09 Current Electricity

Multiple Choice Questions (1 Mark Each)

1. Kirchhoff's second law (voltage law) is based on
   (A) conservation of charge
   (B) conservation of mass
   (C) conservation of energy
   (D) conservation of momentum

2. When unknown resistance is determined by meter bridge, the error due to contact resistance is minimised by
   (A) connecting both the resistances only in one gap
   (B) interchanging the position of known and unknown resistances
   (C) using uniform wire
   (D) obtaining the null point near the ends of the wire

3. The SI unit of potential gradient is
   (A) V/cm (B) V-m
   (C) V/m (D) V-cm

4. Instrument which can measure terminal potential difference as well as electromotive force (emf) is
   (A) Wheatstone's meter bridge
   (B) voltmeter
   (C) potentiometer
   (D) galvanometer

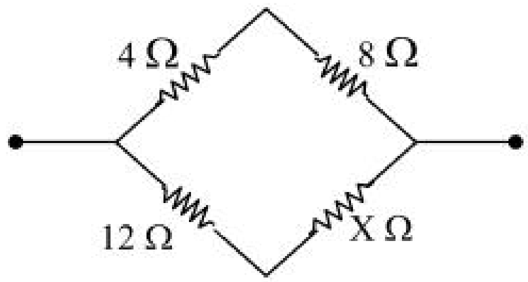
5. When null point is obtained in the potentiometer, the current is drawn from the
   (A) main battery
   (B) cell battery
   (C) both main and cell battery
   (D) neither main nor cell battery

6. If potential gradient of a wire decreases, then its length
   (A) remains constant (B) decreases
   (C) increases (D) none of the above

7. Four resistances 4 Ω, 8 Ω, X Ω and 12 Ω are connected in a series to form Wheatstone's network. If the network is balanced, the value of X is

(A) 24 (B) 18
(C) 12 (D) 8

Hint: Since the network is balanced,



$\therefore \quad \frac{4}{8} = \frac{12}{X}$

$\therefore \quad X = \frac{8 \times 12}{4} = 24\ \Omega$

Very Short Answer (VSA) (1 Mark Each)

Q.1. State Kirchhoff's first (current) law.

Ans: Statement: *The algebraic sum of the currents at a junction is zero in an electrical network.*

i.e., $\sum_{i=1}^{n} I_i = 0$

where I_i is the current in the i^{th} conductor at a junction having n conductors.

Q.2. State Kirchhoff's second (voltage) law.

Ans: Statement: *The algebraic sum of the potential differences (products of current and resistance) and the electromotive forces (emfs) in a closed loop is zero.*

i.e., $\sum IR + \sum E = 0$

Q.3. What is the basis of Kirchhoff's current law and voltage law?

Ans:

i. Kirchhoff's current law is based on the law of conservation of charge.

ii. Kirchhoff's voltage law is based on the law of conservation of energy.

Q.4. Are Kirchhoff's laws applicable to both AC and DC circuits?

Ans: Kirchhoff's laws are applicable for DC as well as AC circuits. They can be accurately used for DC circuits and low frequency AC circuits. In case of AC though, summation of current should be done in vector form or using instantaneous value for the AC components of the circuit.

Q.5. Define potential gradient.

Ans: ***Potential gradient*** *is defined as potential difference per unit length of wire.*

Q.6. On what factors does the potential gradient of the wire depend?

Ans: Potential gradient of the wire depends upon the potential difference between two point on the wire and length of the wire between two points.

Q.7. What is the SI unit of potential gradient?

Ans: SI unit of potential gradient is volt/metre.

Q.8. State any one use of a potentiometer.

Ans:

i. The potentiometer can be used as a voltage divider to continuously change the output voltage of a voltage supply.

ii. Potentiometer can be used as an audio control.

iii. Potentiometer can be used as a sensor.

[Any one use]

Q.9. A voltmeter has resistance of 100 Ω. What will be its reading when it is connected across a cell of emf 6 V and internal resistance 20 Ω?

Ans: Terminal potential, $V = \dfrac{E}{R + r} \times R = \dfrac{6}{100 + 20} \times 100 = 5\ V$

Q.10. In a meter bridge, two unknown resistances R and S, when connected between the two gaps, gives a null point is 60 cm from one end. What is the ratio of R and S?

Ans: Here, $l_R = 60$ cm

∴ $l_S = (100 - 60)$ cm $= 40$ cm

∴ $\dfrac{R}{S} = \dfrac{l_R}{l_S} = \dfrac{60}{40} = \dfrac{3}{2}$

Short Answer I (SA1) (2 Marks Each)

Q.1. What are the disadvantages of a potentiometer over a voltmeter?

Ans:

i. Potentiometer is not portable.

ii. Direct measurement of potential difference or emf is not possible.

Q.2. Distinguish between a potentiometer and a voltmeter.

Ans:

No.	Potentiometer	Voltmeter
i.	Its resistance is infinite.	Its resistance is high but finite.
ii.	It does not draw any current from the source of known e.m.f.	It draws some current from the source of e.m.f.
iii.	The potential difference measured by it is equal to actual potential difference (p.d.).	The potential difference measured by it is less than the actual potential difference (p.d.).
iv.	It has high sensitivity.	It has low sensitivity.
v.	It measures e.m.f as well as p.d.	It measures only p.d.
vi.	It is used to measure internal resistance of a cell.	It cannot be used to measure the internal resistance of a cell.
vii.	It is more accurate.	It is less accurate.
viii.	It does not give direct reading.	It gives direct reading.
ix.	It is not portable.	It is portable.
x.	It is used to measure lower voltage values only.	It is used to measure lower as well as higher voltage values.

[Any four differences]

Q.3. Distinguish between an ammeter and a voltmeter.

Ans:

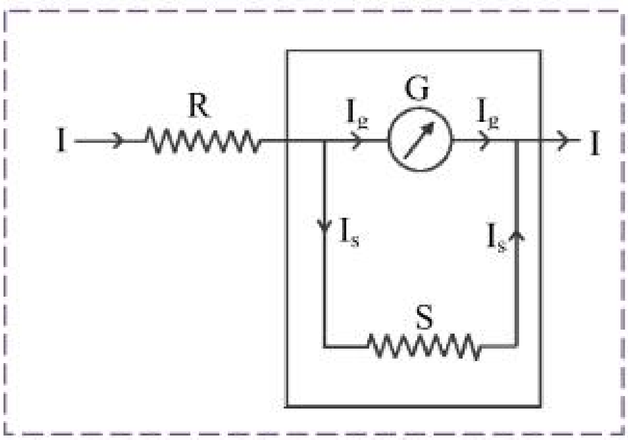
	Ammeter	**Voltmeter**
i.	It measures current.	It measures potential difference
ii.	It is connected in series.	It is connected in parallel.
iii.	It is an MCG with low resistance. (Ideally zero)	It is an MCG with high resistance. (Ideally infinite)
iv.	Smaller the shunt, greater will be the current measured.	Larger its resistance greater will be the potential difference measured.
v.	Resistance of ammeter, $R_A = \frac{SG}{S+G} = \frac{G}{n}$	Resistance of voltmeter, $R_v = G + X = Gn_v$

[Any four differences]

Q.4. How do you calculate the shunt required to increase the range n times?

Ans:

i. In the arrangement as shown in the figure, I and I_g are the current through the circuit and galvanometer respectively.
Therefore, the current through shunt S is, $I_s = (I - I_g)$



ii. Since S and G are parallel, potential difference across them is same.

$\therefore$ $GI_g = S\,I_s$

$\therefore$ $GI_g = S\,(I - I_g)$

$\therefore$ $S = \left(\frac{I_g}{I - I_g}\right)G$ ….(1)

Equation (1) is useful to calculate the range of current that the galvanometer can measure.

iii. If the current I is n times current I_g, then $I = n\,I_g$.
Using this in equation (1),

$$S = \left(\frac{GI_g}{nI_g - I_g}\right)$$

$$\therefore \quad S = \frac{G}{n-1}$$

This is the required shunt to increase the range n times.

[Note: The framing of question is modified to remove the ambiguity from question.]

Q.5. Define: i. electrical circuit ii. Junction

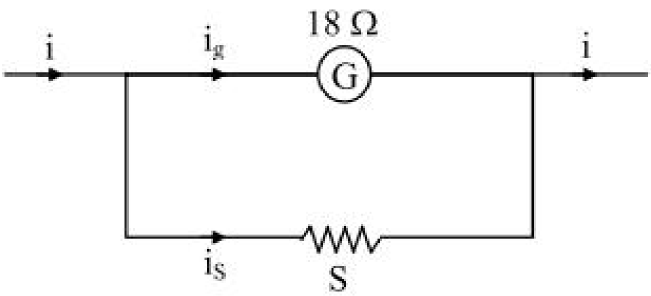
Ans:

i. **Electrical circuit:** *A continuous conducting path consisting of wires and other resistances and a switch between the two terminals of a cell or a battery along which an electric current flow is called a electrical circuit.*

ii. **Junction:** *Any point in an electric circuit where two or more conductors are joined together is a junction.*

Q.6. Calculate the value of the shunt resistance when connected across a galvanometer of resistance 18 Ω will allow 1/10 th of the current to pass through the galvanometer.

Solution:



$$\text{Here, } i_g = \left(\frac{S}{S+18}\right) i$$

$$\text{Given: } i_g = \frac{i}{10}$$

$$\therefore \quad \left(\frac{S}{S+18}\right) i = \frac{i}{10}$$

$\therefore$ 10 S = S + 18

$\therefore$ 9 S = 18

$\therefore$ S = **2 Ω**

Ans: The value of the shunt resistance is **2 Ω**.

Q.7. Four resistances 6 Ω, 6 Ω, 6 Ω and 18 Ω form a Wheatstone bridge. Find the resistance which connected across the 18 Ω resistance will balance the network.

Solution:

Given: P = Q = R = 6 Ω

To find: Resistance (X)

Formula: $\frac{P}{Q} = \frac{R}{S}$

Calculation: Let resistance connected across 18 Ω be X.

Equivalent resistance for 18 Ω and X in parallel is given by,

$$X' = S = \frac{18X}{18+X}$$

From formula,

$$\frac{6}{6} = \frac{6}{\frac{18X}{18+X}}$$

$\therefore$ $1 = \frac{6(18+X)}{18X}$

$\therefore$ 18X = 108 + 6X

$\therefore$ 12X = 108

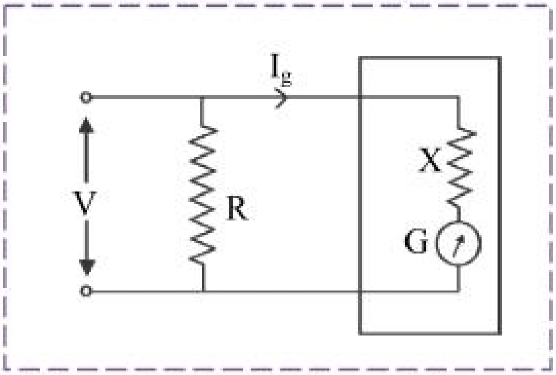
$\therefore$ X = **9 Ω**

Ans: The resistance connected across 18 Ω resistance to balance the network is **9 Ω**.

Q.8. The maximum safe voltage that can be measured using a galvanometer of resistance G is V_m . Find the resistance to be connected in series with the galvanometer so that it becomes a voltmeter of range nV_m.

Ans:

i. Let 'X' be the resistance connected in series with the galvanometer as shown in figure.



ii. If V is the voltage to be measured, then

$V = I_g X + I_g G$

$\therefore$ $I_g X = V - I_g G$

$\therefore$ $X = \frac{V}{I_g} - G$ ….(1)

where I_g is the current flowing through the galvanometer.

iii. If voltage V is n times voltage V_m (voltage across galvanometer) then,

$V = n V_m = n(I_g G)$

Using this in equation (1),

$\therefore$ $X = \frac{nI_g G}{I_g} - G$

$\therefore$ $X = G(n - 1)$

Short Answer II (SA2) (3 Marks Each)

Q.1. Explain with a neat circuit diagram. How you will determine the unknown resistances using a meter bridge.

Ans: Construction:

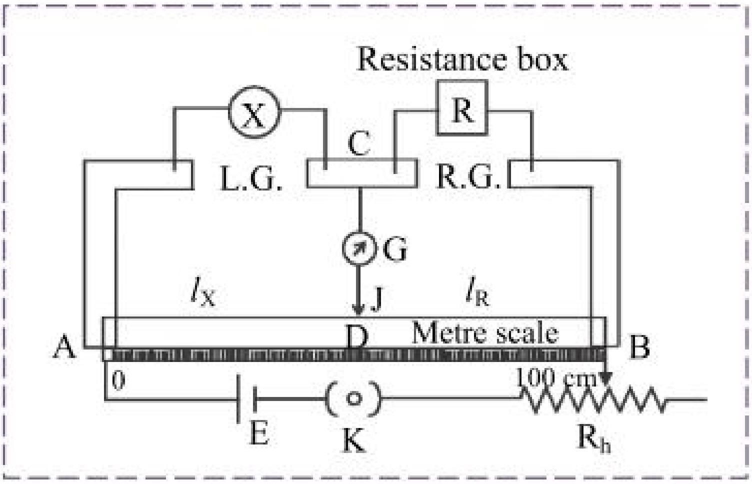
i. Metrebridge consists of a one metre long wire of uniform cross section, stretched on a metre scale which is fixed on a wooden table.

ii. The ends of the wire are fixed below two L shaped metallic strips. A single metallic strip separates the two L shaped strips leaving two gaps, left gap and right gap.

iii. Usually, an unknown resistance X is connected in the left gap and a resistance box is connected in the other gap.

iv. One terminal of a galvanometer is connected to the point C on the central strip, while the other terminal of the galvanometer carries the jockey (J). Temporary contact with the wire AB can be established with the help of the jockey.

v. A cell of emf E along with a key and a rheostat are connected between the points A and B.



Working:

i. A suitable resistance R is selected from resistance box.

ii. The jockey is brought in contact with AB at various points on the wire AB and the balance point (null point), D is obtained. The galvanometer shows no deflection when the jockey is at the balance point (point D).

iii. Let the respective lengths of the wire between A and D, and that between D and C be l_x and l_R .

iv. Then using the balancing conditions,

$$\frac{X}{R} = \frac{R_{AD}}{R_{DB}} \qquad \text{....(1)}$$

where R_{AD} and R_{DB} are resistance of the parts AD and DB of the wire respectively.

v. If l is length of the wire, ρ is its specific resistance, and A is its area of cross section then

$$R_{AD} = \frac{\rho l_x}{A} \qquad \text{....(2)}$$

$$R_{DB} = \frac{\rho l_R}{A} \qquad \text{....(3)}$$

From equations (1), (2) and (3),

$$\frac{X}{R} = \frac{R_{AD}}{R_{DC}} = \frac{\rho l_x / A}{\rho l_R / A}$$

$$\therefore \quad \frac{X}{R} = \frac{l_x}{l_R}$$

$\therefore \quad X = \frac{l_x}{l_R} R$

Thus, knowing R, l_x and l_R, the value of the unknown resistance can be determined.

Q.2. State any two sources of errors in the metre bridge experiment. Explain how they can be minimised.

Ans: Sources of errors:

i. The cross section of the wire may not be uniform.

ii. The ends of the wire are soldered to the metallic strip where contact resistance is developed, which is not taken into account.

iii. The measurements of l_x and l_R may not be accurate.

To minimize the errors

i. The value of R is so adjusted that the null point is obtained around middle one third of the wire (between 34 cm and 66 cm) so that percentage error in the measurement of l_x and l_R are minimum and nearly the same.

ii. The experiment is repeated by interchanging the positions of unknown resistance X and known resistance box R.

iii. The jockey should be tapped on the wire and not slided. The jockey is used to detect whether there is a current through the central branch. This is possible only by tapping the jockey.

[Any two sources and their minimization]

Q.3. What is potential gradient? How is it measured? Explain.

Ans:

i. Potential gradient (K) is defined as potential difference per unit length of wire.

ii. It is measured as, $\frac{V}{L} = \frac{ER}{L(R + r)}$

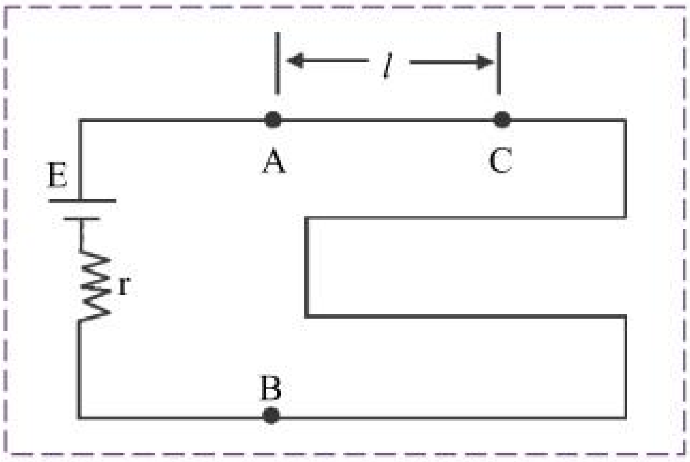
where, V = Potential difference between two points

L = Length (distance) between two points

iii. Explanation:

a. A potentiometer consists of a long wire AB of length L and resistance R having uniform cross sectional area A.

b. A cell of emf E having internal resistance r is connected across AB as shown in the figure.



c. When the circuit is switched on, current I pass through the wire.

Current through AB, $I = \frac{E}{R + r}$ ....(1)

d. Potential difference across AB,

$V_{AB} = IR$

$V_{AB} = \frac{ER}{(R + r)}$ ....[From equation (1)]

e. Therefore, the potential difference per unit length of the wire is,

$\frac{V_{AB}}{L} = \frac{ER}{L(R + r)}$

As long as E remains constant, $\frac{V_{AB}}{L}$ will remain constant.

f. $\frac{V_{AB}}{L}$ is known as potential gradient along AB and is denoted by K. Potential gradient can be defined as potential difference per unit length of wire.

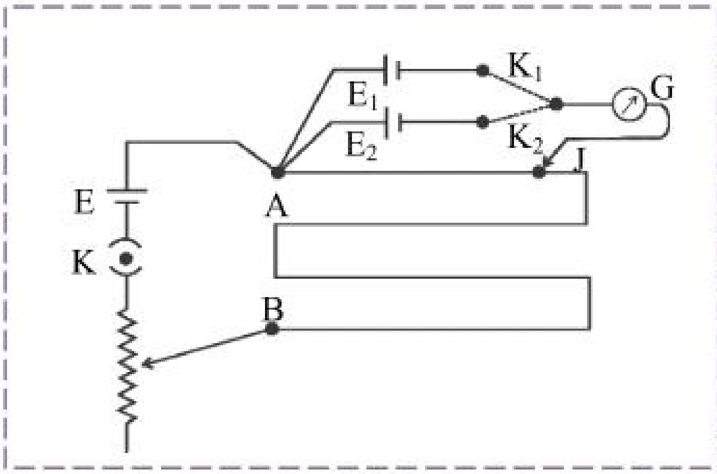
Q.4. Describe how a potentiometer is used to compare the emf's of two cells by connecting the cells individually.

Ans:

i. A potentiometer circuit is set up by connecting a battery of emf E, with a key K and a rheostat such that point A is at higher potential than point B.

ii. The cells whose emfs are to be compared are connected with their positive terminals at point A and negative terminals to the extreme terminals of a two way key K_1 and K_2.

iii. The central terminal of the two ways key is connected to a galvanometer. The other end of the galvanometer is connected to a jockey (J).



iv. Key K is closed and then, key K_1 is closed and key K_2 is kept open. Therefore, the cell of emf E_1 comes into circuit.

v. The null point is obtained by touching the jockey at various points on the potentiometer wire AB.

vi. Let l_1 be the length of the wire between the null point and the point A. Here, l_1 corresponds to emf E_1 of the cell. Therefore,

$E_1 = K\, l_1$ ....(1)

where K is the potential gradient along the potentiometer wire.

vii. Now key K_1 is kept open and key K_2 is closed. The cell of emf E_2 now comes in the circuit. Again, the null point is obtained with the help of the Jockey.

viii. Let l_2 be the length of the wire between the null point and the point A. Here l_2 corresponds to the emf E_2 of the cell.

∴ $E_2 = K\, l_2$ ....(2)

ix. Dividing equation (1) by equation (2),

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

Thus, emfs of the two cells can be compared and if any one of the emfs is known, the other can be determined.

Q.5. A cell of e.m.f 1.5 V and negligible internal resistance is connected in series with a potentiometer of length 10 m and total resistance 20 Ω. What resistance should be introduced in the resistance box such that the potential drop across the potentiometer is one microvolt per cm of the wire?

Solution:

Given: $R = 20\ \Omega$, $L = 10$ m, $E = 1.5$ V,

$K = 1\ \mu V/cm = 1 \times (10^{-6}/10^{-2})\ V/m$

$= 10^{-4}\ V/m$

To find: External resistance (R_E)

Formula: $K = \dfrac{V}{L}$

Calculation: Since, $I = \dfrac{E}{R + R_E}$

Also, $V = IR = \dfrac{ER}{R + R_E}$

From formula,

$$K = \frac{ER}{(R + R_E)L}$$

$$R + R_E = \frac{ER}{KL}$$

$$\therefore \quad R_E = \frac{1.5 \times 20}{10^{-4} \times 10} - 20 = 30000 - 20$$

$$\therefore \quad R_E = \mathbf{29980\ \Omega}$$

Ans: The external resistance should be **29980 Ω**.

Q.6. In a meter bridge, the balance point is found to be at 39.5 cm from the end A when the resistor R is of 12.5 Ω (right gap).

i. Determine the resistance of X (left gap).

ii. Determine the balance point of the bridge if X and R are interchanged?

iii. What happens if the galvanometer and cell are interchanged at the balance point of the bridge?

Ans: Given: $l_X = 39.5$ cm, $R = 12.5\ \Omega$,

$l_R = (100 - l_X) = 100 - 39.5 = 60.5$ cm.

i. Since, the bridge is balanced,

$$\frac{X}{R} = \frac{l_X}{l_R}$$

$$\therefore \quad X = \frac{l_X}{l_R} \times R$$

$$= \frac{39.5}{60.5} \times 12.5 = 8.16\ \Omega$$

ii. When X and R are interchanged then their respective lengths also gets interchange.

∴ The new balance point will be at 60.5 cm

iii. If the galvanometer and the cell are interchanged then the balance point remains unchanged.

Q.7. The emf of a standard cell is 1.5V and is balanced by a length of 300 cm of a potentiometer with 10 m long wire. Find the percentage error in a voltmeter which balances at 350 cm when its reading is 1.8 V.

Solution:

Given: $E_1 = 1.5$ V, $l_1 = 300$ cm, $l_2 = 350$ cm

From individual cell method of potentiometer,

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

∴ $E_2 = E_1 \times \frac{l_2}{l_1}$

$$= 1.5 \times \frac{350}{300} = 1.75 \text{ V}$$

But given reading is 1.8 V

∴ Error = 1.8 – 1.75 = 0.05 V

∴ Percentage error $= \frac{0.05}{1.75} \times 100$

$= \mathbf{2.8571\%}$

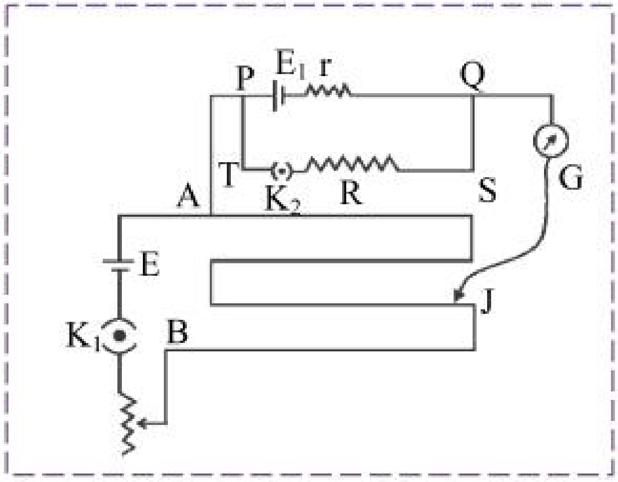
Ans: The percentage error in a voltmeter is **2.8571%**.

Long Answer (LA) (4 Marks Each)

Q.1. Describe with the help of a neat circuit diagram how you will determine the internal resistance of a cell by using a potentiometer. Derive the necessary formula.

Ans:

i. The experimental set up for this method consists of a potentiometer wire AB connected in series with a cell of emf E , the key K_1, and rheostat as shown in figure.



ii. The terminal A is at higher potential than terminal B. A cell of emf E_1 whose internal resistance r is to be determined is connected to the potentiometer wire through a galvanometer G and the jockey J.

iii. A resistance box R is connected across the cell E_1 through the key K_2. The key K_1 is closed and K_2 is open.

iv. The circuit now consists of the cell E, cell E_1, and the potentiometer wire. The null point is then obtained.

v. Let l_1 be length of the potentiometer wire between the null point and the point A. This length corresponds to emf E_1.

$\therefore$ $E_1 = Kl_1$ ….(1)

where K is potential gradient of the potentiometer wire which is constant.

vi. Now both the keys K_1 and K_2 are closed so that the circuit consists of the cell E, the cell E_1 , the resistance box, the galvanometer and the jockey. Some resistance R is selected from the resistance box and null point is obtained.

vii. The length of the wire l_2 between the null point and point A is measured. This corresponds to the voltage between the null point and point A.

$\therefore$ $V = Kl_2$ ….(2)

Dividing equation (1) by equation (2),

$$\therefore \quad \frac{E_1}{V} = \frac{Kl_1}{Kl_2} = \frac{l_1}{l_2} \qquad \text{….(3)}$$

viii. Consider the loop PQSTP,

$E_1 = IR + Ir$ and $V = IR$

$$\therefore \quad \frac{E_1}{V} = \frac{IR + Ir}{IR} = \frac{R + r}{R} = \frac{l_1}{l_2} \qquad \text{….[From equation (3)]}$$

$$\Rightarrow r = R\left(\frac{l_1}{l_2} - 1\right)$$

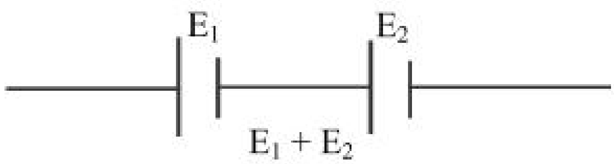
The above equation is used to determine the internal resistance of the cell.

Q.2. Describe how a potentiometer is used to compare the emf's of two cells by the combination method.

Ans:

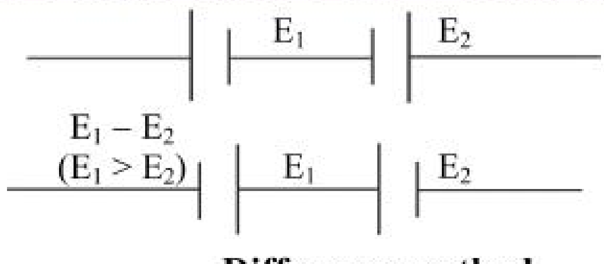
i. The emfs of two cells can be compared using sun and difference method.

ii. When two cells are connected such that the positive terminal of the first cell is connected to the negative terminal of the second cell, the emf of the two cells are added up and the effective emf of the combination of two cells is $E_1 + E_2$. This method of connecting two cells is called the sum method.



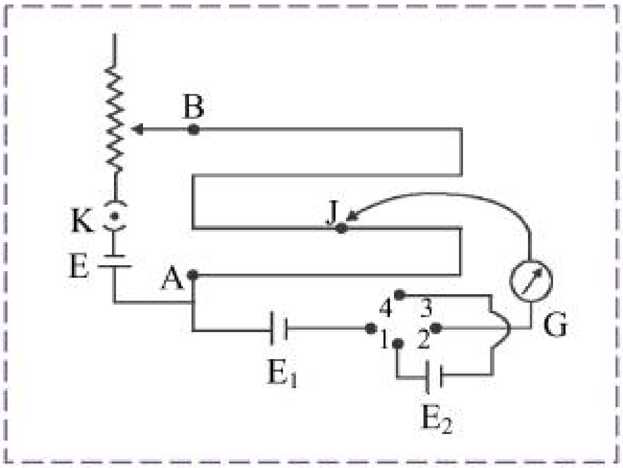
Sum method

iii. When two cells are connected such that their negative terminals are together or their positive terminals are connected together, then their emf oppose each other and effective emf of the combination of two cells is $E_1 - E_2$ (Considering $E_1 > E_2$). This method of connecting two cells is called the difference method.



Difference method

iv. Circuit for sum and difference method is connected as shown in below figure When keys K_1 and K_3 are closed the cells E_1 and E_2 are in the sum mode. The null point is obtained using the jockey.



v. Let l_1 be the length of the wire between the null point and the point A. This corresponds to the emf $(E_1 + E_2)$.

∴ $E_1 + E_2 = K\, l_1$ ….(1)

where K is the potential gradient along the potentiometer wire.

vi. Now the key K_1 and K_3 are kept open and keys K_2 and K_4 are closed. In this case the two cells are in the difference mode.

vii. Again the null point is obtained. Let l_2 be the length of the wire between the null point and the point A. This corresponds to emf $(E_1 - E_2)$.

∴ $E_1 - E_2 = Kl_2$ ….(2)

viii. Dividing equation (1) by equation (2),

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{l_1}{l_2}$$

By componendo and dividendo method,

$$\frac{(E_1 + E_2) + (E_1 - E_2)}{(E_1 + E_2) - (E_1 - E_2)} = \frac{l_1 + l_2}{l_1 - l_2}$$

∴ $$\frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2}$$

Thus, emf of two cells can be compared using sum and difference method.

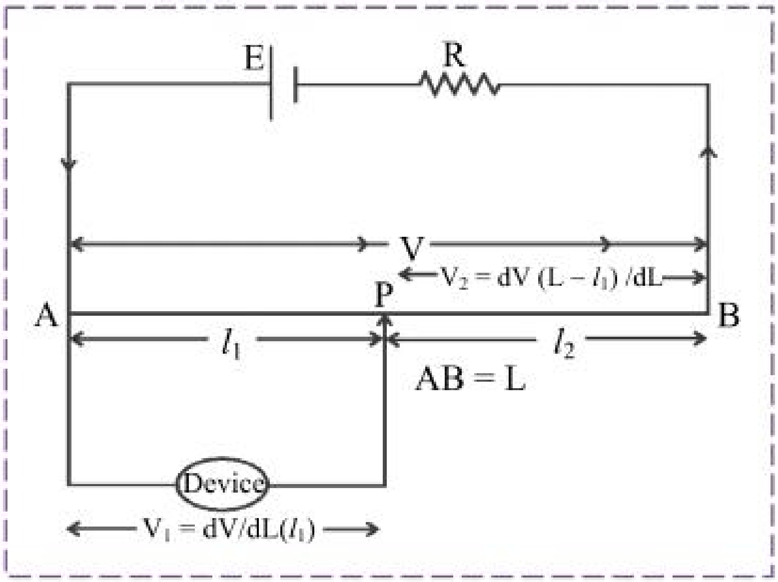
Q.3. State the uses of a potentiometer. Why is a potentiometer preferred over a voltmeter for measuring emf?

Ans:

i. Uses of a potentiometer:

a. Potentiometer as a voltage Divider:

1. The potentiometer can be used as a voltage divider to continuously change the output voltage of a voltage supply.



2. As shown in the above figure, potential V is set up between points A and B of a potentiometer wire.
3. One end of a device is connected to positive point A and the other end is connected to a slider that can move along wire AB.
4. The voltage V gets divided in proportion of lengths l_1 and l_2, such that

$$V_1 = \frac{dV(l)}{dL} \quad \text{and}$$

$$V_2 = \frac{dV(L - l_1)}{dL}$$

b. Potentiometer as an audio control:

1. Sliding potentiometers are commonly used in modern low-power audio systems as audio control devices.
2. Both sliding (faders) and rotary potentiometers (knobs) are regularly used for frequency attenuation, loudness control and for controlling different characteristics of audio signals.

c. Potentiometer as a sensor:

1. If the slider of a potentiometer is connected to the moving part of a machine, it can work as a motion sensor.
2. A small displacement of the moving part causes changes in potential which is further amplified using an amplifier circuit.
3. The potential difference is calibrated in terms of the displacement of the moving part.

ii. Potentiometer preferred over a voltmeter for measuring emf due to following reasons:

a. Potentiometer is more sensitive than a voltmeter.

b. A potentiometer can be used to measure a potential difference as well as an emf of a cell. A voltmeter always measures terminal potential difference, and as it draws some current, it cannot be used to measure an emf of a cell.

c. Measurement of potential difference or emf is very accurate in the case of a potentiometer. A very small potential difference of the order 10^{-6} volt can be measured with it. Least count of a potentiometer is much better compared to that of a voltmeter.