Chapter 13

CURRENT ELECTRICITY

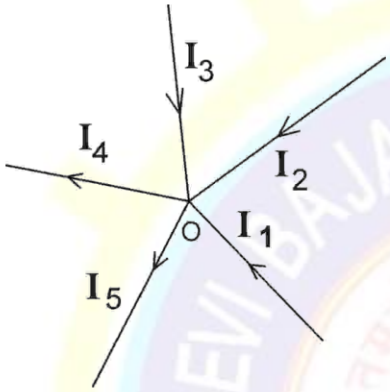
Kirchhoff's Laws:

1) Kirchhoff's current law (KCL):

Statement: The algebraic sum of the currents at any junction is equal to zero in any closed electrical circuit.

i.e.Σ I = 0

Explanation: The currents entering the junction are considered +ve and the currents leaving the junction are considered –ve.



Let, Pt. O is a junction point, then, applying Kirchhoff's current law, we can write –

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

$\therefore$ $I_1 + I_2 + I_3 = I_4 + I_5$

$\therefore$ Total current entering junction = Total current leaving the junction.

i.e. $\Sigma I = 0$

Since, current is nothing but rate of flow of charge,

Therefore, total charge entering the junction is equal to total charge leaving the junction.

Thus, principle of conservation of charge is followed here.

2) Kirchhoff's Voltage law (KVL):

Statement: The algebric sum of EMF's in Any closed electrical circuit is always equal to the algebric sum of product of current and the resistances across each part of the closed circuit.

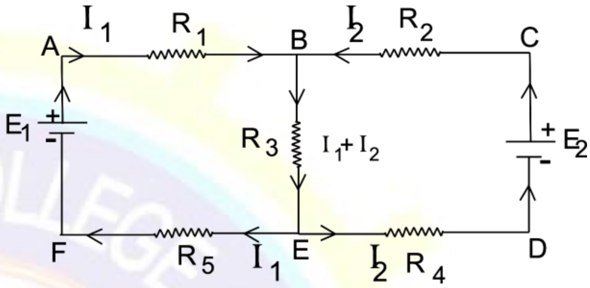
i.e $\Sigma E = \Sigma IR$

Explanation:

Sign Conventions: While applying KVL to a closed electrical circuit following two sign conventions are used.

1) The currents which are in the same direction, in which loop is traced are considered +ve, while those in opposite direction are considered –ve.

2) The EMF of a cell is considered +ve, if it tends to send the current in the direction, in which the lop is traced, otherwise considered as –ve.



In closed loop, ABCDEFA,

By Kirchhoff's Voltage Law.

$E_1 - E_2 = I_1R_1 - I_2R_2 - I_2R_4 + I_1R_5$ ---- (1)

Now, In closed loop, ABEFA by KVL,

$E_1 = I_1R_1 + (I_1 + I_2) R_3 + I_1R_5$ -------- - (2)

Also,

In closed loop, BCDEB by KVL,

$-E_2 = -I_2R_2 - I_2R_4 - (I_1+I_2)R_3$ ------- (3)

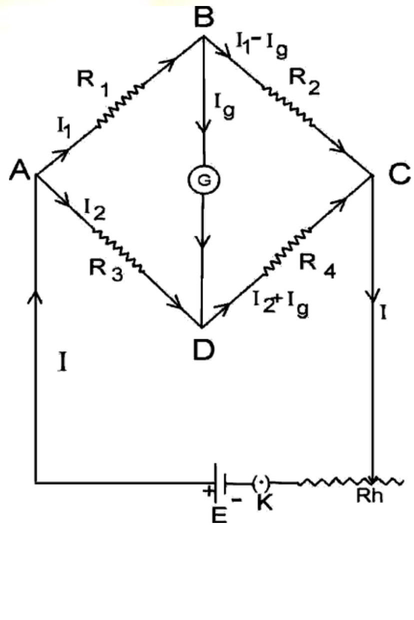
It is observed that,

(2) + (3) = (1).

i.e $\Sigma E = \Sigma IR$.

Σ E represents the total energy supplied to the closed electrical circuit and Σ IR is the total energy used in the circuit. Thus, the Kirchhoff's Voltage law proves the law of conservation of energy.

Whetstone's Bridge (Network):



Construction: The electrical network which is shown in following fig. is called Whetstone's Bridge. This is used for determining unknown resistance.
The network consists of four resistances R_1, R_2, R_3 and R_4 which are connected in such a way that they forms a bridge. Therefore, the network is called as Whetstone's Bridge.

A battery of EMF (E), a key (K), and a rheostat (R_h) are connected in series between 'A' and'C'and a galvanometer of resistance (G) is connected between B and D.

Balanced Condition: When current flowing through galvanometer is zero, then –

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

This is called Balanced condition of Wheatstone's Bridge.

To obtain balanced condition we consider, firstly, closed loop ABCDA,

∴ By applying KVL, to closed loop ABDA, we get,

$$0 = I_1R_1 + I_gG - I_2R_3$$

∴ $$I_1R_1 + I_gG - I_2R_3 = 0$$

In Balanced condition,

$$I_g = 0$$

∴ $$I_1R_1 - I_2R_3 = 0$$

∴ $$I_1R_1 = I_2R_3 \text{ ----------- } (1)$$

Now, Applying KVL to closed loop BCDB,

$$0 = (I_1 - I_g)R_2 - (I_2 + I_g)R_4 - I_gG$$

∴ $$(I_1 - I_g)R_2 - (I_2 + I_g)R_4 - I_gG = 0$$

But, In Balanced condition,

$$I_g = 0.$$

∴ $$I_1R_2 - I_2R_4 = 0$$

∴ $$I_1R_2 = I_2R_4 \text{ ------------- } (2)$$

By (1) ÷ (2),

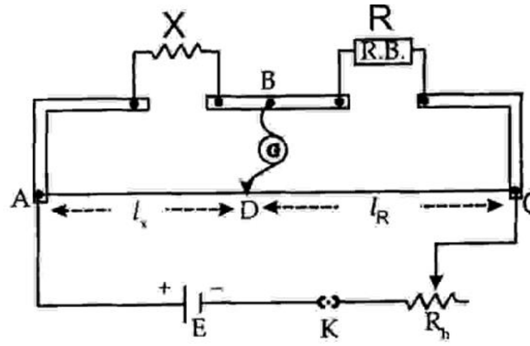
$$\frac{I_1R_1}{I_1R_2} = \frac{I_2R_3}{I_2R_4}$$

∴ $$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ ----------- } (3)$$

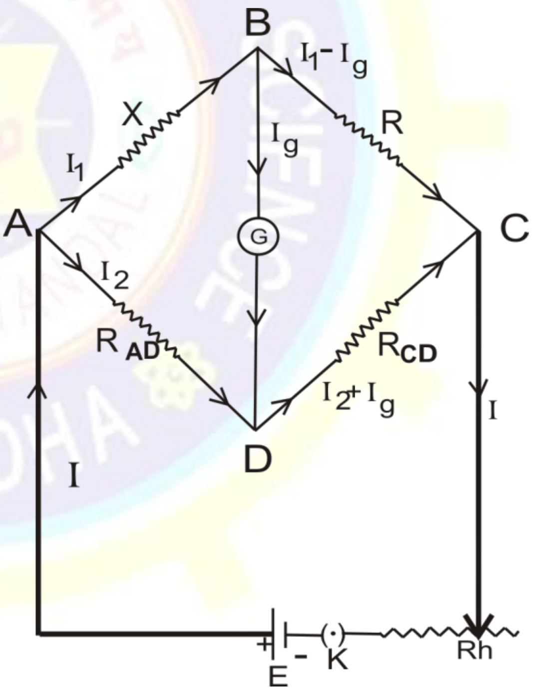
Meter Bridge & Meter Bridge experiment to determine unknown Resistance:

Meter Bridge: It is the simplified form of Whetstone's bridge. It consists of a thin uniform conducting wire of 1m length. This is stretched on a wooden board between two L-shaped metal strips. A third strip is fixed on the board such that it forms two gaps with the L-shaped strips.

Determination of unknown resistance:



An unknown resistance, X, is connected in left gap and a resistance box (R.B.) is connected in the right gap of the Meter Bridge. A cell, a key (K) and a rheostat (R_h) are connected in series with the wire at meter bridge. A galvanometer (G) is connected between X and R and its other terminal is connected to Jockey (J) which can be slide along the wire. It forms a Wheatstone's Bridge as shown in fig.



Closing the key (K) and adjusting rheostat (R_h), a suitable resistance (R) is taken in the resistance box. The jockey is touched to different points of the wire AC and a point of contact (D) on the wire AC is obtained for which galvanometer shows zero deflection. This point D is called Null Point. With the help of Meter Scale attached to the Meter Bridge, distance of the Null point from both the ends is obtained. Let, l_x

be the distance from point A and l_R is the distance from point C. Since, Bridge is in the balanced condition. Therefore,

$$\frac{X}{R} = \frac{\text{Resistance of wire of length AD}(l_X)}{\text{Resistnace of wire of length CD}(l_R)}$$

Let, σ be the resistance per unit length of the wire.

$\therefore \quad R_{AD} = \sigma \,.\, l_X$

And $\quad R_{DC} = \sigma \,.\, l_R$

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

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

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

Using this formula, unknown resistance (X) can be calculated.

Sources of Error:

1) If the wire is not uniform, then resistance per unit length (σ) will not have same value through out the length of wire. Hence, an error is introduced in determination of unknown resistance.

2) Also, an error is introduced due to contact resistance of the points where the ends of the wire gets fixed to the metal strip.

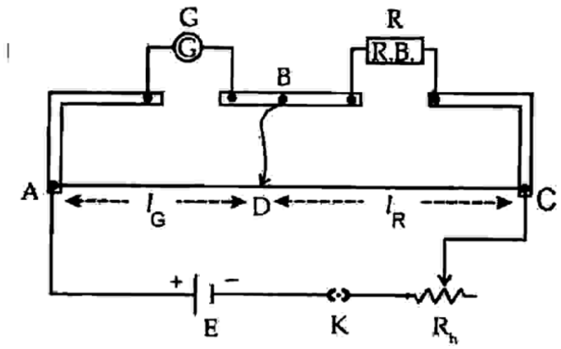
Minimization of Errors:

1) The 1st error can be minimized i.e. error due to non-uniformity at wire by obtaining the null point at the centre of the wire. This can be done by choosing suitable value of resistance (R) from the resistance box.

2) To minimize the error because of contact resistance, readings are taken by interchanging positions of unknown resistance (X) and the resistance box. The average value of the no. of observations gives most correct value of unknown resistance.

Kelvin's Method to determine Resistance of a Galvanometer using Meter Bridge:

The Galvanometer (G) whose resistance has to be determine is connected in one gap



and resistance box (R.B) is connected in other gap of meter bridge. This galvanometer itself is used to determine the balanced condition without obtaining the null point. The junction of G and R.B. is connected to the jockey. The key is closed and rheostat (R_h) is adjusted for suitable deflection in the galvanometer. Now, a suitable resistance (R) is taken in the resistance box and deflection of galvanometer is noted. The jockey is touched at the different points of meter bridge wire and a point 'D' is obtained such that galvanometer shows same deflection as before is determined.

The Pt. D is such that, galvanometer shows same deflection with or without contact of the jockey with the meter bridge wire. This is equal deflection point and in such a case, no current flows through BD and bridge gets balanced.

$\therefore$ In Balanced Condition,

$$\frac{G}{R} = \frac{\textbf{Resistance of wire of length AD}\left(l_G\right)}{\textbf{Resistance of wire of length CD}\left(l_R\right)}$$

If σ be the resistance per unit length of the

wire, then-

$R_{AD} = \sigma \,.\, l_G$

And $R_{CD} = \sigma \,.\, l_R$

$$\therefore \quad \frac{G}{R} = \frac{l_G}{l_R}$$

$$\therefore \quad G = R \times \frac{l_G}{l_R}$$

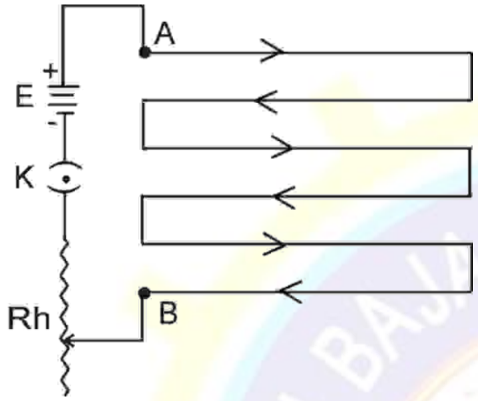
Using this formula, resistance of galvanometer can be calculated.

Note: Sources of errors and their minimization as that of previous experiment.

Potentiometer and Principle of Potentiometer:

Potentiometer is an instrument in which several meter long wire is stretched between two terminals having 5-10 rows of wire parallel to each other.

Principle of Potentiometer:



Consider, a long uniform wire of length (L) and resistance (R) is a stretched between the two terminals A & B of a potentiometer. In series with wire, a battery (E), a key (K) and a rheostat (R_h) is connected.

Closing key (k) and adjusting the rheostat, a uniform current (I) is allowed to flow through the wire, then according to ohm's law -

$$I = \frac{V_{AB}}{R}$$

This current has established P.D., V_{AB} across the wire.

Let, σ be the resistance per unit length of the wire.

$\therefore \quad R = \sigma . L.$

$$\therefore \quad I = \frac{V_{AB}}{\sigma L}$$

$$\therefore \quad \frac{V_{AB}}{L} = I\sigma$$

The L.H.S. in above equation represents potential drop per unit length of the wire which is called as potential Gradient.

For a wire of particular material,
σ = constant.

Also, I = constant

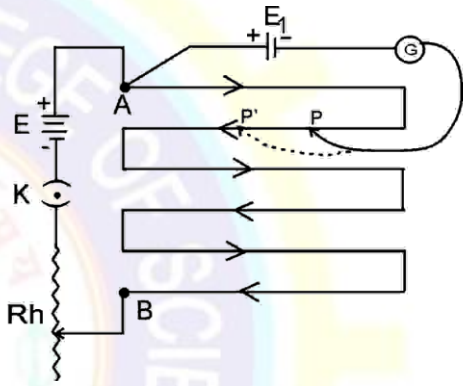
$\therefore \quad I\sigma$ = constant

$$\therefore \quad \frac{V_{AB}}{L} = \text{constant}$$

i.e. $V_{AB} \propto L$

Thus, when a uniform current flows through a wire, the P.D. between any two points of the wire is directly proportional to the length of the wire between those two points. This is **Principle of Potentiometer.**

To compare Unknown EMF of two cells by using Potentiometer (Direct Method):



A Potentiometer consists of uniform wire of several meter long stretched on a wooden board having two terminals A and B. A battery (E), a key (k) and a rheostat (R_h) is connected between points A and B to maintain uniform current (I) through the potentiometer wire.The cell is connected in the circuit in such a way that its positive terminal is connected to terminal A, where +ve of the battery is connected. The negative terminal of E_1 is connected to the Jockey through a sensitive galvanometer.

Now the Jockey is moved along the potentiometer wire and a point of contact P is obtained where galvanometer shows zero deflection, and the balancing length between A and P is measured. Let, it is l_1.

In such a case, potential drop between A and P balances the EMF E_1 of the cell. Therefore,

$E_1 = V_{AP}$

But, $\quad V_{AP} = I \sigma l_1$

$\therefore \quad E_1 = I\sigma l_1$ -------------- (1)

Where, $I\sigma$ = Potential Gradient.

Now, E_1 is replaced by another cell of smaller EMF (E_2) such that + ve terminal of E_2 is connected to the terminal A where the +ve of battery is connected and its –ve terminal is connected to the jockey through a sensitive galvanometer. Again, jockey is touched to the different points of potentiometer wire and another point of contact P' is obtained on the potentiometer wire such that deflection through galvanometer becomes zero. The balancing length between A and P' is measured.
Let, it be l_2. The potential drop across length l_2 balances the EMF of cell (E_2).

$\therefore \quad E_2 = V_{AP'}$

But, $\quad V_{AP'} = I\sigma l_2$

$\therefore \quad E_2 = I\sigma l_2$ -------------- (2)

By (1) ÷ (2),

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

Using this formula, we can compare unknown EMF's of the two cells by using potentiometer.

To compare unknown EMF of two cells by using Potentiometer (Sum and Difference Method):

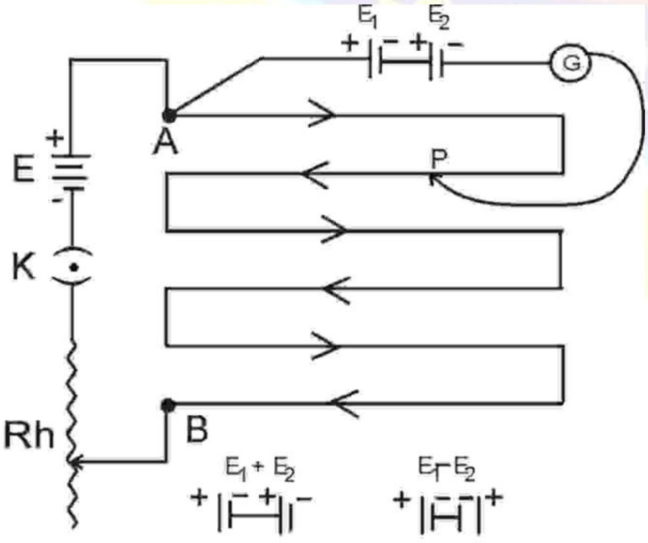


Fig.(i) Fig.(ii)

Potentiometer consists of uniform wire several meters long, stretched on a wooden Board between two terminals A and B. A battery (E), a key (k) and a rheostat (R_h) are connected in series with Potentiometer wire to maintain the uniform current through it. In sum and difference method, the two cells are connected together for comparing their EMF's. Firstly, the cells are connected in such a way that they assists each other, i.e. the resultant EMF is equal to sum of EMF's of both the cells as shown in fig.(i)
Now, the jockey is moved along the potentiometer wire and a point of contact 'P' is obtained for which galvanometer doesn't show any deflection. The length (l_1) between A and P is measured. In such a case –

$E_1 + E_2 = I\sigma l_1$ ------------- (1)

Since, $\quad I\sigma l_1 = V_{AP}$
= Potential drop between Pt. A & P.

Now, cells are connected with potentiometer wire in such a way that they oppose each other i.e. the resultant EMF is equal to difference of EMF's of the two cells, as shown in fig (ii), Again, jockey is moved along the potentiometer wire and a point of contact P' (not shown in fig) is obtained for which deflection through galvanometer is zero. The length (l_2) between A and P' is measured. In this case -

$E_1 - E_2 = I\sigma l_2$ ------------- (2)

Since, $\quad I\sigma l_2 = V_{AP'}$ (P.D. between Pts. A & P')

Where, $\quad I$ = Uniform current through wire.

σ = Resistance per unit length.

By (1) ÷ (2),

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

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

$\therefore \quad E_1 l_2 + E_2 l_2 = E_1 l_1 - E_2 l_1$

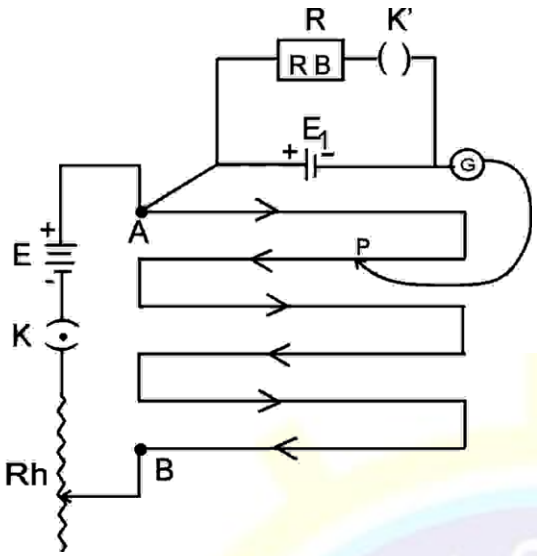
$\therefore \quad E_2 l_2 + E_2 l_1 = E_1 l_1 - E_1 l_2$

$\therefore \quad E_2 (l_1 + l_2) = E_1 (l_1 - l_2)$

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

Using this formula, EMF's of the two cells can be compared by sum and difference method using potentiometer.

To Find Internal Resistance of a cell using Potentiometer:



Pot
entiometer consists of a uniform wire several meters long, stretched on a wooden board between two terminals A and B. A battery (E), a key (k) and a rheostat (Rh) are connected in series between points A and B with potentiometer wire.

Let, E_1 be the cell whose internal resistance is to be determined. Let, its internal resistance be 'r'.E_1 is connected to the same Point A where + ve of the battery (E) is connected, and –ve of the E_1 is connected to a jockey through a sensitive galvanometer.

A resistance box (R. B.) and a key (K') is connected across E_1.

Initially, key (K) is closed and keeping (K') open, a steady current is maintained through the potentiometer wire. Now, taping the jockey at different points of potentiometer wire a point of contact (P) is obtained such that the deflection through galvanometer becomes zero. The balancing length (l_1) between points A and P is measured. In such a case,

$$E_1 = I\sigma l_1 \text{ -------------- (1)}$$

Where, $I\sigma$ = Potential Gradient.

Now, taking some resistance in resistance box R and closing the key (K'), again jockey is taped at different points of the potentiometer wire and a point of contact is obtained on it such that galvanometer shows zero deflection. The balancing length (l_2) is measured such that

$$V = I\sigma l_2 \text{ ------------ (2)}$$

By (1) ÷ (2)

$$\frac{E_1}{V} = \frac{I\sigma l_1}{I\sigma l_2}$$

$$\therefore \quad \frac{E_1}{V} = \frac{l_1}{l_2} \text{ ----------- (3)}$$

According to Ohm's law,
Potential drop across the cell (E_1) is given by –

$$V = I R$$

But, $I = \dfrac{E_1}{R+r}$

Where, r = internal resistance of cell E_1.

$$\therefore \quad V = \frac{E_1}{R+r} \times R$$

$$\therefore \quad \frac{E_1}{V} = \frac{R+r}{R} \text{ --------- (4)}$$

$\therefore$ Equating (3) & (4) ,

$$\frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\therefore \quad 1 + \frac{r}{R} = \frac{l_1}{l_2}$$

$$\therefore \quad \frac{r}{R} = \frac{l_1}{l_2} - 1$$

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

Using this formula, internal resistance of the cell can be determined.

State the advantages of Potentiometer over a Voltmeter.

1) A Voltmeter can not be used to measure a very small potential difference, but by using a very long wire for the potentiometer a suitable potential gradient can be developed for measuring very small potential difference.

2) If a Voltmeter is connected across the cell, it measures terminal potential difference of the cell not the EMF of the cell.

While, in the case of potentiometer, when null point is obtained, no current flows through the cell i.e. cell is open circuit and hence, we can measure its EMF.

3) Accuracy of voltmeter can not be increased, beyond a certain limit as it withdraws the current through the cell, while, accuracy of potentiometer can be increased by increasing the length of wire.

4) Using potentiometer, internal resistance of a cell can also be determined, which can not be done with voltmeter.

5) Voltmeter is portable, but potentiometer is not portable.

6) Voltmeter gives direct readings, but Potentiometer doesn't give direct readings.

State the precautions which are necessary in experiment with potentiometer:

1) The battery in primary circuit should have a constant EMF. The battery discharges rapidly and hence, may show decreasing voltage during the experiment. Hence, the battery should be freshly charged.

2) The EMF of the battery put into the primary circuit should be more than EMF of the cell in the secondary circuit. If this is not done, the null point can not be obtained on the potentiometer wire.

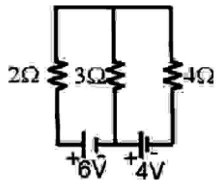
3) The current should be passed in the primary circuit only when null point is to be obtained. Otherwise, the potentiometer wire gets heated and its resistance will increase which causes change in the potential gradient along the wire.

4) There should be no contact resistance where the potentiometer wire is connected to the metal strip.

5) The galvanometer used to determine null point should have a good sensitivity.

NUMERICALS

1. A battery of e.m.f. 4V internal resistance 1Ω is connected in parallel with another battery of EMF 1 volt & internal resistance 1Ω
   Combination is used to send current through an external circuit & resistance 2Ω. Calculate current through external circuit.
2. 2 cells of EMF 1.5 V & 2 V having internal resistant of 1Ω & 2Ω respectively are connected in parallel with similar poles connected together so as to send the current in the same direction through an external resistance of 5Ω. Apply Kirchhoff's law to find current in the external resistant.
3. Use Kirchhoff's law to find current in the resistor of 2Ω, 3Ω, 4Ω.



4. In balanced Metre bridge segment of wire opposite to the resistance of 30Ω is 30 cm. Calculate unknown resistance.
5. An unknown resistance X is placed in the left gap & known resistance 50Ω is placed in right gap of meter bridge. Null point obtained at 40cm from left end of bridge. Find unknown resistance.
6. In meter bridge experiment, with resistance R in left gap & resistance X in right gap the null point is obtained at 40 cm from left gap with resistance R_2 in left gap & same resistance in right gap, null point obtained at 50 cm from left end. Where will null point be obtained if R_1 & R_2 are put in series in left gap, right gap containing X.
7. In meter bridge experiment, with unknown resistance X in left gap & known resistance of 60Ω in right gap. The null point obtained at *l* cm from left end. If unknown resistance shunted by equal resistance. What should be value of resistance in right gap in order to get null point at same place.
8. 2 resistances of values 20Ω & 30Ω are connected in left & right gap of meter bridge. Determine null point when 20Ω is shunted by another resistance of 20Ω.
9. 2 equal resistance are introduced in 2 gaps of Meter Bridge. Find shift in null point if an equal resistance is connected in series with resistance in left gap.
10. 2 coils are connected in series in one gap of meter bridge & null point obtained in middle of wire by putting 75Ω resistance in other gap. 2 coils are then connected parallel & null point obtained in middle of wire with 18Ω resistance in other gap. Find resistance of coils.
11. A coil of unknown resistance is connected in left gap of meter bridge &

resistance R is placed in right gap. Null point is obtained at 40 cm from left end when resistance of 10Ω is connected in series with coil & same resistance R is kept in right gap. Null point is obtained at middle of wire. Find resistance of coil.

12. 4 resistances 10, 10, 10, 15Ω form a Wheatstone network. What shunt is needed across 15Ω resistor to balance bridge?
13. 4 resistances 4, 4, 4, 12Ω forms a Wheatstone network find resistance. Which when connected across $12\ \Omega$ resistor to balance bridge.
14. Two diametric opposite points of a Metal ring are connected two terminals of left gap of meter bridge. In right gap resistance of 15Ω is connected. If null point is obtained at a distance 40 cm from left end. Find resistance of wire used in making ring.
15. Potentiometer wire has a length of 1.5 m & res. of 10Ω. It is connected in series with cell of EMF 4V & internal resistance 5Ω. Calculate potential drop per unit length of wire.
16. Potentiometer has a length of 2 m & resistance 10Ω. It is connected in series with resistance of 990Ω & a cell of EMF 2V. Calculate potential gradient along wire.
17. Potentiometer wire of length 4m has some resistance. The resistance connected in series with wire and accumulator of emf 2V is 16Ω. If potential gradient along wire is 10^{-3} V/cm. Find resistance of Potentiometer wire. The internal resistance of accumulator is negligible.
18. Potentiometer wire of length 4m has resistance of 4Ω. What resistance must be connected in series with this wire & accumulator of E.M.F.
2 V so as to get potential difference of 10^{-3} V/cm of wire.
19. Potentiometer wire of length 10m & resistance 9Ω is connected to a battery of EMF 2.1 V having int. resistance 1.5 Ω. Find potential gradient along the wire. Find balancing length for a cell of EMF 1.08 V.
20. Resistance potentiometer wire 1Ω/m A cell of EMF 1.4 V balances 280 cm on this potentiometer. Calculate current through wire. Also find balancing length for cell of EMF
1.08 V on same potentiometer.
21. Resistance of potentiometer wire is $0.1\ \Omega$/cm. A cell of emf 1.5 V balances at 300 cm on potentiometer wire. Find balancing length for another cell of EMF 1.4 V on same potentiometer wire.
22. Potentiometer wire 10 m long & Potentiometer different 6 V is maintained between its ends. Find EMF of cell which balances against a length of 180 cm of potentiometer wire.
23. In Potentiometer exp. Balancing length found to be 1.8 m for a cell of EMF 1.5 V. Find balancing length of cell of EMF 1V.
24. Potentiometer wire of length 4m has resistance 8Ω. It is connected in series with battery of EMF 2 V & negligible internal resistance. If EMF of cell balances against 217 cm. find EMF of cell. When cell is shunted by a resistance of 15Ω balancing length is reduced to 200 cm. Find internal resistance of cell.
25. 2 cells having unknown EMF E_1 & E_2 ($E_1 > E_2$) are connected in potentiometer circuit so as to assist each other. The null point is obtained at point 8.125 m from higher potential end. When E_2 is connected so as to oppose cell E_1 null point is obtained at 1.25 m from same end. Compare EMF of 2 cells.
26. In potentiometer experiment to compare EMF of 2 cells by sum & different method balancing length of wire is found to be 250 cm & 50 cm respectively. Determine ratio of EMF of 2 cells.
27. Resistor of 5Ω resistance is connected across a cell. Its terminal potential difference is balanced by 150 cm of potentiometer wire. When resistor of 10Ω resistance is connected across cell then potential difference is balanced by 175 cm of potentiometer wire. Calculate internal resistance of cell.
28. EMF of cell is balanced by potential along 281 cm of potentiometer wire. If resistance of 2Ω is connected across cell

balancing length found to be 151 cm. Calculate internal resistance of cell.

29. 2 resistances X & Y in 2 gaps of meter bridge gives null point dividing wire in ratio 2:3. If each resistance increased by $30\,\Omega$, null point divides wire in ratio 5:6. Calculate each resistance.
30. The cold junction of thermocouple is kept at 10^0C. Calculate the temperature at which thermo emf would be maximum. Given that the thermo emf changes sign at 800 K.
31. The emf in a thermocouple changes sign at 600 K. If the neutral temperature is 210^0C, what is the temperature of the cold junction?
32. The emf in a thermocouple changes sign at 700 K. If the neutral temperature is 210^0C, what is the temperature of the cold junction?

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SPACE FOR EXTRA POINTS