Chapter - 6

Electric Circuit

In previous Chapter we studied Ohm's law and series and parallel combination of resistors. In simple electric circuit, electric current and potential difference can be calculated by using Ohm's law. In complicated electric circuits (in which so many resistors and cells are connected in a complex way) to calculate electric current and potential difference, German scientist Robert Kirchhoff gave two laws. In this chapter we will study Kirchhoff's Laws and their uses, Wheatstone bridge and potentiometer is a device used to measure potential difference accurately and its applications.

6.1 Kirchhoff's laws

Junction is a point where three or more than three branches of a circuit meet. In a network of electric circuit in which electric current remains constant is called a branch. A closed circuit consisting of different conductors, resistances and other elements is called a loop or mesh. For complex electric circuits, Kirchhoff's laws are as follows.

6.1.1 Kirchhoff's first law or junction law

According to this law, the algebraic sum of electric currents meeting at a junction is zero.

i.e. $\sum I = 0$

Thus, we can say that the sum of electric currents entering at the junction is equal to the sum of electric currents leaving the junction. This law is known as *Kirchhoff's first law or junction law.*

This law is based on the conservation of charge. In electric circuits, at any junction charge can not be accumulated or generated. Thus, at junctions, the rate of entering charge is equal to rate of leaving charge.

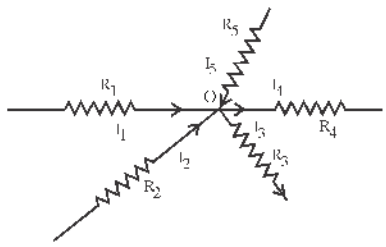


Fig 6.1 Kirchhoff's junction law

In Fig (6.1) at junction O, according to this law,

$$I_1 + I_2 - I_3 - I_4 + I_5 = 0$$

or $\quad I_1 + I_2 + I_5 = I_3 + I_4 \quad \ldots (6.1)$

6.1.2 Kirchhoff's second law or loop law:

Kirchhoff's loop law is applicable for closed electric circuits. Hence, it is called loop rule. According to this rule, for a circuit consisting of resistances and cells. The agebraic sum of voltages in a circuit is zero.

$$\sum V = 0 \quad \ldots (6.2)$$

This law can be represented in a different form as follows.

In any closed loop algebraic sum of potential difference across resistors will be equal to the algebraic sum of emf of cells used.

Thus, $\quad \sum IR = \sum \varepsilon \quad \ldots (6.3)$

While using equation (6.3) following sign conventions are used.

1. In any circuit if we move in the direction of current potential difference across resistance is considered to be positive. If we move in the opposite direction of current, potential differences are considered to be negative.
2. If we move in the circuit in assigned direction of current and move from negative electrode to the positive electrode of a cell, then emf is considered to be positive. Similarly, in the circuit if we move from positive electrode to negative electrode of the cell is considered to be negative.

Kirchhoff's loop rule is based on the law of conservation of energy. Loop rule can be explained by the example given in Fig 6.2

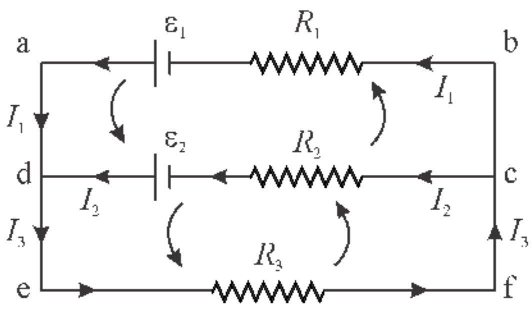


Fig 6.2 A closed circuit

In the given figure, apply junction rule at junction $'d'$. Current in resistance R_3 will be,

$$I_3 = I_1 + I_2 \qquad \ldots (6.4)$$

Applying loop rule for ' a d c b a' loop,

$$I_1R_1 - I_2R_2 = \varepsilon_1 - \varepsilon_2$$

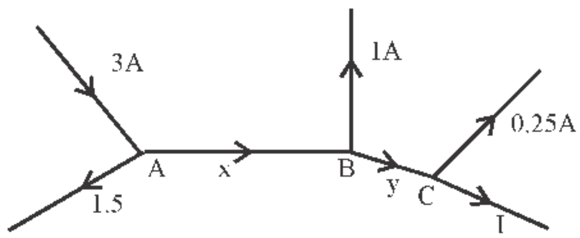
or $$I_2R_2 - I_1R_1 = \varepsilon_2 - \varepsilon_1 \qquad \ldots (6.5)$$

Applying loop rule for '$defcd$' loop,

$$I_3R_3 + I_2R_2 = \varepsilon_2 \qquad \ldots (6.6)$$

On simplifying equations (6.4), (6.5) and (6.6), we can calculate current in different branches and potential difference across different resistances. We will understand these rules by few solved examples.

Example 6.1 : Find the value of I in the network as shown in the figure,



Solution : Let the current through the branches AB and BC are x and y respectively. Using Kirchhoff's junction law, we have,

At junction $3 - 1.5 - x = 0$

or $x = 1.5\,A$

At junction B, $1.5 - y - 1 = 0$

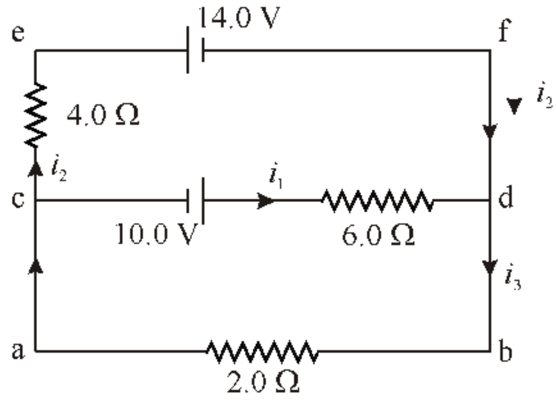
or $y = 0.5\,A$

Similarly, at junction C,

$$0.5 - 0.25 - I = 0$$

or $I = 0.25A$

Example 6.2 : Find the values of currents in the circuit using Kirchhoff's law in the network are given below,



Solution : In the given circuit i_1, i_2 and i_3 are three unknown currents. For calculating these unknowns, we need three equations.

Using junction law at junction C we have,

$$i_3 = i_1 + i_2 \qquad \ldots (\text{i})$$

Using loop law in loop $'acdba'$ we have,

$$+2i_3 + 6i_1 = +10$$

or $$6i_1 + 2i_3 = 10$$

Putting the value of i_3 from equation (i)

$$8i_1 + 2i_2 = 10 \qquad \ldots (\text{ii})$$

Using loop law in loop $'cdfec'$ we have,

$$6i_1 - 4i_2 = 10 + 14$$

or $$6i_1 - 4i_2 = 24 \qquad \ldots (\text{iii})$$

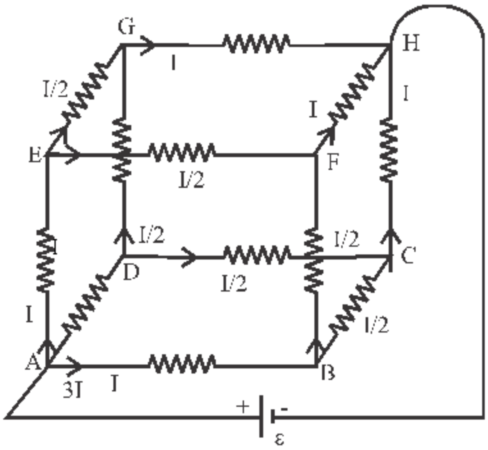
By solving equation (ii) and (iii)

$$i_1 = 2\,A\,,\; i_2 = -3A$$

By putting the value of i_1 and i_2 from equation (i) we get, $i_3 = -1A$

Note : Negative sign of i_2 and i_3 in the solution indicates that their directions will be opposite to the directions shown in the figure 6.2.

Example 6.3 : A battery of emf 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of resistance 1 Ω. Determine the equivalent resistance of the network and the current along each wire of the cube.



Solution : The paths AE, AB and AD are obviously symmetrically placed in the network. Thus, the current in each of these wires must be same. Further, at the corners E, D and B the incoming current I must divide equally into the outgoing branches. In this manner, the current in all the 12 wires of the cube can easily be written in terms of I using Kirchhoff's first law and the symmetry of the problem.

Next, take a closed loop ABCHA and apply Kirchhoff's second law.

$$IR+\frac{I_2R}{2}+IR=\varepsilon$$

or $\varepsilon = \frac{5}{2}IR$ . . . (i)

Here, ε is the emf of the cell and R is the resistance of each edge of the cube.

Total current drawn from the battery is 3I, therefore the equivalent resistance of the Cubical network is,

$$R_{eq}=\frac{\varepsilon}{3I} \qquad \text{. . . (ii)}$$

Put the value of ε from (i) to eq. (ii),

$$R_{eq}=\frac{5}{6}R$$

According to the question $R = 1\Omega$,

Therefore, $R_{eq}=\frac{5}{6}\Omega$

Emf of the cell is given as $E = 10V$, therefore, using equation (ii),

$$3I=\frac{\varepsilon}{R_{eq}}=\frac{10}{3\frac{5}{6}}=4\ A$$

Therefore, the current through each edge of the cube can be calculated from the given figure.

6.2 Wheatstone Bridge:

In 1942, English scientist Prof. C.F. Wheatstone, joined four resistances, one cell and one galvanometer to make a special type of circuit as shown in the figure 6.3. It is known as Wheatstone Bridge. This circuit is used to determine the value of some unknown resistance.

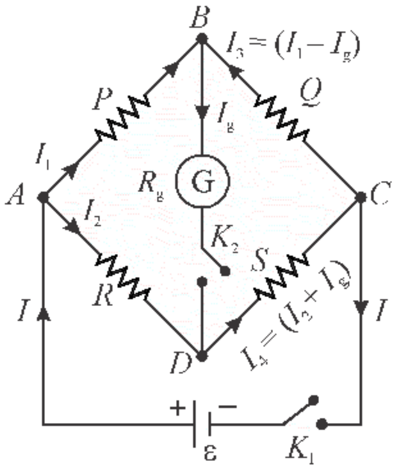


Fig 6.3 Wheatstone Bridge

Construction :

Arrangement of Wheatstone Bridge is shown in the figure (6.3). In this circuit two resistances P and Q are connected in series and remaining two resistances R and S are also connected in series. These two series combinations are connected in parallel. In this way a quadrilateral arrangement is formed between A and C. A cell of emf ε is connected between these terminals along with a key K_1 whereas a galvanometer is connected between the terminals B and D along with key K_2. Keys K_1 and K_2 are used to allow current in the circuit.

Resistance arms P and Q are called ratio arms and the arm AD in which known resistance R is connected is called known resistance arm. The arm CD in which unknown resistances is connected is called unknown resistance arm. Arm AC in which cell is connected is called cell arm. Arm BD in which galvanometer is connected is called galvanometer arm.

6.2.1 Principle of Wheatstone Bridge and condition of Balance :

When key K_1 is closed, current I is flowing and it divides into two parts at junction A. Current through branch AB is I_1 and current through branch AD is I_2. When key K_2 is closed, galvanometer gives deflection. When $V_B > V_D$, then the current in galvanometer flows from B to D. Potentials at points B and D are V_B and V_D. The values of V_B and V_D depends on the values of resistances of the arms. Now we select the resistances in Wheatstone's bridge such that galvanometer gives no deflection and this is called balanced condition. In this condition, potentials at B and D are equal i.e. $I_1 = I_3$ and $I_2 = I_4$. In this condition (refer to figure 6.3)

$$V_B = V_D \quad (I_g = 0) \qquad \ldots (6.7)$$

or $$V_A - V_B = V_A - V_D$$

According to Ohm's law $I_1 P = I_2 R \qquad \ldots (6.8)$

Similarly, $V_B - V_C = V_D - V_C$ (from eq.6.7)

According to Ohm's law, $I_3 Q = I_4 S$

$$I_1 Q = I_2 S \;\; (\; I_1 = I_3 \text{ and } I_4 = I_2) \qquad \ldots (6.9)$$

Dividing equations (6.8) and (6.9)

$$\frac{I_1 P}{I_1 Q} = \frac{I_2 R}{I_2 S}$$

or $$\frac{P}{Q} = \frac{R}{S} \qquad \ldots (6.10)$$

Equation (6.10) is the condition of balanced Wheatstone bridge. It is clear from this equation that in the balanced condition the ratio of resistances in ratio arms is same.

From equation (6.10), unknown resistance can be calculated,

$$S = \frac{Q}{P} R \qquad \ldots (6.11)$$

To determine the value of unknown resistance we connect it in 4th arm of the bridge. Known resistances P and Q are connected in 1st and 2nd arm of the bridge. Known resistance R is adjusted such that galvanometer gives no deflection. Thus, balanced condition is obtained for Wheatstone bridge.

For Wheatstone bridge to be sensitive resistances of all the four branches must be of same order.

6.2.2 Balancing Condition of Wheatstone Bridge using Kirchhoff's Laws

Using Fig (6.4) we can derive the condition of balance of Wheatstone bridge using Kirchhoff's laws. Let the current in the galvanometer be I_g and the its resistance be R_g.

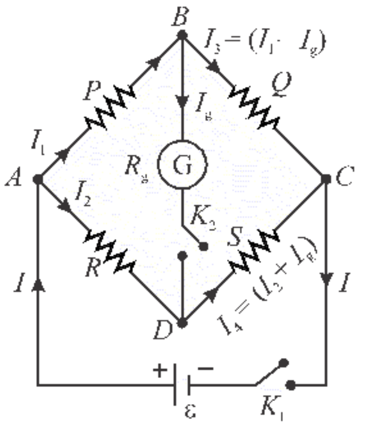


Fig 6.4 Wheatstone Bridge

Apply Kirchhoff's loop rule (Voltage law) in the loop '$abda$'.

$$I_1 P + I_g R_g - I_2 R = 0 \qquad \ldots (6.12)$$

Similarly, apply Kirchhoff's loop rule (Voltage law) in the loop '$bcdb$'.

$$(I_1 - I_g)Q - (I_2 + I_g)S - I_g R_g = 0 \qquad \ldots (6.13)$$

In the balancing condition of the bridge, $I_g = 0$,

Hence from the equations (6.12) and (6.13) we get,

$$I_1 P - I_2 R = 0$$

$$I_1 P = I_2 R \qquad \ldots (6.14)$$

and $$I_1 Q - I_2 S = 0$$

$$I_1 Q = I_2 S \qquad \ldots (6.15)$$

From equations (6.14) and (6.15), we get,

$$\frac{P}{Q} = \frac{R}{S} \qquad \ldots (6.16)$$

Which is the condition of balanced Wheatstone bridge.

6.3 Meter bridge:

Meter bridge is based on the principle of Wheatstone bridge. Meter bridge is a device which consists of a one-meter long resitance wire with uniform cross section. It is used to determine unknown resistance. Outline of the meter bridge is shown in the figure (6.5).

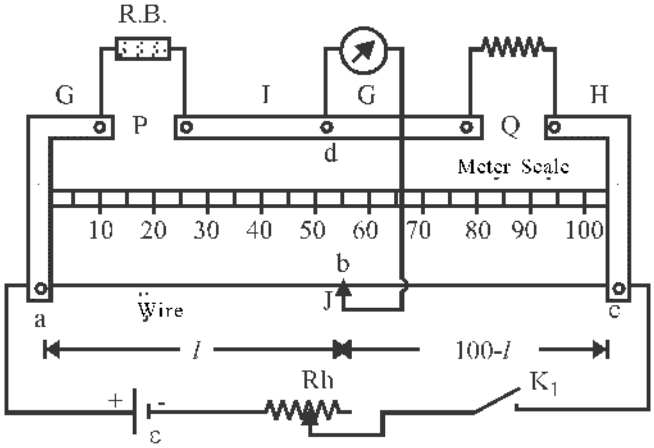


Fig. 6.5 Meter bridge

Construction : A one-meter long constantan or magainin resistance wire is stretched between two screws *a* and *c*. A meter scale is also fixed over the wooden board along the length of wire. Two L shaped copper strips G and H are also joined to the screws a and c. Another copper strip I is also placed between the strips G and H such that a proper gap exists between G and H with I. An unknown resistance S is connected across the gap between I and H strip. A known resistance R is connected across the gap between G and I. J is a sliding key that can be slided on the wire ac, the point of contact of the key, b on the wire divides the wire into arms ab and bc.

Working Principle : In the gaps of meter bridge a resistance box is connected in the left gap and unknown resistance is connected between the right gap with the help of nuts (A nut is a fastened with a threaded hole). In between the points A and C, a leclanche cell, a rheostat and key K are connected. In between d and sliding jockey J, a galvanometer is connected. In this position, meter bridge works as Wheatstone bridge. Now, remove certain plug from the resistance box. To check the correctness of connections, hold the jockey first near the end 'a' of the meter bridge wire and then near the end 'c' of the wire. If the galvanometer shows opposite deflection at the 'a' and 'c' ends of the wire then the connection is said to be correct. Otherwise, choose appropriate resistance R from the resistance box to get this condition. Once we are sure about the correctness of the connections, then slide the jockey over the meter bridge wire and find the null point. Suppose the galvanometer shows the null point when the jockey is at the position b. This is the balanced condition of Wheatstone bridge. At point b if it shows zero deflection, then the part of wire ab works as resistance P and the part 'bc' works as resistance Q .

$$\frac{P}{Q} = \frac{R}{S} \qquad \ldots (6.17)$$

Let point b is at a distance ℓ from the point a. Let R_{cm} be the resistance per unit length of the wire then the resistance of section P of the wire will be $R_{cm}\,\ell$ and that of the section Q of the wire will be $R_{cm}(100 - \ell)$. If the resistance of these sections is P and Q then,

P = resistance of section ab of wire = $R_{cm}\,\ell$ And Q = resistance of section bc of wire = $R_{cm}(100 - \ell)$. By substituting the values of P and Q in equation (6.17) we get,

$$\frac{R}{S} = \frac{R_{cm}\ell}{R_{cm}(100-\ell)}$$

or $$S = \left(\frac{100-\ell}{\ell}\right)R \qquad \ldots (6.18)$$

Knowing the values of l and R we can get the value of unknown resistance. Meter bridge will be sensitive if the null point is obtained near the middle point of the wire.

Limitations of meter bridge :

(i) In the derivation of the formula for meter bridge we have considered the resistance of copper plates (G, H and I) as negligible. But actually, these copper plates do have some resistance due to which there will be error in the result. To eliminate this error, we interchange the position of resistance box and unknown resistance S and then calculate the value of unknown resistance and take the mean of these values to minimise the error.

(ii) Due to the resistance of end points of the meter bridge wire, the sensitivity of the experiment is affected. To eliminate this effect we use, Carey Foster's bridge.

(iii) Do not pass electric current in the meter bridge for a long time otherwise the wire will be heated up due to which the resistance of meter bridge wire will get changed.

(iv) We should not slide the jockey by rubbing over the meter bridge wire, otherwise the uniformity of the area of cross section of wire (and there by the resotance per unit length of the meter bridge wire) will be affected.

Example 6.4 : In an experiment of meter bridge, a resistance of 8Ω is taken out from the resistance box to get a null deflection position at 45.5 cm. Calculate (a) value of unknown resistance, (b) New balance length on interchanging the positions of resistance box and unknown resistance.

Solution : Using meter bridge principle,

$$S = R\left(\frac{100-\ell}{\ell}\right)$$

Here, $R = 8\,\Omega,\ \ell = 45.5\,\text{cm}$

Hence, $S = 8\left(\frac{100-45.5}{45.5}\right)$

$$= 8 \times \frac{54.5}{45.5}$$

$$S = 9.58\,\Omega$$

(b) On interchanging the positions of resistance box and unknown resistance, the new balance point will be $(100-45.5) = 54.5$ cm

6.4 Potentiometer :

Potentiometer is an ideal experimental device or arrangement which is used to measure the emf of a cell or potential difference between any two points in a circuit. In no deflection condition no current will be drawn from the circuit. Therefore, its measurement will be accurate. Potentiometer works as a voltmeter of infinite resistance (i.e. ideal voltmeter). It can be understood by the following fig (6.6)

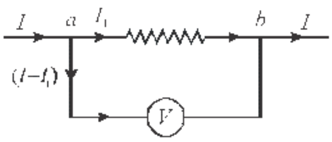


Fig: 6.6 Measurement of potential difference

In figure (6.6), a voltmeter is connected across a current carrying resistance for measuring potential difference. A fraction of current is drawn by the voltmeter due to its own resistance. As a result, the potential difference across the ends a and b of the resistance is observed slightly less than the actual potential difference. Due to this measured potential difference will be less than actual potential difference.

This error in potential difference can be reduced to zero if we use an ideal voltmeter of infinite resistance. But in realistic situation it is not possible at all.

In case of balanced condition, no current is drawn by the potentiometer from the circuit. In state of no deflection, it works as a voltmeter of infinite resistance. So, we can say, that potentiometer is an ideal device to measure potential difference in comparison to voltmeter.

6.4.1 Construction of Potentiometer

Fig 6.7 shows a potentiometer. Mainly potentiometer wire is made up of magainin, eureka, constantan like alloys. The specific resistance of these materials is very high and the temperature coefficient is very low.

It consists of a 10-meter-long resistance wire of uniform cross section area spread over a wooden plank in 10 equal parts each with a length of one meter. The ends of wire are connected across the connecting terminals A and B. A meter scale is also fixed over the wooden plank parallel to the length of the wire. A sliding jockey J is also capable to slide along the wire with the help of a rod which is fixed over the wooden plank. By pressing the jockey, we can establish the electric connection to any wire of the potentiometer wire (Remember, there are 10 wires). The position of the jockey can be determined with the help of meter scale.

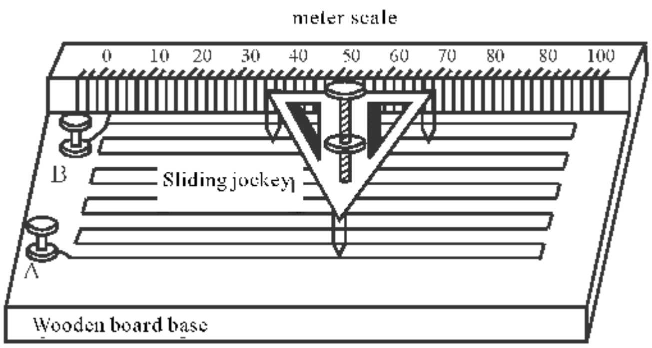


Fig: 6.7 Construction of potentiometer

6.4.2 Principle of Potentiometer

The principle of a potentiometer is that the potential dropped across a segment of a wire of uniform cross-section carrying a constant current is directly proportional to its length. To determine an unknown potential difference (or emf) it is compared with a known potential difference distributed uniformly over the poteniometer wire. In condition of no deflection the unknown potential difference is equal to the known potential difference. This is known as the principle of potentiometer.

To understand this, an electric circuit is made as shown in the figure (6.8). Now we connect a battery of emf ε_P, a key K_1 and a rheostat R_h in series with the potentiometer wire AB. This circuit is called primary circuit of potentiometer. In the secondary circuit, positive terminal of cell ε of emf E is connected to positive terminal A of the potentiometer and negative terminal of the cell is connected to jockey through a galvanometer.

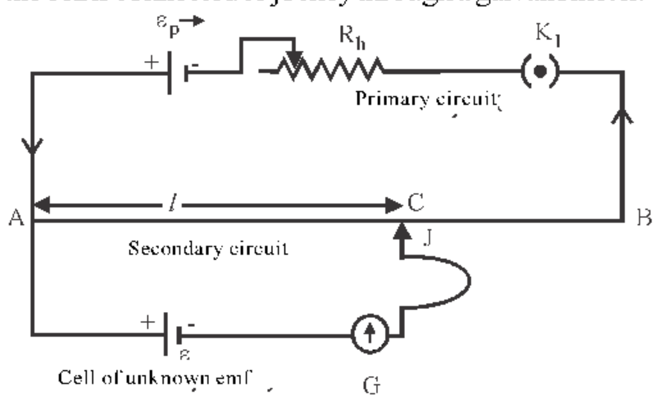


Fig. 6.8 Potentiometer circuit

Here, it is essential that the emf of cell in secondary circuit must be less than the emf of battery in the primary circuit. If in the primary circuit resistance of the rheostat is very low or zero then whole emf ε_P of the battery is uniformly distributed over the potentiometer wire AB. Here, it is considered that potentiometer wire AB has uniform area of cross section. If length of potentiometer wire AB is L, emf of the battery is ε_P then it is uniformly distributed all over the length of potentiometer wire. This fall of potential per unit length is called potential gradient, it is represented by x, thus,

$$x = \frac{\varepsilon_P}{L} \qquad \ldots (6.19)$$

The SI unit of potential gradient is volt/m,

Hence, $\varepsilon_p = V_{AB} = xL$

If the resistance of potentiometer wire is R and the current flowing in the potentiometer wire is I, then,

$$V_{AB} = IR \qquad \ldots (6.20)$$

From Eq (6.19) we get

$$x = I\frac{R}{L} \qquad \ldots (6.21)$$

or $$x = IR_m \qquad \ldots (6.22)$$

Here, $R_m = \frac{R}{L} =$ is the resistance per unit length of the potentiometer wire.

Now we consider some point on the potentiometer wire at a distance l from terminal A, then the potential difference between A and C will be given by.

$$V_{AC} = x\ell \qquad \ldots (6.23)$$

Here we know the value of x and ℓ, therefore, V_{AC} is known potential difference, the value of ℓ is variable, therefore $V_{AC} \propto \ell$. Now by placing jockey at point C on potentiometer wire. If galvanometer gives zero deflection which is called null deflection point and its length from point A, $AC = \ell$ is called balancing length on potentiometer wire for emf ε. In this situation, unknown emf ε will be equal to known potential difference V_{AC} on potentiometer wire.

$$\varepsilon = V_{AC} = x\ell \qquad \ldots (6.24)$$

This is known as principle of potentiometer.

Note : We get two situations if we press jockey J at points C_1 and C_2 shown in the figure (6.9)

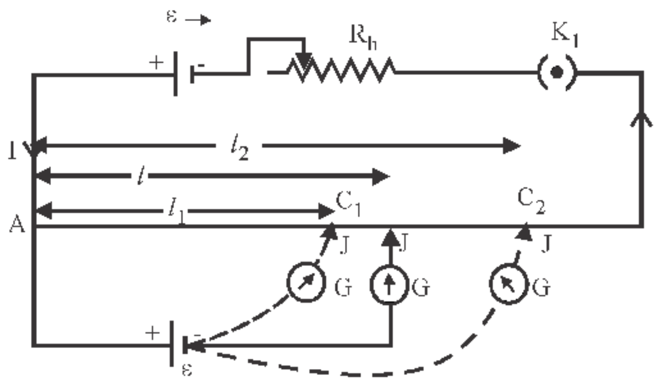


Fig 6.9 Working principle of potentiometer

(i) If, jockey is kept at C_1 and $AC_1 = \ell_1$ in this situation $V_{AC_1} < \varepsilon$, due to which the resultant current flows in sense AC_1, G ε A i.e. clockwise. Thus, the galvanometer shows deflection.

(ii) If we press jockey J at point C_2 then $AC_2 = \ell_2$ at this condition $V_{AC_2} > \varepsilon$. Due to this resultant flow in the secondary circuit is anticlockwise i.e. opposite to what in case (i) ($A\varepsilon GC_2A$). From equation (6.22).

Some important relations for potential gradient,

$$x = IR_m \qquad \ldots (6.25)$$

If in the primary circuit of potentiometer, R' is the external resistance and r is the internal resistance of cell then,

$$I = \frac{\varepsilon_P}{R + R' + r} \qquad \ldots (6.26)$$

Using Eq. (6.25) and (6.26) we get,

$$x = \left(\frac{\varepsilon_P}{R + R' + r}\right)\frac{R}{L}\left(\because R_m = \frac{R}{L}\right) \ldots (6.27)$$

If, $r = 0, R' = 0$, then from eq (6.22) we get the same value as in eq (6.19)

$$x = \frac{\varepsilon_P}{L} \qquad \ldots (6.28)$$

$$x = I\frac{R}{L}$$

If specific resistance of potentiometer wire is ρ and area of cross section is A, then,

$$\left(R = \rho\frac{L}{A}\right)$$

$$x = \frac{I\rho}{A} \qquad \ldots (6.29)$$

If r is the radius of potentiometer wire, then,

$$x = \frac{I\rho}{\pi r^2} \qquad (\because A = \pi r^2) \qquad \ldots (6.30)$$

Thus, we conclude that,

(i) Potential gradient is directly proportional to current I and specific resistance ρ and inversely proportional to area of cross section A of the wire.

(ii) Apparently, the value of potential gradient (x) depends on the emf of the battery connected in the primary circuit, length of the wire and internal resistance of the battery,

(iii) If $r = 0$ and $R' = 0$, then the potential gradient x does not depend on the area of cross section, material of wire and resistance of wire.

6.4.3 Precautions with Potentiometer:

(i) The emf of cell used in primary circuit should be greater than the emf of cell in the secondary circuit otherwise we will not get the situation of null deflection.

(ii) Positive terminals of all the cells must be connected to point A.

(iii) Balanced length is always measured from point A which is at higher potential.

(iv) The potentiometer wire must be of uniform cross section otherwise the value of potential gradient x will not be same at all positions.

(v) In potentiometer wire, current should not be passed over a long-time otherwise wire will get heat up which will change the resistance of the wire and therefore potential gradient will not remain constant.

6.4.4 Standardisation of Potentiometer

In previous section, we studied that potential gradient of potentiometer depends on the emf of cell in primary circuit and its internal resistance and other resistances connected in series with potentiometer wire. In general, the values of these resistances are not known. Hence, potential gradient can be calculated by indirect method. **The procedure of finding the exact potential gradient of potentiometer is called standardisation.**

For standardisation of a potentiometer a standard cell of known emf is connected in the secondary circuit of potentiometer as shown in the fig (6.10). Standard cell is that cell whose emf remains constant for a long time and it can be known precisely. For standardisation we use Cadmium Cell or Danial Cell as standard cell. The values of emf of Cadmium Cell and Danial Cell are 1.0186 V and 1.08 V respectively.

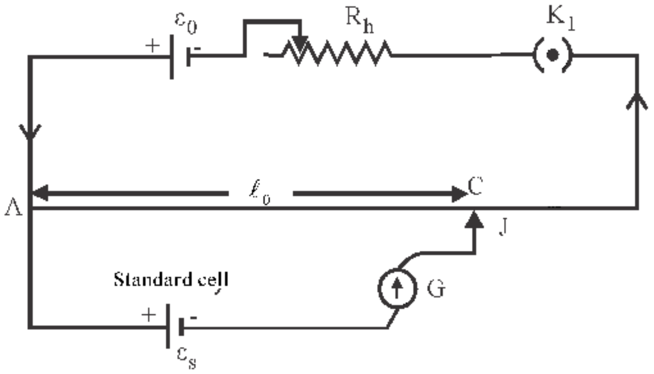


Fig 6.10 Standardisation of Potentiometer

To find the potential gradient of potentiometer with the help of a standard cell by placing a sliding jockey on the potentiometer wire and the balancing length ℓ_0 is determined at this time, (Galvanometer shows zero deflection). If emf of standard cell is ε_s, then, according to the principle of potentiometer

$$\varepsilon_s = x\ell_0$$

or $$x = \frac{\varepsilon_s}{\ell_0} \qquad \ldots (6.31)$$

Here, it is to be kept in mind that after standardisation, there should not be any change in primary circuit otherwise x will change.

6.4.5 Sensitivity of potentiometer

By sensitivity of potentiometer we mean, its ability to measure accurately small value of emf or small value of potential difference. The sensitivity of potentiometer depends on the fall of potential per unit length on the potentiometer wire or potential gradient. Smaller the value of potential gradient, larger will be the sensitivity of potentiometer.

Because balancing length ℓ is measured directly with the help of potentiometer hence. If the value of ℓ is larger then the percentage error in its measurment will be less. Hence, potentiometer is more sensitive if x is small.

$(\because E = x\ell)$

We can increase the sensitivity of potentionmeter (or decrease x).

(i) By increasing the length (L) of potentiometer wire.

(ii) By decreasing electric current in primary circuit.

By decreasing electric current in primary circuit, potential difference across potentiometer wire will also decrease.

Thus, it is better to enhance the sensitivity of potentiometer by increasing the length rather than decreasing the current in primary circuit, Due to this reason the length of potentiometer wire is taken very large.

Example 6.5 : In the primary circuit of a potentiometer experiment, a battery of emf 2.2 V and internal resistance r = 1Ω is connected. If the resistance of rheostat in the primary circuit lies in the range (0-20Ω) and length and resistance of potentiometer wire are 10 m and 20 Ω respectively. Find the minimum and maximum values of the potential gradient.

Solution :

$$x = \frac{\varepsilon_p}{R + r + R'} \times \frac{R}{L}$$

Here,

ε_p = emf of the battery in primary circuit=2.2 V

R = Resistance of the potentiometer wire=20Ω

r = internal resistance of battery=1.0 Ω

L = Length of potentiometer wire=10m

R' – Range of rheostat (0-20Ω)

For minimum value of x, the value of R' should be maximum. Hence R'=20Ω

$$x_{\min} = \left(\frac{2.2}{20+1+20}\right) \times \frac{20}{10}$$

$$= \frac{2.2}{41} \times \frac{2}{1} = \frac{4.4}{41} = 0.11 \text{ V/m}$$

Similarly,

$$x_{\max} = \left(\frac{2.2}{20+1+0}\right) \times \frac{20}{10} = \frac{4.4}{21} = 0.21 \text{ V/m}$$

Example 6.6 : The area of cross section of potentiometer wire is $0.8 \times 10^{-6}\ m^2$ and it has specific resistance $40 \times 10^{-8}\ \Omega m$, If the current through the wire is 0.2 A. Calculate the value of potential gradient.

Solution : The potential gradient is,

$$x = \frac{I\rho}{A}$$

Here, $I = 0.2\ A$,

ρ = specific resitance of wire

$= 40\times10^{-8}\ \Omega m$

$A = 0.8\times10^{-6}\ m^2$

On substituting values

$$x = \frac{0.2\times40\times10^{-8}}{0.8\times10^{-6}} = 0.1\ \text{V/m}$$

6.5 Uses of Potentiometer :

6.5.1 Determination of Internal Resistance of a Primary Cell

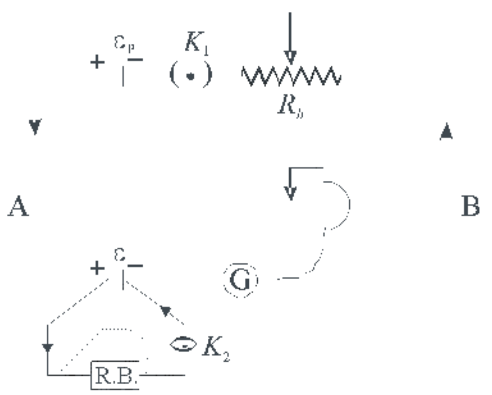


Fig 6.11 Determination of Internal Resistance of a Cell

Circuit Arrangements : A circuit is arranged as shown in the figure 6.11. Primary circuit is made up by joining a battery of emf ε_p, a rheostat R_h and a plug key K_1 in series with the potentiometer wire. To make secondary circuit, positive terminal of cell whose internal resistance is to be measured is connected to the higher potential point A of the potentiometer wire and the negative terminal of the cell is connected to the sliding jockey J through the galvanometer. A resistance box and a plug key K_2 is connected parallel to the cell.

Working Principle : First of all, by keeping primary cell of emf ε in open circuit (i.e. Keeping plug key K_2 open) balance point is obtained by sliding the jockey. Let the balancing length in this case be ℓ_1. If the potential gradient is x, then according to the principle of potentiometer,

$$\varepsilon = x\ell_1 \qquad \ldots(6.32)$$

Next, without changing the configuration of the primary circuit, plug key K_2 is closed, and some resistance R is inserted in the resistance box. The potential drop V across the resistance box is balanced on the potentiometer wire. And balancing length ℓ_2 is obtained with the help of sliding jockey J.

$$V = x\ell_2 \qquad \ldots(6.33)$$

We know, if r is the internal resistance of the cell and I is the current through the resistance R, then,

$$\varepsilon = V + Ir$$

or $$r = \frac{\varepsilon - V}{I}$$

or $$r = \left(\frac{\varepsilon - V}{V}\right)R \qquad (\because\ V = IR) \qquad \ldots(6.34)$$

From eq. (6.32), (6.33) m and (6.34) we get,

$$r = \left(\frac{x\ell_1 - x\ell_2}{x\ell_2}\right)R$$

or internal resitance $= r = \left(\frac{\ell_1 - \ell_2}{\ell_2}\right)R \qquad \ldots(6.35)$

By substituting the values of ℓ_1 and ℓ_2, internal resistance of the primary cell can be determined. For varying the values of R, different values of ℓ_2 are recorded and corresponding values of r are calculated. We see that in all observations the value of r is different. i.e. internal resistance depends on the current drawn from the cell. Thus, while measuring the internal resistance, we should not take the average of the values of r. We must state that, the internal resistance varies between minimum value to maximum value.

Example 6.7 : A battery of emf 2.0 V and internal resistance 2.0 Ω is connected in the primary circuit of the potentiometer of wire of length 10 m and resistance 10 Ω. The emf of primary cell is balanced at 5.0 m length of potentiometer wire. When a current of 0.1 A is drawn from the cell then terminal voltage of the cell is balanced at a length of 4.0 m of potentiometer wire. Find the internal resistance of the cell.

Solution :

$$x = \left(\frac{\varepsilon_p}{R + r}\right)\times\frac{R}{L}$$

$R = 10\,\Omega$

$L = 10\,m$

$\varepsilon_p = 2V$

$r = 2\Omega$

$$x = \left(\frac{2}{10+2}\right) \times \frac{10}{10} = 0.17\,V/m$$

Internal resistance of cell,

$$r = \frac{\varepsilon - V}{I} = \frac{x\ell_1 - x\ell_2}{I}$$

or $$r = \frac{x(\ell_1 - \ell_2)}{I}$$

Here, $\ell_1 = 5.0\,m$, $\ell_2 = 4.0\,m$, $I = 0.1\,A$

After putting the values, we get,

$$r = \frac{0.17(5.0 - 4.0)}{0.1} = \frac{0.17 \times 1}{0.1} = 1.7\,\Omega$$

6.5.2 Comparison of Electro Motive Forces of Two Cells

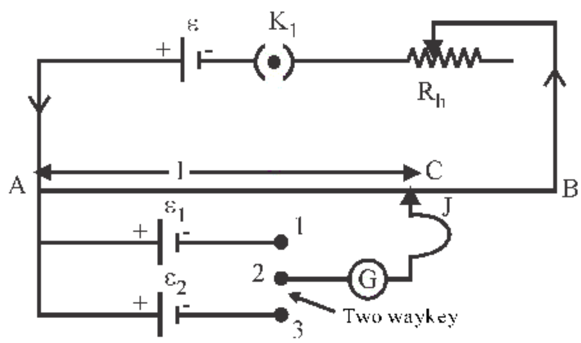


Fig. 6.12 Comparison of emf of two cells

Circuit Arrangements : Circuit is completed as given in the Figure 6.12. Primary circuit is made as explained in previous section. For preparing secondary circuit positive terminal of both cells whose emfs are to be compared are connected to the higher voltage end (i.e. A) of the potentiometer wire. If negative terminals of these cells are connected to terminal 1 and 3 of two-way key. Terminal 2 of the two-way key is connected to sliding jockey through galvanometer.

Working : First of all, switch on the primary circuit by inserting the plug of key K_1. Now insert the plug between terminals 1 and 2 of the two-way key and determine the balancing length ℓ_1 by sliding jockey over the potentiometer wire, for the cell of emf ε_1.

$$\varepsilon_1 = x\ell_1 \qquad ...(6.36)$$

Here x is the potential gradient.

Without disturbing the primary circuit remove the plug between 1 and 2 and insert the plug between terminals 2 and 3 of the two-way key and determine the balancing length ℓ_2 by sliding jockey over the potentiometer wire, for the other cell of emf ε_2

$$\varepsilon_2 = x\ell_2 \qquad ...(6.37)$$

On dividing eq. (6.36) by eq. (6.37), we get

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{x\ell_1}{x\ell_2}$$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2} \qquad ...(6.38)$$

Hence, ratio of emf of cells is equal to the ratio of the corresponding balancing lengths. By changing the value of resistance of rheostat in the primary circuit (i.e. changing the value of potential gradient x), various values of balancing lengths ℓ_1 and ℓ_2 are obtained. In this way various ratios $\varepsilon_1/\varepsilon_2$ are calculated and the mean value is reported.

In this experiment standardisation is not necessary. In laboratory, Leclanche cell is taken as first cell and the Denial cell is taken as the second cell.

If one of the cells is standard cell, then the emf of the second cell can be calculated by using the following formula,

$$\varepsilon_2 = \left(\frac{\ell_2}{\ell_1}\right)\varepsilon_1 \qquad ...(6.39)$$

6.5.3 Measurement of Small resistance :

The essential circuit for measurement of small resistance is as shown in the figure (6.13). The primary circuit of potentiometer is completed in accordance with the previous section as shown in the figure. An unknown low resistance r is connected in series with known high resistance R, Rheostat R_{h_2} the battery of emf ε' and key K_2 is connected in secondary circuit of the potentiometer. Higher potential point of potential difference across resistance R is connected to higher potential point A of potentiometer wire. The low potential ends of the resistances R and r are connected to the terminals 1 and 3 of the two-way key. The terminal 2 (middle terminal) of the two-way key is connected to jockey through a galvanometer.

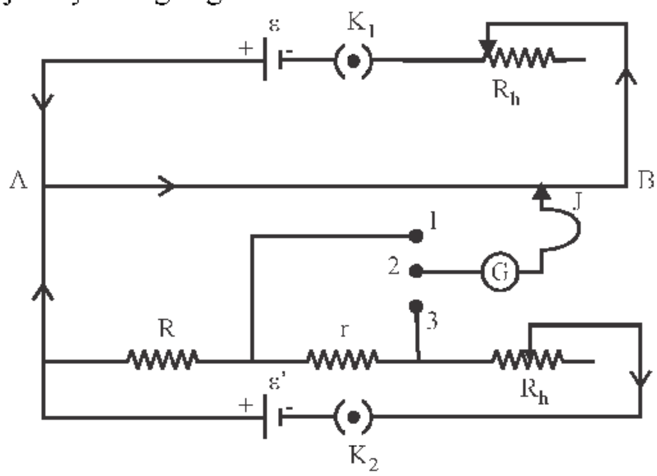


Fig. 6.13 Measurement of small resistance with the help of potentiometer

Working : First of all, we complete the primary circuit by inserting the plug in key K_1 and similarly in secondary circuit by inserting the plug in key K_2. In this condition potentiometer measures potential difference V across the known resistance R. If the current in secondary circuit is I and the balancing length for potential difference V is ℓ_1 according to the principle of potentiometer,

$$V = x\ell_1 \qquad \ldots(6.40)$$

as $V = IR$ (Ohm's law)

so $IR = x\ell_1 \qquad \ldots(6.41)$

Now disconnect the connections between the terminals 1 and 2and join terminals 2 and 3. In this case series combination of resistance R and r will be in the circuit of potentiometer.

Let the potential drop across (R + r) is balanced on the potentiometer wire at a length ℓ_2 and this potential difference is V_1, then

$$V_1 = x\ell_2$$

$$V_1 = I(R+r)$$

$$I(R+r) = x\ell_2 \qquad \ldots(6.42)$$

From equations (6,41) and (6.42)

$$\frac{I(R+r)}{IR} = \frac{x\ell_2}{x\ell_1}$$

$$1+\frac{r}{R} = \frac{\ell_2}{\ell_1}$$

$$\frac{r}{R} = \frac{\ell_2}{\ell_1} - 1$$

$$r = \left(\frac{\ell_2-\ell_1}{\ell_1}\right)R \qquad \ldots(6.43)$$

By substituting the values of R, r and ℓ_1 and ℓ_2 in equation (6,43) we get the value of *r*.

Example 6.8 : For finding a low resistance r, it is connected with a high resistance R and constant current is allowed to pass through it. If the balancing lengths for potential drop across the high resistance R and across the two resistances combined in series are 3.2 m and 3.6 m respectively, then find the ratio of R and *r*.

Solution : Let the current passing through the resistances be I. Balancing length for the potential drop across the resistance R is ℓ_1, then,

$$IR = x\ell_1 \qquad \ldots(1)$$

Balancing length for the potential drop across the resistance (R+r) is ℓ_2, then,

$$I(R+r) = x\ell_2 \qquad \ldots(2)$$

$$\frac{R+r}{R} = \frac{\ell_2}{\ell_1}$$

$$\frac{r}{R} = \frac{\ell_2-\ell_1}{\ell_1}$$

Here, $\ell_1 = 3.20m$ and $\ell_2 = 3.60m$

Thus, $\frac{r}{R} = \frac{3.60-3.20}{3.20} = \frac{0.40}{3.20} = \frac{1}{8}$

Thus, $R : r = 8 : 1$

6.5.4 Calibration of Voltmeter :

The voltmeter readings are not accurate due to certain reasons like mechanical faults, non-uniformities in the spacing of marking on the scale, in the spring constant etc. The potentiometer gives the correct value of potentioal difference. *A method to check the correctness of voltmeter reading with the help of potentiometer is called calibration of voltmeter.*

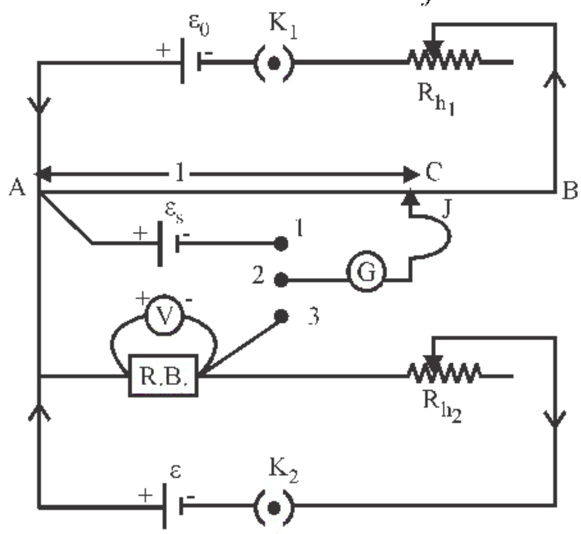


Fig: 6.14 Calibration of voltmeter with the help of potentiometer

The required circuit diagram for voltmeter calibration is shown in the fig 6.14. Primary circuit is completed by joining a battery of emf ε_p, a rheostat R_h and a plug key K_1 in series with the potentiometer wire. In secondary circuit positive terminal of standard cell of emf ε_s is connected to higher potential point (A) of the potentiometer wire AB.

Another cell of emf ε, a rheostat R_{h_2} and a plug key K_2 and resistance box (R.B.) are connected in series. Higher potential point of R.B. is connected to the higher potential point (A) of the potentiometer wire and the low potential point is connected to terminal 3 of the two-way key as shown in the figure. Voltmeter which is to be calibrated is connected in parallel to the resistance box. The middle point (2) of the two-way key is connected to sliding jockey through galvanometer.

Working : First of all, primary circuit is completed as explained in earlier experiments. By inserting plug-in between terminal 1 and 2 of the two-way key, balancing length ℓ_0 is obtained, for the emf of standard cell , then

$$\varepsilon_s = x\ell_0$$

$$x = \frac{\varepsilon_s}{\ell_0} \qquad \text{. . . (6.44)}$$

Here x is the potential gradient. This is known as standardisation of potentiometer. Now removing the plug from the gap between 1 and 2 and inserting it into gap between 2 and 3. Now, closing plug key K_2 we take out appropriate resistance from the resistance box. With the help of rheostat by passing current of desired value such that we obtain some deflection in voltmeter. This voltmeter reading is noted down. This reading is called incorrect reading. To obtain correct reading corresponding to voltmeter reading V, balancing length ℓ_2 is obtained on potentiometer. Then, according to the principle of potentiometer, correct reading will be,

$$V' = x\ell_2$$

$$= \varepsilon_s\left(\frac{\ell_2}{\ell_0}\right) \quad \text{use eq. (6.44)} \qquad \text{. . . (6.45)}$$

Hence, error in the voltmeter reading will be,

$$\Delta V = V - V'$$

With the help of resistance box and varying the value of rheostat R_{h_2}, and adjusting the reading of voltmeter, we can obtain the corresponding correct readings of potential difference. The difference between the voltmeter reading V and potentiometer reading V',

$$\Delta V = V - V'$$

is called error.

A graph is plotted between the error and the voltmeter reading. It is called calibration curve as shown in the figure (6.15). With the help of this graph we can have correct reading for potential difference as $V' = V - \Delta V$.

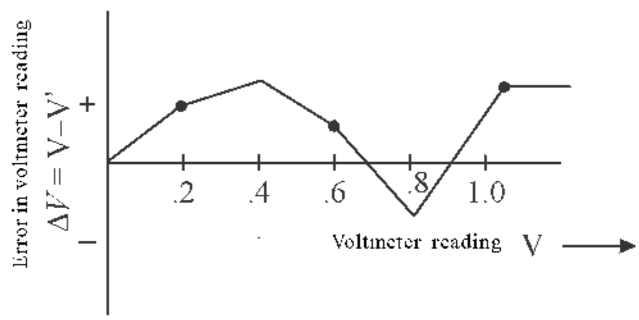


Fig 6.15 Calibration curve of voltmeter

6.5.5 Calibration of ammeter :

A method of checking the correctness of ammeter readings connected in electric circuit with the help of potentiometer is called calibration of ammeter.

The required circuit for calibration of ammeter is shown in the fig 6.16. This circuit is almost similar to the previous circuit used for calibration of voltmeter. Here, the resistance box is replaced by a 1Ω standard resistance coil and in place of voltmeter, an ammeter is connected in series with 1Ω coil. In secondary circuit.

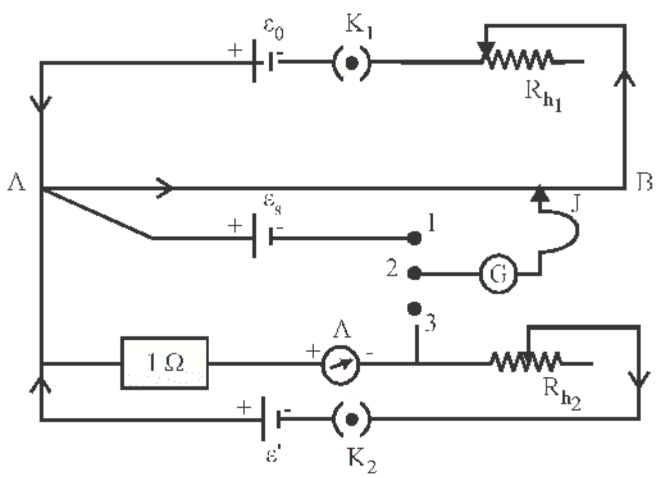


Fig 6.16 Calibration of ammeter

Working : By placing a plug-in key K_2 in the primary circuit and also inserting a plug between the terminals 1 and 2 of the 2-way key, emf ε_s of standard cell is balanced and balancing length ℓ_0 is measured then,

$$\varepsilon_s = x\ell_0$$

$$x = \frac{\varepsilon_s}{\ell_0} \qquad \ldots (6.46)$$

With the help of eq. (6.46), we can determine the value of x. This is called standardisation of potentiometer. Without making any change in the primary circuit (i.e. without disturbing the value of potential gradient, plug is removed from the gap between the terminals 1 and 2, of two-way key and plug is inserted between the terminals 2 and 3. By putting the plug in the plug key K_2, current is made to pass through the secondary circuit. With the help of rheostat R_{h_2}, a desired value of current I is obtained in 1Ω standard resistance coil. This is erroneous value measured by the Ammeter.

According to ohm's law, current flowing through 1 Ω standard resistance coil will be equal to potential difference across its ends. If the balancing length is ℓ_2 and potential difference is V', then,

$$V' = x\ell_2 \text{ but } V' = I'R \text{ or } V' = I' \quad (\because R = 1\Omega)$$

$$I' = x\ell_2$$

or $$I' = \varepsilon_s\left(\frac{\ell_2}{\ell_0}\right) \quad \left(\because x = \frac{\varepsilon_s}{\ell_0}\right) \qquad \ldots (6.47)$$

Here I' is the correct value of current measured with the help of potentiometer. In this way error in the current measured by the ammeter $\Delta = I - I'$ is determined. Next we determined the correct value of ammeter reading with the help of potentiometer for different readings of ammeter and calculate the corresponding errors ($\Delta = I - I'$). A graph is plotted between the error and ammeter reading. It is called calibration curve of ammeter. It may be a Zig-Zag curve (or of any shape).

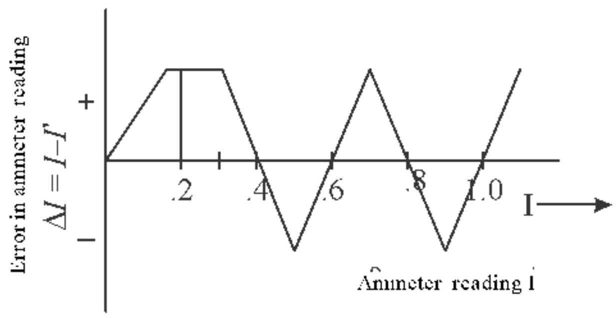


Fig 6.17 Calibration curve.

Now we can determine the correct value of the ammeter with the help of calibration curve as.

$$I' = I - \Delta I \qquad \ldots (6.48)$$

Important Points

1. Kirchhoff's first law is based on the conservation of charge and it is also called as junction rule. According to this law, at any junction algebric sum of the currents is zero. i.e. $\sum I = 0$.
2. Kirchhoff's second law is called voltage law or loop rule. It is based on the law of conservation of energy. According to this law, $\sum V = \sum \varepsilon \Rightarrow \sum IR = \sum \varepsilon$.
3. In balanced condition of Wheatstone bridge, the ratio of ratio arms is equal.
4. Meter bridge is based on Wheatstone bridge. Here of unknown resistance is given by

$$S = \left(\frac{100 - \ell}{\ell}\right) R$$

5. Potentiometer is an experimental device with the help of which we can measure the potential difference between any two points or emf of cell accurately.
6. Potentiometer is based on no deflection method. At no deflection it works as an ideal voltmeter of infinite resistance.
7. Fall of potential per unit length on potentiometer wire is called potential gradient. It's unit is V/m. Potential gradient is equal to $x - I(R_m)$, Here I = Current through the primary circuit and R_m = resistance per unit length of potentiometer wire.
8. To find the potential gradient with the help of a standard cell is called standardisation of potentiometer.
9. The sensitivity of potentiometer is inversely proportional to potential gradient. By increasing the length of potentiometer wire sensitivity can be increased.
10. Formula for measuring the internal resistance with help of potentiometer is,

$$r = \left(\frac{\ell_1 - \ell_2}{\ell_2}\right) R$$

Here, ℓ_1 and ℓ_2 are the balancing lengths in open and closed circuit and R is the resistance taken out from the resistance box.

11. If ε_1 and ε_2 are the emfs of two cells and ℓ_1 and ℓ_2 are corresponding balancing lengths on potentiometer wire, then

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$$

12. Formula for measuring the low resistance with the help of potentiometer,

$$r = \left(\frac{\ell_2 - \ell_1}{\ell_1}\right) R$$

Here, ℓ_2 = Balancing length for the potential difference across the series combination of $R + r$

ℓ_1 = Balancing length for the potential difference across resistance R .

13. Correctness of the measured value of ammeter and voltmeter is carried out by means of potentiometer and it is called calibration of ammeter and voltmeter.

Questions for Practice

Multiple Choice Type Questions

1. Kirchhoff's first law and second law are based on,

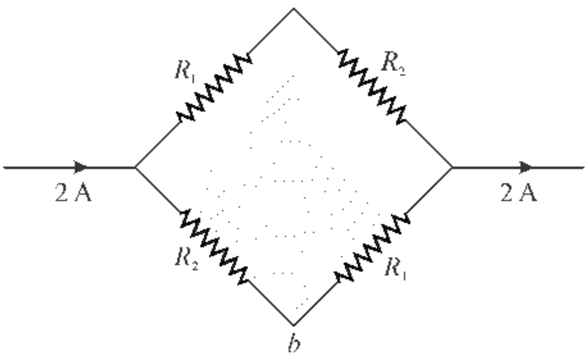
   (a) Law of conservation of charge and energy.

   (b) Law of conservation of current and energy.

   (c) Law of conservation of mass and charge.

   (d) None of the above.

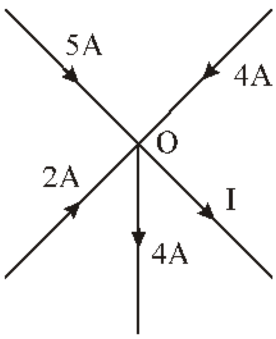
2. For the circuit shown in the figure, the potential difference between point a and b will be,



   (a) $R_1 - R_2$ (b) $R_2 - R_1$

   (c) $\dfrac{R_1R_2}{R_1+R_2}$ (d) Zero

3. In the given figure, the value of I will be,



   (a) 6A (b) 11A

   (c) 7A (d) 5A

4. On inter changing the position of battery and galvanometer in Wheatstone bridge respectively, the new balance point,

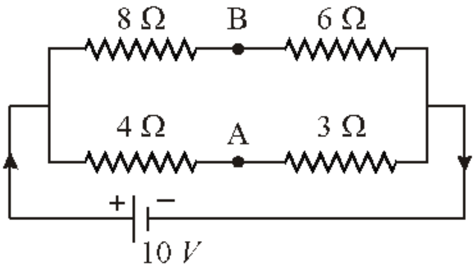
   (a) remains unchanged.

   (b) will change.

   (c) nothing can be said.

   (d) it may change or not will depend on the resistance of battery and galvanometer.

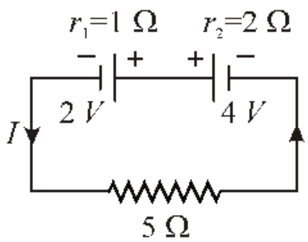
5. In the given figure, the potential difference between the terminals A and B will be,



   (a) $\dfrac{20}{7}V$ (b) $\dfrac{40}{7}V$

   (c) $\dfrac{10}{7}V$ (d) Zero

6. In the given figure, the value of I will be,



   (a) 2.5A (b) 0.75A

   (c) 0.5A (d) 0.25A

7. Potentiometer is such a measuring apparatus to measure the potential difference whose effective resistance is,

   (a) Zero (b) Infinite

   (c) uncertain

   (d) depends on external resistance.

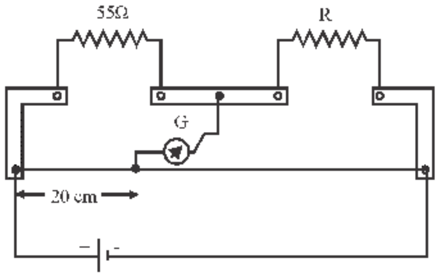
8. Which of the following quantities cannot be measured with the help of Potentiometer,

   (a) emf of a cell

   (b) capacitance and inductance

   (c) resistance (d) current

9. In the given figure, the galvanometer shows no deflection. What is the value of R?



(a) 220 Ω (b) 110 Ω

(c) 55 Ω (d) 13.75 Ω

10. The temperature coefficient of resistance of a potentiometer wire should be,

(a) high (b) low

(c) negligible (d) infinite

11. The formula for internal resistance of a cell will be, (Here ℓ_1 and ℓ_2 are the balancing lengths of cell in open and closed circuit respectively.)

(a) $r = \left(\frac{\ell_1 - \ell_2}{\ell_2}\right)R$ (b) $r = \left(\frac{\ell_2 - \ell_1}{\ell_2}\right)R$

(c) $r = \left(\frac{\ell_1 - \ell_2}{\ell_1}\right)R$ (d) $r = \left(\frac{\ell_2 - \ell_1}{\ell_1}\right)R$

12. In a potentiometer experiment, the emf e of a cell is balanced at L length. Another cell of same emf ε is connected parallel to it, then, new balancing length will be,

(a) 2L (b) L

(c) L/2 (d) L/4

13. In a potentiometer experiment, a standard cell of emf 1.1 V is balanced at 2.20 m length. Potential difference across a resistance wire is balanced at 95 cm length and voltmeter read this potential difference as 0.5 V. Then, error in the voltmeter will be,

(a) +0.025 V (b) +0.525 V

(c) -0.025 V (d) -0.525 V

Very Short Answer Type Questions

1. Write down the mathematical expression of Kirchhoff's junction law?
2. On what conservation, law Kirchhoff's voltage rule is based?
3. Write down the condition of balanced Wheatstone bridge.
4. On what principle, meter bridge works.
5. Why potential gradient of potentiometer depends on the temperature of wire?
6. What happens if the emf of cell in the primary circuit is less than the emf of cell in the secondary circuit?
7. Write down the definition of potential gradient.
8. Why area of cross section of the potentiometer wire should be uniform?
9. For standardisation of potentiometer which cell is used other than the Danial cell?
10. How the sensitivity of potentiometer can be increased?
11. Length of a potentiometer wire is 10 m. A standard cell of emf 1.1 volt is balanced at length 8.8 m of potentiometer wire. How much potential difference can be measured from it?
12. Why copper wire is not used in potentiometer?
13. Potential gradient of potentiometer wire is 0.3 V/m. In an experiment for calibration of ammeter, potential difference across 1Ω resistance is balanced across 1.5 meter length of potentiometer wire. If the reading of ammeter connected in circuit 0.28 A, Calculate the error in ammeter reading.

Short Answer Type Questions

1. State Kirchhoff's junction Law and loop law.
2. How is the resistance of a wire determined with the help of a meter bridge? Obtain required formula and draw circuit diagram.
3. What is Wheatstone bridge, derive its balanced condition for balance using Kirchhoff's law.
4. What is potential gradient? On what factors does it depend?
5. What do you mean by the standardisation of potentiometer? Explain it by drawing a circuit diagram.
6. What do you mean by the sensitivity of a potentiometer? How we can increase it?

7. How will you compare the emf's of two cells with the help of potentiometer? Explain with the help of proper circuit diagram and derive its formula.

8. A standard cell of emf 1.2 V is balanced on a 2.4 m length of potentiometer wire. Obtain the balancing length across a resistance 3.5 Ω, if a current of 0.2 A is flowing through it. Also calculate the potential gradient.

[Ans : $x = 0.5\ V/m\ \ell = 1.40\ m$]

9. Why correct emf of a cell or potential difference cannot be measured with the help of a voltmeter? How it is possible to determine the correct value?

10. Why do we try to obtain the null point near the middle of meter bridge wire?

11. Why the current through the potentiometer wire should not be passed for a long time?

12. Why the current in the primary circuit of potentiometer is kept constant?

13. Write two precaution while using the potentiometer.

14. What do you mean by calibration of a voltmeter. Draw necessary circuit diagram.

15. Draw required circuit diagram for the measurement of low resistance with the help of potentiometer.

Essay Type Questions

1. State Kirchhoff's loop rule and junction rule. With the help of these rules deduce the condition of balanced Wheatstone bridge. Draw necessary diagram?

2. What is meter bridge? On what principal it is based. Explain the construction of meter bridge and derive an expression for unknown resistance of a wire. Draw essential diagram?

3. What do you mean by the internal resistance of a cell? Explain the method to determine the internal resistance of a cell with the help of potentiometer and obtain the required formula with the help of circuit diagram.

4. What do you mean by the calibration of ammeter or voltmeter? Explain the method of calibration of voltmeter with the help of potentiometer. Draw the necessary circuit diagram. Draw the calibration curve.

5. What is potentiometer? Explain its principle. With the help of potentiometer describe the method to determine the value of a low resistance and derive proper formula. Draw necessary circuit diagram.

Answer Key (Multiple Choice Questions)

1. (a) 2. (b) 3. (c) 4. (a) 5. (d)

6. (d) 7. (b) 8. (b) 9. (a) 10. (c)

11. (a) 12. (b) 13. (a)

Short answer Type Questions

1. $\Sigma I = 0$

2. Based on law of conservation of energy.

3. Balanced condition of Wheatstone bridge is that ratio $\frac{P}{Q} = \frac{R}{S}$ of arms will remains same.

4. Meter bridge is based on the principal of Wheatstone's bridge.

5. One increasing the temperature of potentiometer wire, the resistance of wire increases. Hence, potential gradient will be affected.

6. We will not obtain the condition of null point on potentiometer wire.

7. Fall of potential per unit length on the potentiometer wire is called potential gradient.

8. So, the potential gradient remains same at all the points of potentiometer wire.

9. Cadmium cell

10. By increasing the length of potentiometer wire.

11. Potential gradient (x)

$$x = \frac{\varepsilon_s}{\ell_0} = \frac{1.1V}{8.8} = 0.125 V/m$$

Maximum potential-gradient that can be measured,

$$V_{AB} = xL = 0.125 \times 10 = 1.25 Volt$$

12. Temperature coefficient of resistance of copper wire is very small and specific resistance is very low.

13. 1 x Ammeter reading I = 0.28 A

For actual value of current

I' = current in 1Ω resistance,

= Potential difference across 1Ω resistance

$= V = x\ell$

I' = 0.3 × 1.5 = 0.45 A

Error in measurement of current = Δ I

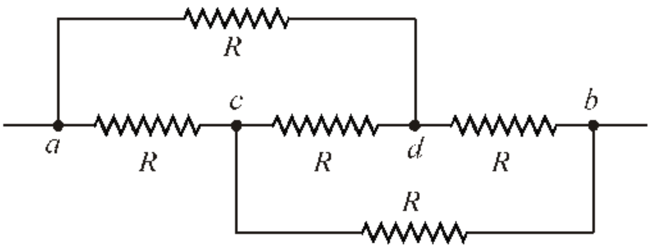
= I - I'

= 0.28 - 0.45

= - 0.17 *A*

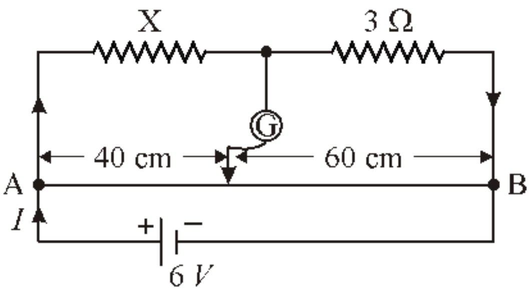
Numerical Questions

1. Find the equivalent resistance between terminal 'a' and 'b' of the network shown in the figure.



[Ans : R Ω]

2. In the following figure, a balanced meter bridge is shown. If the resistance of the wire of meter bridge is 1 Ω/m, then find the value of resistance X and the current passing through the resistance X.



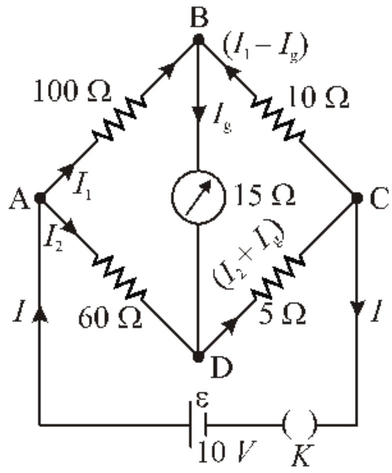
[Ans: X=2 Ω; I=1.26 A]

3. The resistances of four arms of the Wheatstone bridge are given in the circuit given below.

   $R_{AB} = 100\ \Omega$, $R_{BC} = 10\ \Omega$,

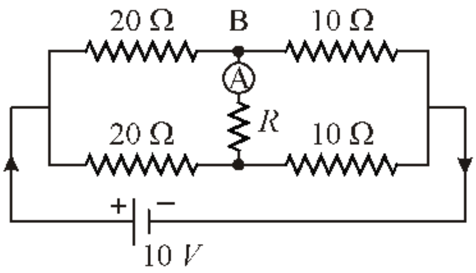
   $R_{CD} = 5\ \Omega$ and $R_{DA} = 60\ \Omega$.

   A galvanometer of 15Ω is connected between the terminals B and D. Calculate the current flowing through the galvanometer. The potential difference between terminals A and C is given as 10V.



[Ans: 4.87 mA]

4. What will be the value of resistance R for the network shown in the figure so that the current in ammeter may be zero.

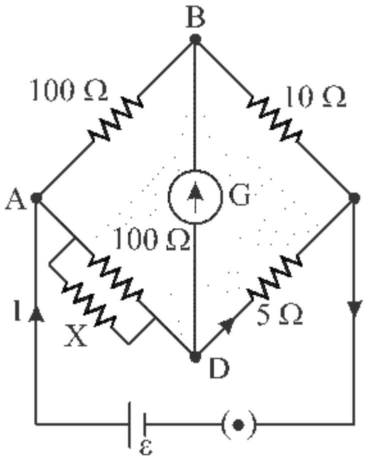


[Ans: Ammeter reading will be zero for all values of R]

5. The length of potentiometer wire is L. The primary circuit consists of a battery of emf 2.5 V and a resistance of 10Ω connected in series. In an experiment the balancing length for emf of 1 V is obtained at L/2. Find the new balancing length if the value of series resistance in the primary circuit is doubled.

[Ans: 0.6L]

6. In a Wheatstone bridge the branch resistances are as shown in the following circuit diagram. What will be the value of X in balancing condition of the Wheatstone bridge?



[Ans: X=100 Ω]

7. In a potentiometer experiment for the calibration of ammeter, the balanced length of a battery of emf 1.1 V is obtained at 0.88 m. The potential difference across one-ohm resistance is balanced at 0.20 m of potentiometer wire. If the reading of the ammeter connected in series is 0.20 A, calculate the error in ammeter.

[Ans: 0.05 A]

8. In a potentiometer experiment, the balancing length for cell of emf 1.25 V is 4.25 m. The balancing length with another cell is obtained at 6.80 m. Determine the emf of cell.

[Ans: 2.00 V]

9. The resistance of a 10 m long potentiometer wire is 1 Ω/m. An accumulator of 2.2 V emf, negligible internal resistance and a high resistance are connected in series. What is the value of high series resistance, if potential gradient on the potentiometer wire is 2.2 mV/m.

[Ans: 900 Ω]

10. In a potentiometer experiment, the balancing length for two cells of emf ε_1 and ε_2 $(\varepsilon_1 > \varepsilon_2)$ connected in series is observed as 60 cm. On reversing the position of terminals of one cell (of smaller emf) in the arrangement of experiment, the new balancing length is observed as 20 cm. Find the ratio of emfs ? ($\varepsilon_1 / \varepsilon_2$) of the cells.

[Ans : $\frac{\varepsilon_1}{\varepsilon_2} = \frac{2}{1}$]