Electrical Measurements

Measurement of Resistance

Classification:

The classification of resistances from the point of view of measurement is as follows:

(i) Low Resistance: All resistances of the order of 1Ω and under may be classified as low resistance.
(ii) Medium Resistance: This class includes resistances from 1Ω upwards to about 0.1MΩ.
(iii) High Resistance: Resistances of the order of 0.1MΩ and upwards are classified as high resistances.

The classification outlined above is not rigid, but forms a basis for techniques, followed or measurement, which may be different for different classes.

Measurement of Medium Resistances:

The different methods used for measurement of medium resistances are:

(i) Ammeter-Voltmeter method;
(ii) Substitution method;
(iii) Wheatstone Bridge method;
(iv) Ohmmeter method.

(i) Ammeter-Voltmeter method:

This method is very popular since the instruments required for this test are usually available in the laboratory. There are two types of connections employed. In both cases if readings of ammeter and voltmeter are taken then the measured value of resistance is given by

$R_m = \frac{Voltmeter\ reading}{Ammeter\ reading} = \frac{V}{I}$ …………………(1)

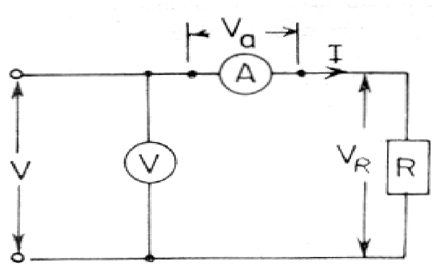


Fig.1.

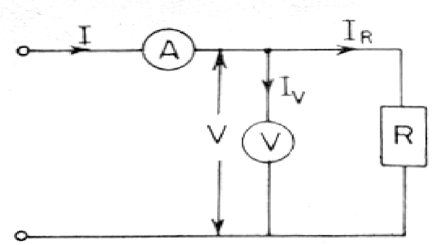


Fig.2.

The measured value of resistance R_m would be equal to the true value R, if the ammeter resistance is zero and the voltmeter resistance is infinite, so that the conditions in the circuit are not disturbed. However in practice this is not possible and hence both the methods give in accurate results.

Consider circuit Fig.1 the ammeter measures the true value of the current through the resistance but the voltmeter does not measure the true voltage across the resistance. The voltmeter indicates the sum of the voltages across the ammeter and the measured resistance.

Let R_a be the resistance of the ammeter

∴ Voltage across the ammeter, $V_a = IR_a$

Now measured value of resistance,

$R_{m1} = \frac{V}{I} = \frac{V_R + V_a}{I} = \frac{IR + IR_a}{I} = R + R_a$ ……………….……..(2)

∴ True value of resistance,

$R = R_{m1} - R_a = R_{m1}\left(1 - \frac{R_a}{R_{m1}}\right)$ ………………….….….(3)

Thus the measured value of resistance is higher than the true value. It is also clear from above that the true value is equal to the measured value only if the ammeter resistance, R_a is zero.

∴ Relative error, $\varepsilon_r = \frac{R_{m1} - R}{R} = \frac{R_a}{R}$ ……………………(4)

It is clear from equation (4) that the error in measurements would be small if the value of resistance under measurement is large as compared to the internal resistance of the ammeter. Therefore this circuit should be used when measuring high resistance values.

In fig.2 the voltmeter measures the true value of voltage but the ammeter measures the sum of currents through the resistance and the voltmeter.

Let R_V be the resistance of the voltmeter.

∴ Current through the voltmeter, $I_V = \frac{V}{R_V}$

Measured value of resistance,

$R_{m2} = \frac{V}{I} = \frac{V}{I_R + I_V} = \frac{V}{\frac{V}{R} + \frac{V}{R_V}} = \frac{R}{1 + \frac{R}{R_V}}$

∴ True value of resistance,

$R = \frac{R_{m2} R_V}{R_V - R_{m2}} = R_{m2} \frac{1}{\left(1 - \frac{R_{m2}}{R_V}\right)}$ ……………(5)

From equation (5) it is clear that the true value of resistance is equal to the measured value if the resistance of voltmeter, R_V is infinite. However, if the resistance of voltmeter is very large as compared to the resistance under measurement:

i.e. $R_V \gg R_{m2}$ and therefore $\frac{R_{m2}}{R_V}$ is very small

We have: $R = R_{m2}\left(1 + \frac{R_{m2}}{R_V}\right)$ ……………..(6)

Thus the measured value of resistance is smaller than the true value.

∴ Relative error, $\varepsilon_r = \frac{R_{m2} - R}{R} = \frac{{R_{m2}}^2}{R_V R}$ …………(7)

The value of R_{m2} is approximately equal to R.

$$\therefore \varepsilon_r = -\frac{R}{R_V} \quad \ldots\ldots\ldots\ldots\ldots(8)$$

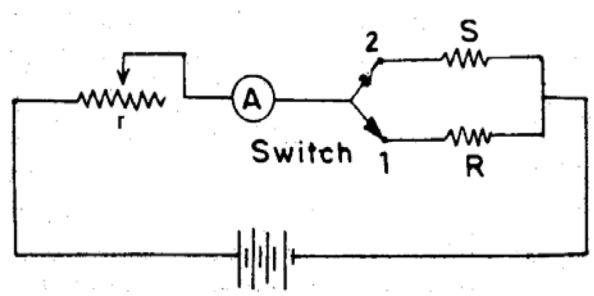
It is clear from equation (8) that the error in measurement would be small if the value of resistance under measurement is very small as compared to the resistance of the voltmeter. Hence the circuit of fig.2 should be used when measuring low resistance values.

The relative errors for the two cases are equal when:

$$\frac{R_a}{R} = \frac{R}{R_V}$$

i.e. $R = \sqrt{R_a R_V}$

(ii) <u>Substitution Method:</u>



The connection diagram for this method is shown in above figure. R is unknown resistance while S is a standard variable resistance. 'A' is an ammeter and 'r' is a regulating resistance. There is a switch for putting R and S into the circuit alternately.

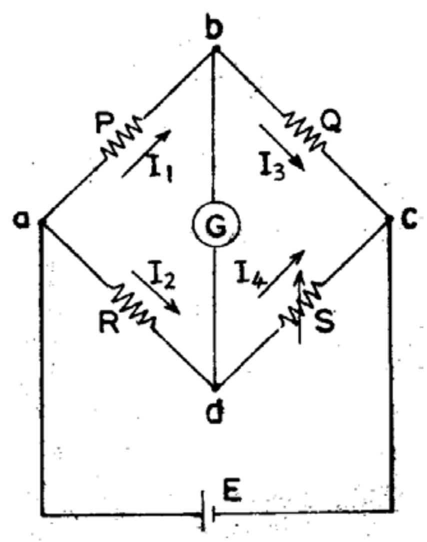
The switch is put at position '1' and resistance R is connected in the circuit. The regulating resistance r is adjusted till the ammeter pointer is at a chosen scale mark. Now the switch is thrown to position '2' putting the standard variable resistance S in the circuit. The value of S is varied till the same deflection as was obtained with R in the circuit is obtained. The settings of the dials of S are read. Since the substitution of one resistance for another has left the current unaltered and provided that the emf of battery and position of r are unaltered, the two resistances must be equal to the dial settings of resistance S.

However the accuracy of this method is greatly affected if there is any change in the battery emf during the time readings on the two settings are taken. Thus in order to avoid errors on this account, a battery of ample capacity should be used so that its emf remains constant.

This method is not widely used for simple resistance measurements and is used in a modified from for the measurement of high resistances.

(iii) Wheatstone Bridge:

A very important device used in the measurement of medium resistances is the Wheatstone bridge. A Wheatstone bridge has been in use longer than almost any electrical measuring instrument. It is still an accurate and reliable instrument and is extensively used in industry. The Wheatstone bridge is an instrument for making comparison measurements and operates upon a null indication principle. This means the indication is independent of the calibration of the null indicating instrument or any of its characteristics. For this reason, very high degrees of accuracy can be achieved using Wheatstone bridge.



In the above figure shows the basic circuit of a wheatstone bridge. It has four arms, consisting of resistance P, Q, R, and S together with a source of emf and a null detector, usually a galvanometer depends on the potential difference between points c and d. The bridge is said to be balanced when there is no current through the galvanometer or when the potential difference across the galvanometer is zero. This occurs when the voltage from the point 'b' to point 'a' equals the voltage from point 'd' to point 'a' or by referring to the other battery terminal, when the voltage from point 'd' to point 'c' equals the voltage from point 'b' to point 'c'.

For bridge balance, we can write:

$$I_1P = I_2R \qquad \text{..................(1)}$$

For the galvanometer current to be zero, the following condition also exist:

$$I_1 = I_3 = \frac{E}{P+Q} \qquad \text{..................(2)}$$

$$I_2 = I_4 = \frac{E}{R+S} \qquad \text{..................(3)}$$

Where, E = emf of the battery

Combining equation (1), (2) & (3) and simplifying

$$\frac{P}{P+Q} = \frac{R}{R+S} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\frac{P}{Q} = \frac{R}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Equation (5) is the well known expression for the balance of Wheatstone bridge, where R is the unknown resistance, S is called the 'standard arm' of the bridge and P and Q are called the ratio arms.

Sensitivity of Bridge:

It is frequently desirable to know the galvanometer response to be expected in a bridge which is slightly unbalanced so that a current flows in the galvanometer branch of the bridge network. This may be used for:

i) Selecting a galvanometer with which a given unbalance may be observed in a specified bridge arrangement.
ii) Determining the minimum unbalance which can be observed with a given galvanometer in the specified bridge arrangement and
iii) Determining the deflection to be expected for a given unbalance.

The sensitivity to unbalance can be computed by solving the bridge circuit for a small unbalance. The solution is approached by converting the Wheatstone bridge to its 'Thevenin Equivalent' circuit.

Assume that the bridge is balanced when the branch resistances are P, Q, R and S. So that $\frac{P}{Q} = \frac{R}{S}$. Suppose the resistance R is changed to (R + ΔR) creating an unbalance. This will to cause an emf e to appear across the galvanometer branch. With galvanometer branch open, the voltage drop between points a and b is:

$$E_{ab} = I_1P = \frac{EP}{P+Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Similarly $$E_{ad} = I_2(R + \Delta R) = \frac{E(R + \Delta R)}{(R + \Delta R + S)} \quad \ldots\ldots\ldots(7)$$

Therefore voltage difference between points d and b is:

$$e = E_{ad} - E_{ab} = E\left[\frac{R + \Delta R}{R + \Delta R + S} - \frac{P}{P+Q}\right] \quad \ldots\ldots\ldots\ldots\ldots(8)$$

and since $\frac{P}{P+Q} = \frac{R}{R+S}$

$$\therefore e = E\left[\frac{R+\Delta R}{R+\Delta R+S} - \frac{R}{R+S}\right]$$

$$= \frac{ES\Delta R}{(R+S)^2 + \Delta R(R+S)}$$

$$= \frac{ES\Delta R}{(R+S)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

As $\Delta R(R+S) \ll (R+S)^2$

Let S_V be the voltage sensitivity of galvanometer. Therefore the deflection of galvanometer is,

$$\theta = S_V e = S_V \frac{ES\Delta R}{(R+S)^2} \quad \ldots\ldots\ldots\ldots(10)$$

The bridge sensitivity S_B is defined as the deflection of the galvanometer per unit fractional change in unknown resistance.

$$\therefore \text{Bridge sensitivity, } S_B = \frac{\theta}{\Delta R/R} = \frac{S_v ESR}{(R+S)^2} \quad \ldots\ldots\ldots\ldots(11)$$

From equation (11) it is clear that the sensitivity of the bridge is dependent upon bridge voltage, bridge parameter and the voltage sensitivity of the galvanometer.

Rearranging the terms in the expression for sensitivity,

$$S_B = \frac{S_v E}{(R+S)^2/SR} = \frac{S_v E}{\frac{R}{S} + 2 + \frac{S}{R}} = \frac{S_v E}{\frac{P}{Q} + 2 + \frac{Q}{P}} \quad \ldots\ldots\ldots\ldots\ldots(12)$$

From equation (12) it is apparent that maximum sensitivity occurs where $\frac{R}{S} = 1$. As the ratio becomes either larger or smaller, the sensitivity decreases. Since the accuracy of measurement is dependent upon sensitivity a limit can be seen to the usefulness for a given bridge, battery and galvanometer combination.

For a bridge with equal arms R = S = P = Q

$$\text{Bridge sensitivity, } S_B = \frac{S_v E}{4} \quad \ldots\ldots\ldots\ldots(13)$$

Thus the sensitivity decreases considerably if the ratio $\frac{P}{Q} = \frac{R}{S}$ is greater or smaller than unity. This reduction in sensitivity is accompanied by a reduction in accuracy with which a bridge can be balanced.

Limitations of Wheatstone bridge:

The use of Wheatstone bridge is limited to the measurement of resistances ranging from a few ohms to several megohm. The upper limit is set by the reduction in sensitivity to unbalance caused by high resistance values. The upper limit can be extended to a certain extent by increasing the emf applied to the bridge but in this case care has to be taken to avoid overheating of any arms of the bridge. In accuracy may also be introduced on account of leakage over insulation of the bridge arms when measuring very high resistances.

The lower limit for measuring is set by the resistance of the connecting leads and by contact resistance at the binding points. The error caused by leads may be corrected fairly well, but contact resistance presents a source of uncertainty that is difficult to overcome. The lower limit for accurate measurement is in the neighborhood of 1 to 5 ohm. For low resistance measurements, therefore a Kelvin bridge is generally preferred.

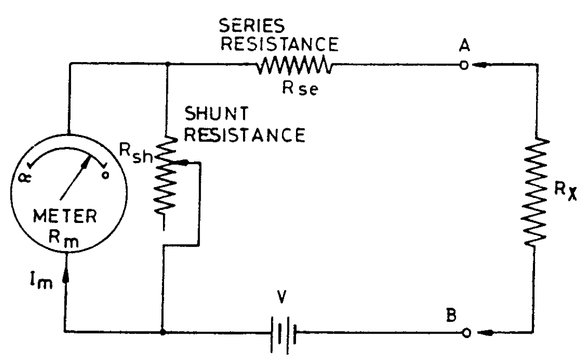
(iv) Ohm Meters:

The ohmmeter is direct reading device for the measurement of resistance. Through this method of measuring resistance is very simple, convenient and fast but its accuracy is rather of low degree. This instrument has a large field of application and it gives an approximate value by a direct meter reading with practically no adjustment required by the operator so its low accuracy does not have much importance.

An ohmmeter is widely employed for the approximate measurement and sorting of resistances used in electronic circuits, measurement of resistance of heater elements, field coils of motors etc. It is also for checking circuit continuity. In the precision measurement of resistance, it is used along with bridge circuit and saves the time in bridge balancing as an approximate value of the resistance under test is obtained first by an ohmmeter.

Series-Type Ohmmeter:

This instrument essentially consists of a sensitive dc instrument connected in series with a resistance and a battery to a pair of terminals to which the resistance under test is connected. So the indication of the instrument depends on the magnitude of current flowing through the meter which ultimately depends on the value of resistance under test, provided the instrument is properly calibrated.



Series Type Ohmmeter

When terminals A and B are shorted together and the value of shunt resistor R_{sh} is adjusted so that the instrument indicates the full scale reading on the scale then this position of the pointer corresponds to zero resistance. When terminals A and B are left open no current flows through the meter and it does not give any movement on the scale and this position of pointer corresponds to ∝ resistance.

If the battery V, series resistance R_{se} and shunt resistance R_{sh} are constant, then marking can be placed on the scale for the position of pointer corresponding to different values of R_x and the accuracy of the reading depends on the calibration process and accuracy of the instrument. Resistance R_{sh} is a variable resistor and is adjusted to counter act the effect of change in battery voltage due to use and age. Adjustment of series resistor, R_{se} can also bring the pointer to full scale deflection but this would change the calibration all along the scale and cause a large error. As the shunt resistance, R_{sh} and the resistance of the meter coil is very low, in comparison to series resistance R_{se} so change in resistance R_{sh} required for adjustment does not alter the calibration very much. This circuit does not compensate completely for ageing in the battery, but it does a reasonably good job within the expected limits of accuracy of the instrument.

A convenient quantity to use in the design of a series type ohmmeter is the value of R_x which causes half-full scale deflection of the instrument. At this position the resistance across terminals A and B is defined as the half scale position resistance, R_h. If full scale deflection current of the meter, I_{fm} and internal resistance of the meter, R_m, the battery voltage, V and the half scale resistance R_h are given then the circuit can be analysed and the value of R_{se} and R_{sh} can be determined.

The design can be approached by recognizing the fact that, if introduction of the resistance R_h reduces the full scale deflection current I_f to half, then value of R_h must be equal to the total resistance R_{se} in series with parallel combination of R_{sh} and R_m

So $$R_h = R_{se} + \frac{R_{sh}R_m}{R_{sh} + R_m}$$

So the total resistance presented to the battery equals to $2R_h$ and the battery current requied to supply the half-full scale deflection is I_h given by the expression

$$I_h = \frac{V}{2R_h}$$

For full scale deflection, the battery current will be doubled and will be given by the expression

$$I_f = 2I_h = \frac{V}{R_h}$$

The current through shunt resistance R_{sh}

$$I_{sh} = I_f - I_{fm}$$

But $\qquad I_{sh}R_{sh} = I_{fm}R_m$

or, $\qquad R_{sh} = \frac{I_{fm}R_m}{I_{sh}}$

Substituting $I_{sh} = I_f - I_{fm}$ in the above expression we have

$$R_{sh} = \frac{I_{fm}R_m}{I_f - I_{fm}}$$

or, $\qquad R_{sh} = \frac{I_{fm}R_m}{\frac{V}{R_h} - I_{fm}} = \frac{I_{fm}R_mR_h}{V - I_{fm}R_h}$

Again, $\qquad R_{se} = R_h - \frac{R_{sh}R_m}{R_{sh}+R_m}$

$$= R_h - \frac{\left(\frac{I_{fm}R_mR_h}{V - I_{fm}R_h}\right)R_m}{\left(\frac{I_{fm}R_mR_h}{V - I_{fm}R_h}\right) + R_m}$$

$$= R_h - \frac{I_{fm}{R_m}^2R_h}{I_{fm}R_mR_h + R_m(V - I_{fm}R_h)}$$

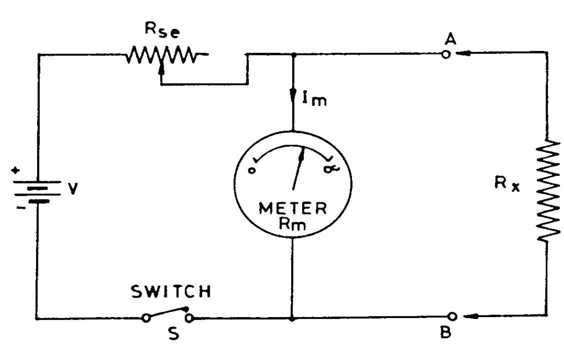
$$= R_h - \frac{I_{fm}R_mR_h}{I_{fm}R_h + V - I_{fm}R_h}$$

$$= R_h - \frac{I_{fm}R_mR_h}{V}$$

From the above expressions R_{se} and R_h can be computed in terms of I_{fm}, R_m, R_h and V.

Shunt Type Ohmmeter:

In this instrument a battery is connected in series with a D'Arsonval galvanometer and a adjustable resistor R_{se}. The resistance under test is connected across the terminals A and B in parallel to the meter. In this circuit it is necessary to provide a on-off switch in order to keep battery from running down when the instrument is not in use.



Shunt Type Ohmmeter

When terminals A and B are shorted i.e. when $R_x = 0$, the meter current is zero and if R_x is removed i.e. when $R_x = \propto$ the pointer rises on the scale and can be adjusted to the full scale point by proper selection of the resistor R_{se}. So this ohmmeter accordingly has zero mark at the left and $\propto$ mark at the scale which is just opposite to the series type ohmmeter.

The circuit may be analysed as follows:

With terminals A and B open-circuited, the current flowing through the meter

$$I_{fm} = \frac{V}{R_{se}+R_m}$$

With terminals A and B connected across resistance under test, R_x battery current,

$$I_B = \frac{V}{R_{se}+\frac{R_m R_x}{R_m+R_x}}$$

And the current flowing through the meter,

$$I_m = \frac{V}{R_{se}+\frac{R_m R_x}{R_m+R_x}} \cdot \frac{R_x}{R_m+R_x}$$

The meter current expressed as a fraction of the full scale deflection current,

$$S = \frac{I_m}{I_{fm}} = \frac{R_x(R_{se}+R_m)}{R_{se}(R_m+R_x)+R_m R_x}$$

$$S = \frac{R_x}{R_x+\frac{R_{se}R_m}{R_{se}+R_m}}$$

$$= \frac{R_x}{R_x+R_p} \text{ where } R_p = \frac{R_{se}R_m}{R_{se}+R_m}$$

From the above expression for S it is obvious that the half-way mark on the scale occurs when $R_x = R_p$. The distribution of scale marking is almost linear in the lower part i.e. for $R_x << R_p$ and it becomes progressively more crowded as R_x increases.

So half-full scale reading will be when

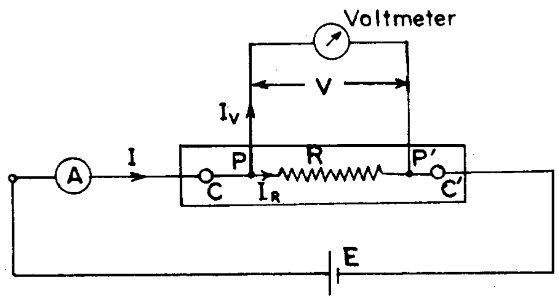
$$R_h = \frac{R_{se}R_m}{R_{se}+R_m}$$

This type of ohmmeter is particularly suited for the measurement of low value resistors.

Measurement of Low Resistance:

Errors owing to contact resistance, resistances of leads and lack of sensitivity render the Wheatstone bridge unsuitable for the measurement of low resistances. Further any method of low resistance measurement must provide for the four terminal connections which is usually used for resistors of low values.

For example a contact resistance of 0.002Ω causes a negligible error when a resistance of 100Ω is being measured but the same contact resistance would cause an error of 10% if a low resistance of the value of 0.02Ω is measured. Hence special types of construction and techniques have to be used for the measurement of low resistances in order to avoid serious errors occurring on account of the factors.



Low resistances are constructed with four terminals as shown in above figure. One pair of terminals cc' (called the current terminal) is used to lead current to and from the resistor. The voltage drop is measured between the other two terminals pp' called the potential terminals.

The voltage V; indicated in the above figure is thus I_R times the resistance R between terminals pp' and does not include any contact resistance drop that may be present at the current terminals cc'.

Resistors of low values are thus measured in terms of resistance between potential terminals which become perfectly and precisely definite in value and are independent of contact resistance drop at the current terminals. Contact resistance drop at the potential terminals need not be a source of error, as current crossing at these terminals is usually extremely small or even zero for null methods.

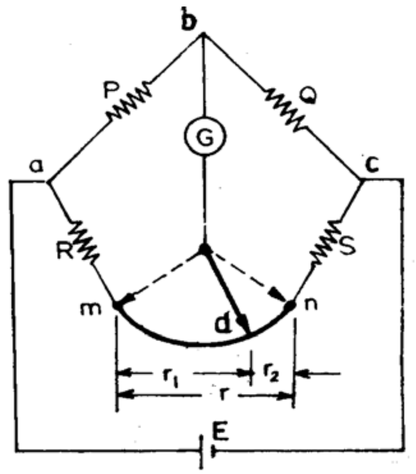
Also this contact resistance now becomes a part of the potential circuit and is therefore a negligible part of total resistance of the potential circuit since have a high value of resistance.

There are basically three methods for measurements of low resistance are:

i) Ammeter-Voltmeter method;
ii) Kelvin's Double bridge method;
iii) Potentiometer method.

Kelvin Double Bridge Method for Measurement of Low Resistances

The Kelvin Bridge is a modification of the Wheatstone bridge and provides greatly increased accuracy in measurement of low value resistances. An understanding of the Kelvin Bridge arrangement may be obtained by a study of the difficulties that arise in a Wheatstone bridge on account of the resistance of the leads and the contact resistances while measuring low valued resistances.



Consider the bridge circuit above where r represents the resistance of the lead that connects the unknown resistance R to standard resistance S. Two galvanometer connections indicated by dotted lines are possible. The connections may be either to point m or to point n. When the galvanometer is connected to point m the resistance r of the connecting leads is added to the standard resistance S, resulting in indication of too low an indication for unknown resistance R. When the connection is made to point n, the resistance r is added to the unknown resistance resulting in indication of too high a value for R.

Suppose that instead of using point m, which gives a low result or n, which makes the result high, we make the galvanometer connection to any intermediate point 'd' as shown by full line. If at point 'd' the resistance r is divided into two points r_1 and r_2. Such that

$$\frac{r_1}{r_2} = \frac{P}{Q} \text{ ....(1)}$$

Then the presence of r_1 the resistance of connecting leads, causes no error in the result. We have,

$R + r_1 = \frac{P}{Q}(S + r_2)$ But $\frac{r_1}{r_2} = \frac{P}{Q}$ ....(2)

or, $\frac{r_1}{r_1 + r_2} = \frac{P}{P+Q}$

or, $r_1 = \frac{P}{P+Q} r$ As $r_1 + r_2 = r$

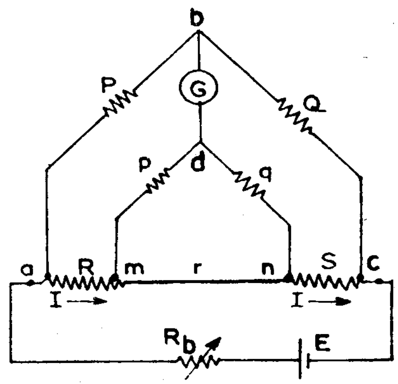
or, $r_2 = \frac{Q}{P+Q} r$

$\therefore \left(R + \frac{P}{P+Q} r\right) = \frac{P}{Q}\left(S + \frac{Q}{P+Q} r\right)$

or, $\frac{P}{Q} = \frac{R}{S}$

Therefore we conclude that making the galvanometer connection as at C, the resistance of leads does not affect the result.

The process described above is obviously not a practical way of achieving the desired result, as there would certainly be a trouble in determining the correct point for galvanometer connections. It does however suggest the simple modification that two actual resistance units of correct ratio to connect between point's m and n, the galvanometer be connected to the junction of the resistors. This is the actual Kelvin bridge arrangement.



The Kelvin double bridge incorporates the idea of a second set of ratio arms – hence the name double bridge – and the use of four terminal resistors for the low resistance arms. The first ratio arms are P and Q. The second set of ratio arms p and q is used to connect the galvanometer to a point d at the appropriate potential between point's m and n to eliminate the effect of connecting lead of resistance r between the known resistance, R and the standard resistance, S.

The ratio $\frac{p}{q}$ is made equal to $\frac{P}{Q}$. Under balance conditions there is no current through the galvanometer which means that the voltage drop between a and b, E_{ab} is equal to the voltage drop E_{amd} between a and d.

Now, $E_{ab} = \frac{P}{P+Q} E_{ac}$

& $E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$ …………………(4)

And $E_{amd} = I\left[R + \frac{p}{p+q}\left\{\frac{(p+q)r}{p+q+r}\right\}\right]$

$= I\left[R + \frac{pr}{p+q+r}\right]$ ……………….(5)

For zero galvanometer deflection $E_{ab} = E_{amd}$

or, $\frac{P}{P+Q}$ I $\left[R + \frac{p}{p+q}\left\{\frac{(p+q)r}{p+q+r}\right\}\right]$ = I $\left[R + \frac{pr}{p+q+r}\right]$

$$R = \frac{P}{Q} S + \frac{qr}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

If $\frac{P}{Q} = \frac{p}{q}$

$$\therefore \frac{P}{Q} = \frac{R}{S} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

The above equation is the usual working equation for the Kelvin bridge. It indicates that the resistance of connecting lead, r has no effect on the measurement provided that the two sets of ratio arms have equal ratios. Equation (6) is useful, however as it shows the errors that is introduced in case the ratios are not exactly equal. It indicates that it is desirable to keep r as small as possible in order to minimize the errors in case there is a difference between ratios $\frac{P}{Q}$ and $\frac{p}{q}$.

The effect of thermo-electric emfs can be eliminated by making another measurement with the battery connections reversed. The true value of R being the means of the two readings.

In a typical Kelvin bridge the range of resistance covered is 0.1μΩ to 1.0Ω. The accuracies are as under:

From 1000μΩ to 1.0Ω:	0.05%
From 100μΩ to 1000μΩ:	0.2% to 0.05%
From 10μΩ to 100μΩ:	0.5% to 0.2% limited by thermo emf.

In this bridge there are four internal resistance standards of 1Ω, 0.1Ω, 0.01Ω and 0.001Ω respectively.

Measurement of High Resistances:

As already mentioned the resistance exceeding 100KΩ are termed as high resistance.

The methods of measurement of resistances already described are not suitable for high resistance measurements as in such measurements the resistance offered to the flow of current along the surface of insulation is comparable to the resistance to be measured.

Measurement of high resistance is involved in determination of:

i) Insulation resistance of cables and built up electrical equipment of all types;
ii) Resistance of high resistance circuit elements;
iii) Volume resistivity of a material;
iv) Surface resistivity.

Difficulties in Measurement of High Resistances:

High accuracy is rarely required in such measurements hence simple circuits are used. Since the resistances under measurement have high values, very small currents are encountered in the measurement circuits. This aspect leads to several difficulties:

i) The insulation resistance of the resistor may be comparable with the actual value of the resistor. Thus leakage currents are produced. These leakage currents are comparable magnitude to the current being measured and must be eliminated from the measurement. Leakage currents no doubt introduce errors, but they generally vary from day to day, depending upon the humidity conditions and therefore cause additional unpredictable complications

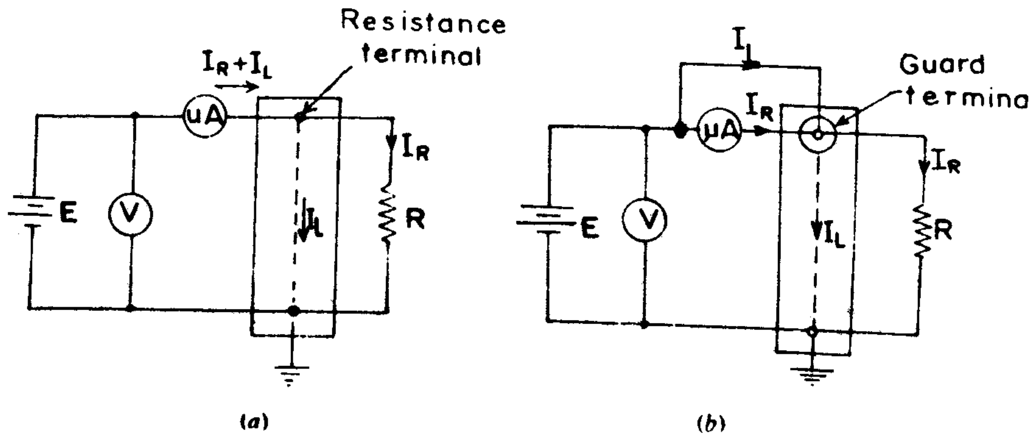
ii) Due to electrostatic effect, stray changes can appear in the measuring circuit causing errors. Alternating fields can also effect the measurements considerably. Therefore critical points of the measuring circuit must be carefully screened.

iii) In order to obtain definite ratios in the potential distribution with respect to surroundings, one point of the circuit may be connected to earth for accuracy in measurements.

iv) In measurement of insulation resistance the specimen often has considerable capacitance. On application of a direct voltage a large charging current flows initially which gradually decays down after a short interval. Further, insulating materials possess the property of dielectric absorption i.e. after the main charging current has decayed down, further charge is slowly absorbed over a considerable period of time, perhaps for minutes or even hours. Thus measurement of the true conduction current should be delayed until after the cessation of the charging and absorbing currents. But since the absorbing currents take a considerably long time to decay, it is usually inevitable that the conduction current measured includes some absorption in current. The testing conditions, including the time between the application of voltage and observation of the current, must be specified.

v) When measuring the resistance of low conductivity conductors, insulating materials and products, the effect of various factors upon their resistance should be taken into account. Thus a change in the temperature of cardboard from 20^0 to 40^0 is accompanied by a 13 fold change in its resistance, changes in humidity from 10% to 60% cause a 30 fold change in resistance of porcelain. Besides temperature and humidity, the kind of current employed for measurement the magnitude and duration of the applied voltage and other factors also effect the resistance being measured.

vi) Fairly high voltages are used in tests in order to raise the currents to reasonable values in order to be measured. So normally a sensitive galvanometer or micro-ammeter is required and adequate steps have to be taken to prevent damage to these delicate instruments.



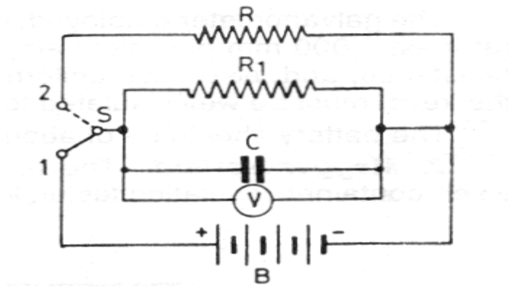
Application of guard circuit for measurement of high resistance.

Some form of guard circuits are generally used to eliminate the errors caused by leakage currents over insulation. In the figure (a) a high resistance mounted on a piece of insulating material is measured by the ammeter-voltmeter method. The micro-ammeter measures the sum of the current through the resistor (I_R) and the current through the leakage path around the resistor (I_L). The measured value of resistance computed from the readings indicated on the voltmeter and the micro-meter, will not be true value but will be error. In figure (b) guard terminal has been added to resistance terminal block. The guard terminal surrounds the resistance terminal entirely and is connected to the battery side of the micro-ammeter. The leakage current I_L now by pass the micro-ammeter which then indicates the current I_R through the resistor and thus allows the correct determination of the resistance value from the readings of voltmeter and micro-ammeter. The guard terminal and resistance terminal are almost at the same potential and thus there will be no flow of current between them.

Among the above high resistance measurements the measurement of insulation resistance of cable is of practical importance and will be measure in the following methods:

I) Loss of charge method;
II) Price’s Guard-wire method;
III) Megger Method.

Loss of Charge Method:



In the circuit C is a capacitor of known capacitance, V is electro static voltmeter, R_1 is the total leakage resistance of the capacitor and voltmeter and R is the resistance to be measured.

In this method the capacitor is first charged by means of a battery to some suitable voltage by putting switch S on stud 1 and then allowed to discharge through the resistances R and R_1 by throwing switch S to stud 2. The time taken t for the potential difference to fall from V_1 to V_2 during discharge is observed by a stop watch.

Let the equivalent resistance of R_1 and R connected in parallel be R'.

If at any instant (say time t) the voltage across the discharging capacitor is V volts; the charge on the discharging capacitor is q coulombs and the capacity of the capacitor is C farads then current I at this instant is given by the expression

$$i = -\frac{dq}{dt} = -C\frac{dv}{dt}$$

And also $i = \frac{Potential\ drop\ across\ R'}{R'} = \frac{V}{R'}$

Comparing two expressions for instantaneous current through the circuit we have

$$\frac{V}{R'} = -C\frac{dv}{dt}$$

$$\text{or, } \frac{dV}{V} = -\frac{dt}{CR'}$$

Integrating both sides for limits of V from V_1 to V_2 and for time from 0 to t we have

$$\int_{V_1}^{V_2}\frac{dV}{V} = -\int_0^t \frac{dt}{CR'}$$

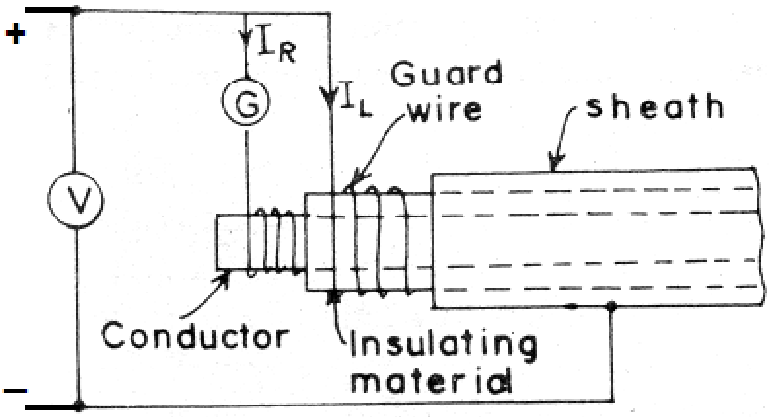
$$\text{or, } \log\frac{V_2}{V_1} = \frac{t}{CR'}$$

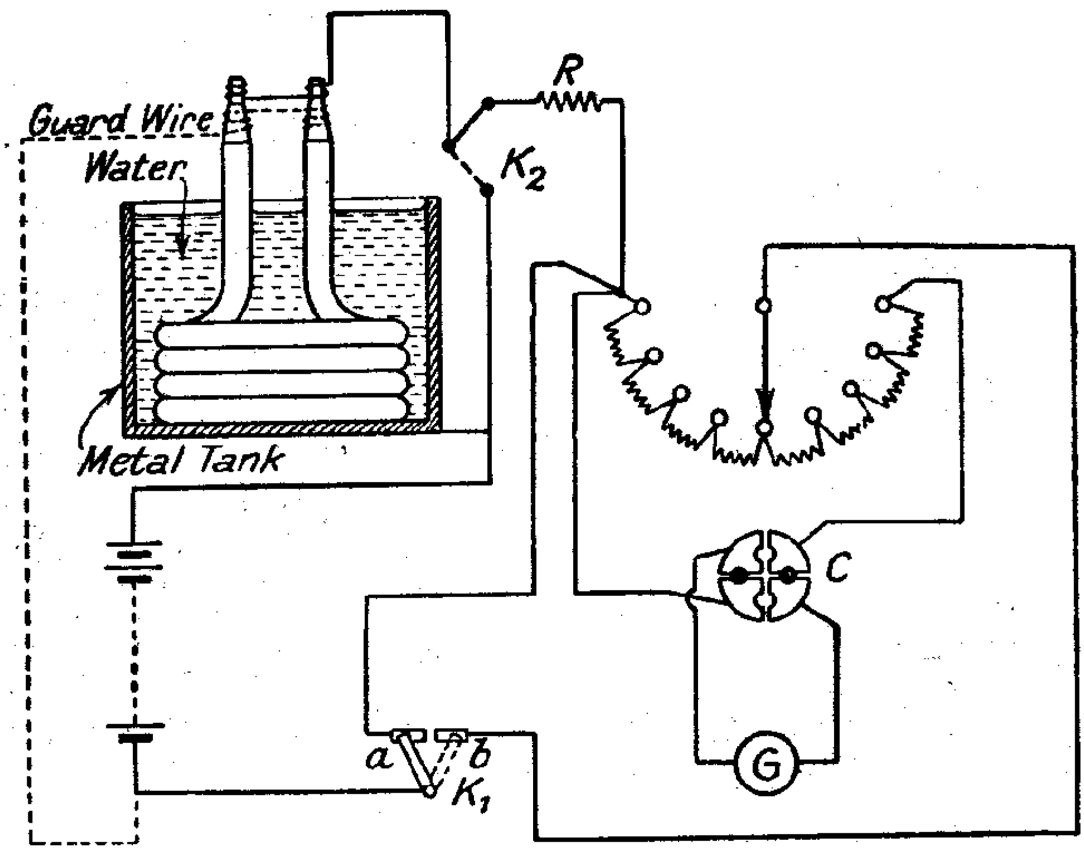
$$V_2 = V_1 e^{t/CR'}$$

From the above expression the value of R' can be determined. The test is then repeated with unknown resistance R disconnected, the capacitor being discharged through R_1 only. Thus the value of leakage resistance R_1 can also be determined. Knowing the values of R' and R_1 the value of unknown resistance can be determined from the relation

$$\frac{1}{R} = \frac{1}{R'} - \frac{1}{R_1}$$

The value of R_1 then can be obtained directly from the expression $V_2 = V_1 e^{-t/CR}$ where V_1 is the voltage at the start instant of discharging and V_2 is the voltage across the object under test after t seconds.





PRICE'S GUARD-WIRE METHOD OF MEASURING HIGH RESISTANCE

Principle of Measurement:

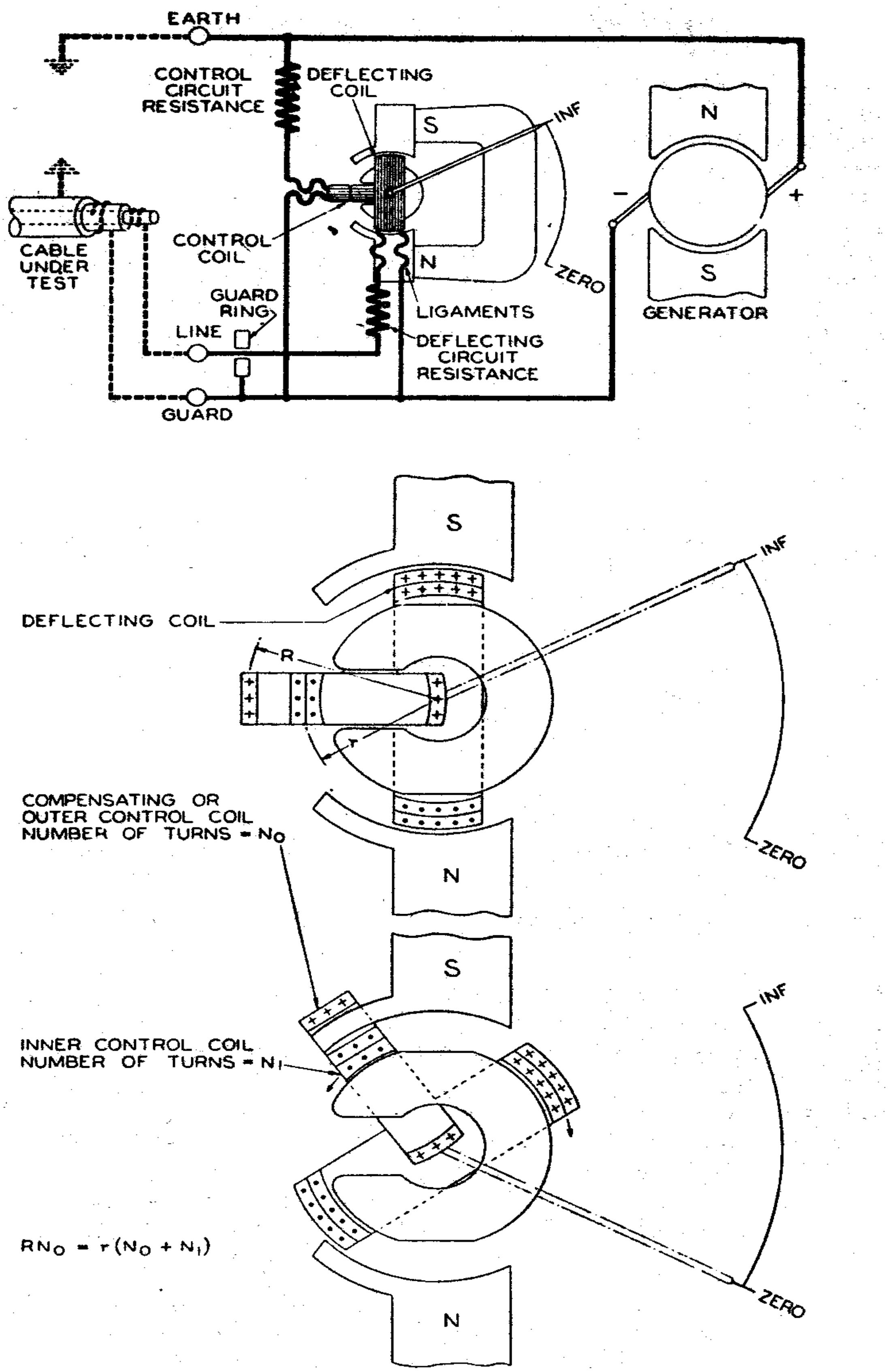
The cable to be tested is immersed in saline water for about 24 hours. The galvanometer G, measures the current I_R between the conductor and the sheath of the cable through the insulation. The leakage current I_L, over the surface of insulating material is carried by the guard wire wound on the insulation and therefore does not flow through galvanometer. The saline water and the tank then form the return path for the current.

The insulation resistance of the cable $R = V / I_R$.

In some cases, the deflection of the galvanometer is observed and its scale is afterwards calibrated by replacing the insulation by a standard high resistance (usually 1 MΩ), the galvanometer shunt being varied as required giving a deflection of desired order.

During tests on cable, the galvanometer should be bypassed initially when the supply is switched on using key $\mathbf{K_1}$. The bypassing connection is removed only after sufficient time has elapsed so that charging current ceases to flow. The galvanometer should be well shunted during the early stages of measurement and it is normally desirable to include a protective series resistance (of the order of 100 kohm) in the galvanometer circuit. The value of this resistance should be subtracted from the observed resistance value in order to determine the true resistance. A high voltage battery of about 500V emf is required and its emf should remain constant throughout the test.

After the test, the cable capacitance should be short circuited using key K_2.



Megger Insulation Tester

Operating Principle of Megger:

The megger is an instrument used for the measurement of high resistance and insulation resistance. Essentially the megger insulation tester consists of a hand driven/motorized dc generator and a direct reading ohmmeter. A simplified diagram of electric connections of the instrument is shown in figure.

In a megger, permanent magnet provides the field for both the generator and the ohm-meter. The moving element of the ohm-meter consists of two coils, known as ***deflecting** (or current) coil, control (or pressure) coil .* ***Control coil*** is divided into two parts- ***inner control coil*** and ***outer control coil***. These two control coils are connected in **series opposition**. Sometimes, the outer control coil is also called ***compensating coil***. Coils are mounted rigidly to a pivoted central shaft and which are free to rotate over a stationary C-shaped iron core. The coils are connected to the circuit by means of flexible leads (or ligaments) that exert no restoring torque on the moving element. Hence the moving element may take up any position over the scale when the generator is idle. The **deflecting coil** is connected in series with the resistance ***R*** between one generator terminal and the test terminal marked 'Line (L)'. The series resistance **R** protects the **deflecting** coil in case the test terminals are short-circuited and also control the range of the instrument. The control coils are in series opposition with each other and in series with a protection resistance **R'.** They are connected across the generator terminals as shown in the figure.

When the current from the generator flows through the control coils, they tend to set themselves at right angles to the field of the permanent magnet. With the test terminals open, corresponding to infinite resistance, no current flows through deflecting coil. The control coil arrangement thus governs the motion of the moving element, causing it to move to its extreme counter clockwise position. The point on the scale indicated by the pointer under this condition is marked **infinite** resistance

Current coil is wound to produce clockwise torque on the moving element. With the test terminals marked **Line (L)** and **Earth (E)** short-circuited, corresponding to zero external resistance, the current flowing through the current coil is large enough to produce torque to overcome the counter clockwise torque of control coil. This moves the pointer to its extreme clockwise position. The point on the scale indicated by the pointer under this condition is marked as **zero** resistance. When a finite resistance under test is connected between the test terminals L and E, the opposing torques of the coils balance each other so that the pointer comes to rest at some intermediate point on the scale. The scale is calibrated in mega-ohms and thousands of ohms so that the pointer indicates directly the value of resistance under test.

The **guard ring** is provided to shunt the surface leakage current without passing through the current coil of the instrument and thus eliminates errors due to it. Usually a terminal known as *guard terminal* is provided by means of which this guard ring may be connected to a guard wire on the insulation under test. The test voltage (usually 500, 1000, 2500 volts) is generated by the generator **G** which in many portable sets, is driven by means of the hand/motor operated crank. The higher test voltages are used in the instruments with the higher resistance ranges.

Since the same magnet system for both instrument and the generator, the instrument indications are independent of the magnet strength and in turn the supply voltage. **[Remember that, variation of battery voltage was a problem for series type ohmmeter]**

To avoid the effect of charging and discharging currents, which are due variation in applied voltage, a special type of slipping clutch/ speed controller is fitted to the handle so that the generator speed and output voltage remains constant even when the handle speed is variable.

Measurement: The resistance under test is connected between the test terminals (L and E). The generator handle is then steadily turned at uniform speed. The turning of the handle must be kept up until the pointer gives a steady reading. Time should be allowed for charging current to die down, which may be a few minutes. The larger the capacitance of the object under test the longer it will take to charge and to give a steady reading. The equilibrium position of the pointer will give the direct reading the insulation resistance.