in f and e in x being the total E.M.F. in the circuit.

Substituting in (3) the values $F = A + B$
and $X = B$

and in (2) the values $W = A$
and $X = B$

equations (3) and (2) may be written

$$f(A+B) + aA + xB = E + e \quad . \quad . \quad . \quad (3)$$

$$\text{and } xB - w'A = e \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Dividing (3) by (2)

$$\frac{E+e}{e} = \frac{f(A+B) + aA + xB}{xB - w'A} \quad . \quad . \quad (4)$$

$$\therefore \quad \frac{E+e}{e} = \frac{Af + Bf + aA + xB}{xB - w'A}$$

$$\therefore \quad \frac{E+e}{e} = \frac{B(x+f) + A(f+a)}{xB - w'A}.$$

Now, by equation (1), $aA = bB$,

$$\therefore \quad A = \frac{b}{a}B.$$

Substituting this value of A in equation (4),

$$\frac{E+e}{e} = \frac{B(x+f) + \frac{b}{a}B(f+a)}{xB - \frac{w'b}{a}B}.$$

Dividing numerator and denominator by B,

$$\frac{E+e}{e} = \frac{x + f + \frac{b}{a}(f+a)}{x - \frac{w'b}{a}} \quad . \quad . \quad (5)$$

$$\therefore \quad \frac{E}{e} + 1 = \frac{a(x+f) + b(f+a)}{ax - bw'}.$$

Let $$\frac{E}{e} = y$$

then $$1 + y = \frac{a(x+f) + b(f+a)}{ax - bw'}$$

$$\therefore \quad ax - bw' + y(ax - bw') = a(x+f) + b(f+a)$$

$$\therefore \quad y(ax - bw') = ax + af + bf + ab - ax + bw'$$

$$\therefore \quad y(ax - bw') = a(b+f) + b(f+w'). \quad . \quad . \quad (6)$$

$$\therefore \quad y = \frac{a(b+f) + b(f+w')}{ax - bw'}. \quad . \quad . \quad (7)$$

Now, suppose the testing battery E to be reversed

$$(= -E),$$

then, by a similar process,

$$1 - \frac{E}{e} = 1 - y = \frac{b(a+f) + a(x+f)}{ax - bw''}$$

$$\therefore \quad y(bw'' - ax) = a(b+f) + b(f+w'') \quad . \quad . \quad (8)$$

$$\therefore \quad y = \frac{a(b+f) + b(f+w'')}{bw'' - ax} \quad . \quad . \quad . \quad . \quad (9)$$

Now, from equations (6) and (8),

$$y(ax - bw') = a(b+f) + b(f+w')$$

and $$y(bw'' - ax) = a(b+f) + b(f+w'')$$

$\therefore$ by addition

$$y(bw'' - bw') = 2ab + 2af + bw' + bw'' + 2b$$

and $$y = \frac{E}{e} = \frac{b(w' + w'') + 2f(a+b) + 2ab}{b(w'' - w')} \quad . \quad . \quad (10)$$

Again, equations (6) and (8) may be written

$$axy - bw'y = ab + af + bf + bw'$$

and $$-axy + bw''y = ab + af + bf + bw''$$

$\therefore$ by subtraction,

$$2axy - bw'y - bw''y = bw' - bw''$$

$$\therefore \quad 2axy = by(w' + w'') + b(w' - w'')$$

$$\therefore \quad x = \frac{b(w' + w'')}{2a} + \frac{b(w' - w'')}{2ay}.$$

APPENDIX B.

Substituting the value of y from equation (10)

$$x = \frac{b\,(w'+w'')}{2a} + \frac{b\,(w'-w'')}{2a\,.\,\dfrac{b\,(w'+w'')+2f\,(a+b)+2ab}{b\,(w''-w')}}$$

$$\therefore\ x = \frac{b\,(w'+w'')}{2a} + \frac{b^2\,(w'-w'')\,(w''-w')}{2a\,\{b\,(w'+w'')+2f\,(a+b)+2ab\}}$$

$$\therefore\ x = \frac{b}{a}\,.\,\frac{w'+w''}{2} + \frac{b\,(w'-w'')\,(w''-w')}{2\,[b\,(w'+w'')+2\,\{ab+f\,(a+b)\}]}.$$

Now $\quad (w'-w'')\,(w''-w') = -w''^2+2w'w''-w'^2$

$$= -(w''-w')^2$$

$$= -(w''-w')\,(w''-w')$$

$$\therefore\ x = \frac{b}{a}\,.\,\frac{w'+w''}{2} - \frac{b\,(w''-w')\,(w''-w')}{2\,[b\,(w'+w'')+2\,\{ab+f\,(a+b)\}]}\ . \qquad (11)$$

Now the following proof (Solution XVIII.) goes on to show that the ratio

$$\frac{e}{E} = N = \frac{b\,(w''-w')}{b\,(w'+w'')+2\,\{ab+f\,(a+b)\}}$$

and, substituting N for this expression in equation (11),

$$x = \frac{b}{a}\left\{\frac{w'+w''}{2} - N\,.\,\frac{w''-w'}{2}\right\}*$$

or, with equal branches a and b,

$$x = \frac{w'+w''}{2} - N\,.\,\frac{w''-w'}{2}.\dagger$$

* Formula III. Testing Instructions.

† Formula V. Testing Instructions.

APPENDIX B.

SOLUTION XVIII.

To find *e* the electromotive force of a natural current in the line in terms of *E* the E.M.F. of the testing battery.

$$e = \frac{w'' - w'}{w'' + w' + 2(a + 2f)} \cdot E.^*$$

* § 310.

PROOF.

Referring to the preceding proof (Solution XVII.), it has been shown by equation (10) that

$$y = \frac{E}{e} = \frac{b(w' + w'') + 2f(a+b) + 2ab}{b(w'' - w')}$$

$$\therefore \quad \frac{e}{E} = \frac{b(w'' - w')}{b(w' + w'') + 2\{ab + f(a+b)\}}$$

and calling the ratio $\frac{e}{E} = N$,

$$N = \frac{b(w'' - w')}{b(w' + w'') + 2\{ab + f(a+b)\}} \cdot \dagger$$

† Formula IV. Testing Instructions.

Or, with equal branches a and b,

$$N = \frac{w'' - w'}{(w' + w'') + 2a + 2f} \cdot \ddagger$$

‡ Formula VI. Testing Instructions.

Or,

$$e = \frac{w'' - w'}{w' + w'' + 2(a + 2f)} E.$$

APPENDIX B

SOLUTION XIX.

To find g the corrected relay resistance from the measured values $\mathfrak{I}$, $\mathfrak{CU}$, and $\mathfrak{w}$.

$$g = \frac{\mathfrak{I}\,(\mathfrak{CU} - \mathfrak{w})}{\mathfrak{I} - \mathfrak{CU}}.\text{*}$$

* § 312.

PROOF.

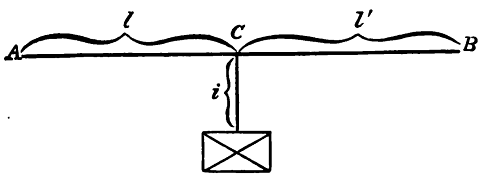

FIG. 86.

Let AB represent a telegraph line, of which L = the corrected conduction resistance;

Let l = the corrected conduction resistance from A to the resultant fault (at C);

And l' = the corrected conduction resistance from C to B.

$$(\text{Thus } L = l + l')$$

and let i = the corrected insulation resistance of the whole line.

Then, in the case of the circuit test, in which a relay R is included, it follows, from the law of derived circuits,[1] that

$$\mathfrak{CU} = l + \frac{i\,(l'+R)}{i+l'+R} \quad . \quad . \quad . \quad (1)$$

In the conduction test

$$\mathfrak{w} = l + \frac{il'}{i+l'} \quad . \quad . \quad . \quad . \quad (2)$$

and in the insulation test

$$\mathfrak{I} = l + i \quad . \quad . \quad . \quad . \quad . \quad (3)$$

And suppose the insulation of the line to be uniform, i.e. $l = l'$,

[1] Law 8, App. A.

Subtracting (1) from (3)

$$\mathfrak{J} - \mathfrak{W} = i - \frac{i\,(l+R)}{i+l+R}$$

$$\therefore \quad \mathfrak{J} - \mathfrak{W} = \frac{i^2 + il + iR - il - iR}{i+l+R}$$

$$\therefore \quad \mathfrak{J} - \mathfrak{W} = \frac{i^2}{i+l+R} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

And subtracting (2) from (1)

$$\mathfrak{W} - \mathfrak{w} = \frac{i\,(l+R)}{i+l+R} - \frac{il}{i+l}$$

$$\therefore \quad \mathfrak{W} - \mathfrak{w} = \frac{(il+iR)\,(i+l) - (i+l+R)\,il}{i^2 + il + iR + il + l^2 + lR}$$

$$\therefore \quad \mathfrak{W} - \mathfrak{w} = \frac{i^2l + i^2R + il^2 + ilR - i^2l - il^2 - ilR}{i^2 + il + iR + il + l^2 + lR}$$

$$\therefore \quad \mathfrak{W} - \mathfrak{w} = \frac{i^2R}{i^2 + 2il + iR + l^2 + lR} \quad . \quad . \quad . \quad (5)$$

Dividing (4) by (5)

$$\frac{\mathfrak{J} - \mathfrak{W}}{\mathfrak{W} - \mathfrak{w}} = \frac{i^2}{i+l+R} \times \frac{i^2 + 2il + iR + l^2 + lR}{i^2R} \quad . \quad (6)$$

Now by (3) $\mathfrak{J} = l + i$

$$\therefore \quad l = \mathfrak{J} - i.$$

And substituting this value of l in equation (6)

$$\frac{\mathfrak{J} - \mathfrak{W}}{\mathfrak{W} - \mathfrak{w}} = \frac{i^2 + 2i(\mathfrak{J}+i) + iR + (\mathfrak{J}-i)^2 + R\,(\mathfrak{J}-i)}{iR + R\,(\mathfrak{J}-i) + R^2}$$

$$\therefore \quad \frac{\mathfrak{J} - \mathfrak{W}}{\mathfrak{W} - \mathfrak{w}} = \frac{i^2 + 2i\mathfrak{J} - 2i^2 + iR + \mathfrak{J}^2 - 2i\mathfrak{J} + i^2 + R\mathfrak{J} - iR}{iR + R\mathfrak{J} - iR + R^2}$$

$$\therefore \quad \frac{\mathfrak{J} - \mathfrak{W}}{\mathfrak{W} - \mathfrak{w}} = \frac{\mathfrak{J}^2 + \mathfrak{J}R}{R^2 + \mathfrak{J}R}$$

$$\therefore \quad \frac{\mathfrak{W} - \mathfrak{w}}{\mathfrak{J} - \mathfrak{W}} = \frac{R\,(\mathfrak{J}+R)}{\mathfrak{J}\,(\mathfrak{J}+R)} = \frac{R}{\mathfrak{J}}$$

$$\therefore \quad \frac{\mathfrak{J}\,(\mathfrak{W} - \mathfrak{w})}{\mathfrak{J} - \mathfrak{W}} = R.$$

And expressing by g this corrected value of R,

$$g = \frac{\mathfrak{J}\,(\mathfrak{W} - \mathfrak{w})}{\mathfrak{J} - \mathfrak{W}}.^*$$

* Formula XXVI. Testing Instructions.

APPENDIX B.

SOLUTION XX.

To find i the corrected absolute insulation of any line from the measured values $\mathfrak{J}$, $\mathfrak{M}$, and $\mathfrak{w}$.

$$i = \sqrt{\frac{(\mathfrak{J} - \mathfrak{M})(\mathfrak{J} - \mathfrak{w})R}{\mathfrak{M} - \mathfrak{w}}}.*$$

* § 315.

PROOF.

Subtracting equation (1) from (3) in the preceding proof (Solution XIX.)

$$\mathfrak{J} - \mathfrak{M} = i - \frac{i(l'+R)}{i+l'+R}$$

$$\therefore \quad \mathfrak{J} - \mathfrak{M} = \frac{i^2 + il' + iR - il' - iR}{i+l'+R}$$

$$\therefore \quad \mathfrak{J} - \mathfrak{M} = \frac{i^2}{i+l'} + R$$

$$\therefore \ i\mathfrak{J} + \mathfrak{J}l' + \mathfrak{J}R - i\mathfrak{M} - l'\mathfrak{M} - \mathfrak{M}R = i^2 . \qquad (7)$$

And subtracting (2) from (3) (Solution XIX.)

$$\mathfrak{J} - \mathfrak{w} = i - \frac{il'}{i+l'} = \frac{i^2 + il' - il'}{i+l'}$$

$$\therefore \quad \mathfrak{J} - \mathfrak{w} = \frac{i^2}{i+l'}$$

$$\therefore \quad \mathfrak{J}i + \mathfrak{J}l' - i\mathfrak{w} - l'\mathfrak{w} = i^2 \qquad (8)$$

Thus, from equations (7) and (8)

$$i\mathfrak{J} + \mathfrak{J}l' + \mathfrak{J}R - i\mathfrak{M} - l'\mathfrak{M} - \mathfrak{M}R = \mathfrak{J}i + \mathfrak{J}l' - i\mathfrak{w} - l'\mathfrak{w}$$

$$\therefore \quad \mathfrak{J}R - i\mathfrak{M} - l'\mathfrak{M} - \mathfrak{M}R = - i\mathfrak{w} - l'\mathfrak{w}$$

$$\therefore \quad l'\mathfrak{M} - l'\mathfrak{w} = i\mathfrak{w} - i\mathfrak{M} - \mathfrak{M}R + \mathfrak{J}R$$

$$\therefore \quad l'(\mathfrak{M} - \mathfrak{w}) = R(\mathfrak{J} - \mathfrak{M}) - i(\mathfrak{M} - \mathfrak{w})$$

$$\therefore \quad l' = \frac{R(\mathfrak{J} - \mathfrak{M}) - i(\mathfrak{M} - \mathfrak{w})}{\mathfrak{M} - \mathfrak{w}}. \qquad (9)$$

Now, it has been shown above, that subtracting (2) from (3) (Solution XIX.)

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$$\mathfrak{Z} - \mathfrak{w} = i - \frac{il'}{i + l'}$$

whence

$$i = \mathfrak{Z} - \mathfrak{w} + \frac{il'}{i + l'}.$$

And substituting in this equation the value of l' found by equation (9)

$$i = \mathfrak{Z} - \mathfrak{w} + \frac{\dfrac{iR\,(\mathfrak{Z} - \mathfrak{TA}) - i^2\,(\mathfrak{TA} - \mathfrak{w})}{\mathfrak{TA} - \mathfrak{w}}}{i + \dfrac{R\,(\mathfrak{Z} - \mathfrak{TA}) - i\,(\mathfrak{TA} - \mathfrak{w})}{\mathfrak{TA} - \mathfrak{w}}}$$

$$\therefore\ i = \mathfrak{Z} - \mathfrak{w} + \frac{\dfrac{iR\,(\mathfrak{Z} - \mathfrak{TA}) - i^2\,(\mathfrak{TA} - \mathfrak{w})}{\mathfrak{TA} - \mathfrak{w}}}{\dfrac{i\,(\mathfrak{TA} - \mathfrak{w}) + R\,(\mathfrak{Z} - \mathfrak{TA}) - i\,(\mathfrak{TA} - \mathfrak{w})}{\mathfrak{TA} - \mathfrak{w}}}$$

$$\therefore\ i = \mathfrak{Z} - \mathfrak{w} + \frac{\dfrac{iR\,(\mathfrak{Z} - \mathfrak{TA}) - i^2\,(\mathfrak{TA} - \mathfrak{w})}{\mathfrak{TA} - \mathfrak{w}}}{\dfrac{R\,(\mathfrak{Z} - \mathfrak{TA})}{\mathfrak{TA} - \mathfrak{w}}}$$

$$\therefore\ i = \mathfrak{Z} - \mathfrak{w} + \frac{iR\,(\mathfrak{Z} - \mathfrak{TA}) - i^2\,(\mathfrak{TA} - \mathfrak{w})}{R\,(\mathfrak{Z} - \mathfrak{TA})}$$

$$\therefore\ i = \mathfrak{Z} - \mathfrak{w} + \frac{iR\,(\mathfrak{Z} - \mathfrak{TA})}{R\,(\mathfrak{Z} - \mathfrak{TA})} - \frac{i^2\,(\mathfrak{TA} - \mathfrak{w})}{R\,(\mathfrak{Z} - \mathfrak{TA})}$$

$$\therefore\ i = \mathfrak{Z} - \mathfrak{w} + i - \frac{i^2\,(\mathfrak{TA} - \mathfrak{w})}{R\,(\mathfrak{Z} - \mathfrak{TA})}$$

$$\therefore\ \frac{i^2\,(\mathfrak{TA} - \mathfrak{w})}{R\,(\mathfrak{Z} - \mathfrak{TA})} = \mathfrak{Z} - \mathfrak{w}$$

$$\therefore\ i^2 = \frac{(\mathfrak{Z} - \mathfrak{w})\,(\mathfrak{Z} - \mathfrak{TA})\,R}{\mathfrak{TA} - \mathfrak{w}}$$

$$\therefore\ i = \sqrt{\frac{(\mathfrak{Z} - \mathfrak{TA})\,(\mathfrak{Z} - \mathfrak{w})\,R}{\mathfrak{TA} - \mathfrak{w}}}.\text{*}$$

* Formula XXIV. (*a*) Testing Instructions.

APPENDIX B.

SOLUTION XXI.

To find L the corrected absolute conduction resistance of any line from the corrected insulation.

$$L = \mathfrak{I} + \frac{(\mathfrak{I} - \mathfrak{UA})\,R}{\mathfrak{UA} - \mathfrak{w}} - 2i.^{*}$$

* § 315.

PROOF.

It has been already shown by fig. 86, Solution XIX., that

$$L = l + l',$$

and by equation (3), Solution XIX., that

$$l = \mathfrak{I} - i,$$

and by equation (9), Solution XX., that

$$l' = \frac{R(\mathfrak{I} - \mathfrak{UA}) - i(\mathfrak{UA} - \mathfrak{w})}{\mathfrak{UA} - \mathfrak{w}}.$$

Whence

$$L = \mathfrak{I} - i + \frac{R(\mathfrak{I} - \mathfrak{UA}) - i(\mathfrak{UA} - \mathfrak{w})}{\mathfrak{UA} - \mathfrak{w}}$$

$$\therefore\ L = \frac{\mathfrak{I}\mathfrak{UA} - \mathfrak{I}\mathfrak{w} - i\mathfrak{UA} + i\mathfrak{w} + R(\mathfrak{I} - \mathfrak{UA}) - i(\mathfrak{UA} - \mathfrak{w})}{\mathfrak{UA} - \mathfrak{w}}$$

$$\therefore\ L = \frac{\mathfrak{I}(\mathfrak{UA} - \mathfrak{w}) + R(\mathfrak{I} - \mathfrak{UA})}{\mathfrak{UA} - \mathfrak{w}} - \frac{2i(\mathfrak{UA} - \mathfrak{w})}{\mathfrak{UA} - \mathfrak{w}}$$

$$\therefore\ L = \mathfrak{I} + \frac{R(\mathfrak{I} - \mathfrak{UA})}{\mathfrak{UA} - \mathfrak{w}} - 2i.^{\dagger}$$

† Formula XXV. (*a*) Testing Instructions.

Note.—The value of i is found by the formula in the preceding solution (XX.)

When g is within 15 per cent. of R, and consequently

$$l = l',^{\ddagger}$$

‡ § 312.

the following simpler values for i and L are true :

$$i = \sqrt{\mathfrak{Z}(\mathfrak{Z}-\mathfrak{w})}$$

$$L = 2\{\mathfrak{Z} - \sqrt{\mathfrak{Z}(\mathfrak{Z}-\mathfrak{w})}\}.$$

For, when $l = l'$,

by equation (2), Solution XIX.

$$\mathfrak{w} = l + \frac{il}{i+l} \quad . \quad . \quad . \quad . \quad . \quad (a)$$

and by equation (3), Solution XIX.

$$l = \mathfrak{Z} - i \quad . \quad . \quad . \quad . \quad . \quad (b)$$

and substituting this value of l in (a)

$$\mathfrak{w} = \mathfrak{Z} - i + \frac{i(\mathfrak{Z}-i)}{i+\mathfrak{Z}-i}$$

$$\therefore \quad \mathfrak{w} = \frac{\mathfrak{Z}^2 - i^2 - i\mathfrak{Z} + i\mathfrak{Z}}{\mathfrak{Z}}$$

$$\therefore \quad \mathfrak{Z}\mathfrak{w} = \mathfrak{Z}^2 - i^2$$

$$\therefore \quad i^2 = \mathfrak{Z}^2 - \mathfrak{Z}\mathfrak{w}$$

$$\therefore \quad i = \sqrt{\mathfrak{Z}^2 - \mathfrak{Z}\mathfrak{w}} = \sqrt{\mathfrak{Z}(\mathfrak{Z}-\mathfrak{w})}.$$

Now, as $l = l'$,

$$L = 2l.*$$

$$\therefore \text{ from } (b) \quad L = 2(\mathfrak{Z} - i)$$

$$\therefore \quad L = 2\{\mathfrak{Z} - \sqrt{\mathfrak{Z}(\mathfrak{Z}-\mathfrak{w})}\}.$$

* See figure 86, Solution XIX.

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SOLUTION XXII.

To find l the conduction resistance of a line from the testing station to the resultant fault, and z the resistance of the fault.

$$l = \frac{\Sigma\left(\frac{r}{y}\right)}{\Sigma\left(\frac{1}{y}\right)}.*$$

$$z = \frac{1}{\Sigma\left(\frac{1}{y}\right)}.*$$

* § 317.

PROOF.

Let AB represent the circuit of the conduction test of a uniformly insulated line.

First, supposing the line to contain only two faults, y', y'', all other points of the line between A and B being insulated from the earth :

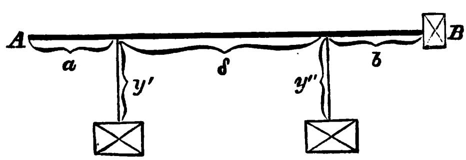

FIG. 87.

Expressing by small letters the resistances of the five branches a, y', δ, y'', b, and by corresponding capitals the currents which flow through them respectively :

A being thus the current starting from A, flowing through a, and arriving at y', and B the amount of current arriving at B through b, we have, by the laws of current strength in derived circuits,[1] the following expression for the amount of current flowing through δ to the second fault y'' :

$$D = A\frac{y'}{y' + \delta + \frac{y''b}{y''+b}}$$

[1] Law 9, App. A. and Solution IV. App. B.

$$\therefore \quad D = A \frac{y'b + y'y''}{(y' + \delta)(y'' + b) + by''}.$$

Similarly, the current flowing through b and reaching B is as follows :

$$B = D \frac{y''}{y'' + b}$$

$$\therefore \quad B = A \cdot \frac{y'b + y'y''}{(y' + \delta)(y'' + b) + by''} \cdot \frac{y''}{y'' + b}$$

$$\therefore \quad B = A \cdot \frac{y'y''b + y'y''^2}{\{(y' + \delta)(y'' + b) + by''\}(y'' + b)}.$$

$$\therefore \quad B = A \cdot \frac{y'y''(y'' + b)}{\{(y' + \delta)(y'' + b) + by''\}(y'' + b)}$$

$$\therefore \quad B = A \cdot \frac{y'y''}{(y' + \delta)(y'' + b) + by''}.$$

Now suppose that in the line AB instead of the two faults y', y'' there be only one fault, of resistance z (l being the resistance of the line from A to z), and l' the resistance beyond,

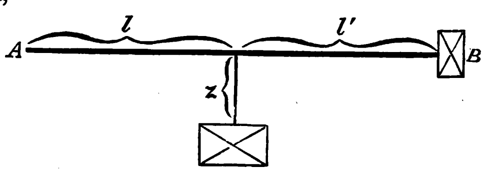

FIG. 88.

Then the current flowing through l' and arriving at B is as follows :

$$L' = L \frac{z}{l' + z}.$$

But $\quad L' = B,$

and $\quad L = A.$

$$\therefore \quad \frac{y'y''}{(y' + \delta)(y'' + b) + by''} = \frac{z}{l' + z} \quad . \quad . \quad (1)$$

Next, suppose the earth to be removed from B, i.e. the line AB to be insulated at its distant end, then by the same reasoning, in the case of two faults y' and y'',

$$A = \frac{Constant}{a + \dfrac{y'(y'' + \delta)}{y' + y'' + \delta}}.$$

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Or, in the case of only one fault z,

$$L = \frac{Constant}{l + z}.$$

But $$L = A,$$

$$\therefore \quad l + z = a + \frac{y'(y'' + \delta)}{y' + y'' + \delta} \quad . \quad . \quad . \quad (2)$$

Further $$l + l' = a + \delta + b \quad . \quad . \quad . \quad . \quad (3)$$

And, from equations (1), (2), (3),

$$l = a + \frac{y'\delta}{y' + y'' + \delta} \cdot \frac{b(y' + \delta) + y''b - y'y''}{b(y' + \delta) + y''(b + \delta) - y'y''} \quad . \quad (4)$$

$$z = a - l + \frac{y'(y'' + \delta)}{y' + y'' + \delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Now suppose y' and y'' to be invariably so close together (as they are in an ordinary line containing an innumerable number of faults, each of great resistance) that δ can be neglected against b,

Then the right-hand factor in equation (4) approximates to unity very rapidly, and we have

$$l = a + \frac{y'\delta}{y' + y'' + \delta} \quad . \quad . \quad . \quad (6)$$

and, substituting this approximate value of l in equation (5),

$$z = \frac{y'y''}{y' + y'' + \delta} \quad . \quad . \quad . \quad . \quad (7)$$

Now, in a working line, as y' and y'' must be so large, as compared with b, that b can be neglected, much more can δ (a small portion of b) be neglected against the sum of them. Thus,

$$l = a + \frac{y'\delta}{y' + y''} \quad . \quad . \quad . \quad . \quad (8)$$

And $$z = \frac{y'y''}{y' + y''} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Now, calling r' and r'' the resistances from A to y' and y'' respectively,

Then, from equation (8),

$$l = \frac{r''y' + r'y''}{y' + y''} \quad . \quad . \quad . \quad . \quad (10)$$

i.e. for any fault y whose distance from A (in resistance) $= r$

$$l = \frac{\textit{the sum of } (ry)}{\textit{the sum of } (y)} = \frac{\Sigma\,(ry)}{\Sigma\,(y)}$$

whence, dividing numerator and denominator by y^2,

$$l = \frac{\Sigma\left(\frac{r}{y}\right)}{\Sigma\left(\frac{1}{y}\right)}.*$$

From equation (9)

$$z = \frac{y^2}{\Sigma\,(y)}$$

And dividing again by y^2,

$$z = \frac{1}{\Sigma\left(\frac{1}{y}\right)}.\dagger$$

* Formula XXIV. (*c*) Testing Instructions, App. XI. (*a*).

† Formula XXIV. (*c*) App. XI. (*a*) Testing Instructions.

APPENDIX B.

SOLUTION XXIII.

To find $\mathfrak{w}$ and $\mathfrak{I}$ the absolute conduction and insulation resistance of the distant section of a highly insulated line, where measured values do not require correction.

$$\mathfrak{w} = \mathfrak{w}_2 - \mathfrak{w}_1 \,{}^*$$

$$\mathfrak{I} = \frac{\mathfrak{I}_1 \mathfrak{I}_2}{\mathfrak{I}_1 - \mathfrak{I}_2}.^*$$

* § 318.

Referring to the figure in para. 318, it is obvious in the case when the insulation of the line *ABC* is so good that measured values are correct, that

$$\mathfrak{w} = \mathfrak{w}_2 - \mathfrak{w}_1.$$

It will be observed here that $\mathfrak{w}$ occupies the same position with regard to the line *AB* that *R*, the measured relay, does in the case of a circuit test of the line *AB*.

Thus, the above equation,

$$\mathfrak{w} = \mathfrak{w}_2 - \mathfrak{w}_1,$$

is identical with

$$R = \mathfrak{W} - \mathfrak{w}.^\dagger$$

† § 311.

And as $\mathfrak{W}$ corresponds with $\mathfrak{w}_2$ in figure (para. 318), and $\mathfrak{w}_1$ corresponds with $\mathfrak{w}$ in the same figure,

$$\mathfrak{w} \text{ (the resistance of } BC) = R.$$

Now let $\mathfrak{I}$, $\mathfrak{I}_1$, $\mathfrak{I}_2$ represent the absolute insulation resistance of the sections whose absolute conduction resistance is expressed by $\mathfrak{w}$, $\mathfrak{w}_1$, $\mathfrak{w}_2$ respectively.

Then, by the law of derived circuits,[1]

$$\mathfrak{I}_2 = \frac{\mathfrak{I}\mathfrak{I}_1}{\mathfrak{I} + \mathfrak{I}_1}$$

$$\therefore \quad \mathfrak{I}\mathfrak{I}_1 = \mathfrak{I}\mathfrak{I}_2 + \mathfrak{I}_1\mathfrak{I}_2$$

$$\therefore \quad \mathfrak{I}\,(\mathfrak{I}_1 - \mathfrak{I}_2) = \mathfrak{I}_1\mathfrak{I}_2$$

$$\therefore \quad \mathfrak{I} = \frac{\mathfrak{I}_1\mathfrak{I}_2}{\mathfrak{I}_1 - \mathfrak{I}_2}.$$

[1] Law 8, App. A.

SOLUTION XXIV.

To find $\mathfrak{w}$ and $\mathfrak{J}$ the absolute conduction and insulation resistance of the distant section of an imperfectly insulated line.

$$\mathfrak{w} = \frac{\mathfrak{J}_1 (\mathfrak{w}_2 - \mathfrak{w}_1)}{\mathfrak{J}_1 - \mathfrak{w}_2} *$$

* § 318.

and

$$\mathfrak{J} = \frac{\mathfrak{J}_1 (\mathfrak{J}_2 - \mathfrak{w}_1)}{\mathfrak{J}_1 - \mathfrak{J}_2} *$$

PROOF.

Again referring to the figure in para. 318, it has been shown in the preceding proof (Solution XXIII.) how (in the case of measured values) $\mathfrak{w}$, the resistance of the section *BC*, corresponds with *R* the measured relay resistance in the circuit test.

Similarly, in the case where corrections become necessary on account of defective insulation, $\mathfrak{w}$ would correspond with *g* the *corrected* relay resistance.[1]

[1] § 312.

Now it has been proved (Solution XIX.) that

$$g = \frac{\mathfrak{J} (\mathfrak{W} - \mathfrak{w})}{\mathfrak{J} - \mathfrak{W}}.$$

And substituting for *g*, $\mathfrak{J}$, $\mathfrak{W}$, and $\mathfrak{w}$, the values as represented in the figure (para. 318),

$$\mathfrak{w} = \frac{\mathfrak{J}_1 (\mathfrak{w}_2 - \mathfrak{w}_1)}{\mathfrak{J}_1 - \mathfrak{w}_2}.$$

Similarly, for the corrected insulation $\mathfrak{J}$ of the section *BC*,

Putting $$g = \mathfrak{J}$$

$$\mathfrak{J} = \frac{\mathfrak{J}_1 (\mathfrak{J}_2 - \mathfrak{w}_1)}{\mathfrak{J}_1 - \mathfrak{J}_2}.$$

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SOLUTION XXV.

To calculate n the distance in miles of a fault in a line composed of wires of different gauges from x the measured conduction resistance.

$$n = \Sigma\lambda + a\left\{\frac{x}{r} - \Sigma\mu\right\}.*$$

* § 323.

PROOF.

Let AB represent a telegraph line, between any two points C and D of which a fault exists.

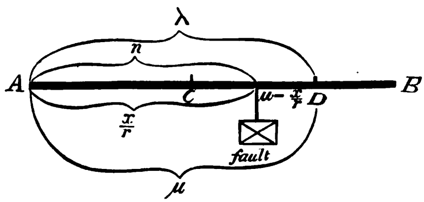

FIG. 89.

The references above the line relate to actual length (in miles), and those below the line to reduced length (in miles).

Thus n = actual distance from A to fault.
,, λ = actual distance from A to end of section CD in which fault lies.
,, μ = reduced length from A to end of section CD in which fault lies.

Let x = the absolute conduction resistance up to the fault,

and r = the reduced conduction resistance per mile up to the fault.

Then, obviously,

$$\frac{x}{r} = \text{the reduced length in miles to the fault.}$$

Hence $\mu - \frac{x}{r} =$ the reduced length from the fault to D.

And as

$$m = \frac{l}{a},^{*}$$

* § 315.

i.e. the reduced length of any gauge of wire $\Big\} = \frac{\textit{actual length}}{a}$

∴ Actual length from fault to D

$$= a\left(\mu - \frac{x}{r}\right).$$

Hence, from the figure,

$$n = \lambda - a\left(\mu - \frac{x}{r}\right)$$

$$\therefore \quad n = \lambda + a\left(\frac{x}{r} - \mu\right).$$

Now, supposing the portion of the line AD to be made up of several sections of different gauges, of which CD is one,

Then $\lambda =$ the sum of their lengths $= \Sigma\lambda$

And $\mu =$ the sum of their reduced lengths $= \Sigma\mu$

$$\therefore \quad n = \Sigma\lambda + a\left(\frac{x}{r} - \Sigma\mu\right).^{\dagger}$$

† Formula XXXIX. Testing Instructions.

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SOLUTION XXVI.

To find x the conduction resistance to fault in the case of a partial earth on a single wire.

$$x = w - \sqrt{(L - w)(I - w)}\,*$$ * § 325.

or

$$x = I - \sqrt{\frac{(I - W)(I - w)R}{W - w}}\,*$$

PROOF.

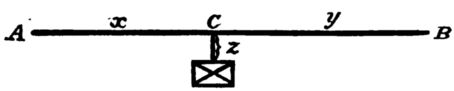

FIG. 90.

Let AB represent a telegraph line containing a fault at C. As the fault is a *partial* earth it contains resistance in itself.

Let this resistance $= z$,

And the resistance of the line from A to $C = x$,

And the resistance of the line from C to $B = y$.

First. **To find x from a conduction test only.**

Let $w =$ the conduction resistance of the faulty line measured from A (B to earth).

" $I =$ the resistance of the faulty line when insulated at B.

" $L =$ the known resistance of AB when the line is in order.

Then $$L = x + y \quad . \quad . \quad . \quad . \quad (1)$$

$$I = x + z \quad . \quad . \quad . \quad . \quad (2)$$

$$w = x + \frac{yz}{y + z}\,\dagger \quad . \quad . \quad . \quad (3)$$ † Law 8, App. A.

Whence $$y = L - x$$

$$z = I - x.$$

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And substituting these values in (3)

$$w = x + \frac{(L - x)(I - x)}{L - x + I - x} \quad . \quad . \quad . \quad (4)$$

$$\therefore \quad w = x + \frac{LI - Lx - Ix + x^2}{L + I - 2x}$$

$$\therefore \quad w = \frac{Lx + Ix - 2x^2 + LI - Lx - Ix + x^2}{L + I - 2x}$$

$$\therefore \quad w = \frac{LI - x^2}{L + I - 2x}$$

$$\therefore \quad Lw + Iw - 2xw = LI - x^2$$

$$\therefore \quad x^2 - 2xw = LI - Lw - Iw.$$

Adding $+w^2$ to both sides of the equation

$$x^2 - 2xw + w^2 = LI - Lw - Iw + w^2$$

$$\therefore \quad (x - w)^2 = (L - w)(I - w)$$

$$\therefore \quad x - w = \pm \sqrt{(L - w)(I - w)}\ *$$

$$\therefore \quad x = w - \sqrt{(L - w)(I - w)}.\dagger$$

Second. **To find x when the circuit test is practicable.**

In this case $I = l + i$‡

(i being the corrected insulation of the line AB).

And further it has been proved that

$$i = \sqrt{\frac{(I - W)(I - w)R}{W - w}}.\S$$

Now, comparing the above figure with that in Solution XIX.

$$l = x$$

and

$$i = z,$$

∴ in this case

$$z = \sqrt{\frac{(I - W)(I - w)R}{W - w}}$$

And by equation (2), above,

$$x = I - z$$

$$\therefore \quad x = I - \sqrt{\frac{(I - W)(I - w)R}{W - w}}.\|$$

* The − sign is always taken, as the + value would obviously make x too large.

† Formula XLIII. Testing Instructions.

‡ See fig. 86, Solution XIX.

§ See Solution XX.

‖ Formula XLII. Testing Instructions.

APPENDIX B.

SOLUTION XXVII.

To find x the conduction resistance to fault in the loop test.

$$x = \frac{L - W}{2}.*$$

* § 326.

PROOF.

Referring to fig. 73, para. 326, it is obvious that

(i) $x + y = L$, the total resistance of the looped wires when not connected anywhere with the earth.

And (ii) $x + W = y$ when balance is obtained.

$\therefore$ adding (i) and (ii),

$$2x + W + y = L + y$$

$$\therefore \quad 2x = L - W$$

$$\therefore \quad x = \frac{L - W}{2}.\dagger$$

† Formula XLVI. Testing Instructions.

SOLUTION XXVIII.

To find x the conduction resistance between testing station and fault of two wires in contact in the case when the contact itself offers resistance.

$$X = w - \sqrt{(R - w)(W - w)}.^{*}$$

* § 327.

PROOF.

Referring to para. 327, in which the letters composing the above formula are explained, it follows that when the distant ends of the two lines in contact are insulated

$$W = x' + x'' + z \quad . \quad . \quad . \quad (a)$$

and when looped at the distant end that

$$w = x' + x'' + \frac{z\,(L' - x' + L'' - x'')}{z + L' - x' + L'' - x''}\dagger \quad . \quad (b)$$

† Law 8, App. A.

(By definition, $L' - x' =$ resistance of one line *beyond* the contact

" " $L'' - x'' =$ resistance of the other line *beyond* the contact)

And calling $x' + x'' = X$

" " $L' + L'' = R,$

then from equation (a)

$$W = X + z \quad . \quad . \quad . \quad . \quad (c)$$

And from (b)

$$w = X + \frac{z\,(R - X)}{z + R - X} \quad . \quad . \quad . \quad (d)$$

Now from (c)

$$z = W - X.$$

And substituting this value in (d)

$$w = X + \frac{(W - X)\,(R - X)}{W - X + R - X}$$

APPENDIX B.

$$\therefore \quad w = \frac{WX - 2X^2 + RX + WR - WX - RX + X^2}{W - 2X + R}$$

$$\therefore \quad wW - 2wX + wR = - X^2 + WR$$

$$\therefore \quad X^2 - 2wX = WR - wW - wR.$$

Adding $+w^2$ to both sides of the equation

$$X^2 - 2wX + w^2 = WR - wW - wR + w^2$$

$$\therefore \quad (X - w)^2 = (W - w)(R - w)$$

$$\therefore \quad X - w = \pm\sqrt{(W - w)(R - w)}\,^*$$

$$\therefore \quad X = w - \sqrt{(W - w)(R - w)}.^\dagger$$

* The − sign must be taken, as the + value would obviously make X too large.

† Formula XLVII. Testing Instructions.

SOLUTION XXIX.

To find the values of x, y, and z the several resistances of three earths from their collective resistances when measured in pairs.

Let $x+y=w'$ . . . (1)
„ $x+z=w''$ . . . (2)
„ $y+z=w'''$ . . . (3)

These values are found by either of the methods described in paras. 335–338

$$\left.\begin{aligned} x &= \frac{w' + w'' - w'''}{2} \\ y &= \frac{w' + w''' - w''}{2} \\ z &= \frac{w'' + w''' - w'}{2} \end{aligned}\right\}*$$

* § 336.

To find x.

By adding (1) and (2)

$$2x + y + z = w' + w''' \quad . \quad . \quad . \quad (4)$$

From (3) $\quad y + z = w'''.$

Subtracting (3) from (4)

$$2x = w' + w'' - w'''$$

$$\therefore \quad x = \frac{w' + w'' - w'''}{2}.$$

Similarly, to find y.

By adding (1) and (3)

$$2y + x + z = w' + w''' \quad . \quad . \quad . \quad (5)$$

From (2) $\quad x + z = w''.$

Subtracting (2) from (5)

$$2y = w' + w''' - w''$$

$$\therefore \quad y = \frac{w' + w''' - w''}{2}.$$

APPENDIX B.

Similarly, to find z.

By adding (2) and (3)

$$2z + x + y = w'' + w''' \qquad (6)$$

From (1) $x + y = w'$.

Subtracting (1) from (6)

$$2z = w'' + w''' - w'$$

$$\therefore \quad z = \frac{w'' + w''' - w'}{2}.$$

SOLUTION XXX.

To measure the resistance of earths by means of the tangent galvanometer and a testing battery.

$$w = \left(\frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}} - 1 \right) (f + g).^*$$

* § 337.

PROOF.

In the above formula

w represents the resistance of any *pair* of earths;
c° the mean of + and − deflections from the testing battery through *thick* coil of galvanometer;
a°, b° } the deflections through the pair of earths with reverse currents;
f the resistance of the testing battery;
E its E.M.F.;
e the electromotive force of the natural current;
g the galvanometer resistance (thick coil).

First, considering the testing current and natural current flowing in the same direction

$$E + e \propto \tan a^\circ \, (f + g + w).$$

When opposite in direction

$$E - e \propto \tan b^\circ \, (f + g + w).$$

∴ (by addition)

$$2E \propto (\tan a^\circ + \tan b^\circ)\,(f + g + w)$$

$$\therefore \quad E \propto \frac{\tan a^\circ + \tan b^\circ}{2}\,(f + g + w).$$

Now suppose the deflection c° to be produced by another battery of electromotive force E' and resistance f' through a known external resistance w'.

Then by the former reasoning

$$E' \propto \tan c^\circ \, (f' + g + w').$$

APPENDIX B.

Whence

$$\frac{E}{E'} = \frac{\frac{\tan a^\circ + \tan b^\circ}{2}(f + g + w)}{\tan c^\circ \quad (f' + g + w')}$$

$$\therefore \frac{f + g + w}{f' + g + w'} = \frac{E}{E'} \cdot \frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}}$$

$$\therefore f + g + w = \frac{E}{E'} \cdot \frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}} (f' + g + w')$$

$$\therefore w = \frac{E}{E'} \cdot \frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}} (f' + g + w') - (f + g)$$

And if $E' = E$ and $f' = f$

$$w = \frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}} (f + g + w') - (f + g).$$

Further, when $w' = o$ (i.e. no external resistance)

$$w = \left(\frac{\tan c^\circ}{\frac{\tan a^\circ + \tan b^\circ}{2}} - 1 \right) (f + g).*$$

* Formula LXXII. Testing Instructions.

APPENDIX B.

SOLUTION XXXI.

To calculate the external resistance w to be added in order to test any required range n.

$$w = \left(\frac{qn}{p} - 1\right) R + (n - 1)\, qf.^*$$

* § 344.

PROOF.

Referring to para. 71 (sec. C) and para. 344 (sec. F) and using the nomenclature employed therein,

The strong current c in the second observation may be expressed :

$$C = \frac{pe}{pf + R}$$

and the weak current c in the first observation

$$c = \frac{qe}{qf + R + w}$$

$$\therefore \quad \frac{C}{c} = \frac{p\,(qf + R + w)}{q\,(pf + R)}.$$

But $\frac{C}{c}$ represents the range of the instrument (n);

$$\therefore \quad n = \frac{p}{q}\,\frac{(qf + R + w)}{(pf + R)}$$

whence $$\frac{wp + pqf + pR}{pqf + qR} = n$$

$$\therefore \quad \frac{wp}{pqf + qR} = n - \frac{pqf + pR}{pqf + qR}$$

$$\therefore \quad wp = n\,(pqf + qR) - \frac{pqf - pR}{pqf + qR} \cdot pqf + qR$$

$$\therefore \quad w = \frac{npqf + nqR - pqf - pR}{p}$$

$$\therefore \quad w = \frac{nqR}{p} - R + nqf - qf$$

$$\therefore \quad w = \left(\frac{qn}{p} - 1\right) R + (n - 1)\, qf.†$$

† Formula XCII, Testing Instructions.

APPENDIX B.

SOLUTION XXXII.

To calculate the ratio $\frac{p}{q}$, i.e. the relative battery power to be used, in order to find a given range n with a fixed external resistance w.

$$p = \frac{nqR}{R + w - (n - 1)\,qf}.^{*}$$

* § 344.

PROOF.

In the preceding proof (Solution XXXI.) it is shown that

$$n = \frac{p}{q} \cdot \frac{(qf + R + w)}{(pf + R)}.$$

whence

$$n\,(pqf + qR) = pqf + pR + pw$$

$$\therefore \quad p\,(nqf - qf) + nqR = p\,(R + w)$$

$$\therefore \quad p\,(R + w) - (n - 1)\,qf = nqR$$

$$\therefore \quad p = \frac{nqR}{R + w - (n - 1)\,qf}.^{\dagger}$$

† Formula LXXXIX. Testing Instructions.

SOLUTION XXXIII.

To calculate $R_{t'}$ the value of any resistance R at temperature t' from R_t the known resistance of R at the temperature t.

$$R_{t'} = \frac{1 + (t' - 32)\,a}{1 + (t - 32)\,a} R_t.^*$$

* § 307.

PROOF.

32° Fahrenheit being taken as the standard of temperature, it follows that a resistance of one unit at that temperature becomes $1 + a$ † at one degree above 32°, and at any given temperature t it becomes $1 + (t - 32)\,a$ units. Similarly, at any other temperature t' it becomes

$$1 + (t' - 32)\,a \text{ units.}$$

† The coefficient a being = ·0021, as explained in § 307.

Expressing by R_t the value of a certain resistance at temperature t, and by $R_{t'}$ the value of the same resistance at temperature t', it follows that

$$\frac{R_{t'}}{R_t} = \frac{1 + (t' - 32)\,a}{1 + (t - 32)\,a}$$

whence

$$R_{t'} = \frac{1 + (t' - 32)\,a}{1 + (t - 32)\,a} R_t.$$

TABLE OF

NATURAL SINES				&	NATURAL TANGENTS		
Deg.	Sine	Deg.	Sine	Deg.	Tan	Deg.	Tan
1	·0175	46	·7193	1	·0175	46	1·0355
2	·0349	47	·7314	2	·0349	47	1·0724
3	·0523	48	·7431	3	·0524	48	1·1106
4	·0698	49	·7547	4	·0699	49	1·1504
5	·0872	50	·7660	5	·0875	50	1·1918
6	·1045	51	·7771	6	·1051	51	1·2349
7	·1219	52	·7880	7	·1228	52	1·2799
8	·1392	53	·7986	8	·1405	53	1·3270
9	·1564	54	·8090	9	·1584	54	1·3764
10	·1736	55	·8192	10	·1763	55	1·4281
11	·1908	56	·8290	11	·1944	56	1·4826
12	·2079	57	·8387	12	·2126	57	1·5399
13	·2250	58	·8480	13	·2309	58	1·6003
14	·2419	59	·8572	14	·2493	59	1·6643
15	·2588	60	·8660	15	·2679	60	1·7321
16	·2756	61	·8746	16	·2867	61	1·8040
17	·2924	62	·8829	17	·3057	62	1·8807
18	·3090	63	·8910	18	·3249	63	1·9626
19	·3256	64	·8988	19	·3443	64	2·0503
20	·3420	65	·9063	20	·3640	65	2·1445
21	·3584	66	·9135	21	·3839	66	2·2460
22	·3746	67	·9205	22	·4040	67	2·3559
23	·3907	68	·9272	23	·4245	68	2·4751
24	·4067	69	·9336	24	·4452	69	2·6051
25	·4226	70	·9397	25	·4663	70	2·7475
26	·4384	71	·9455	26	·4877	71	2·9042
27	·4540	72	·9511	27	·5095	72	3·0777
28	·4695	73	·9563	28	·5317	73	3·2709
29	·4848	74	·9613	29	·5543	74	3·4874
30	·5000	75	·9659	30	·5774	75	3·7321
31	·5150	76	·9703	31	·6009	76	4·0108
32	·5299	77	·9744	32	·6249	77	4·3315
33	·5446	78	·9781	33	·6494	78	4·7046
34	·5592	79	·9816	34	·6745	79	5·1446
35	·5736	80	·9848	35	·7002	80	5·6713
36	·5878	81	·9877	36	·7265	81	6·3138
37	·6018	82	·9903	37	·7536	82	7·1154
38	·6157	83	·9925	38	·7813	83	8·1443
39	·6293	84	·9945	39	·8098	84	9·5144
40	·6428	85	·9962	40	·8391	85	11·43
41	·6561	86	·9976	41	·8693	86	14·30
42	·6691	87	·9986	42	·9004	87	19·08
43	·6820	88	·9994	43	·9325	88	28·64
44	·6947	89	·9998	44	·9657	89	57·29
45	·7071	90	1·0000	45	1·0000	90	Infinite

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N.B.—*The numbers refer to the paragraphs in which the items occur, not to the pages.*

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