Chapter 15.

ELECTRICAL MEASURING INSTRUMENTS

15.1 Introduction

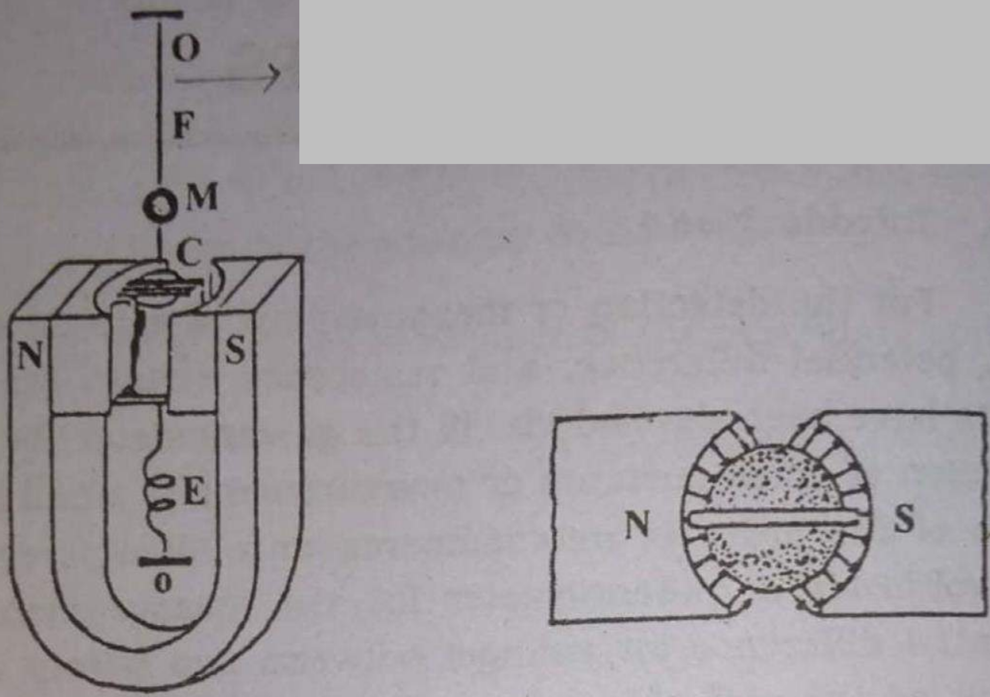
For the detection or measurement of electric current, potential difference, and resistance certain instruments have been devised viz. (i) the galvanometer for the detection of small currents or measurement of small currents of the order of microamperes or milliamperes (ii) the voltmeter or potentiometer for the measurement of potential difference (or voltage) between two points of a circuit or the emf of a source (iii) the ammeter for the measurement of large currents (iv) the wheatstone bridge, the meter bridge, the post office box and the Ohmmeter for the measurement of resistance.

15.2 The moving coil galvanometer

The moving coil galvanometer is a basic electrical instrument. It is used for the detection (or measurement) of small currents.

Its underlying principle is the fact that when a current flows in a rectangular coil placed in a magnetic field it experiences a magnetic torque. If it is free to rotate under a controlling torque, it rotates through an angle proportional to the current flowing through it. The rotation or deflection thus indicates a current through it. Although the galvanometer deflects full-scale by a small current (a few microamperes or milliamperes), nevertheless it can measure such small currents if the deflection is properly calibrated.

The primitive form of the moving coil galvanometer was developed by the French scientist D'Arsonval. Edward Weston improved upon D'Arsonvals original version and gave us the modern moving-coil galvanometer



(a) Moving coil galvanometer.
Fig: 15.1

(b) Concave pole piece and soft iron cylinder makes the field radial and stronger.

As shown in Fig. 15.1, the essential parts of a moving coil galvanometer are:

i) A U-shaped permanent magnet with cylindrical concave pole-pieces

ii) A flat coil of thin enamel insulated wire (usually rectangular)

iii) A soft iron cylinder.

iv) A pointer

v) A scale

The flat rectangular coil of thin enamel insulated wire of suitable number of turns wound on a light non-metallic (or aluminium) frame is suspended between the cylindrically concave pole pieces of the permanent U-shaped magnet by a thin phosphor bronze strip. One end of the wire of the coil is soldered to the strip. The other end of the strip is fixed to the frame of the galvanometer and connected to an external terminal. It serves as one current lead through which the current enters or leaves the coil. The other end of the wire of the coil is soldered to a loose and soft spiral of wire connected to another external terminal. The soft spiral of wire serves as the other current lead. A soft-iron cylinder, coaxial with the pole pieces, is placed within the frame of the coil and is fixed to the body of the galvanometer. In the space between it and the pole pieces, where the coil moves freely, the soft iron cylinder makes the magnetic field stronger and radial such that into whatever position the coil rotates, the magnetic field is always parallel to its plane.

When a current passes through the galvanometer coil it experiences a magnetic deflecting torque which tends to rotate it from its rest position. As the coil rotates it produces a twist in the suspension strip. The twist in the strip produces ah elastic restoring torque. The coil rotates until the elastic restoring torque due to the strip does not equal and cancel the deflecting magnetic torque and then it attains equilibrium and stops rotating any further.

In the previous chapter the, deflecting magnetic torque was derived as:

Deflecting magnetic torque = BIAN cos α

Where B = strength of the magnetic field.

I = current in the coil

A = Area of the coil

N = Number of turns in the coil

and α = the angle of deflection of the coil

The restoring elastic torque is proportional to the angle of twist of the suspension strip provided it obeys

Hooke's Law. Thus restoring elastic torque = $c\theta$, where θ is the angle of twist of the suspension strip (θ is different from but proportional to α), and c is the torque per unit twist of the suspension strip for equilibrium.

Deflecting magnetic torque = Restoring elastic torque

or $$BIAN \cos \alpha = c\theta$$

or $$I = \frac{c}{BAN \cos \alpha} \theta \quad \text{------------(15.1)}$$

If the magnetic field were uniform (as with flat pole-pieces) α would continuously increase with θ and cos α factor would not be constant. Then the current I would not be proportional to θ and the scale of the galvanometer not linear. However, due to the radial magnetic field the plane of the coil is always parallel to the field irrespective of the position the coil rotates. So, α, the angle between the plane of the coil and the direction of the field is always zero, hence cos α = 1 i.e. constant as are B,A and N.

The equation 15.1 therefore, reduces to

$$I = \frac{c}{BAN} \theta \quad \text{------------------(15.2)}$$

$$\therefore I \propto \theta$$

Thus the current through the coil is directly proportional to the angle of twist of the suspension (or deflection), θ, giving a linear scale

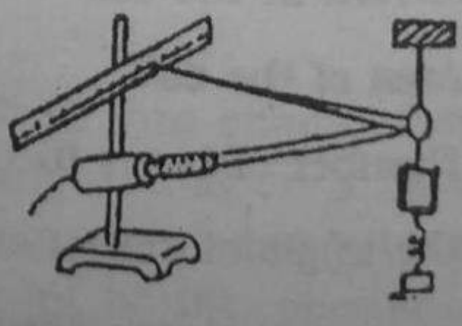


Fig. 15.2 Lamp and Scale Arrangement

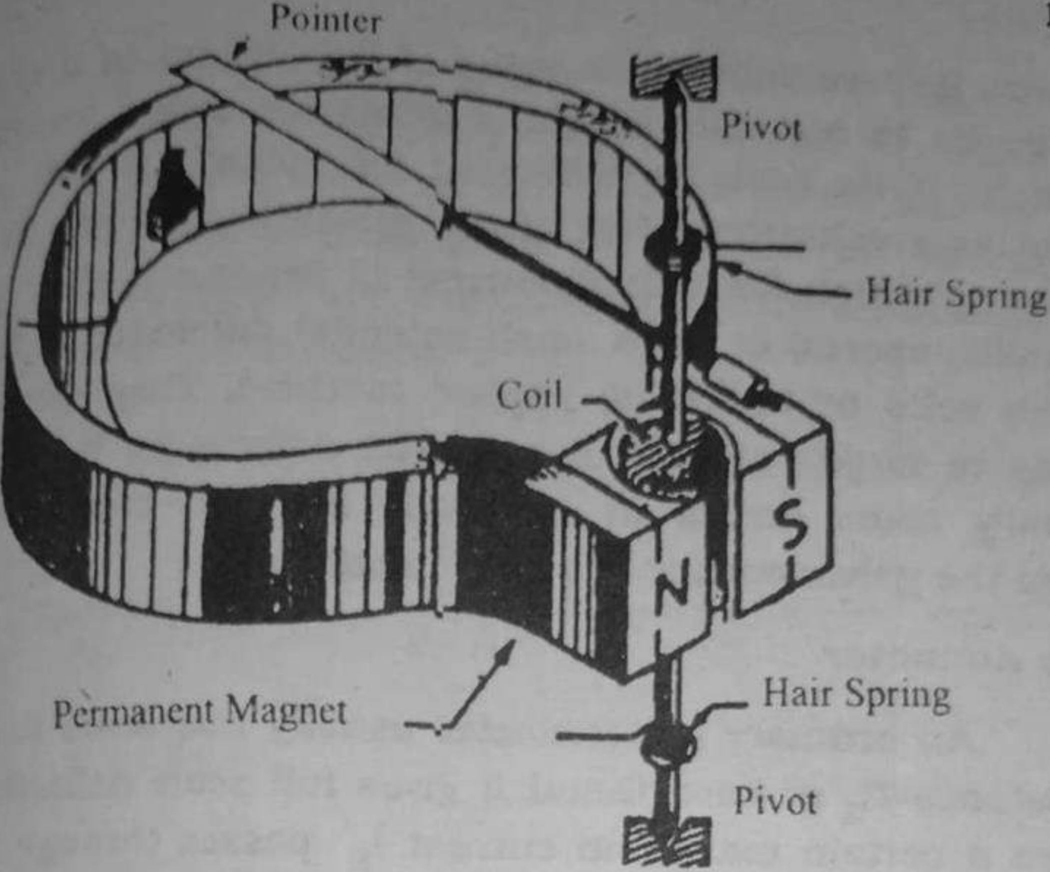


Fig. 15.3 Pivoted moving coil galvanometer

The coil instead of being suspended by a strip is pivoted between two jewelled bearings. The controlling (restoring) torque is provided by two hair-springs one on either side of the coil and curling in the opposite sense. The two ends of the coil are connected one to each spring. The hair springs thus also serve as current leads to the coil. A light aluminium pointer is fixed to the coil which moves over a calibrated circular scale with equal divisions which measures the deflection (in divisions) or current (in micro amperes) directly.

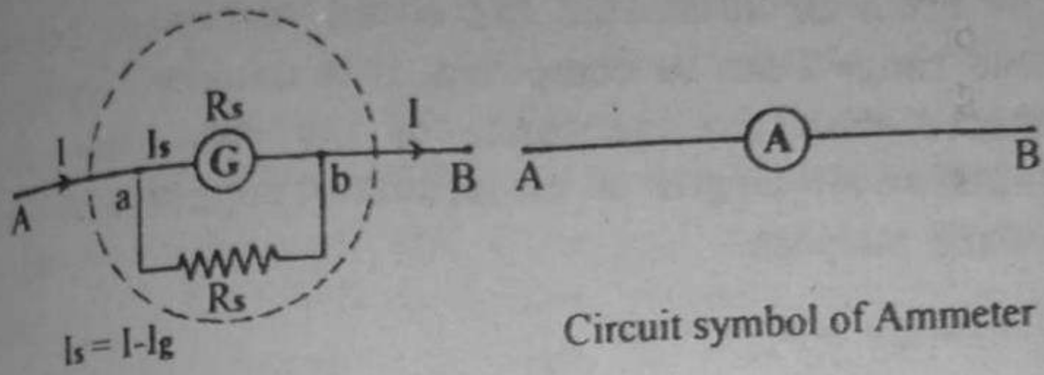
15.3 Ammeter and Voltmeter.

Ammeters and voltmeters are simple pivoted type moving coil galvanometers with suitable modifications. We have already seen that when a current flows in the galvanometer its coil is deflected. The current is proportional to the deflection. If the scale is calibrated for the current, it can be used as an ammeter. Again since the galvanometer coil has a fixed resistance, the current in it is proportional to the potential difference (or voltage) across its terminals. Each value of the current in it corresponds to a certain potential difference across its terminals. If its scale is calibrated for voltage, it can be used as a voltmeter. Most of the galvanometers give full scale deflection for a small current (a few micro amperes or milliamperes) or for a small potential difference (a few micro volts or millivolts) applied to them. They cannot measure large currents or potential differences that we usually come across in our daily life. For measuring them the galvanometer has to be modified.

The Ammeter

An ordinary galvanometer usually has some fixed resistance R_g of its coil and it gives full scale deflection when a certain maximum current I_g passes through it. This maximum current is called the range of the unaided galvanometer. A current that lies within this range can be measured directly with the galvanometer, thus it can serve as an ammeter. For measuring a current this ammeter must be connected in series with the circuit to allow through it the full current which is to be measured. If R_g is large, the insertion of this ammeter will increase the resistance in the circuit and decrease the current it is intended to measure an undesirable situation. So as not to affect the current to be measured an ammeter essentially must have very small resistance.

On the other hand if it is desired to measure a current much larger than I_g the galvanometer cannot be used directly as an ammeter. If tried it will certainly be changed. To measure any current upto I larger than I_g, the galvanometer has got to be modified such that while the current in the main circuit is I, the current in the galvanometer coil never exceeds I_g. This objective is achieved by connecting a by-pass resistance, called a shunt, of appropriate small value across in parallel with the galvanometer coil which allows the large excess current through itself while a known fraction of I within the value I_g passes through the galvanometer coil. The main current in the galvanometer coil and the shunt together is always a simple multiple of the current in the coil which can be found and the scale calibrated accordingly to read the main current directly.



Circuit symbol of Ammeter

(a) (b)

Figure 15.4

Consider a galvanometer G whose resistance is R_g and which gives full scale deflection when current I_g flows through it. Fig. 15.4. Suppose we want to modify it into an ammeter to measure a maximum current I (or to increase its range to I). A shunt R_s of appropriate small resistance sheuld be connected in parallel with the galvanometer such that while the current in the main circuit is I the current in the galvanometer coil is I_g producing full scale deflection and that in the shunt is $I_s = I - I_g$.

As it is clear, the galvanometer coil of resistance R_g and the shunt resistance R_s are connected in parallel between junctions a and b. the potential difference, V_g, across the galvanometer and that across the shunt, V_s are the same, so $V_g = V_s = V$, say

From Ohm's Law (V = IR). we have :

$$V_g = I_g R_g$$

and $$V_s = I_s R_s = (I - I_g) R_s$$

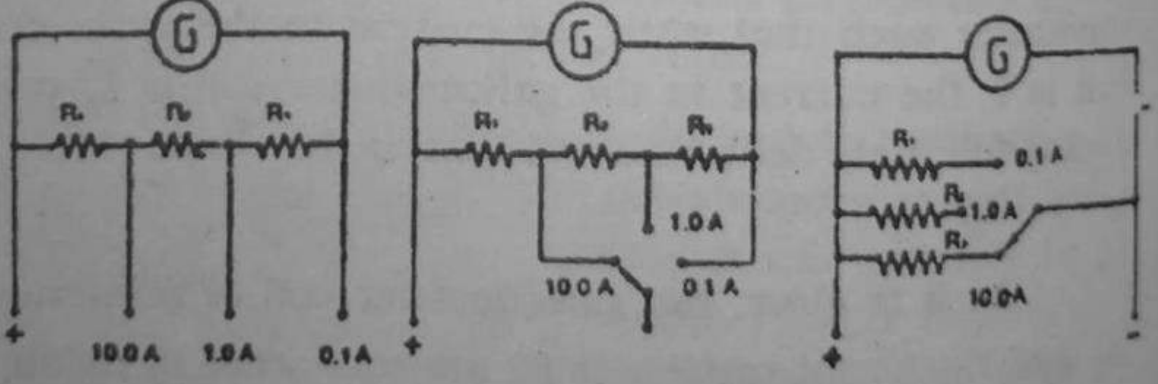
Hence $$(I - I_g) R_s = I_g R_g$$

$$\therefore R_s = \left(\frac{I_g}{I - I_g} \right) R_g \qquad \text{----------(15.3)}$$

From equation 15.3 the shunt resistance for any desired range I can be computed. It is usually very small compared with the resistance of the galvanometer. A suitable small length of an ordinary copper wire may serve the purpose.

Multi-range Ammeters.

Sometimes an ammeter has more than one range which means it has as many different shunts as the ranges. The desired range is selected by inserting the proper shunt in position. In one type, one end of each shunt is permanently connected to a common terminal while the other end of each is connected through a range switch to a second common terminal (Fig. 15.5(c)).



(a) (b) (c)

Fig. 15.5

In the other type the shunts are arranged as shown in Fig. 15.5 (a) and (b). In (a) separate range terminals are provided together with the common terminal marked (+) and in (b) the proper range terminal can be connected by a range switch to the second common terminal.

The Voltmeter.

A voltmeter measures the potential difference between any two points of a current carrying circuit (or between the two terminals of a source). For doing so its terminals must be connected to these points. Evidently, used as a voltmeter, the galvanometer cannot directly measure the potential difference between two points of a circuit with accuracy even if the p.d. is within its small range V_g for full scale deflection, because when the galvanometer is connected between the two points its coil provides a conducting path of no large resistance. A current flows through the galvanometer and the original current between the points decreases and the p.d. between the points decreases too, since it is proportional to the current. Thus this voltmeter changes the p.d. it is called upon to measure. Moreover for measuring a p.d. much higher than its small range V_g the galvanometer will be unsuitable. Thus for measuring the p.d. accurately without affecting it in any way the voltmeter must not draw any current i.e. it must essentially have very large resistance

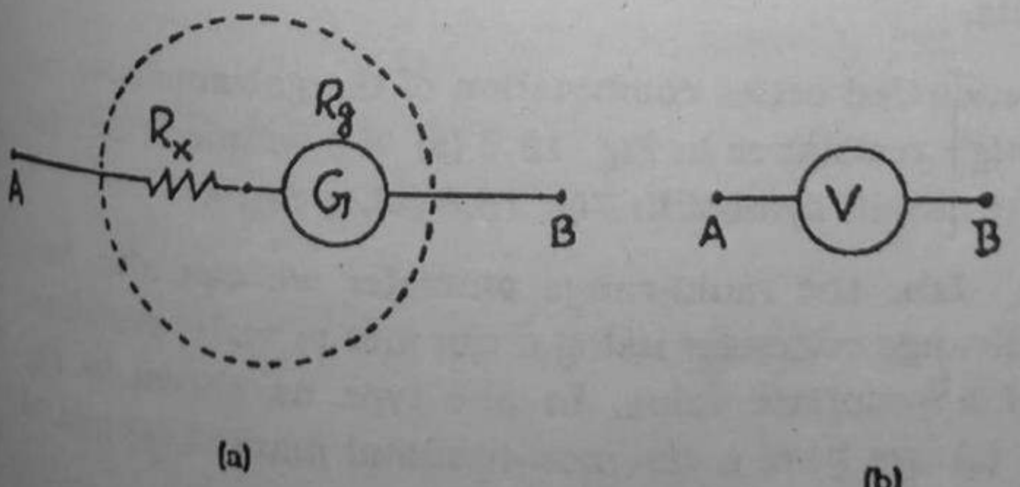


Fig. 15.6

For converting a galvanometer in to a voltmeter of a desired range an appropriate high resistance of the order of kilo ohms is connected in series with it. This resistance is commonly known as multiplier resistance. Consider a galvanometer G whose resistance is R_g and which deflects full scale for the current I_g. Suppose we want to convert it into a voltmeter measuring a p.d up to V volts. An appropriate high resistance R_x must be connected in series with it such that for the p.d.V applied between the ends of the above combination the current in the galvanometer is Ig which produces full scale deflection. Now the total resistance between the terminals is $R_x + R_g$. Thus by ohms law,

$$(R_x + R_g)\, I_g = V$$

$$R_x + R_g = \frac{V}{I_g}$$

$$\therefore\ R_x = \frac{V}{I_g} - R_g \qquad \text{-----------------} \quad (15.4)$$

The equation (15.4) helps to calculate the value of the series high resistance for the conversion of the galvanometer into a voltmeter of any desired range V volts. When the proper high resistance is connected in series with the galvanometer it is converted into a voltmeter of range V volts. The scale can then be calibrated from O to V volts.

The encircled series combination of the galvanometer and the high resistance in Fig. 15.6 (a) is a voltmeter denoted by the circuit symbol in Fig. 15.6 (b).

Like the multi-range ammeter we can also have multi-range voltmeter using a number of series resistances of appropriate value. In one type as shown in Fig. 15.7 (a), we have a common terminal marked (+) and as many other terminals as the ranges.

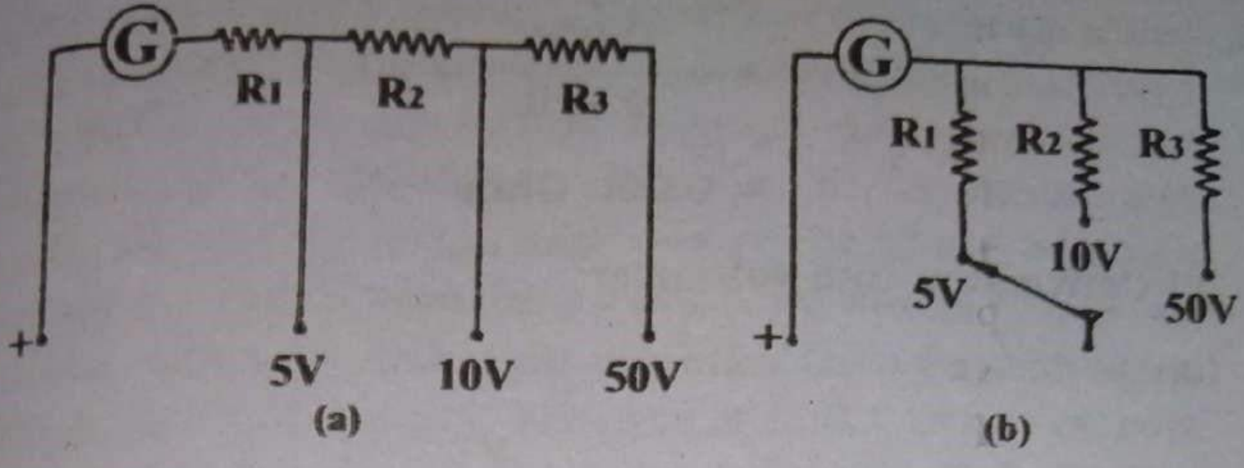


Fig. (15.7)

In the other type one terminal is common marked (+) while different range terminals can be connected by a range switch to the other common terminal (Fig.15.7[b])

Example: 15.1

A galvanometer has a resistance of 20 ohms and gives full-scale deflection when a current of 0.001 ampere flows in it. Find out (i) the value of the shunt resistance to convert it into an ammeter of range 10 amperes. (ii) the value of the series resistance to convert it into an voltmeter of range 10 volts.

Solution:

Resistance of the galvanometer, $R_g = 20$ ohms

Current for full scale deflection, $I_g = 0.001$ A.

(i) conversion into ammeter :

Range desired = 10 amperes

shunt resistance $= R_s = \left(\frac{I_g}{I - I_g}\right) R_g$

$$= \left(\frac{0.001}{10 - 0.001}\right) \times 20$$

$$= \frac{0.001}{9.999} \times 20$$

$$= 0.002 \text{ Ohm}$$

(ii) Conversion into voltmeter:

Range desired = 10 volts

Series high resistance, $R_x = \frac{V}{I_g} - R_g$

$$= \frac{10}{0.001} - 20$$

$$= 10000 - 20$$

$$= 9980 \text{ ohms}$$

(i) shunt resistance = 0.002 ohms
(ii) series high resistance = 9980 ohms Ans.

15.4. Wheatstone Bridge

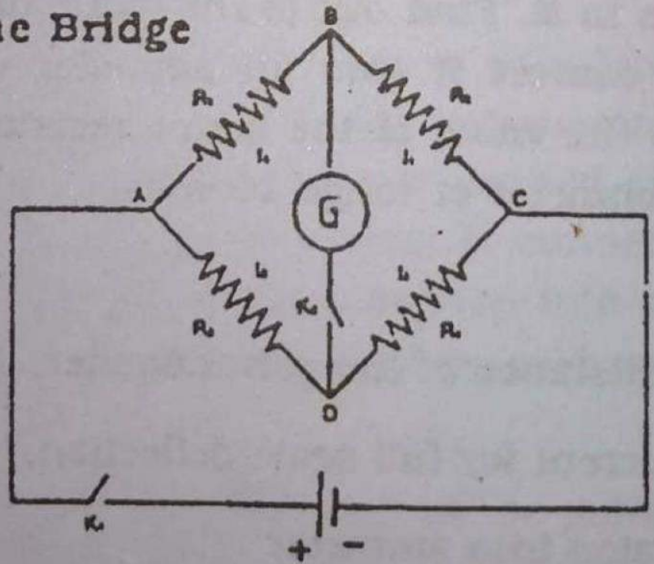


Fig. 15.8

If four resistances R_1, R_2, R_4 and R_3 are connected end-to-end in order to form a closed mesh ABCDA and between one pair of opposite junctions, A and C, a cell is connected through a key while between the other pair of opposite junctions, B and D, a sensitive galvanometer G is connected through another key, the circuit so formed is called a wheatstone bridge.

In the above bridge if the key K_1 is closed first some current flows through the cell and the resistances R_1, R_2, R_3 and R_4. If the key K_2 is also closed a current will usually be found to flow through the galvanometer indicated by its deflection. However, if the resistances R_1, R_2, R_3 and R_4 (or at least one of them) are adjusted a condition can always be attained in which the galvanometer shows no deflection at all i.e. no current passes through it. Then the p.d. between B and D must be zero i.e. B and D must be at the same potential. This implies that the p.d. between B and A (i.e. across R_1) must equal that between D and A (i.e. across R_3). Also the p.d. between B and C (i.e. across R_2) must equal that between D and C (i.e. across R_4). Since no current flows through the galvanometer the current in R_1 equals that in R_2, say I_1 and the current in R_3 equals that in R_4, say I_2. since

$V_{BA} = V_{DA}$ it follows from Ohm's Law that

$$I_1R_1 = I_2 R_3 \qquad \text{------------------ (15.5)}$$

also since $\quad V_{BC} = V_{DC}$,

$$I_1R_2 = I_2R_4 \qquad \text{------------------ (15.6)}$$

From equations (15.5) and (15.6) we have

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \text{-----------(15.7)}$$

This is an important relation true only for a balanced wheatstone bridge i.e. when no current flows in the galvanometer with both keys K_1 and K_2 closed. Under balance condition if any three resistances are known the fourth (unknown) can easily be computed. A number of resistance measuring instruments have been devised which make use of this important principle. Examples are the meter bridge, the post office box Carey Foster's bridge, callendar and Griffiths bridge, etc. Here we will discuss only the first two.

15.5 Meter Bridge

The meter bridge, also called slide-wire bridge, is an instrument based on Wheatstone Principle. It consists of a long, thick copper strip bent twice at right angles. Two small portions are cut off from it near the bends to provide the gaps across which two resistances a known one and an unknown may be connected. Each of the three pieces of the strip is provided with binding screws. A uniform wire (of manganin or constantan) one meter long and of fairly high resistance is stretched alongside a meter scale and connected to the ends of the strip (Fig. 15.9). It is this one meter long wire to which the instrument owes its name.

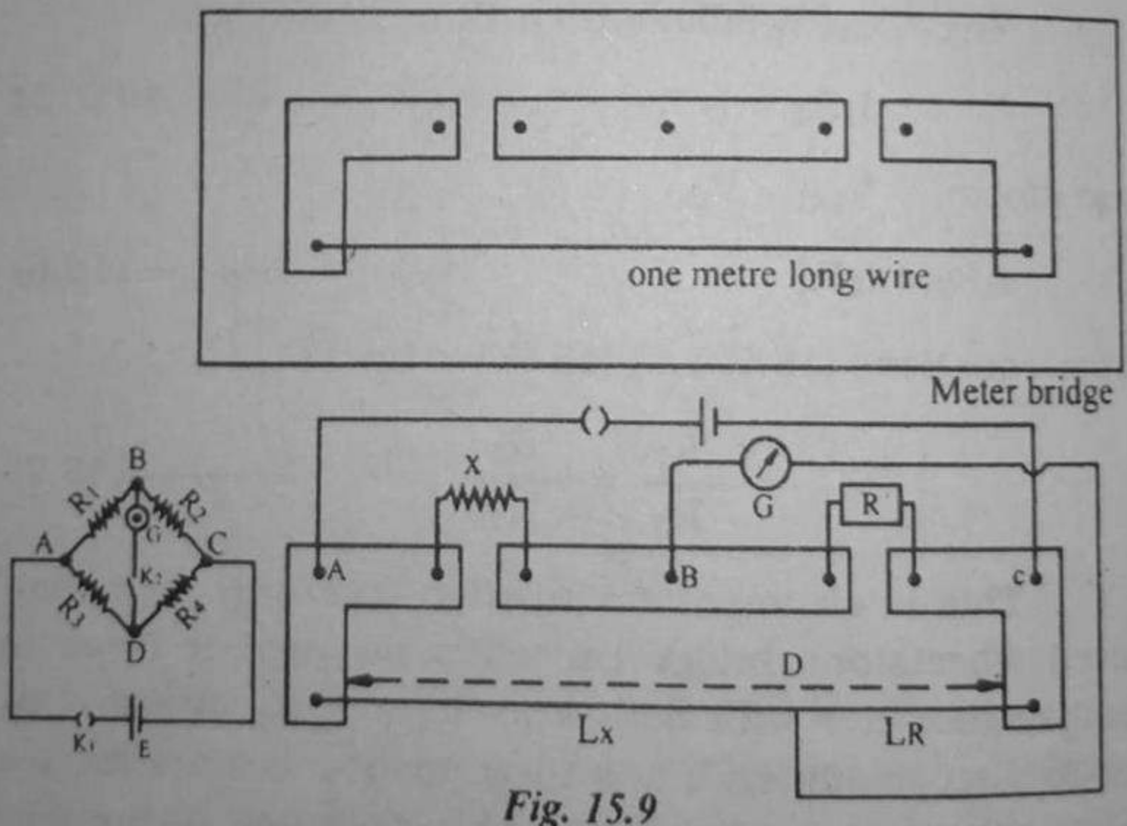


Fig. 15.9

For measuring an unknown resistance X, it is connected in one gap of the meter bridge and a standard resistance box, R, in the other. A cell and a galvanometer are connected as shown. The jockey is moved along the wire to obtain the balance point D. Under balance condition if the length of the wire segment AD towards X is L_x and the length of the wire segment BD toward R is L_R, then their resistances are ρL_x and ρL_R respectively, where ρ is the resistance per unit length of the wire. Then according to Wheatstone Principle:

$$\frac{X}{R} = \frac{\rho L_x}{\rho L_R} \quad \text{or} \quad \frac{X}{R} = \frac{L_x}{L_R}$$

Using this formula, X can be calculated if R is a known resistance.

15.6 Post Office Box (P.O.Box)

Post Office Box is another instrument based on Wheatstone Principle. It is so named because it was first introduced for finding the resistance of telegraph wires and for fault-finding work in the post and telegraph office. It is more compact and easier to use.

In a P.O Box the arms P and Q called the ratio arms, usually consist of three resistances each, viz. 10, 100, and 1000 ohms, so that any decimal ratio from 1:100 to 100:1 may be used. The third arm, R, is an ordinary set of resistances. The unknown resistance, X, to be measured, forms the fourth arm.

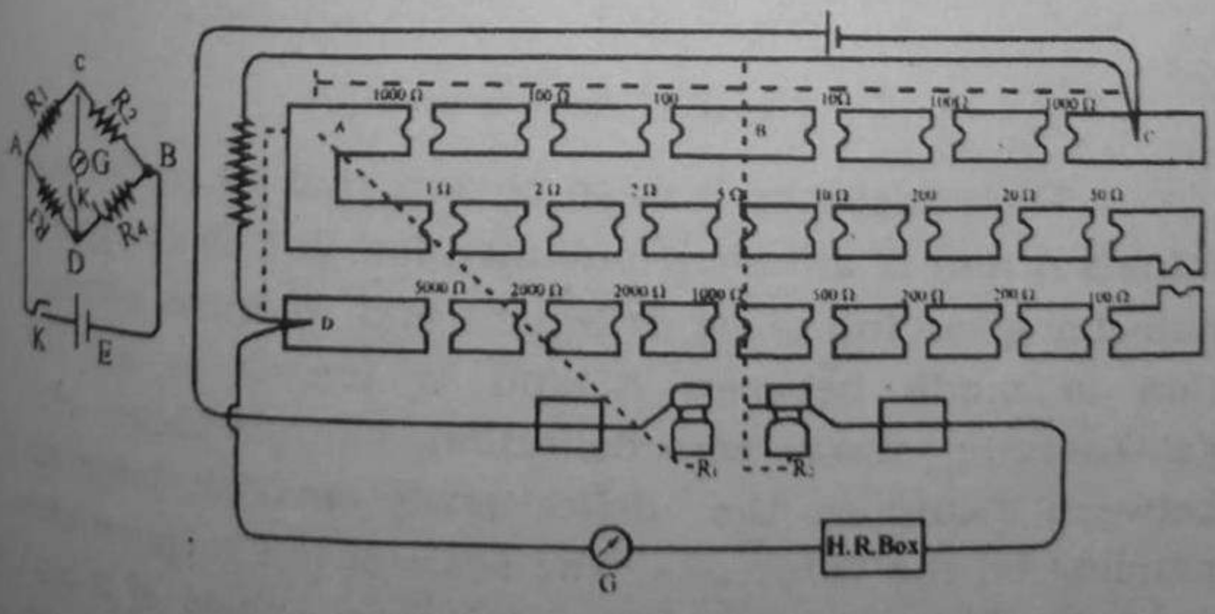


Fig. 15.10

Introducing the ratios 1:1, 10:1, 100:1 in turn the balance or null position is traced by adjusting R. Balance is usually obtained at the ratio 100:1 for some value of R. With this value of R, the value of X can easily be calculated using the relation of Wheatstone Bridge:

$$\frac{P}{Q} = \frac{R}{X} \quad \text{or } X = R\left(\frac{Q}{P}\right)$$

15.7. The Ohmmeter

Although not a very accurate instrument, the Ohmmeter is a useful device for quick measurement of resistance. It includes a sensitive galvanometer G, adjustable resistor R and a torch cell E connected in series between two terminals A and B as in Fig. 15.11.

The unknown resistance X to be measured is connected between the terminals A and B.

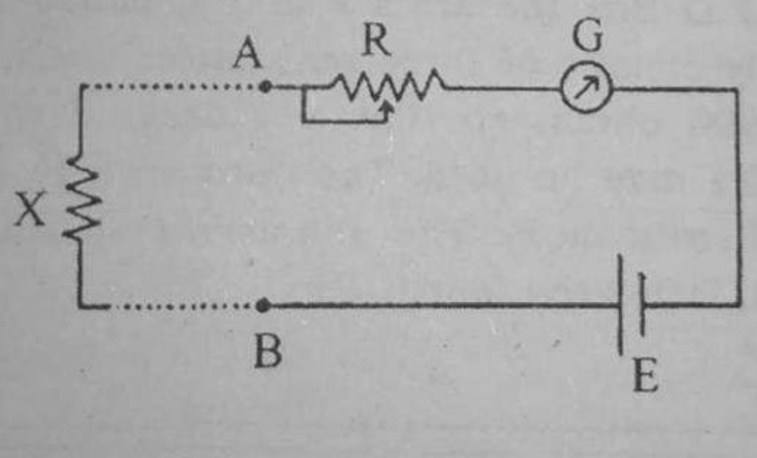


Fig. 15.11 An Ohmmeter

The resistance R is so chosen that when the terminals A and B are short circuited (i.e. $X = 0$) the galvanometer gives full scale deflection and when no connection is made between A and B (i.e. $X = \infty$) the galvanometer shows zero deflection. For the values of x between o and ∞ the deflection is small or large depending on the value of x. The scale of the galvanometer is first calibrated with different known values of x and then the circuit serves as an Ohmmeter to measure any unknown resistance approximately.

The scale of the Ohmmeter, however, is not linear.

Using different combinations of R in series and different shunts across the galvanometer worked by a range in switches. The Ohmmeter can be adopted for different accuracies eg: 1Ω accuracy, accuracy in tens of ohms in hundreds of ohms in thousands of ohms (kilo ohms) in mega ohms, etc.

15.8. Potentiometer

A potentiometer is a device for measuring the potential difference (or voltage) between two points of a circuit or the E.M.F. of a current source.

Consider a uniform resistance wire AB of length L and resistance R, across which is connected a source of constant E.M.F. (e.g. an accumulator) through a key and a rheostat to adjust and maintain a constant current I through it. (Fig. 15.12)

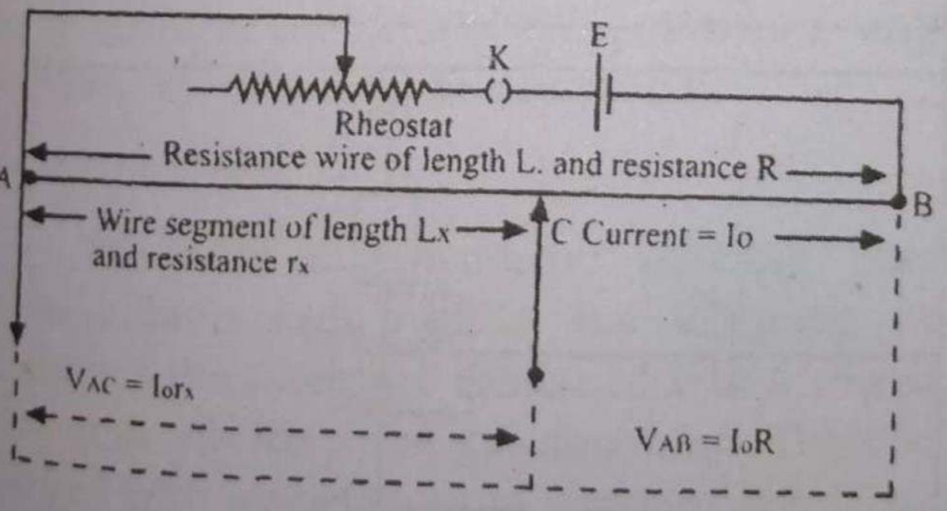


Fig. 15.12 A Potential divider

As the current flows, the potential difference between A and B = V_{AB} = IR.

A running point C can be considered on the wire such that the length of the wire AC = l_x, and its resistance = r_x. The potential difference between A and C =

$V_{AC} = I.r_x$. As C is a running point, the resistance r_x and the potential difference V_{AC} change continuously from zero value to the maximum values R and V_{AB} as C moves from A to B. V_{AC} is zero when C coincides with A. It continuously increases as C moves away from A. It is maximum (= V_{AC}) when C coincides with B. The point C thus divides the p.d., V_{AB}, across the wire AB into two parts — V_{AC} which can be applied usefully to some other circuit, and V_{CB} which may be kept idle or may be applied elsewhere. Therefore, this circuit is called potential divider. (Instead of one point C more than one point: C_1, C_2, C_3, etc. can also be chosen to divide V_{AB} into as many parts as the number of wire segments AC_1, $C_1 C_2$,--- ----------etc.).

The potential divider of Fig. 15.12 can be used to measure an unknown E.M.F (of a cell) or some other potential difference, or the ratio of the E.M.Fs of two cells. When used in this way, it is called a Potentiometer.

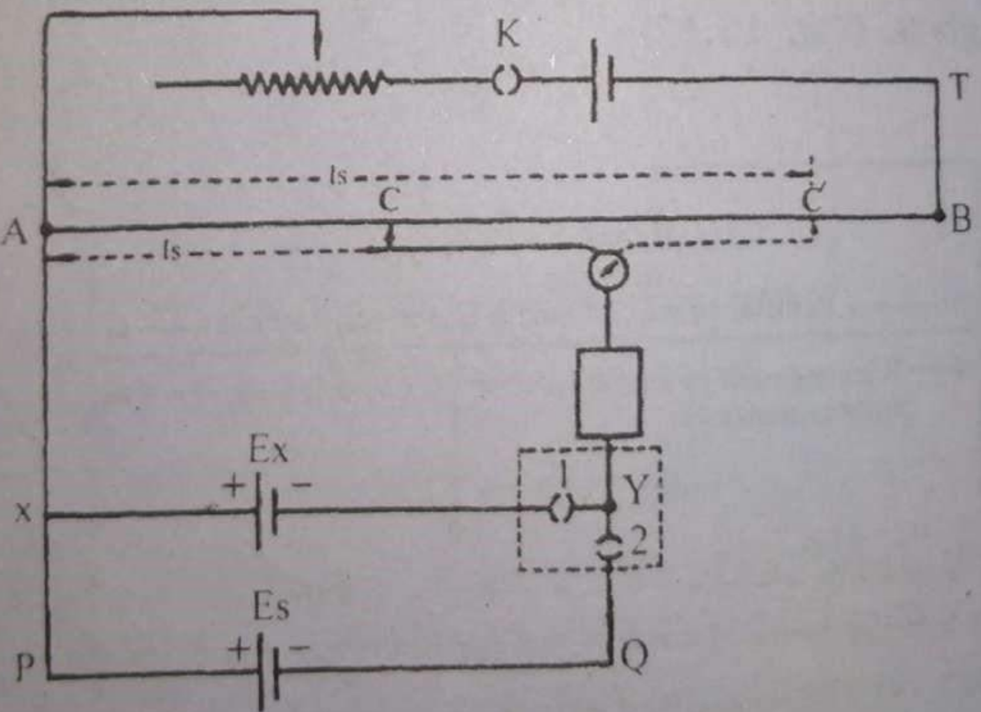


Fig. 15.13 A Potentiometer

In a potentiometer the length of the wire AB may be 1.0 meter or 5.0 or 10.0 meters. The larger the length, the greater is the accuracy of measurement.

The circuit is set up as shown in Fig. 15.13. The positive terminals of a cell of unknown E.M.F. E_x. and a standard cell of E.M.F.Es are connected to the terminal A to which the positive terminal of the current driving battery of E.M.F.E is connected The negative terminals of both the cells are joined to the jockey through a two-way key and a sensitive galvanometer.

Using the two-way key first cell E_x only is introduced into the galvanometer branch and the balance point C and length 1x are found for it. At the balance.

$$E_x = V_{AC} = Ir_x = 1\rho \ell_x \qquad \text{------------------(15.8)}$$

where ρ is the resistance per unit length of the wire.

Then putting E_x out of circuit, cell E_s only is introduced and the balance point 'C' and length ℓ_s are determined.

Now $$E_s = V_{AC} = Ir_s = I\rho\ \ell_s \qquad \text{---------- (15.9)}$$

Therefore, $$\frac{E_x}{E_s} = \frac{\ell_x}{\ell_s} \qquad \text{--------- (15.10)}$$

The equation (15.10) gives the ratio of the two emf in terms of the ratio of their balancing lengths. If E_s is known, E_x can easily be computed.

The AVOmeter

The multi-range ammeter, voltmeter and Ohmmeter have been explained in the foregoing discussion. Sometimes the three are combined into a compact single metre with one common galvanometer. The circuit is so arranged with a selector-cum-range switch that it can be used to measure the currents, the voltages or the resistances of different ranges (or orders). A rectifier circuit is also included in the instrument to convert A.C currents into D.C currents before they pass through the galvanometer. Thus r.m.s. values of A.C currents and voltages can also be measured with the instrument. This compact meter is usually called universal meter or an Ampere-Volt-Ohm-meter abbreviated as AVOmeter.

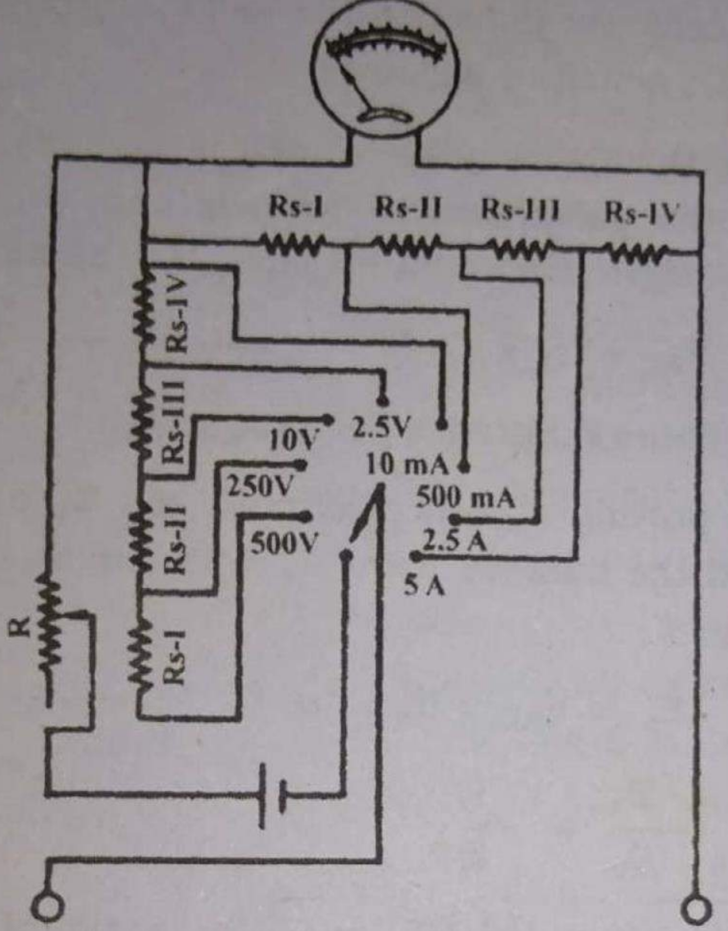


Fig. 15.14

QUESTIONS.

15.1 What is the function of the concave pole pieces and the coaxial soft-iron cylinder in the moving coil galvanometer?

15.2 Why is it necessary to have some form of controlling couple in the moving coil galvanometer?

15.3 What is meant by the sensitivity of a galvanometer? On what factors does it depend? How can we have large sensitivity of a moving coil galvanometer?

15.4 Which galvanometer usually has greater sensitivity, Aluminium pointer and scale type or lamp and scale type? Why?

15.5 We want to convert a galvanometer into (a) an ammeter (b) a voltmeter. What do we need to do in each case?

15.6 Why is it necessary for an ammeter to have zero or negligibly small resistance?

15.7 What necessary condition must a voltage-measuring device satisfy?

15.8 Why must an ammeter be connected to a circuit in series and a voltmeter in parallel?

15.9 An ammeter and a voltmeter of just suitable ranges are to be used in a circuit. What might happen if by mistake their positions are interchanged?

15.10 The terminals of ammeters are usually made of thick and bare wire while those of voltmeters are quite thin and well insulated. Explain why?

15.11 Why is a potentiometer considered one of the most accurate voltage measuring device?

15.12 Describe a circuit that gives a continuously varying potential difference between zero and a certain maximum value.

15.13 What is a wheatstone bridge? How is it used for measuring an unknown resistance?

15.14 In a balanced wheatstone bridge, will the balance be affected if the positions of the cell and the galvanometer are interchanged?

15.15 In a slide-wire bridge, is it absolutely necessary to have the bridge wire one metre long?

15.16 A Post Office Box is a compact wheatstone bridge. Then why is it so named?

15.17 Which is the more accurate instrument a meter bridge or a P.O.Box?

PROBLEMS

15.1 A galvanometer has a resistance of 50 Ohms and it deflects full scale when a current of 10 milliamperes flows in it. How can it be converted into an ammeter of range 10 amperes?

Ans. (By connecting a shunt of 0.05 Ω)

15.2 A galvanometer whose resistance is 40 Ohms deflects full-scale for a potential difference of 100 millivolts across its terminals. How can it be converted into an ammeter of 5 ampere range?

Ans. (By connecting a shunt of 0.02 Ω)

15.3 The coil of a galvanometer which has a resistance of 50 ohms and a current of 500 micro amperes produces full-scale deflection in it. Show by a diagram how it can be converted to (a) an ammeter of 5 ampere range and compute the shunt resistance. (b) a volt meter of 300 volt range and compute the series resistance.

Ans.((a) R_s = 0.005 Ω (b) R_x = 599950 Ω

15.4 A galvanometer of resistance 2.5 ohms deflects full-scale for a current of 0.05 amperes. It is desired to convert this galvanometer into an ammeter reading 25 amperes full-scale. The only shunt available is of 0.03 ohm. What resistance R must be included in series with the galvanometer coil as shown in Fig. 15.15 for using this shunt?

Ans.(12.47Ω)

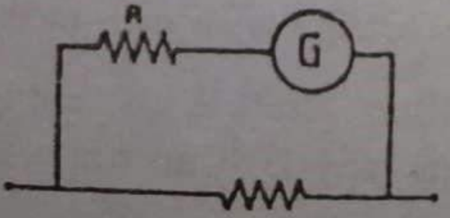


Fig. 15.15

15.5 An ammeter deflects full-scale with a current of 5 amperes and has a total resistance of 0.5 ohms what sunt resistance must be connected to it to measure 25 amperes full-scale?

Ans.(0.125 Ω)

15.6 A moving coil galvanometer G has a resistance of 50 ohms and deflects full-scale with a current of 0.005 ampere. What resistance R_1, R_2 and R_3 must be connected to it as shown in Fig. 15.16

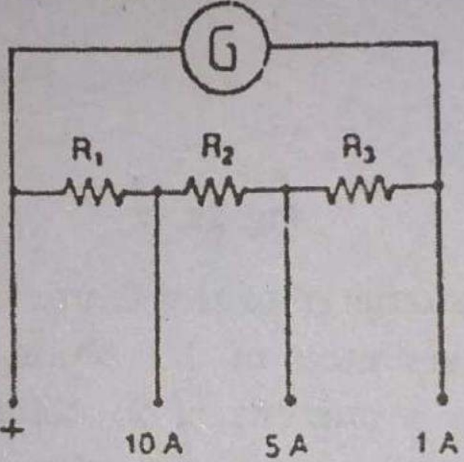


Fig. 15.16

to convert into a multi-range ammeter having ranges of 1A, 5A and 10A.

Ans.(R_1 = 0.0251 Ω, R_2 = 0.05 Ω R_3 = 0.201 Ω)

15.7 A 300-volt voltmeter has a total resistance of 20,000 ohms. What additional series resistance must be connected to it to increase its range to 500 volts?

Ans: (R_x = 13333 Ω)

15.8 The resistance of a moving-coil galvanometer is 25 ohms and current of 1 milliampere causes full-scale deflection in it. It is to be converted into a multi-range voltmeter. Find the series resistances R_1, R_2 and R_3 to give the range of 5 volts, 50 volts and 500 volts at the range terminals as shown in Fig. 15.17.

(Ans. R_1 = 4975 Ω, R_2 = 45000 Ω, R_3 = 450000 Ω)

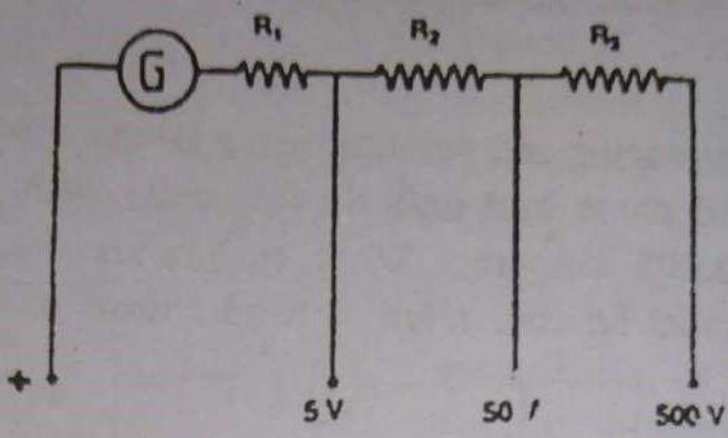


Fig. 15.17

15.9 The galvanometer of the Ohmmeter in Fig. 15.11 has a resistance of 25 ohms and deflects full scale with a current of 2 milliamperes in it. The e.m.f. E of its cells is 1.5 volts.

(i) What is the value of the series resistance R?

(ii) To what values of x connected to its terminals do the deflection of $\frac{1}{5}$, $\frac{1}{2}$ and $\frac{4}{5}$ full-scale correspond?

(iii) Is the scale of the Ohmmeter linear?

Ans. (i) R = 725 Ω, (ii) X_1 = 3000 Ω, X_2 = 750 Ω, X_3 = 187.5 Ω, (iii) No.)

15.10 A constant potential difference of 25 volts is applied across a uniform resistance wire AB, 100 cm long. Terminals are soldered to three points C,D,F on the wire respectively 16,32 and 64 cm from A, Fig. (15.18). Find the potential differences (between each pair of points given in the subscripts) (i) V_{AC} (ii) V_{AD} (iii) V_{AF} (iv) V_{CD} (v) V_{CF} (vi) V_{DF} (vii) V_{CB} (viii) V_{DB} and (ix) V_{FB}.

Ans. (i) 4V, (ii) 8V, (iii) 16V (iv) 4V ,(v) 12V, (vi)

8V, (vii) 21V, (viii) 17V , (ix) 9V

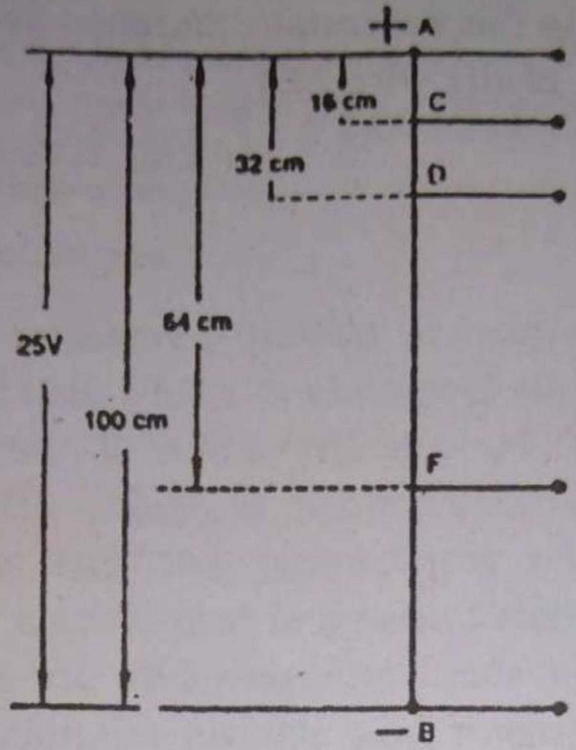


Fig. 15.18

15.11 A potentiometer is set up to measure the emf, E_x of cell (Fig. 15.19). The potentiometer wire is 120 cm long. E_s is the emf of a standard

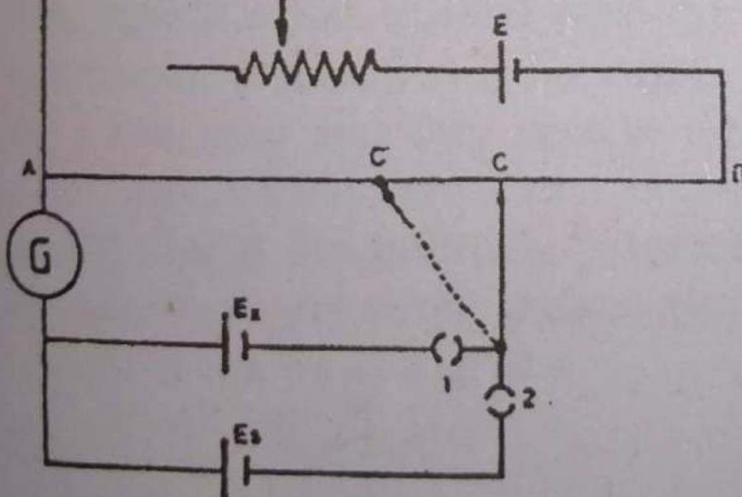


Fig. 15.19

cadmium cell equal to 1.018 volts. When the key 1 only is closed to include the emf E_x in the galvanometer circuit, the galvanometer gives no deflection with the sliding contact at C,56.4 cm from A. When the key 2 only is closed to include the emf E_s in the galvanometer circuit, the balance is obtained at C′,43.2 cm from A.

(a) What is the emf E_x of the cell?

(b) What is the potential difference across the entir length of the wire AB?

(Ans.(a) 1.329V (b) 2.828