ELECTRICAL MEASUREMENTS

MEASUREMENT OF RESISTANCE

WHEATSTONE BRIDGE

The *Wheatstone bridge* is used more than any other one method for the measurement of resistance, and is suitable for the measurement of all resistances except those very large or very small. In Fig. 1 is shown the theoretical diagram of the Wheatstone bridge. It can be shown that if the resistance *ac* : resistance *ad* = the resistance *cb* : resistance *db*, then there is no difference of potential between the points *c*, *d*, and consequently no current will flow through the galvanometer *G*. By arranging four resistances in a circuit of this kind, and varying the resistance of the three arms *ac*, *ad*, and *db* until the galvanometer gives no deflection, the unknown resistance

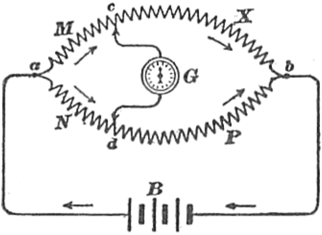

FIG. 1

$$X = \frac{M \times P}{N}$$

In Fig. 2 is shown a form of portable testing set, including a Wheatstone bridge, four dry cells, a galvanometer *G*, a battery key *Ba*, a galvanometer key *Ga*, and an arrangement of brass block *A*, *R*, *B*, *X* for reversing the position of the balance arms *aA* and *aB*, with reference to the rheostat arm *dikb* and the resistance *X* that is to be measured. Being connected together by a short, heavy wire *f*, the two blocks *a*, *a* are really one and the same point. With one plug between *A* and *X* and another between *R* and *B*, which is the arrangement for measuring a resistance *X* not over 6,100 ohms, $A : B = X : R$. With one plug between *A* and *R* and another between *B* and *X*, which is the arrangement for measuring a resistance *X* not under 6,100 ohms,

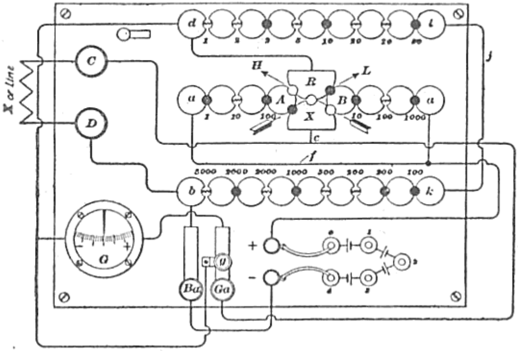

FIG. 2

$A : B = R : X$. *A* stands for the resistance in the arm *aA*, *B* for the resistance in the arm *aB*, and *R* for the resistance in the arm *dikb*.

In using a Wheatstone bridge, the battery circuit is first closed by pressing the battery key *Ba* and then the galvanometer key *Ga*, which, in this case, first opens a short circuit around the galvanometer, and almost immediately connects the galvanometer from *d* to *C*. If the galvanometer deflects, both keys are released, the known resistances are readjusted, and the keys again closed in the same order as before. This operation is repeated until no deflection can be detected; then the unknown resistance can be calculated from the known resistances in the three arms of the bridge.

RATIO ARM VALUES FOR WHEATSTONE BRIDGE

Resistance	Make *A* Equal to	Make *B* Equal to	Place Plugs Between
Below 1.5 ohms	1	100	*A*,*X* and *R*,*B*
Between 1.5 and 11 ohms	1	100	*A*,*X* and *R*,*B*
Between 11 and 78 ohms	10	100	*A*,*X* and *R*,*B*
Between 78 and 1,100 ohms	100	1,000	*A*,*X* and *R*,*B*
Between 1,100 and 6,100 ohms	100	100	*A*,*X* and *R*,*B* or *A*,*R* and *B*,*X*
Between 6,100 and 110,000 ohms	100	1,000	*A*,*R* and *B*,*X*
Between 110,000 and 1,110,000 ohms	10	100	*A*,*R* and *B*,*X*
Between 1,110,000 and 11,110,000 ohms	1	1,000	*A*,*R* and *B*,*X*

The table on page 182 shows the values of A and B to be chosen when measuring any resistance within the range of the set, and is applicable to almost any Wheatstone bridge having the same resistances in the rheostat and balance arms.

SLIDE-WIRE BRIDGE

For measuring low resistances, a modification of the Wheatstone bridge, known as the *slide-wire bridge*, is used; a diagram of it is shown in Fig. 3. The pointer n is moved along a German-silver wire ab of uniform resistance until a point is found where the galvanometer gives no deflection. The unknown resistance X can then be calculated from the formula

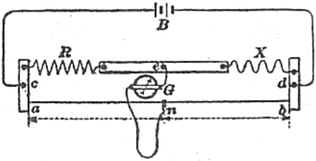

FIG. 3

$$X = R\frac{\text{distance } nb}{\text{distance } an}$$

The *resistance of electrolytes* may be measured with the slide-wire bridge by using a telephone receiver in place of the galvanometer G, and some source of alternating or rapidly interrupted current in place of the battery B.

MEASUREMENT OF HIGH, OR INSULATION, RESISTANCE

Wheatstone-Bridge Method.—A *high*, or *insulation*, *resistance* may be measured in the ordinary manner by the Wheatstone bridge, if it does not exceed about 2,000,000 ohms. Another way is to measure a resistance, as high as can be accurately determined with the bridge and call it y ohms. Then, connect this resistance y in parallel with the high, or insulation, resistance and measure the joint resistance of the two in parallel, and call this z ohms. Then, if x is the unknown high, or insulation, resistance,

$$x = \frac{y \times z}{y - z}$$

Direct-Deflection Method.—Complete connections for measuring insulation resistance by the direct-deflection method are shown in Fig. 4. In this figure, *G* represents a galvanometer sufficiently sensitive for the purpose; *S*, an Ayrton, or universal, shunt; *A* and *D*, reversing switches; and *R*, a known high resistance, at least $\frac{1}{10}$ megohm, but sometimes as high as 1 megohm is required. Enough cells must be used at *B* to give a deflection of the galvanometer when connected with the insulation resistance to be measured. The plug is first placed at *n*, so as to connect the battery and galvanometer in series with the known resistance *R*, the reversing switches *A* and *D* being closed and the shunt *S* adjusted so that a readable deflection of the galvanometer will probably be obtained. The key *K* is cautiously depressed. If the galvanometer gives a readable deflection, the deflection is noted; otherwise, the shunt is readjusted and the observation repeated until a good deflection is obtained. The plug is then removed from *n* and placed at *m*, and the deflection of the galvanometer obtained as before. Where the insulation resistance of long cables is measured in this manner, the deflection is likely to be large at first and then decrease in value. As it is impracticable to wait in many cases until a steady deflection is obtained, the usual custom is to observe the deflection at exactly 1 minute after the circuit is closed. This is

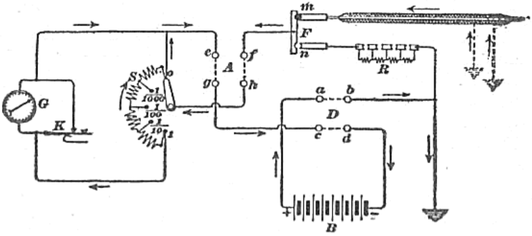

FIG. 4

usually stated thus: insulation resistance after 1 minute's electrification, 400 megohms.

The unknown resistance X, expressed in megohms, is given with sufficient accuracy for most purposes by the formula

$$X = \frac{Rmd}{m'd'},$$

in which R is the known resistance expressed in megohms; m, the multiplying power of the shunt used when the deflection d is obtained; and, similarly, m' the multiplying power of the shunt when the deflection d' is obtained.

The multiplying powers of a galvanometer shunt are usually marked on the shunt box. In order to determine the insulation resistance per mile of a cable or a line wire, multiply the insulation resistance obtained by the measurement by the length of the cable or the line expressed in miles or a fraction thereof. Rmd is called the constant of the testing set.

Leakage Method.—The direct-deflection method is not suitable for measuring resistances over 1,000 megohms with E. M. F. less than several hundred volts. There are, however, the variously called *loss-of-charge*, *fall-of-charge*, or *leakage methods* for measuring higher resistances. These methods require some capacity as well as a very high resistance in the insulation to be measured. At least as accurate results can be obtained by the following leakage method, and, moreover, the calculations required are less complicated than for other leakage methods.

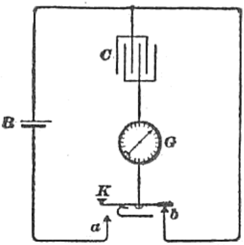

FIG. 5

The method consists in charging the cable as a condenser, then allowing it, while insulated, to leak for an observed number of seconds, and, finally, again charging it to the same potential as before through the galvanometer. The ballistic galvanometer required may be calibrated by any method, but the most convenient way is probably by means of a condenser connected as shown in Fig. 5. All apparatus and connections must be very highly insulated throughout this test, and the condenser must be thoroughly discharged. By pressing the key K the condenser is charged, producing a throw of the galvanometer; on letting up the key so that it touches b, the condenser discharges, producing another deflection.

Let d' be the mean of the two deflections, E_1 the E. M. F. of the cell B, and C_1 the capacity of the condenser; then, the quantity of electricity per unit deflection, that is, the constant of the ballistic galvanometer, is

$$K = \frac{C_1 E_1}{d_1}$$

The cable to be tested is then connected as shown in Fig. 6. If the cable is on a reel, it should be immersed in a tank of water, and particular care should be taken to insulate the ends of the cable so as to avoid surface leakage. With the switch N and key K closed, charge the cable. For a preliminary test, a charge lasting 1 min. is sufficient, as poor insulation may render a longer charge useless. Then, open the circuit at K for a carefully observed number of seconds, say 30, in the meantime opening the switch N and noting the zero reading of the galvanometer. At the end of the 30 sec., close the key K and note the throw d_2 of the

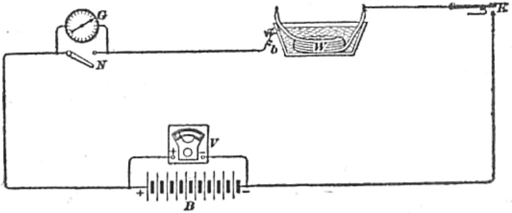

FIG. 6

galvanometer G. This throw, corrected for the zero reading, indicates the quantity of electricity passing through the galvanometer, and hence the quantity required to replace that part of the charge lost by leakage or absorption during the observed time that the cable was disconnected.

In order to obtain a series of values that will show the condition of the insulation and the amount of absorption, repeat the foregoing observation after equal periods of charge of at least 1 min., and for equal periods of discharge, say 30 sec. The insulation resistance may then be calculated by the formula

$$R=\frac{E_2}{E_1}\times\frac{d_1}{d_2}\times\frac{t}{C_1},$$

in which E_2 is the E. M. F. of the battery, which may be most conveniently measured by the voltmeter V; d_2, the deflection observed with the connections used in Fig. 6; and t, the number of seconds (in this case 30) during which the cable is disconnected and the charge allowed to escape.

If C_1 is expressed in farads, R will be in ohms, but it is usually more convenient to express C_1 in microfarads, in which case R will be in megohms. Constant results may not be obtained unless the insulation is very high, and not even then, unless the cable is charged until absorption ceases, requiring in many cases at least ½ hr. If the deflections decrease as the time the cable is allowed to remain on open circuit is lengthened, it indicates absorption; the greater the decrease, the greater is the absorption. The higher the insulation resistance, the easier is the application of this method. In any one cable, the discharge intervals or the E. M. F. or both should be regulated to give desirable deflections.

PUNCTURE TEST

A *puncture*, or *breakdown*, *test* of insulating materials is now considered fully as important as an insulation test. The connections for this test are shown in Fig. 7, in which V represents the electrostatic voltmeter, and V' an electromagnetic voltmeter connected to the circuit through its own transformer. One voltmeter is desirable, although not really necessary; either one may be used. *A* is called a spark-gap gauge, means being provided for accurately determining the distance across the air between the points of the two steel needles. The transformer *T* is so constructed that any ordinary alternating-current potential of about 125 volts acting on the primary winding *p* will produce an E. M. F. in the secondary winding *s* sufficiently high for the test. The spark gap *A* and the insulator *W*, or other insulating material to be tested, are connected in parallel.

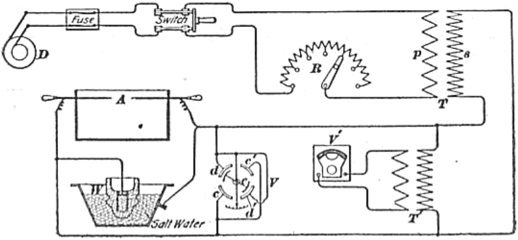

FIG. 7

The spark gap prevents the application of a greater potential to the insulator than will produce a spark across its points at the particular distance to which they may have been separated. A spark will jump across the spark gap, provided the insulators have not already given away, when the voltage has been raised to the highest value at which it is desired to test the insulators.

This distance *A* between the needle points for the maximum voltage desired may be determined by the curve given in Fig. 8. The test is started with all the resistance in *R*; then gradually reduce *R*, leaving it remain in each position 1 min., thus slowly increasing the potential between the inside and outside of the insulator until the insulator either punctures, or an arc is formed over its surface, or until the desired test potential is reached, thereby causing a spark to pass across the air gap *A*. New needles should be used at the gap after each discharge crosses it, otherwise the potential necessary to produce a spark across the gap may not follow the curve given. The difference of potential applied to the insulator may be determined either by the distance between the points of the needles at *A*, in connection with the accompanying curve, or by the reading of the voltmeter *V* or *V′*, whichever is used. To test insulators under such conditions as prevail during a rainstorm, a stream of water through a sprinkler under a pressure of

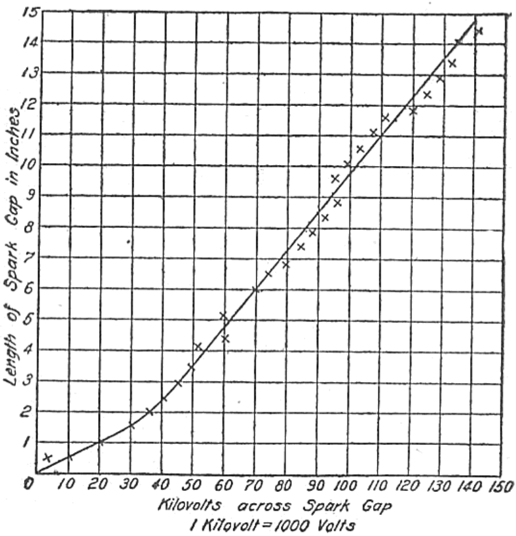

FIG. 8

at least 50 lb. per sq. in. should be played on the insulator at an angle of about 30° from the horizontal. The insulator should not arc over from the wire to the pin at less than the potential that will exist in service between any two conductors.

ELECTROSTATIC CAPACITY

The *electrostatic capacity* of well-insulated condensers may be measured by any one of a number of methods, but the various methods fail to a greater or less extent with leaky condensers, submarine and underground cables, and overhead lines. The direct-deflection method is the simplest and probably the most generally used, except perhaps for submarine cables and for alternating-current apparatus; for the latter the alternating-current method is usually preferred. The results obtained by the direct-deflection method are hardly correct, even under favorable conditions, to within 1%.

DIRECT-DEFLECTION METHOD FOR MEASURING ELECTROSTATIC CAPACITY

In the *direct-deflection method*, the capacity is measured by comparing the extreme swing of the galvanometer produced by discharging the cable to be measured through the galvanometer with that produced by the discharging through the same galvanometer a condenser of known capacity charged to the same potential. If no shunt is used with the galvanometer, or if the same shunt is used in each case, the two capacities will vary in proportion to the respective swings of the galvanometer. Thus, calling d the deflection obtained with the known condenser whose capacity is C, and d' the deflection produced by the cable whose capacity is C',

$$C' = \frac{Cd'}{d}$$

The capacity of the cable per mile is found by dividing its total capacity by the length of the cable in miles. If a shunt is used with the galvanometer, the deflections d

and *d'* must each be multiplied by the multiplying power of the shunt used in each case. Shunts are liable to introduce errors, hence their use should be avoided as much as possible. Fig. 9 shows a diagram of connections for determining the electrostatic capacity of a cable by the direct-deflection method. *A* and *D* represent reversing switches, *C* the condenser whose capacity is known, *C'* the cable whose capacity is to be measured, and *K* a charge-and-discharge key. First, thoroughly discharge the cable *C'* by connecting it to ground. With *p* upon a suitable point

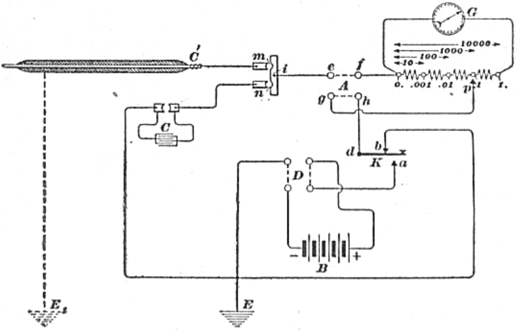

FIG. 9

of the galvanometer shunt, a plug in hole *m*, the reversing switches *A*, *D* closed, and the galvanometer perfectly at rest—its position of rest being noted—depress the key *K* and note the extreme first swing of the galvanometer. Reverse the switch *A* so as to obtain the next deflection on the same side of the scale, and when the galvanometer comes to rest, let up the key *K* and observe the discharge deflection. Thoroughly discharge the cable and repeat the same observations with the plug in hole *n*. The average of both charge and discharge deflections will give the best results. For this test, a ballistic galvanometer is preferable, although a Thomson or D'Arsonval galvanometer may be used, if the system is arranged to make one-half a complete vibration in from 10 to 15 sec., that is, one swing in one direction and back to zero. Thus, a charge of several seconds' duration may act on the moving system before it is moved from its position of rest.

GOTT'S METHOD FOR MEASURING CAPACITY

Gott's method for measuring electrostatic capacity is probably more accurate than the direct-deflection method, and, moreover, any kind of a sufficiently sensitive galvanometer may be used. The connections for this test are shown in Fig. 10, in which C is the known capacity of a condenser, C' the unknown capacity of a condenser or cable,

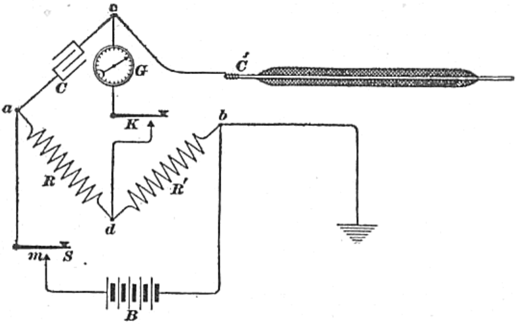

FIG. 10

and R, R' two adjustable resistances. R and R' may have any suitable values, but $R+R'$ should be as large as possible or convenient. Close the switch S, and after 5 or 10 sec. close the key K and note the deflection of the galvanometer G. The battery circuit must remain closed until after the galvanometer deflection is observed. Then, open S, and thoroughly discharge both C and C' by holding K

closed at least several times as long as the battery circuit previously remained closed. After readjusting R or R', always keeping $R+R'$ large, the foregoing operation is repeated until, on closing K with S resting on m, no deflection of the galvanometer is produced. The capacity of the unknown condenser C' can be computed from the formula

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

If the insulation of the cable is less than several megohms to the microfarad, the capacity obtained by Gott's method will be appreciably greater than the actual capacity. Both leakage and absorption tend to increase the apparent capacity of the cable as obtained by this method. The best conditions are to have the known and unknown capacities about equal and the total resistance $R+R'$ high; also, the battery should supply as large a current as $R+R'$ will safely carry. In order to obtain uniform results in the final adjustments, it is necessary to make the duration of charge the same for each observation. With long submarine cables, the duration of charge should be at least 15 sec. For electric-light, telephone, and telegraph cables, which have much less absorption, about 5 sec. is sufficient.

MEASUREMENT OF CAPACITY WITH ALTERNATING CURRENTS

Method No. 1.—Connect the condenser C, Fig. 11, in series with the alternating-current ammeter A and the generator of alternating currents D; also, connect the alternating-current voltmeter V across the terminals of the condenser.

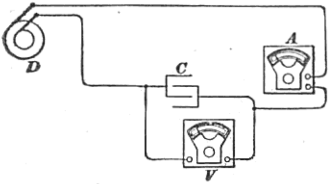

FIG. 11

If the resistance and inductance of the whole circuit are negligible compared to $\frac{1}{2\pi nC}$, then the capacity of the condenser is given by the formula,

$$C=\frac{I}{2\pi nE},$$

in which I is the current measured by A; E, the difference of potential measured by V; and n, the frequency or number of cycles per second made by the alternating current.

If the generator D has p pairs of poles and makes s revolutions per second, then $n=ps$. If I is expressed in amperes and E in volts, C will be in farads.

If a non-inductive resistance R is included in series with the condenser, and the voltmeter is connected so as to measure the drop of potential through both R and C, then, the inductance being negligible,

$$C=\frac{I}{2\pi n\sqrt{E^2-I^2R^2}}$$

R should be measured by a Wheatstone bridge or with direct current if a voltmeter and ammeter are used.

Method No. 2.—Connect a non-inductive resistance (an incandescent lamp or graphite resistance) in series with the condenser. Also, measure, as nearly simultaneous as possible, the difference of potential E' across the non-inductive resistance and the difference of potential E across the condenser terminal; then,

$$C=\frac{E'}{ER2\pi n}$$

In this method a known resistance R is required, but no ammeter.

MEASUREMENT OF INDUCTANCE

The *self-inductance of a coil* is a quantity that is strictly constant only when no magnetic material, or mass of metal, or closed coils are near it. Constant values cannot be expected from measurements of the inductance of coils unless great care is taken to remove all iron, metal, or closed coils from the neighborhood of the coil. Moreover, if the inductance itself is variable, there is little use in striving for great accuracy in its measurement. If possible, the inductance of a coil, especially when it contains iron, should be determined with exactly the same current flowing through it as when in use.

MAXWELL-REMINGTON METHOD

In Fig. 12 is shown a diagram of connections of the Maxwell-Remington method. M, N, and P represent three non-inductive resistances, while R is the coil whose inductance L is to be determined. Some form of adjustable resistance must be used for the arm *ad*, so that the position of *e* can be adjusted without in any way alternating the total resistance N from *a* to *d* after the proper value for this total resistance has been once determined. First, balance the bridge in the usual manner by closing K_1 for 1 or 2 sec., and then K, adjusting M, N, and P until the galvanometer G gives no deflection. From the values of M, N, and P so obtained, R can be computed. If the resistance of the arm *cb* containing the coil R is low, it is well to add enough non-inductive resistance, so that M may be made equal to N. In any case, R in the formula to be given, will be the total resistance of the arm *cb*. A point *e* should be located along *ad* where no kick of the galvanometer is produced by first closing K and then K_1. Let n be the resistance from *d* to *e* after this balance is obtained. The inductance of the coil R may then be calculated by the formula

$$L = \frac{Cn^2R}{N}$$

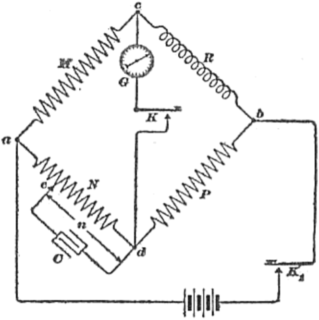

FIG. 12

L will be in henrys if the capacity C is expressed in farads, and the resistances n, R, and N in ohms. An ordinary Thomson or D'Arsonval galvanometer may be used, provided the rate of change of the current in the condenser C does not vary so much from the rate of change of the current in the coil R as to make G deflect in spite of C and L being otherwise balanced. Otherwise, a ballistic galvanometer, which, however, requires more time and is more troublesome, should be used.

ALTERNATING-CURRENT METHOD

To determine the self-inductance L, Fig. 13, of a coil whose resistance is R with alternating current, connect the coil in series with an alternating-current ammeter A and an alternating-current dynamo D, using, if possible, an adjustable resistance S to regulate the strength of the current. Across the terminals of the coil connect an alternating-current voltmeter V, preferably an electrostatic voltmeter, and read both instruments A and V as nearly simultaneously as possible. Then, the inductance, in henrys, may be calculated from the formula

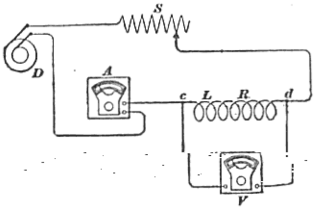

FIG. 13

$$L = \frac{\sqrt{E^2 - I^2R^2}}{2\pi n I},$$

in which E is the difference of potential from c to d; I, the current in the coil; R, the resistance of the coil; and n, the frequency, or number of cycles per sec., made by the alternating current. If E is expressed in volts, I in amperes, and R in ohms, then L will be in henrys. R can be measured by a Wheatstone bridge or with direct current and a voltmeter and ammeter. There must be no appreciable electrostatic capacity between the points c, d.

POTENTIOMETER

The principles of a *potentiometer*, which is an instrument suitable for measuring E. M. F., current, very low resistances, and for calibrating ammeters and voltmeters, can be explained by the aid of Fig. 14, in which R is an adjustable resistance whose value need not be known, and D a steady source of E. M. F. for which a storage battery of one or two cells answers admirably. The E. M. F. of D must be at least a trifle greater than that of B. Like poles or terminals of D and B must be joined together at the same end of a very uniform wire *ab* stretched over a divided scale.

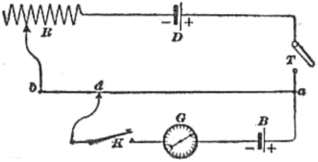

FIG. 14

The distance *ab* is usually divided into 1,000 or 1,500 equal parts. At B is first placed a standard cell whose E. M. F. is known, and the slider d is set at the division of the scale corresponding to this known E. M. F. Suppose that *ab* is divided into 1,500 equal divisions and that the E. M. F. of the standard cell B is 1.431 volts; then, set d at a point 1,431 divisions from a, and adjust R until the galvanometer gives no deflection when both circuits are closed, first at T and then at K, in which case the E. M. F. of B must just balance the fall of potential from a to d, due to the current supplied by D. The length *ad* then represents 1.431 volts, and hence each division represents .001 volt. An E. M. F. not exceeding 1.5 volts may now be measured by substituting it for the cell B. Without disturbing any part of the circuit containing D, and with T closed, adjust d along the slide wire *ab* until no deflection of the galvanometer is produced on closing K. Suppose that the scale reads 1,324 at the point where the balance is obtained, then the E. M. F. measured is 1.324 volts. Instead of having all the resistance in one slide wire, it is now very customary to use a number of equal resistance coils for part or even for all of *ab*.

Measurement of Current.—To measure a current or to calibrate an ammeter, it is necessary to have a known low resistance through which the current to be measured may be allowed to flow. By then measuring the drop of potential through this known resistance by the potentiometer, the current in the circuit including the ammeter may be calculated by Ohm's law.

Measurement of Low Resistance.—Two low resistances—a standard whose value is known, and the one to be measured—are connected in series, preferably, with an adjustable resistance and a source of very constant current. The resistance is adjusted, or the number of cells varied, until the fall of potential across each one of the resistances will fall within the range of potential that can be measured on the potentiometer. The current through the resistances must remain steady long enough to determine the drop in potential across each resistance. Then, the unknown resistance is to the known resistance as the potentiometer reading across the unknown resistance is to the potentiometer reading across the known resistance, from which the unknown resistance can be calculated.

CALIBRATION OF VOLTMETERS

A voltmeter may be calibrated by connecting it in parallel with a voltmeter of suitable range whose readings are known to be correct, or by connecting it across a suitable known resistance that is connected in series with a standard ammeter and a battery or other suitable source of current, or the drop across this known resistance may be determined with a potentiometer.

Franklin's Method.—To calibrate a voltmeter by Prof. W. S. Franklin's method, connect as shown in Fig. 15, in which *R* is an adjustable resistance; *D*, a steady source of E. M. F.; *B*, one or more standard cells connected in series;

V, the voltmeter to be calibrated; *H*, a high resistance whose value need not be known; and *G*, a sufficiently sensitive galvanometer with a shunt. Adjust *R* until no deflection of the galvanometer is observed when the key *K* is closed. Then, the E. M. F. of the standard cells corrected for temperature gives the E. M. F. at the terminals of the galvanometer. By varying the number of standard cells at *B*, as many points as desirable may be calibrated on the voltmeter scale. The high resistance *H* may be short-circuited, and the shunt resistance *S* cut out for the final adjustment. The E. M. F. of *D* must exceed that of *B*.

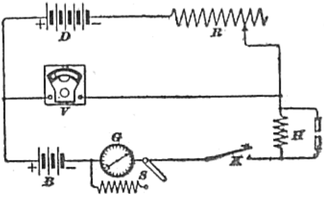

FIG. 15

Carhart's method for calibrating a voltmeter is shown in Fig. 16, in which *D* is a storage battery having a sufficient number of cells to give the desired reading on the voltmeter *V*, and *R*, *R′* are adjustable resistances For a high-reading voltmeter, *R′* should be at least as high as 100,000 ohms, while the range of *R* will depend on the number of standard cells used at *B* and the reading desired on the voltmeter. Adjust the resistances *R*, *R′* until no deflection of the galvanometer *G* is produced when the key *K* is closed, the high resistance *H*

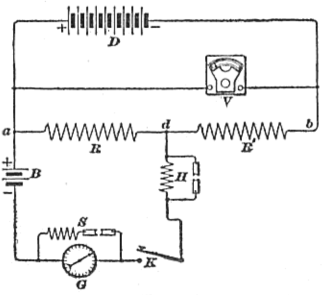

FIG. 16

being short-circuited and S opened for the final balance. Then, the reading of the voltmeter should be

$$V = nE\frac{R+R'}{R},$$

in which E is the E. M. F. of one standard cell corrected for its temperature during the test; n the number of standard cells used; and R, R', the resistances inserted at R, R', respectively.

For a voltmeter not reading over 3 or 4 volts, a slide wire can be used instead of the resistance boxes R, R', and the point d moved along the slide wire until no deflection of the galvanometer is obtained. Since $\frac{R+R'}{R}$ is merely a ratio, the distance along the slide wire from a to d can be used in place of R, and the distance a to b in place of $R+R'$.

CALIBRATION OF AMMETERS

An ammeter may be calibrated by connecting it in series with an ammeter of similar range whose readings are known to be correct. Another way is to connect the ammeter in series with a copper or silver voltmeter, by which the current may be determined for one reading of the ammeter. This is one of the most accurate methods, but in most cases is too slow. A third method, which is very satisfactory, requires the use of a potentiometer and a low resistance whose value is accurately known.

Calibration of Ammeter by Potentiometer.—Connect the ammeter in series with a battery or direct-current dynamo, the current from which may be regulated, and a suitable known resistance, the fall of potential across which may be determined with a potentiometer. Having measured the fall of potential and knowing the resistance, the current that flows through both the known resistance and the ammeter may be calculated.

Calibration of Ammeter by Franklin's Method.—Franklin's method for calibrating an ammeter is shown in Fig. 17, in which D is a steady source of E. M. F., preferably a storage battery; *A*, the ammeter to be calibrated; and *R* a standard known resistance. With a suitable number of standard cells at *B*, adjust the resistance *P* until the galvanometer *G* gives no deflection when *K* is closed; then, the E. M. F. between the terminals of the standard resistance *R* is equal to the E. M. F. of the battery *B*. The E. M. F. of the standard cells divided by *R* will give the current through the ammeter *A*. The high resistance *H*, equivalent to about 10,000 ohms or more per cell at *B*, may be short-circuited and the shunt *S* open-circuited when making the final adjustment. By the use of a different number of standard cells, various points on the ammeter scale may be calibrated. The E. M. F. of *D* must always exceed that of *B*.

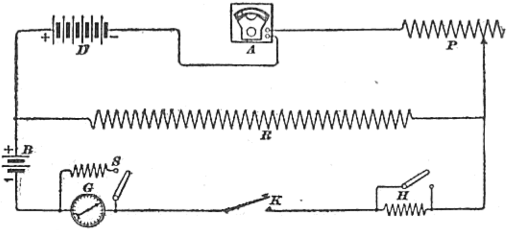

FIG. 17

OHMMETERS

Ohmmeters are instruments from whose scale may be directly read the value, in ohms, of a resistance that is being measured. The principle of the slide-wire ohmmeter may be explained by means of Fig. 18 (*b*). When the plug *P* is inserted in a hole, say the brown hole, the corresponding coil constitutes the known resistance arm *CD*, while the two long wires *CB* and *BA*, joined by a bar *B* of negligible resistance, constitute two adjustable arms of a Wheatstone bridge. The manufacturers mark along the wire in colors

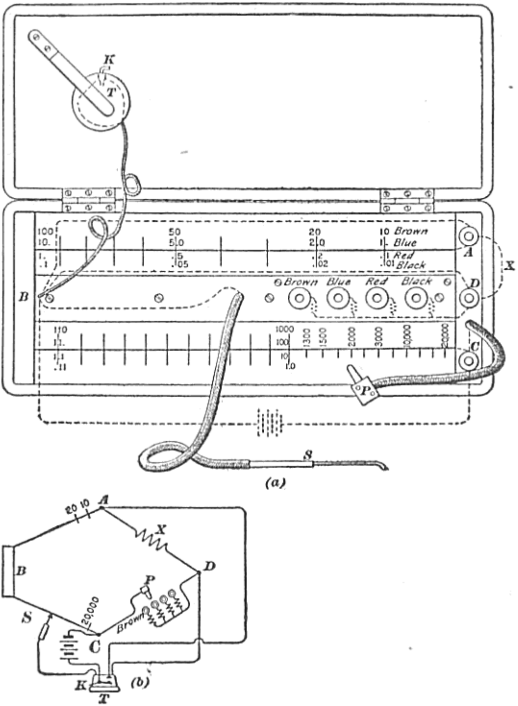
K
T
100
10.
1.
.1
50
5.0
.5
.05
20
2.0
.2
.02
10 Brown
1. Blue
.1 Red
.01 Black
A
X
B
Brown
Blue
Red
Black
D
110
11.
1.1
.11
1000
100
10
1.0
1300
1500
2000
3000
10,000
20,000
C
P
S
(a)
20
10
A
X
B
D
P
S
20,000
Brown
C
K
T
(b)

FIG. 18

scales that read directly in ohms; the color of the scale to be used corresponds to the color of the hole in which the plug P is inserted. The divisions per ohm are not equal in length but gradually decrease in length as the resistance at X increases. The red coil has exactly 10, the blue 100, and the brown 1,000 times the resistance of the black coil.

Having once calibrated the bridge wire with known resistances at X, any unknown resistance at X that would bring the balance point S somewhere on the bridge wire may be measured and its resistance read directly from the point of balance found on the scale.

Using a Sage Ohmmeter.—To measure the unknown resistance, usually designated as X, connect it between posts A and D, as indicated in Fig. 18 (*a*). Put plug P in the brown hole, place telephone T to the ear, being certain to press circuit-closing key K, and tap the stylus S along slide wire ABC until the click of the telephone ceases or is a minimum. The brown number under the balance point gives the value of X in ohms. If the approximate value of X is very low, the balance point, using the brown hole, will be so close to the A end of the slide wire that an accurate reading cannot be made. In such a case, change the plug successively to the blue, red, and black holes, if necessary, remembering that the scale to be used, when a balance is obtained, must be of the same color as that marked on the hole in which the plug is placed.

When the telephone will emit no sound between certain limits on the slide wire, a more accurate result may be obtained as follows: Suppose that the brown hole and scale are in use and that on starting from A the telephone becomes silent at the 695 mark and remains silent until mark 705 is reached, when it begins to click again; by taking the 700 mark, half way between the two, the result is more nearly accurate than if either limit is taken. It is not absolutely accurate, because the intervening divisions are not of the same length.

Two *inductances* may be compared, provided the resistance of each coil is negligible compared with its reactance ($2\pi nL$), by connecting the coils X, Y as shown in Fig. 19. I represents an ordinary induction coil or other arrangement by which alternating current may be obtained at the terminals AC. Obtain a balance by first closing K and adjusting S until

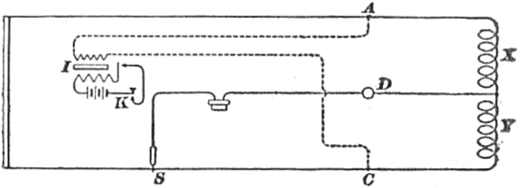

FIG. 19

a point giving a minimum sound is found. If only a battery can be obtained for use across AC, the balance point is that which gives a minimum sound when the slide wire is tapped. Then, the inductance of X is to the inductance of Y as the length AS is to the length SC.

Two *capacities* may be compared in a similar manner, but in this case the capacities are inversely proportional to the resistances; that is, the capacity at X is to the capacity at Y, as the length SC is to the length AS. In either case,

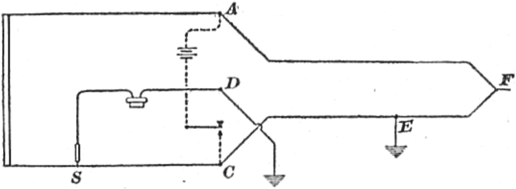

FIG. 20

when one inductance or one capacity is known, the other can be calculated.

A *ground* on one of a pair of line wires may be located by using the ohmmeter as indicated in Fig. 20. In order to use this method, a good wire AF of the same material and size as the line wire CF should be joined to the faulty wire at some point F beyond the fault E. Then, if S is the point of balance,

$$\text{distance } CE = \frac{\text{length } SC \times \text{distance } AFC}{\text{length } ASC}$$

The *resistance of electrolytes* may also be measured with the ohmmeter by connecting the electrolytic resistance in the unknown arm of the bridge and using an alternating current from an ordinary induction coil or other source in place of a battery.

MEASUREMENTS WITH COMMERCIAL INSTRUMENTS

AMMETERS AND VOLTMETERS

An *ammeter* is an instrument for measuring the current flowing in a circuit. The ammeter, or its shunt, is connected directly in series with the circuit through which the current is flowing.

A *voltmeter* is an instrument for measuring the difference of potential between two points; this is done by connecting the voltmeter across the two points.

The *range of an ammeter* may be increased by connecting a shunt across its terminals. Let R be the resistance of the ammeter and S the resistance of the shunt connected around the ammeter terminals; I the highest reading, that is, the present range of the ammeter; and I' the range desired. Then the resistance of the shunt required is

$$S = \frac{RI}{I' - I}$$

When thus shunted, the indicated reading must be multiplied by $\frac{I'}{I}$ to obtain the total current flowing in the main circuit.

The *range of a voltmeter* may be increased by connecting a resistance in series with the voltmeter. Let R be the resistance of the voltmeter; R' the resistance connected in series with it; V, the highest reading of the voltmeter; and V' the highest reading desired. Then,

$$R' = R\left(\frac{V'-V}{V}\right)$$

When the resistance R is connected in series with the voltmeter, the scale readings must be multiplied by $\frac{V'}{V}$ to give the difference of potential across the circuit.

Double, or *two-scale, voltmeters* are usually connected internally, as shown in Fig. 21. The resistance of the non-inductive coil ab, together with that of the movable coil, that is, the resistance from a to p', may be 15,000 ohms for a 15-volt scale, and the total resistance from p to p'' 150,000 ohms for a 150-volt scale. When using a double-scale voltmeter, care must be taken not to apply too high a voltage to the terminals of the lower resistance coil that is associated with the lower reading scale.

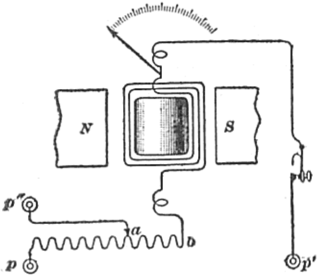

FIG. 21

Measurement of Resistance by Voltmeter and Ammeter. A resistance R may be measured by connecting an ammeter A in series with the resistance R and a battery B or other source of current, and connecting a voltmeter VM around the resistance, as shown in Fig. 22. Then, by Ohm's law, $R=\frac{E}{I}$. It is quite customary and sometimes necessary to connect the voltmeter across the terminals t, t' of the resistance to be measured, instead of including, as shown in this figure, the ammeter A between the voltmeter terminals. Usually, either method of connecting the voltmeter will give sufficiently accurate results, but it generally introduces less of an error to connect the voltmeter as shown in this figure. By using instruments of the proper range, resistances from quite low to quite high values may be measured.

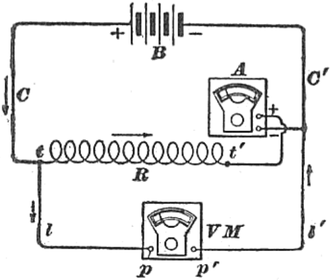

FIG. 22

Resistance Measurement With Voltmeter and Known Resistance.—A resistance may be measured by connecting it in series with a dynamo or battery *B* and with a known resistance *R′*, as shown in Fig. 23. With the voltmeter

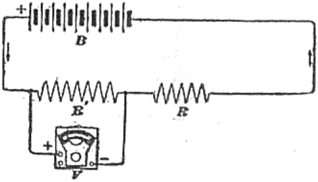

FIG. 23

first connected across the ends of *R′*, let the reading be *E′* volts; with the voltmeter connected across the ends of the unknown resistance *R*, let the reading be *E* volts. If *R′* is very different from *R* it is sometimes very convenient to measure one on the higher-reading scale and the other on the lower-reading scale of a double-scale voltmeter.

High-Resistance Measurement With Voltmeter.—High-resistance voltmeters may be used to measure very high resistances, such as insulation resistances, by connecting as shown in Fig. 24, in which *R* is the insulation or high resistance to be measured; *BC* the battery or other source of E. M. F., which should be as high as the range of the voltmeter *VM* will allow; and *K* a switch for short-circuiting the resistance *R*. Then,

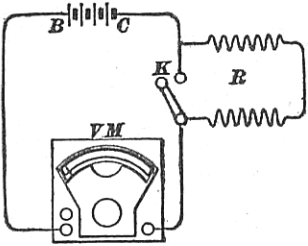

FIG. 24

$$R=r\left(\frac{d}{d'}-1\right)$$

in which *d* is the reading of the voltmeter with the key *K* closed; *d'* the reading of the voltmeter with the key *K* open; and *r* the resistance of the voltmeter, which is usually marked upon the instrument or the case.

Insulation Resistance With Voltmeter.—The method just described may be used to measure the insulation resistance of telephone, telegraph, and electric-light and power circuits, and also of dynamos and motors while the system is in operation, no shutting down being necessary. In Fig. 25 is shown the connections for measuring the insulation resistance of a line while the dynamo *D* is supplying current to the lamps *l*. Let R_a represent the joint resistance of all leakage paths between the main line *AA* and the ground, and R_b the same between *BB* and the ground. First, connect a suitable voltmeter *Vm* between the mains *ef*, and let the reading be V_m volts. Then, connect the same voltmeter between the ground *G* and the main *AA* by closing switch S on contact a, and let this reading be V_a volts. Finally, connect the voltmeter between the ground G and the main BB by closing S on b and let the reading be V_b volts. To obtain the last reading with most voltmeters, it will be necessary to reverse the connections at the voltmeter in

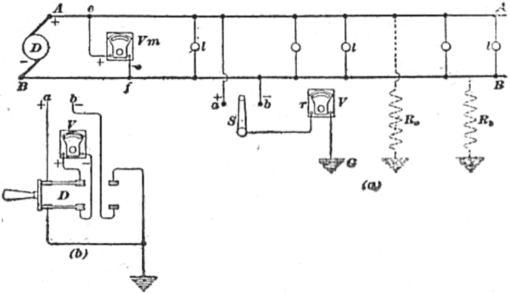

FIG. 25

order to make the needle deflect in the right direction. If r is the resistance of the voltmeter, and R the joint resistance of all possible paths between both mains and the ground, the insulation of the whole system will be

$$R=r\left(\frac{V_m}{V_a+V_b}-1\right) \qquad (1)$$

If the insulation resistance of one side, for instance BB, is extremely high, and the other side AA is poorly insulated or partially grounded, the voltmeter reading V_a between the partially grounded side and the ground will be practically zero, because there is no path for any current back to the well-insulated main. The formula for the insulation resistance of the side AA then reduces to

$$R=r\left(\frac{V_m}{V_b}-1\right) \qquad (2)$$

Hence, to measure the insulation resistance of one side of a system only, take two readings—one between the two mains and the other between the other or good side and the ground.

If the ratio $\frac{V_m}{V_b}$ in formula 2 is very much greater than 1, the formula reduces to

$$R = r\left(\frac{V_m}{V_b}\right) \qquad (3)$$

This is an approximate formula that is often used for ordinary measurements.

If the voltmeter has two scales and the reading V_a or V_b is less than the largest reading on the lower reading scale, a more accurate result may be obtained by using the lower reading scale for determining V_a or V_b. In the formula, r will be the resistance of the voltmeter coil used in obtaining the reading V_a or V_b; the resistance of the coil used in obtaining the reading V_m will not enter into the result.

When this insulation-resistance test is to be made repeatedly, a convenient arrangement is shown in Fig. 25 (*b*), in which the double-throw switch *D* is so connected as to make the voltmeter deflect in the proper direction, whether connected to *a* or to *b*. The switches and connections should be very much better insulated than the system to be tested, and the voltmeter readings should be taken as quickly as possible, one after the other, as the formula assumes that all readings are observed simultaneously. Slight variations in the E. M. F. of the source of supply do not affect the results very materially. The insulation resistance of a dynamo may be measured in the same way as that of a line circuit.

ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE OF BATTERIES

The *internal resistance* of a battery or cell is a very variable quantity; hence, it is somewhat difficult to measure, and very exact results should not be expected. The voltmeter-and-ammeter method is about the most satisfactory, as it enables both the electromotive force and the internal resistance of the battery to be measured under actual working conditions.

Wheatstone's Method.—Wheatstone's method for comparing the E. M. F. of voltaic cells by means of a voltmeter is as follows: First, connect one of the cells so as to be in series with the voltmeter V and the resistance R, as shown in Fig. 26, and note the reading d when the key K is closed. Then, increase the external resistance by opening the key K with r_1 ohms and note the deflection d'. Repeat these two observations with the second cell connected at E in place of the first cell; but, with the key K closed, first make the resistance R of such a value as to give exactly the same deflection d as with the first cell. Then, open the switch K and make the additional resistance r_2 of such a value as to get exactly the same deflection d' as under similar connections for the first cell. Then, $E_1 : E_2 = r_1 : r_2$. If E_1 is smaller than E_2, the resistance of the voltmeter itself may be taken for R_1 when E_1 is connected in the circuit. It is preferable to make r_1 about twice as large as the combined resistance of E_1 and R_1. With a suitable voltmeter, this method is correct to about 1%.

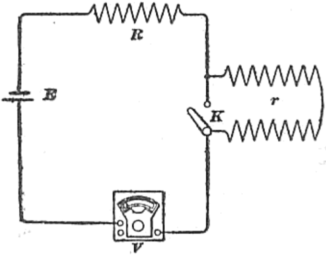

FIG. 26

Voltmeter-and-Ammeter Method.—By the voltmeter-and-ammeter method, both the internal resistance and the E.M.F. of a cell may be determined from the same observations; and, moreover, the measurements may be made when the cell or battery is generating current at its normal or desired rate. Connections for this method are shown in Fig. 27, in which R is a resistance of such value that the battery B to be tested will furnish its normal amount of current.

With the key K open, read the voltmeter V, which will give E, the E. M. F. of the battery when practically no current is flowing, that is, when the battery is practically on open circuit; then close the key, and read as nearly simultaneously as possible both the ammeter A and voltmeter V. These two readings give the difference of potential E' at the battery terminals and the current I which is flowing through the circuit. Then, the internal resistance $B = \frac{E-E'}{I}$. If the total resistance R external to the battery is known, the ammeter will not be necessary, for the current I is equal to $\frac{E'}{R}$ and can therefore be calculated.

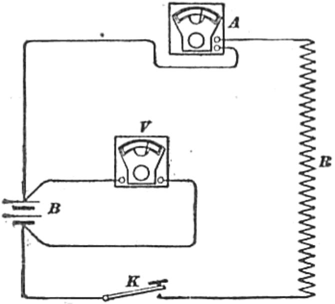

FIG. 27

MEASUREMENT OF POWER

The *power* expended in a direct-current circuit may be determined by measuring the current and the difference of potential, the product of these two measurements giving the power expended. Such measurements can be readily made with a voltmeter and an ammeter. Voltmeters and ammeters, however, cannot generally be used in this manner to determine the power consumed in alternating-current circuits.

MEASUREMENT OF POWER WITH VOLTMETER AND AMMETER

Fig. 28 shows the method of connecting voltmeters and ammeters to determine the power expended in direct-current circuits. The product of the simultaneous readings of V_3 and A_3 gives the power in watts expended by the dynamo *D* in the whole circuit; that of the simultaneous readings of V_2 and A_2 gives the power consumed by the motor *M*; and that of the simultaneous readings of *V* and *A* gives the power expended in the group of lamps *L*.

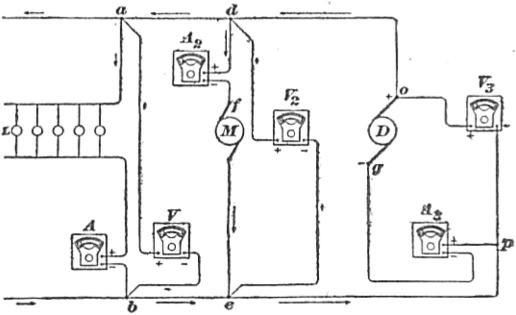

FIG. 28

DYNAMOMETERS

The *dynamometer* is an instrument that may be used to measure currents, E. M. F., and power in both direct- and alternating-current circuits. Instruments of this type consist of two coils, one fixed and the other arranged to revolve a limited amount inside the fixed coil. The movable coil, which is usually suspended by a helical spring that tends to keep it at right angles to the fixed coil, has a pointer attached to it.

In the Siemen's dynamometer, the helical spring is secured to a nut, called the torsion head, to which is also fastened a pointer that moves over a circular scale. When a current passes through both coils the swinging coil is deflected, but is brought back to its zero position by turning the torsion head. The number of degrees through which it is necessary to turn the torsion head is the reading of the instrument, and is proportional to the product of the currents in the two coils.

Commercial, portable, and switchboard instruments of the dynamometer type are constructed on the same principle, except that the scale is calibrated by the makers, so that the position of a pointer attached to the movable coil indicates directly the current, voltage, or power, depending on how the two coils are connected.

Measuring Current.—If the two coils of a dynamometer are connected in series so that the same current flows through each coil, the rotating force is proportional to the square of the current, and the scale may be calibrated to indicate the strength of the current.

Measuring Difference of Potential.—When the dynamometer is used to measure the difference of potential, the fixed and movable coils and a sufficiently high non-inductive resistance are connected in series across the two points in a circuit between which the difference of potential is to be measured. Then the deflections are proportional to the square of the currents as before, but the currents, since the resistance remains constant, are proportional to the potential differences; hence, the deflections are proportional to the squares of the potential differences, and the scale may be calibrated to indicate directly the difference of potential across the instrument.

Measuring Power.—If the swinging-coil circuit has a constant and high resistance and is connected between two points, the currents through it will be proportional to the difference of potential between those two points. If the fixed coil is connected in series with a circuit joined to the same two points, practically the whole current in the circuit will pass through the fixed coil; consequently, the torsion will be proportional to the product of potential difference and current, that is, to the power being expended in the circuit.

The earth's field may produce an error in the dynamometer reading, but it may be eliminated if the average of two readings is taken for one in which the current through both coils is reversed in direction. In such cases, the earth's field increases the torsion for one reading as much as it diminishes it for the other. The dynamometer type of instrument is even more suitable for measuring alternating currents, E. M. F.'s, and power than for direct current, for then the earth's field has no effect on it. Commercial wattmeters have their scales calibrated to read amperes, volts, or watts directly. So-called multipliers, that is, non-inductive resistances, are made for use with wattmeters; the multipliers increase the capacity of the instrument, usually in volts, with the maximum current capacity remaining unchanged.

Weston Compensated Wattmeter.—In measuring power with a voltmeter and an ammeter, the product of the two readings includes not only the power consumed in the lamps or other devices, but also the power consumed in one of the instruments. The same error occurs in the results obtained by the use of a non-compensated wattmeter. This error is eliminated in the Weston compensated wattmeter by winding the wire running to the potential coil alongside of each turn in the current coil, the current circulating in the two turns in opposite directions. So far as the magnetic action of the current in the current coil is concerned, the result is the same as if the current in the potential coil were subtracted from the current in the current coil.

Fig. 29 shows the connections of the Weston instrument. A and B are the current terminals connected to the current coils c, c'. The compensating coil e is connected in series with the swinging coil D, and the protective resistance R. The potential binding posts that are ordinarily used for measuring the power supplied to a given load are ab. When a reading is taken, the button k is pressed, thus allowing current to pass through the swinging coil. A third binding post *I* is provided for use when the field and pressure terminals are connected to independent circuits. Such connections are required when the instrument is being checked by passing a current through the current coils and applying a variable pressure to the potential coil; also, in cases where a test is being made with a constant current and varying

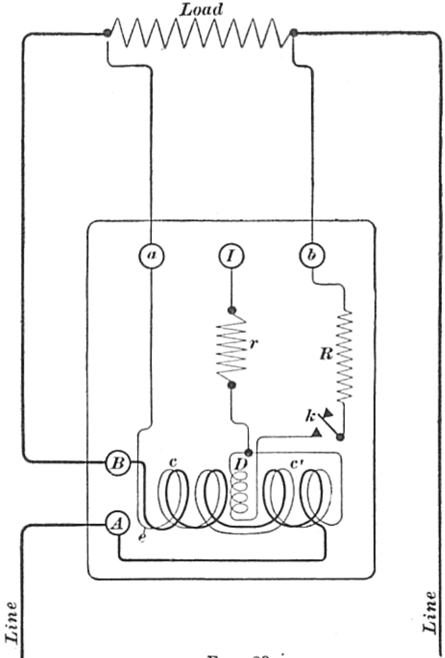

FIG. 29

pressure. If an independent potential circuit is used in this way, the potential terminals are connected to posts *Ib*, thus cutting out the compensating coil. The small resistance *r* takes the place of coil *e*, so that the resistance of the potential circuit remains unaltered.

Recording Wattmeters.—Instruments that show the value of the watts expended at any instant are frequently called *indicating wattmeters* to distinguish them from *recording wattmeters*, which measure the total work done during the given time. The recording wattmeter indicates the product of watts and time, usually in watt-hours or kilowatt-hours. Strictly speaking, these recording instruments are work-meters, not wattmeters, because they record work, not power. Large numbers of recording wattmeters are used for measuring the electrical energy supplied to customers on electric-light and power circuits; the watt-hours or kilowatt-hours are read about once a month from a dial similar to that of a gas meter.

LOCATION OF FAULTS

Faults on a line may be of three kinds: (1) The line may be broken; (2) an unbroken line may be grounded at one or more points; and (3) an unbroken line may be in contact with another line. The first fault is called a *break*, or an *open;* the second, a *ground;* and the third, a *cross*. A break may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired, so as to form also a cross or a ground. A ground or a cross may be of such low resistance as to form a dead ground or a short circuit, respectively, or may possess high resistance, thus forming what is termed a *leak*. The existence of a wire whose insulation and continuity are known to be good is termed a *good wire*.

Line Resistance When Three Conductors Are Available. The best method for measuring the resistance of a line wire, where there are three or more line wires or two line wires and a ground-return circuit between the same two offices, is as follows: Let the resistance of the three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together; then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and call it a ohms. Then, have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined and measure the resistance of this loop, calling it c ohms. Then, $x+y=a$; $x+z=b$; $y+z=c$. Solving these equations for x, y, and z gives:

$$x=\frac{a+b-c}{2} \qquad (1)$$

$$y=\frac{a+c-b}{2} \qquad (2)$$

$$z=\frac{b+c-a}{2} \qquad (3)$$

Elimination of Earth Currents.—Where the ground is used as a part of the circuit, *earth currents* will often render measurements very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may be usually eliminated by making a measurement and then reversing the battery and making another measurement. The average of the two measurements should be taken as the correct result. For good results, the earth current should not only be steady but it should also be small compared with the testing current.

TESTS FOR LOCATING A BREAK

NO GOOD WIRES AVAILABLE

Measurements From One End Only, Using a Condenser. When there is not a single good wire available, but the total capacity and length or capacity per mile of the conductor is known, or can be measured, the distance to a break may be determined as follows: Let d be the deflection, or throw, of a ballistic galvanometer obtained by charging or discharging through it a condenser of known electrostatic capacity C, and let d' be the throw when charging or discharging the broken line wire whose capacity is C', using the same battery in each case. Then,

$$C' = \frac{Cd'}{d}$$

The electrostatic capacity per mile of the broken line must be known; then, by dividing C' by this electrostatic capacity per mile, the number of miles to the break is obtained. By using the foregoing method, this electrostatic capacity per mile may be determined by measuring the total electrostatic capacity of the line when it is in good condition—that is, free from breaks, grounds, and crosses—and dividing this total electrostatic capacity by the total length of the line. The electrostatic capacity per mile may be obtained approximately from the following table:

ELECTROSTATIC CAPACITY PER MILE

Number and Gauge 1	Diameter In. 2	Capacity in Microfarads per Mile, 30 Ft. Above Ground: Between One Wire and Ground (Grounded at Both Ends) 3	Capacity in Microfarads per Mile, 30 Ft. Above Ground: Wire to Wire 12 In. Apart 4
8 B. & S.	.128	.00958	.00854
9 B. & S.	.114	.00946	.00835
10 B. & S.	.102	.00935	.00818
12 B. & S.	.0808	.00913	.00785
14 B. & S.	.0641	.00892	.00754
16 B. & S.	.0508	.00871	.00726
12 B. W. G.	.109	.00942	.00828
14 B. W. G.	.0830	.00915	.00788

The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially whether any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. It will also vary with the number of insulator supports per mile and the moisture on them. When one overhead wire is grounded at one end and insulated at the other end, the capacity is twice as great as when both ends are grounded; that is, twice as great as the capacity given in column 3 in the table. When a high inductance, such as a high-resistance (1,200-ohm) bridging bell, is connected between one end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is open and insulated.

The capacity C, in microfarads, per mile of one wire .104 in. in diameter, grounded at both ends and suspended at a height of h ft. above the ground, is given in the accompanying table. If there are two such wires .104 in. in diameter, 1 ft. apart, and grounded at both ends, the capacity between either wire and the ground is .01171 microfarad per mile when both wires are 20 ft. above the ground, and .0115 microfarad when both wires are 30 ft. above the ground. The capacity, in microfarads per mile, between two wires .104 in. in diameter, and forming one metallic circuit is .008503 when the two wires are 10 in. apart, .008218 when 12 in. apart, .007992 when 14 in. apart, .007806 when 16 in. apart, and .007649 when 18 in. apart.

ELECTROSTATIC CAPACITY OF SINGLE LINE WIRES
(Grounded at both ends)

h Ft. Above Ground	C Microfarads per Mile
10	.010600
20	.009796
30	.009379
40	.009105

Measurements From Each End, Using a Condenser.—Another method of locating a break when no good wire is available is as follows: Determine the discharge deflection d from the broken wire at one end of the cable, also the discharge deflection D from a condenser of known capacity C. Then, determine the discharge deflection d' from the other end of the broken wire, and the discharge deflection D' from a condenser of the same capacity, or preferably from the same condenser. The same amount of battery must be used for both tests at one end, but the same amount of battery need not be used at one end as at the other. This method gives very satisfactory results. Let L be the length of the cable; then, the distance x to the break is given by the formula

$$x=\frac{Ld}{d+\frac{D}{D'}d'}$$

ONE OR MORE GOOD WIRES AVAILABLE

Three Good Wires Available.—A method that has been successfully used for the location of breaks in telephone-cable conductors is shown in Fig. 30, in which V and B represent any suitable means for supplying a reversible, interrupted, or alternating current—in this case a rotating device—for reversing rapidly the current from the battery B.

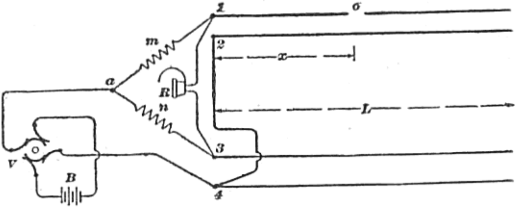

Fig. 30

The conductor *1* is open at o, while its mate *2* and the pair *3*, *4* are supposed to be good wires: m and n represent two adjustable arms of a Wheatstone, or slide-wire, bridge. The resistance in the arms m, n is adjusted until no sound, or a minimum sound, is produced in the receiver R. Then, the distance to the fault o is given by the formula

$$x=\frac{n}{m}L$$

The wires *1, 2, 3, 4* should be well insulated at the distant end. For cables 1,000 ft. long, the battery B should give 60 to 120 volts, and the resistance in the arm n may have to be 100 or 1,000 ohms. The larger the capacity between the wires, the less need be the number of cells at B and the less the resistance in the arm n.

One Good Wire Available.—When one good wire having the same capacity to ground per mile as the broken wire is accessible, deflections may be taken on the broken wire and on the good wire with the distant end open.

Let d' = throw on the broken wire;
d = throw on good wire;
x = distance to break;
L = total length of good wire.

Then,

$$x = \frac{d'L}{d}$$

In a telephone cable, it is best to use the mate of the broken wire as the good wire, and to ground to the lead sheath all the conductors except the one from which the deflection is being obtained. At least the mate of the faulty wire should be grounded at the testing end when the discharge deflection of the faulty wire is observed, and both ends of the faulty wire should be grounded when the discharge deflection of its mate is being observed.

The method for locating a break in a line wire by comparing the capacity of the broken wire with that of a similar good wire is reliable, provided the insulation resistance is high and the break is so complete that no current passes through the point of rupture. In using these methods, therefore, it is best to first measure the insulation resistance of the broken wire and also of the good wire. If the insulation resistance of the good wire is near 1 megohm, capacity methods are not very reliable. The insulation resistance of the good wire should preferably be about 20 megohms in order to obtain reliable results. Breaks in cables cannot be as accurately located as grounds or crosses under favorable conditions, because the electrostatic capacity is much less uniform than the resistance of the wire; in fact, the electrostatic capacity of a conductor in a telephone cable may vary as much as 5%.

TESTS FOR LOCATING A GROUND

Accidental connections with the ground occur much more frequently than breaks, and are often difficult to locate, especially if more than one ground occurs on the same line wire. Various methods for locating grounds will be given, as no one method is always applicable.

Ground on a Line of Known Resistance.—Where there is a dead ground on a line whose length and resistance are known, let f be the known resistance of the line and L the length of the line, in miles. Then, if the line wire is uniform in size and material, $\frac{f}{L}$ is the normal resistance of the line per mile. To locate the distance to a dead ground in such a case, measure the resistance between the home end of the line and the ground and call it a ohms. Then, the number of miles x from the testing station to the dead ground is given by the formula

$$x=\frac{aL}{f}$$

TESTS FROM BOTH ENDS WITHOUT A GOOD WIRE

Earth Overlap Method.—Where there is no available good wire and tests can be made from each end of a grounded wire, the *earth overlap method* may be used. This method is especially valuable for the location of high-resistance faults,

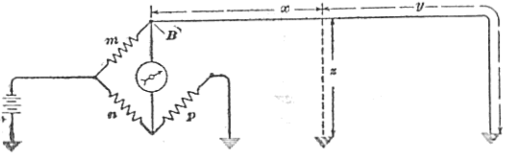

FIG. 31

and experience seems to show that it is the best practical method for locating grounds in submarine cables, provided there is only one ground and no good wire is available. Let x represent the resistance from one end of the conductor to the fault; y the resistance from the other end of the conductor to the fault itself; and f the normal resistance of the faulty wire. Then, $f=x+y$.

First, measure, with a Wheatstone bridge, the resistance from the x end with the other end grounded, the connections being made as shown in Fig. 31; call the resistance thus measured a ohms. Second, measure, in the same manner, the resistance of the grounded wire from the other, or y, end with the distant end grounded; call the resistance so determined b ohms. Then,

$$x=\frac{a(f-b)}{a-b}\left[1-\sqrt{\frac{b(f-a)}{a(f-b)}}\right] \qquad (1)$$

$$y=\frac{b(f-a)}{b-a}\left[1-\sqrt{\frac{a(f-b)}{b(f-a)}}\right] \qquad (2)$$

The zinc, or negative, terminal of the battery should be connected toward the line, and the tests in the earth overlap method should be made alternately and as rapidly as possible from each end, so that pairs of readings may be secured while the fault undergoes as little change as possible.

When one end of a good line is grounded and its resistance measured, the result, called its *apparent resistance*, will be less than the true resistance of the conductor when perfectly insulated. Better results will be obtained in the earth overlap method if the apparent resistance of the wire measured under normal conditions, that is, free from faults, is used for f, rather than its true resistance, which is usually determined from a wire table. The shorter the line or the better its insulation, the less is the error due to using the true resistance.

TEST FROM ONE END WITHOUT A GOOD WIRE

Blavier Test.—The *Blavier method* for locating a partial ground or an escape is about the only one that can be used where there is no available good wire and when the test must be made from one end only. However, this method is rather unreliable in practice, because, if the resistance of the partial ground changes between the two measurements, the result cannot be depended on; and, moreover, the normal, or total, resistance of the line must be known from some previous measurement, obtained from a wire table, or calculated from the length, size, and conductivity of the line wire. Let the total resistance of the line wire be f. First, measure the resistance of the line with the distant end open, and call the resistance so obtained b; also, measure the resistance of the line with the distant end grounded, and call this resistance c. Then, the resistance x to the partial ground from the testing station is given by the formula

$$x = c - \sqrt{(b-c)(f-c)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurement, obtained from a wire table or calculated by the length, size, and conductivity of the line wire, the distance to the partial ground is obtained. If L is the length of a cable and f the total resistance of the bad wire to the distant end of the cable, the distance to the fault equals $\frac{xL}{f}$.

The accuracy of the result obtained by this test depends on the resistance of the fault remaining the same during both measurements. The farther the fault lies from the testing station, the more accurate will be the result. Therefore, the more reliable result will be that obtained by making the test from the end farthest from the fault. However, if two faults exist, the best result is obtained by making the test at the end nearest to the one to be located. Where a series of observations are taken, the most accurate result is secured by using the lowest of all the readings taken with the distant end open and the lowest with the distant end grounded; but if the resistance of the fault is very unsteady, the means of each series may be used.

LOOP TESTS WITH ONE OR MORE GOOD WIRES

Varley Loop Test.—Where there is one available good wire, the *Varley loop method* is probably the most convenient and best for locating a ground or a cross on a line. The distant ends of the good and bad wires are joined together, and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown in Fig. 32. Balance the bridge, and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then, connect one end of the battery to the ground instead of to D, as shown in Fig. 33. Call y the resistance from B through E to F and x, the resistance from D to F. R, the total resistance of the loop, is equal to $x+y$. Then, when the bridge is balanced, $\frac{m}{n}=\frac{y}{p+x}$. Hence, the resistance,

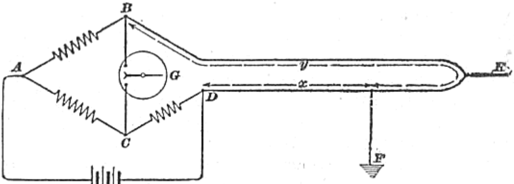

FIG. 32

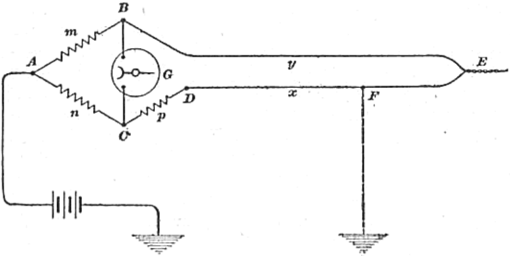

FIG. 33

$$x=\frac{nR-mp}{m+n}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the wire per foot, the distance to the fault is readily calculated.

Murray Loop Test.—The *Murray loop test* is quite similar to the Varley loop test. Under favorable and suitable conditions, the Varley test gives more correct results, but the great simplicity of the Murray test recommends it, especially for underground-cable work, where it is generally only necessary to locate the fault between manholes. First, have the distant ends of the available good and bad wires joined together. Then, connect the loop so formed to the bridge, as shown in Fig. 32 for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Evidently

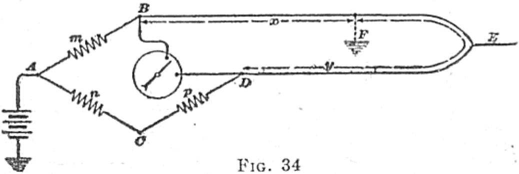

FIG. 34

$R=x+y$. Then connect the loop and battery as in Fig. 34, thus having really only two adjustable arms, because AC and CD now form only one arm. F is now the junction between the arms x and y. When the bridge is balanced,

$$\frac{m}{n+p}=\frac{x}{y}$$

Solving the two equations for x, the resistance of the line wire to the fault is

$$x=\frac{mR}{m+n+p} \qquad (1)$$

A test made by this method gives a result that is independent of the resistance at the fault. If the good and bad wires constitute a pair of wires in a cable or at least two wires of equal length, size, and material, x may be called the distance to the fault, while twice the length L of the cable may be used for R. The formula may then be written,

$$\text{Distance to fault}=\frac{2mL}{m+n+p} \qquad (2)$$

A check on the result obtained by the Murray loop test may be secured by reversing the connections of the good and bad wires with the bridge, obtaining another balance and result, and taking the mean of the two.

For reliable results with the Murray loop test, the good wire should have an insulation resistance of at least ten times that of the bad wire. Some good wire should be selected and the insulation resistance of the good and bad wires measured or compared by some suitable and convenient method to determine if this condition is fulfilled.

It is best to connect the good and bad wires directly to the bridge; but if lead wires must be used, R in the formula for this test must be increased by the resistance of the two lead wires, and later the resistance of the lead wire in series with the bad wire must be subtracted from the calculated resistance to the fault to get the correct result. If the leading wires are short and differ from the cable wires by one or two sizes only, the error introduced does not amount to more than a few feet, which is usually negligible if the length of one of the two equal lead wires is added to the length L of the cable in formula 2, and this same length is then subtracted from the final result.

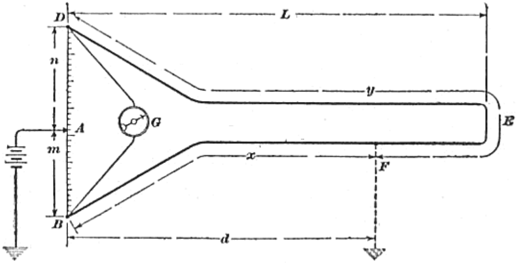

FIG. 35

Murray Loop Test With Slide-Wire Bridge.—A very simple and sometimes a very convenient way of locating a ground on a line wire consists in using a slide-wire bridge, as shown in Fig. 35, in place of the two adjustable arms of a Wheatstone bridge in the Murray loop method. If A is a point on the slide wire that can be touched without producing a deflection of the galvanometer, then $\frac{n}{m}=\frac{y}{x}$, and $y+x=R$. Hence,

$$\text{resistance } x=\frac{mR}{n+m}, \qquad (1)$$

in which x will be the resistance along the bad wire to the ground and R the resistance of the loop, which, if not already known, must be determined by another measurement or calculated by means of a wire table.

This method is especially useful, however, when both x and R are considered as distances in miles or feet. If the two line wires are of the same size, length, and material, their resistances are proportional to their lengths; hence, the distance to the fault is

$$d=\frac{2mL}{n+m}, \qquad (2)$$

in which L is the length of one line wire, or the length of the cable containing the line wires, and d, the distance from B to the fault F.

The length $2L$ will usually be twice the length of one line wire plus the length of any lead wires (preferably of the same size and material as the line wire) that may be used to connect the two line wires to the points B, D.

If all the conductors in a cable have become defective, but some are much more heavily grounded than others, the Murray loop test may still be used with fair success, provided there is no disturbing difference of potential from an outside source between the two wires selected for the test. Even if all the conductors in a cable are heavily or equally grounded, the Murray loop test may still be successfully applied, provided there is available a good aerial wire or conductor in another cable that can be joined to the faulty conductor at the distant end.

Murray Loop Test Requiring Two Good Wires.—Where a good wire of the same size as the faulty conductor is not available, but where two good wires of any size and material either inside or outside the cable, are available, the following modification of the Murray loop test, made by H. W. Fisher, may be used. It must be possible to connect together the distant end of the faulty conductor BE and the two good available wires i, j, as shown in Fig. 36. These conductors are connected together at E and to the bridge as shown in (a). The arms m and n are adjusted until the galvanometer gives no deflection, and their values are recorded. The wire h running from the battery to the lead sheath of the cable is then connected to the conductor j, as shown in (b), after which the bridge arms are adjusted until values m' and n' are obtained that again produce no deflection of the galvanometer. If L is the total length of the faulty conductor and x the distance to the fault, then

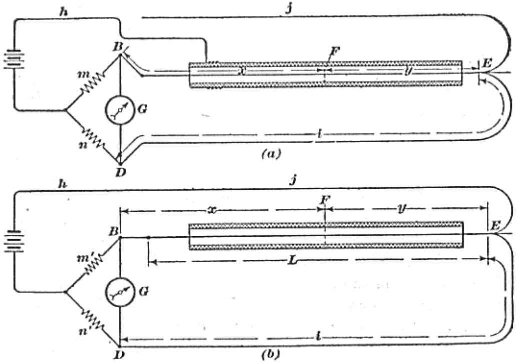

FIG. 36

$$x = \frac{m(m'+n')L}{m'(m+n)}$$

In the application of this method, the resistance of conductors i, j may be quite different without affecting the result; hence, before the test is made, lead wires of the proper length may be used at either end for making the connections with the conductors i, j. Usually, the same values for m and m' can be used, thereby reducing the calculations. If the faulty wire cannot be conveniently connected to the Wheatstone bridge, a wire of the same size and material as the cable conductor may be used to make the connections; then it will be necessary to add the length of this wire to the length of the bad wire or cable, using this total length for L in the formula, and subtract the length of this lead wire from the calculated distance x to the fault.

Goodrum Slide-Wire Bridge Method.—One of the best and simplest loop methods for locating grounds and crosses where two good wires are available is that proposed by C. L. Goodrum. Theoretically, it is the same as the method just explained, but a slide-wire bridge is used instead of a regular Wheatstone bridge, thereby simplifying the test. In Fig. 37, BC represents a slide wire, which may be a piece of No. 24 B. & S. German-silver or iron wire stretched between posts B and C, so as to be over a scale divided into exactly 1,000 equal divisions, preferably millimeters. The smoother and more uniform the diameter and material of the wire BC, the more accurate will be the results. This method may be used to determine the distance x to a fault at F, which may be either a ground on wire *2* or a cross between wires *1* and *2*. Have all the wires joined together at the distant end, and

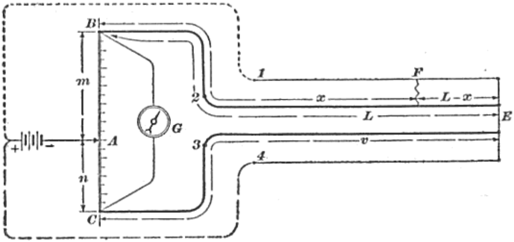

FIG. 37

at the testing end join *B* to *2*, *C* to *3*, and the battery to *4*; the dotted-line connection from the battery to line *1* is not made at this time. *G* represents a galvanometer or a sufficiently sensitive millivoltmeter. Adjust the pointer along the slide wire until a point *A* is found where *G* gives no deflection. The connecting wire from *B* to *2* should be sufficiently short or large in diameter, or both, so that its resistance may be neglected. Then,

$$\frac{L}{v}=\frac{m}{n}$$

in which L = length of cable;
v = length of wire *3*;
m = distance BA, that is, the scale reading from the end B to the point of balance A;
n = distance AC, that is, the length $BC-m$.

If line *2* is crossed at *F* with line *1*, then connect the positive terminal of the battery to this wire *1*, as represented by the light dotted line, instead of to line *4*, as represented by the dash line. If line *2* is grounded at *F*, connect the positive terminal of the battery to ground instead of to line *1*. In either case, the procedure is as follows: Again, balance the bridge and let m' be the new reading on the slide-wire scale from *B* to the new point of balance. Then,

$$\frac{x}{L-x+v}=\frac{m'}{n'}$$

Solving these equations for x gives

$$x=\frac{m'L}{m}$$

Although two good wires *3* and *4* are required, they may be of any reasonable size, material, or length, and they may be wires inside or outside the cable. The distance x to the ground or cross is merely a certain ratio $\frac{m'}{m}$ of the total length L of the cable, and this distance is independent of the length of the good wires. The only requisite necessary for extreme accuracy is that the faulty wire *2* shall twist in the same uniform manner throughout the entire length of the cable. If it starts as an inside wire, it must continue as such. Most loop tests not only assume this to be the case, but also assume that the good and faulty wires are of exactly the same length, which is not true when one is an inside wire and the other an outside wire in a telephone or telegraph cable, because the latter twists around the inner wires and is therefore somewhat longer than any wire inside of it. This method requires only two balances, and only one connection has to be changed. An apparatus, called the *lineman's faultfinder*, has been placed on the market for locating faults by practically this method.

For the location of grounds, some form of loop test is usually superior to all others. When the leakage along the lines is great, the loop tests may be seriously vitiated thereby, in common with other methods. The next best method is the earth overlap, which is more suitable than the Blavier method for a fault that has a varying resistance or much polarization. Since the earth overlap method requires tests from both ends of the line, it is not always applicable, in which case the best alternative method is the Blavier.

OTHER METHODS OF LOCATING GROUNDS

Receiver Method.—The following method is said by A. B. Dungan to be very simple and reliable for locating grounds on aerial cable conductors, provided the cable is free from dead grounds against other cables and guy wires. In Fig. 38 is shown the necessary connections, consisting of a lead-covered cable with its sheath connected to one side of a 110-volt lighting circuit. The conductor or conductors grounded at some point F are connected through a suitable resistance, such as five 110-volt, 16-c.-p. lamps in parallel, to the other side of the 110-volt lighting circuit; either direct or alternating current may be used. If a portion of the cable is water-soaked or the cable is injured so that one or more

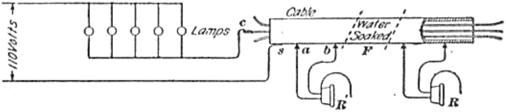

FIG. 38

conductors are more or less grounded on the lead sheath, then some current will pass from the conductors at the fault to the sheath, through which it returns to the office. If an ordinary head-telephone receiver wound to a very low resistance, about $\frac{1}{500}$ ohm, has its two terminals touched to two points a, b, as far apart as convenient on the lead sheath of the cable and at any place between the exchange and the point F, a noticeable click will be heard in the receiver, due to a part of the current passing through it. If the same connection is made beyond the point F, no sound whatever will be heard in the receiver. The points a, b should be kept the same distance apart for all comparative tests. In this way, the most inexperienced lineman is said to be able to locate within a few inches such a ground in a cable. A similar test may be made with a millivoltmeter, the terminals of which are touched to the lead sheath a few feet apart. On the home end of the fault, the deflection will always be in the same direction; beyond the fault, there will be no deflection.

Location of Ground by Voltmeter.—The distance to a ground on a line can be determined only approximately by means of a voltmeter, and then only when the resistance at the ground is negligible compared with the resistance of the bad wire from the testing end to the ground. To estimate the distance to the ground, connect the voltmeter across the terminals of a suitable battery and call the reading d. Then connect the same battery and voltmeter in series with the line to be tested and the ground, thus forming a circuit through the battery, voltmeter, line, and ground. Let the voltmeter reading be d'. Then, if r is the resistance of the voltmeter, the resistance of the circuit is

$$R=r\left(\frac{d}{d'}-1\right) \qquad (1)$$

This is the same formula used in determining the insulation resistance of a line. Since the line is grounded at some point, R is only larger than r by the resistance of the line, earth return, and ground contacts. Hence, the resistance x to the ground is $R-r$ and is given by the formula

$$x=r\left(\frac{d}{d'}-2\right) \qquad (2)$$

Locating a Bad Escape.—A method of locating a *bad escape* on a telegraph or telephone line wire is to insert, at the testing office, between the line and the ground, a voltmeter and a battery in series. Then have the intermediate offices open the line wire in turn, beginning at an office beyond the escape. A voltmeter needle will indicate the amount of escape until the first office between the escape and the testing office opens the wire, then the needle will show practically no deflection if the insulation of the line is in proper condition.

LOCATING CROSSES

Where the two crossed wires run parallel and have the same resistance per mile, it is a rather simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered. As a rule, the loop methods given for locating grounds can also be employed for locating crosses, in which case one of the crossed wires is used instead of the ground.

RESISTANCE AT CROSS NEGLIGIBLE

To Determine the Resistance of Cross.—It is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines with a Wheatstone bridge, as shown in Fig. 39, so as to measure the resistance from *B* to *D* through the cross *F*; call this *a*. Then, $x+y=a$.

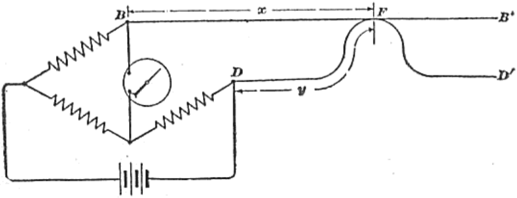

FIG. 39

Now have the wires connected together at the nearest station beyond the cross and again measure the resistance; call this b. If b is only a little less than a, the resistance of the cross is probably negligible, but not necessarily perfectly so; for if the cross is near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible.

Cross Between Two Wires of Same Size and Material.—If the resistance of the cross is negligible, and if the two wires are of the same size and material and run along parallel the whole distance from the testing station to the cross, the distance x to the fault, in miles, is given by the following formula:

$$x=\frac{a}{2s}$$

in which s is the resistance per mile along one wire, and a, the resistance of the loop through the cross.

Resistance of Two Line Wires per Unit Length Not Equal. If the wires are still parallel with each other, but the resistance of one is w ohms per mile and of the other v ohms per mile, the formula just given becomes

$$x=\frac{a}{w+v}$$

RESISTANCE OF CROSS NOT NEGLIGIBLE BUT CONSTANT

Where the resistance of the cross is constant, but not negligible, either the Varley or the Murray loop method explained for locating grounds may be used; in this case, one of the crossed wires is used instead of the ground.

Method Requiring Three Measurements.—First, measure the resistance of the line as connected in Fig. 40. Let this resistance be a ohms; hence,

$$x+u=a$$

Then, measure the resistance of the loop from B to D through the cross whose resistance will be called z ohms, with the distant ends of the two crossed wires open. Let the resistance so measured be b; hence,

$$x+z+y=b$$

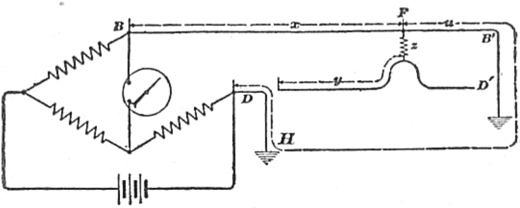

FIG. 40

Finally, measure the resistance through y, z, and u, as connected in Fig. 41. Let this resistance be c; hence,

$$y+z+u=c$$

Then, the resistance along BB' to the cross is

$$x=\frac{a+b-c}{2}$$

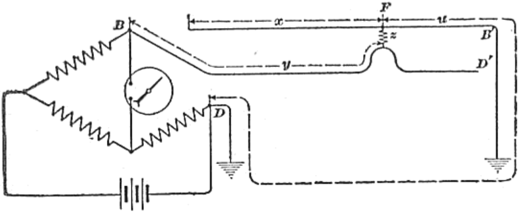

FIG. 41

It will be noticed that the resistance of the cross z is eliminated, so that if z remains constant during the second and third measurements, the formula is accurate and independent of the value of z. This method has the disadvantage of requiring three measurements, during two of which the resistance of the fault is supposed to remain constant.

RESISTANCE OF CROSS NEITHER NEGLIGIBLE NOR CONSTANT

A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. First, connect up as shown in Fig. 40, and measure the resistance of the line *BB′*, including the ground return path. Let this be a; hence,

$$x+u=a$$

Then, connect the bridges as shown in Fig. 42, using only two arms p and n of the bridge. The resistance of the cross z and that portion y of the line *DD′* is included in the galvanometer circuit, and, therefore, this resistance z and y will not enter into the result; also, the final formula is entirely independent of the resistance of the cross whether it is constant or not. After adjusting the bridge until there is no deflection,

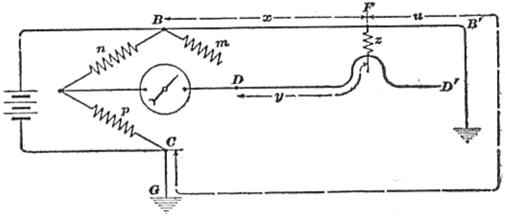

FIG. 42

$$nu=px$$

Solving these equations for x, the following formula for the resistance along the wire *BB′* to the cross is obtained:

$$x=\frac{na}{p+n} \qquad (1)$$

Finally, by dividing x by the resistance of the line *BB′* per mile, the distance in miles from *B* to the cross *F* is obtained.

If more convenient to do so, the end *B* of the wire may be joined to the end of the arm m. In this case, x in the second equation must be changed to $m+x$, which results in the following formula:

$$x=\frac{na-pm}{p+n} \qquad (2)$$

Slide-Wire Bridge Method.—To locate a cross between two wires of equal size by means of a slide-wire bridge, connect as shown in Fig. 43. A good wire, which is necessary in addition to the two crossed wires, is connected to either of the crossed wires at some point beyond the cross. The home end of the crossed wire, to which the good wire is connected, is joined to the bridge at *g*; and one terminal of the galvanometer is connected to the other crossed wire, which must be open at the distant end. Then, find a point *n* on the slide wire that produces no deflection of the galvanometer. Then, the

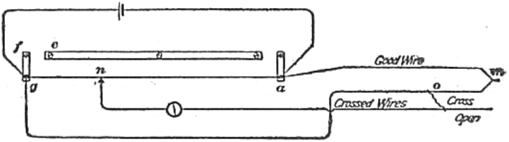

FIG. 43

$$\text{distance } go = \text{distance } goma \times \frac{\text{length } gn}{\text{length } ga}$$

For the distance *goma*, twice the length of one line wire or twice the length of a cable being tested may be used. This result is independent of the resistance of the fault, even if it varies during the test. This is practically the Murray loop test made with a slide-wire bridge.

One Wire in Use.—The method about to be described may be used to determine the resistance of one wire or the distance to a cross between that wire and another wire while the latter is in regular use as a telegraph line. The result is not, however, independent of the resistance of the cross. By this method, low-resistance crosses and grounds may be located, and if a balance can be secured while the fault exists, swinging crosses and grounds may be approximately located.

The connections for this test are shown in Fig. 44, in which *BC* represents a slide-wire bridge; *R*, a known resistance; *G*, a sensitive galvanometer with its usual shunt *r* and short-circuiting key *k*; *CFg'*, the wire in use; and *HF*, the line wire, which is crossed at *F* with the other line wire and is open beyond the cross.

To make the test, set the slide about midway along the slide wire *BC*, short-circuit or remove all the resistance at *R*, open the galvanometer short-circuit key *k*, and adjust the position of *A* along the slide wire until the galvanometer returns to its normal position of rest. The telegraph relays may be in service all the time the test is made, although the test is more readily made with this relay circuit permanently closed. Remove or open the galvanometer shunt, adjust the position of *A* until the galvanometer gives no deflection, and note the lengths *m* and *n*. Then, insert the resistance *R* between *B* and the crossed wire *HF*, move the pointer *A* until the bridge is balanced again, and note the lengths *m'* and *n'*. The resistance *x* of the working wire from *C* to the cross *F* may then be calculated by the formula

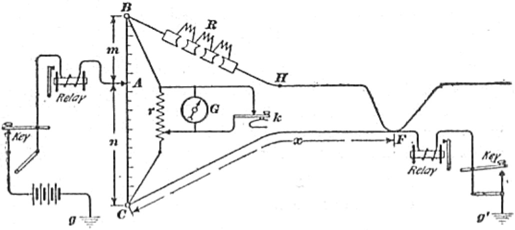

FIG. 44

$$x = \frac{n \times n' \times R}{(m' - m)(m + n)}$$

$m + n$ is the total length of the slide wire and is usually 1,000 or 100. The resistance used at *R* should be enough to make the two points of balance quite different. The greater the resistance of *CF*, that is, the greater the distance to the cross, the greater must be *R*.

ROUGH TESTS

It is frequently necessary to make *rough tests* to show whether circuits are continuous or broken, whether crossed, grounded, or properly insulated. These tests do not require accurate measurements, as they are made merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

TESTS WITH MAGNETO-GENERATOR AND BELL

Magneto Testing Set.—A very common and useful testing instrument consists of a magneto-generator and polarized ringer, together with a simple telephone, all mounted compactly in a box provided with a strap for convenience in carrying. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt.

Continuity Tests.—In testing wires for continuity, the terminals of the magneto-set should be connected to the terminals of the wire and the generator operated, the switch, if one is provided on the testing set, being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be relied on with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current to flow through the bell to operate it, even though the line or lines are open at some distant point.

Testing for Crosses.—In testing a line for crosses, one terminal of the magneto-set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto-set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. Under these conditions, a ringing of the bell will indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross. As in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists, if the line under test is very long. The insulation may be perfect and yet a sufficient current may pass to and from the line, due to its static capacity, and through the bell to cause it to ring.

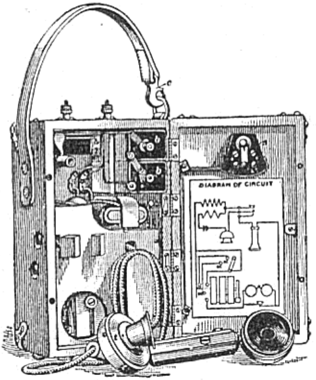

Fig. 45

Telephone Testing Set.—In many forms of testing sets, microphone transmitters and batteries for operating them are also included. A portable telephone testing set, shown in Fig. 45, contains a standard three- or four-bar generator, a 1,000-ohm bell, and other telephone devices. The receiver and transmitter are secured to one handle, the granular-carbon transmitter *t* being provided with a metal mouthpiece that prevents the breaking of the same. In the handle of the *microtelephone*, as it is termed, is a push button that, when closed, connects the batteries *b*, *b* in the transmitter circuit. This prevents the exhaustion of the batteries when not actually in use for talking purposes. The door of the testing set may be closed when the microtelephone is outside. When the full voltage of the generator is desired for ringing on a line, the bell can be cut out of the circuit by means of a push button. The generator is provided with collecting devices by means of which either alternating or direct pulsating currents may be obtained; a switch *s* through which the desired current may be obtained is placed on the inside of the cover, where a diagram of the wiring of the set is shown.

TESTS WITH VOLTMETER OR CURRENT-DETECTOR GALVANOMETER

In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto-set, a cheap galvanometer for detecting currents, a voltmeter, or millivoltmeter may be used. In testing for grounds or crosses, the voltmeter or galvanometer should be connected in series with several cells of battery, and one terminal of this circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the needle may take place whenever the circuit is first closed, due to the rush of current that is necessary to charge the wire. If the insulation is good, the needle will soon return to zero; but if a leak exists from a line to ground or to the other wire with which it is being tested, the needle will remain permanently deflected. Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about fifty cells is used, but if a very high insulation resistance must be measured with more accuracy, more sensitive methods should be employed.

In testing for continuity, the distant end of the line should be grounded and the voltmeter, or galvanometer, and battery applied between the wire under test and ground or the distant end of the line should be connected with another wire, known to be good, and the voltmeter, or galvanometer, and battery applied between the wire under test and the good wire. In this case, a permanent deflection of the needle will denote that the wire is continuous; while if the needle returns to zero, it is an indication of a broken wire. If the needle is very unsteady, there is probably a loose connection somewhere.

TESTS WITH TELEPHONE RECEIVER

A good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than a magneto testing set or a detector galvanometer. The ordinary watch-case receiver with a head-band for attaching it to the ear of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminal may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

Tests for Grounds and Crosses With a Receiver.—In using the receiver for making rough tests for grounds or crosses on conductors in a lead-covered cable, one terminal of the testing circuit, including the receiver and battery, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at both ends. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must be carefully separated from each other and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire, even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire; but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, hold the terminal of the testing set against the wire several seconds, and then break and quickly remake the connection. If no sound is heard at the instant the connection is again made, the insulation is good, while a continuance of the clicks each time the circuit is remade will indicate that the wire is grounded. The loudness of the click depends on the sensitiveness of the telephone used, the number and voltage of the cells used, the electrostatic capacity of the conductor, the resistance of the insulation, and the interval of time between the break and make. Under ordinary conditions, with a telephone cable from 1,000 ft. to a few miles in length, 1 sec. between a break and the next make, and a battery of 1 volt, no click usually means at least 50 megohms resistance between the conductor and the ground. This number increases about in proportion to the increase in electromotive force used.

Tests for Continuity With a Receiver.—In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires in succession at the near end of the cable, all the wires at this end being carefully separated from each other. In this case, a continuation of the clicks, on tapping, will indicate that the wire being tested is continuous, while the cessation, after a few taps, will indicate that it is broken. It is probably better in making this test, to use an ordinary vibrating bell or buzzer instead of a receiver, for then, if the wire is ruptured in such a manner as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it might allow enough to pass to produce a decided click in the receiver.

When the conductors in a cable are to be tested and their ends numbered and connected to terminals, the first thing to do is to test out a pair that may be used for communication during the rest of the test. A common method of locating this talking pair is to have the man at the distant end *M*, Fig. 46 (*a*), connect his head-receiver between one conductor and the lead sheath, all conductors at that end being preferably fanned out and at least insulated from the conductor that is being tested. The man at the office end *O* then connects one terminal of his head-receiver to the sheath, and the other terminal to two or three dry cells *B*, while with the free end *d* he taps all the conductor terminals, one at a time, until both men get a decided click in their receivers, which indicates to them that the wire to which the pole man *M* has his receiver connected has been found by the office man *O*.

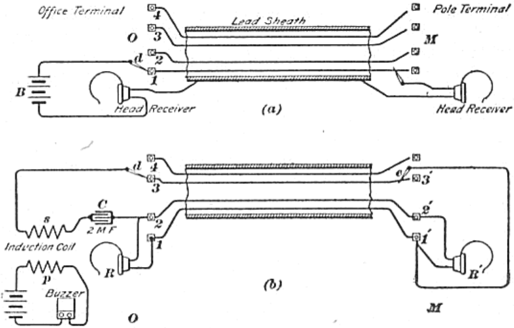

FIG. 46

The other wire *2* of this pair can be readily found, and, if necessary, tested in a similar manner.

The connections shown at both ends of Fig. 46 (*b*) are then made, and the pair *1–2* used to talk over. The pole man *M* then connects his terminal *e* to any wire whose location and number he desires, and the office man *O* feels for this wire by touching, with *d*, all his terminals until a loud hum indicates to both of them that the desired wire has been picked up by the office man *O*. The buzzer makes and breaks the circuit containing the primary winding *p* of an induction coil, thereby inducing an alternating electromotive force in the secondary winding *s*. This may, at all times, produce a slight hum in the receivers, due to the slight charging and discharging of the 2-microfarads condenser *C*, but the hum will be very much louder when the circuit of *s* is completed through a conductor.

The office man *O* then removes his needle *d* from the conductor just found and tells the pole man *M* its number, so that the latter can connect it to the terminal of the same number at his end. Should the loud hum be also obtained if the office man *O* touches his needle to *4* while the pole man *M* keeps his needle against *3′*, conductors *3* and *4* are probably crossed; and if the loud hum should be obtained if the office man *O* touches the sheath, the conductor touching *e* is probably grounded. In this way, each conductor may be tested for a cross or ground. When testing cables while in use on central-energy systems, the source of current should be at the office end in any case. As the charging and discharging of an open cable line, especially a long one, may cause a click or hum in a receiver, many prefer to use a buzzer instead of a receiver for such tests.

WIRE CHIEF'S TESTING CIRCUIT FOR A MAGNETO-EXCHANGE

A wire chief's testing circuit suitable for use in medium-sized magneto exchanges is shown in Fig. 47. Jacks *1* to *11* may be mounted in a position to suit the testing apparatus. Jacks *1* and *4* connect to the line side and jacks *2* and *3* to the switchboard side of the test clip adapted to fit in the arrester springs at the terminal rack. Any circuit can thus be tested toward the switchboard or line. To jacks *5*, *6*, and *7* are connected two batteries of any suitable voltage, and by means of the resistance *r* the strength of the current may be regulated, provided jack *7* is used. Jack *8* is connected to a good ground. Jacks *9* and *10* are connected to a two-conductor plug at the switchboard, where it may be inserted in any line to be tested from that point for grounds, crosses, short-circuits, etc. Jack *11* and its drop are connected with a jack and drop at the switchboard, so that inspectors may be connected to the wire chief when they call up the exchange from any subscriber's station. The wire chief may also ring up

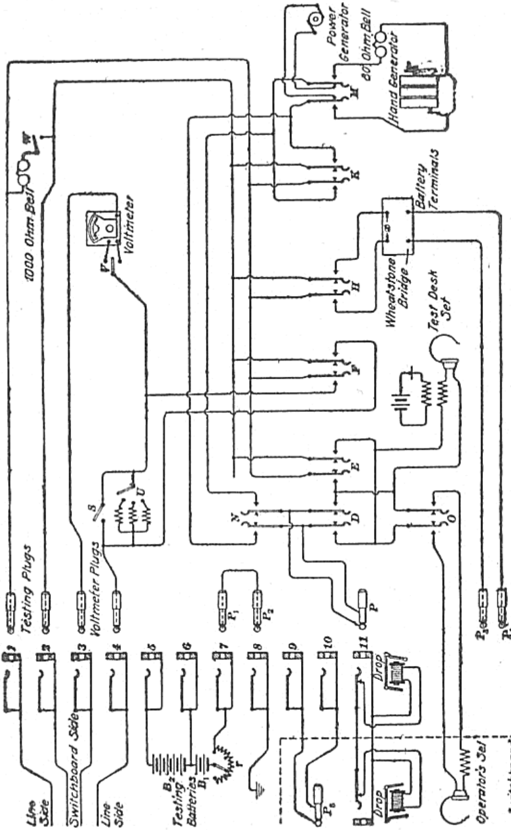
Line Side
Switchboard Side
Line Side
Testing Batteries
B_2
B_1
r
1
2
3
4
5
6
7
8
9
10
11
Drop
Drop
P_5
Operator's Set
Switchboard
Testing Plugs
Voltmeter Plugs
P_1
P_2
P
P_3
P_4
S
U
N
D
O
E
F
H
K
M
V
Voltmeter
1000 Ohm Bell
W
Power Generator
80 Ohm Bell
Hand Generator
Battery Terminals
Wheatstone Bridge
Test Desk Set

FIG. 47

the operator over the same circuit by inserting the plug P in jack *11* and closing key N.

The testing plugs are connected to a number of keys that are normally open. If it is desired to test a subscriber's instrument, the testing plugs may be inserted in jacks *1* and *4* or in *9* and *10*. Then, closing K should ring the subscriber's bell with current from the power generator; if it is desired to use a hand generator and an ordinary 80-ohm bell, close key M in addition to key K. A cross or open circuit in local apparatus or on short lines, where the electrostatic capacity is not large, may be determined by using the hand generator and bell. By closing switch W, the ability of a subscriber's generator to ring a 1,000-ohm, or other suitable bell, may be tested. By closing the key H, the Wheatstone bridge may be connected to the testing plugs for a resistance or loop test on any line or either side of any line. The battery terminals of the bridge are connected to plugs so that the testing battery terminating at jacks *5*, *6*, and *7* may be used to facilitate the making of loop tests. To measure the loop resistance through the two sides of a crossed or grounded line, insert, for instance, the testing plugs in jacks *1* and *4*, close key H, and insert plugs P_3 and P_4 in jacks *6* and *7*. To obtain the second balance, which requires one side of battery to be grounded, remove the proper plug P_3 or P_4 from jack *6* or *7*, and ground that side of the battery by connecting jack *6* or *7* to jack *8* with the plugs P_1 and P_2. Where the testing set has its own battery, it will simply be necessary to have one side of its own battery connected to one plug for insertion in the grounded jack *8* for the second balance. If the ground seems to be on the wrong side of the line, reverse the position of the test plugs in the jacks. A voltmeter will readily determine which side of the line is grounded. These connections are very convenient for making loop tests.

To test for insulation resistance or crosses with the voltmeter, insert the voltmeter plugs in the jacks of the testing battery—one of the testing plugs in the jack of the line to be tested, and the other testing plug in jack *8*, and close key F. Switch V allows either scale of the voltmeter to be used, switch *S* allows the voltmeter to be connected directly across the testing battery, and switch *U* enables readings of the voltmeter to be taken across any one of three known resistances. This is convenient for estimating the resistance, by voltmeter readings, to a ground or cross, for with the same battery the reading of the voltmeter will be inversely proportional to the total resistance of the circuit. Closing key *E* connects the test-desk set across the testing plugs; closing *D* connects it across the calling plug *F*, which may be used to call up an operator or to converse with an inspector. Closing key *O* connects the test-desk set through an order wire to a switchboard operator's set. *O*, *D*, *E*, *F*, *H*, and *M* should be keys, or cams, that will remain in either position, but keys *K* and *N* should return to their normal positions, as indicated in the figure, when released.

WIRE CHIEF'S TESTING CIRCUIT FOR A CENTRAL-ENERGY EXCHANGE

In Fig. 48 are shown the circuits of a wire chief's testing table used in connection with a central-energy exchange. With this arrangement, the wire chief may make tests with a voltmeter or a Wheatstone bridge and ring or talk over a line metallic or from either side to ground. By using a four-point plug or test clip suitable for insertion in the terminal head where the heat coils are located, tests can be made on a circuit either out on the line or through the exchange. The wire chief's telephone may be used independent of the test circuits as an ordinary instrument. The generator has an 80-ohm ringer in series with it, so as to obtain the same results as when testing with a magneto. An extra key could be readily connected so that either a power or hand generator could be used.

The operation of the set is as follows: After inserting the test plug between heat-coil springs on the cable terminal, key *5* is thrown. This puts the voltmeter *VM* and test battery across the line. To test one side to ground, key *6* is thrown; and by throwing both keys *6* and *7* the other side is tested to ground. To listen on the line, key *3* is thrown. This cuts out the voltmeter, and if it is desired to talk,

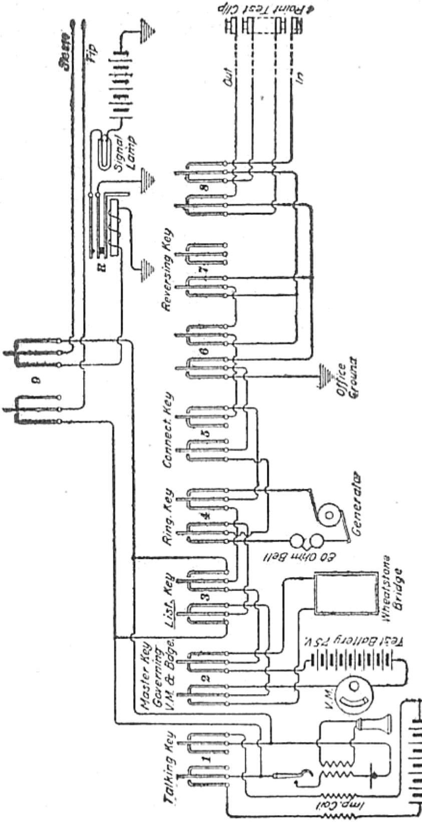
Sleeve
Tip
Signal Lamp
4 Point Test Clip
Out
In
R
8
Reversing Key
7
6
Office Ground
Connect Key
5
9
Ring Key
4
Generator
60 Ohm Bell
List. Key
3
Wheatstone Bridge
Test Battery 75 V.
Master Key Governing V.M. & Bdge.
2
V.M.
Talking Key
1
Imp. Coil
Storage Batt. 40 V.

FIG. 48

close key *1*, which supplies both wire chief's and subscriber's telephone with battery. Ringing is done with key *4*. Key *2* places the Wheatstone bridge in circuit instead of the voltmeter and battery, and by using key *8*, the wire chief can talk, ring, or test back toward the exchange.

The test telephone may be used as a regular instrument by throwing key *9*. This places the wire chief's telephone across a line running to the switchboard, and the operator receives a signal in the same manner as from a subscriber. An operator may signal the wire chief by inserting a plug in the jack corresponding to this telephone number. In doing this, the positive battery is put on the sleeve of the jack, which connects with the relay *R* controlling the signal lamp on the testing table. When the wire chief answers by throwing key *9*, the relay circuit is opened, putting out the lamp. It is not necessary to use key *1* in talking through the switchboard.