Current Electricity

1. ELECTRIC CURRENT

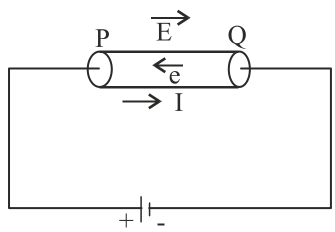
(a) Time rate of flow of charge through a cross section area is called **Current**.

$$I_{av} = \frac{\Delta q}{\Delta t} \text{ and instantaneous current } i = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

(b) Direction of current is along the direction of flow of positive charge or opposite to the direction of flow of negative charge. But the current is a scalar quantity.

$\xrightarrow{\quad} i$ $\qquad\qquad$ $\xleftarrow{\ i\ }$

$q\oplus \longrightarrow$ velocity $\qquad$ $q\ominus \longrightarrow$ velocity



SI unit of current is ampere and

1 Ampere = 1 coloumb/sec

1 coloumb/sec = 1A

Ex. 1 Find no. of electrons passing across a cross-section of metal wire in 5 minutes when steady current of 1.6 amp flows through the wire. Given charge on electron (e) $= 1.6 \times 10^{-19}$ C.

Sol^n : $I = \dfrac{\text{charge}}{\text{time}}$ $\qquad 1.6 = \dfrac{N \times 1.6 \times 10^{-19}}{5 \times 60}$

$\boxed{\therefore\ N = 300 \times 10^{19}}$

Ex. 2 Charge through a cross-section of a conductor is given by $q = (3t^2 + 2t)$ coloumb. Find the current through the conductor at the insant t = 2 sec

Sol^n : $I = \dfrac{dq}{dt}$ $\qquad I = 6t + 2$ $\qquad$ Put t = 2 sec

$\therefore\ I = 6 \times 2 + 2$ $\qquad$ $\boxed{\therefore\ I = 14 \text{ amp}}$

2. CONDUCTOR :

In some materials, the outer electrons of each atoms or molecules are only weakly bound to it. These electrons are almost free to move throughout the body of the material and are called free electrons. They are also known as conduction electrons. When such a material is placed in an electric field, the free electron move in a direction opposite to the field. Such materials are called conductors.

3. **INSULATOR**

Another class of materials is called insulators in which all the electrons are tightly bound to their respective atoms or molecules. Effectively, there are no free electrons. When such a material is placed in an electric field, the electrons may slightly shift opposite to the field but they can't leave their parent atoms or molecules and hence can't move through long distances. Such materials are also called dielectrics.

4. **SEMICONDUCTOR**

In semiconductors, the behaviour is like an insulator at low levels of temperature. But at higher temperatures, a small number of electrons are able to free themselves and they respond to the applied electric field. As the number of free electrons in a semiconductor is much smaller than that in a conductor, its behaviour is in between a conductor and an insulator and hence, the name semiconductor. A freed electron in a semiconductor leaves a vacancy in its normal bound position. These vacancies also help in conduction.

Specific Resistance :

Experimently it has been found that at given temperature resistance (R) of a conductor is

1) directly proportional to length (l) of conducor.
2) inversely proportional to area of cross section (A) of the coductor
3) and depends upon material of conductor i.e.

$R \alpha \, l$ .... (1) $\qquad R \alpha \frac{1}{A}$ .... (2)

from (1) and (2)

$R \alpha \frac{l}{A}$ $\qquad \therefore R = \rho \frac{l}{A}$ .... (3)

ρ = constant and called specific resistance OR resistivity of material of conductor.

The reciprocal of resistivity $(\frac{1}{\rho})$ is called conductivity.

Re-arranging (3), We get,

$\rho = \frac{RA}{l}$ Put A = 1 and l = 1 we get $\qquad \rho = R$

Thus specific resistance of the matrial of conductor is defind as resistance offered by conductor having unit length and unit cross section area.

Unit : Specific resistance $\rho = \frac{\text{Ohm x m}^2}{\text{m}}$

ρ = Ohm x. m

Dependence of Resistance on various factors

$R = \rho \frac{\ell}{A}$ Therefore R depends as

(1) $\propto \ell$ $\qquad$ (2) $\propto \frac{1}{A}$

Dependence of Resistance on Temperature :

The resistance of most conductors and all pure metals increases with temperature, but there are a few in which resistance decreases with temperature. If R_o and R be the resistance of a conductor at 0^o C and at t° C, then it is found that

$R = R_o\ (1 + \alpha t)$. Where α is temperature coefficient of resistance. The unit of a is K^{-1} or $^oC^{-1}$.

Ex. 3 Specific resistance of nicrome wire is $2.65 \times 10^{-8}\ \Omega m$. Find the resistance of a nicrome wire of length 100 m & diameter 0.2 mm.

Sol^n : Given : $\rho = 2.65 \times 10^{-8}\ \Omega m$, $l = 100 m$

$d = 0.2 mm,\ r = 0.1\ mm = 10^{-4}\ m$

To Find: - R

$$R = \rho \frac{l}{A}$$

$$\therefore\ R = 2.65 \times 10^{-8} \times \frac{100}{\pi r^2}$$

$$\therefore\ R = \frac{2.65 \times 10^{-8} \times 100}{3.14 \times 10^{-8}}$$

$\therefore\ R = 265/3.14$ $\qquad$ $\therefore R = 84.39 \Omega$

Ex. 4 A cylindrical metal wire has length 3.14 m & diameter 2 mm. If resistance of wire is 10Ω, find its resistivity (specific resistance)

Sol^n : Given :- $l = 3.14 m,\ d = 2 mm$

$r = 1 mm = 10^{-3}\ m,\ R = 10\Omega$

To find - ρ

$$R = \rho \frac{l}{A} \qquad \therefore\ \rho = \frac{RA}{l}$$

$$\therefore \rho = \frac{10 \times \pi r^2}{3.14} = \frac{10 \times 3.14 \times (10^{-3})^2}{3.14}$$

$$\therefore\ \rho = 10^{-5}\ \Omega m$$

Ex. 5 Two wires have lengths in the ratio 1 : 4, radii in the ratio 1 : 2, specific resistance in the ratio 3 : 1 Find the ratio of resistance R.

Sol^n : Given ; - $\frac{l_1}{l_2} = \frac{1}{4}, \frac{r_1}{r_2} = \frac{1}{2},$

$\frac{\rho_1}{\rho_2} = \frac{3}{1}$

To find : - $\frac{R_1}{R_2}$

We know that - $R = \frac{\rho l}{A}$

For first wire -

$$R_1 = \frac{\rho_1 l_1}{A_1} \qquad .... \text{(I)}$$

For second wire -

$$R_2 = \frac{\rho_2 l_2}{A_2} \qquad .... \text{(II)}$$

Dividing (I) by (II)

$$\frac{R_1}{R_2} = \frac{\rho_1 l_1}{A_1} \times \frac{A_2}{\rho_2 l_2}$$

$$\therefore \frac{R_1}{R_2} = \frac{\rho_1}{\rho_2} \times \frac{l_1}{l_2} \times \frac{A_2}{A_1}$$

$$\therefore \frac{R_1}{R_2} = \frac{\rho_1}{\rho_2} \times \frac{l_1}{l_2} \times \frac{\pi r_2^2}{\pi r_1^2} \quad (\because A = \pi r^2)$$

$$\therefore \frac{R_1}{R_2} = \frac{3}{1} \times \frac{1}{4} \times \frac{4}{1}$$

$$\therefore \frac{R_1}{R_2} = \frac{3}{1}$$

$$\therefore R_1 : R_2 = 3:1$$

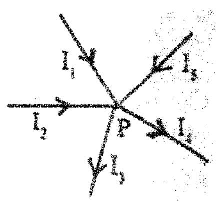
KIRCHHOFF'S LAWS :

KIRCHHOFF'S FIRST LAW :(Kirchhoff's Current law (KCL)) : Algebric sum of all the current at the junction is zero. i.e. $\Sigma I = 0$

Sign Convension.

1) Current entering the junction is taken as positive while current leaving the junction is taken as negative.
2) Junction is a meeting point of two or more circuit elements.

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



Thus sum of currents (total current) flowing towards a junction is equal to the sum of currents (total current) flowing away from the junction. This law is in accordance with conservation of charge; since there is no accumulation (gain) or loss of charge at the junction.

2) **Kirchooff's Second Law (KVL) :** (Voltage law or loop theorem) **Electrical Network** It is a combination of various electric circuit elements (components) and sources of e.m.f. connected in complicated manner.

Statement : The algebraic sum of potential differences (products of current and resistance) and electromotice forces applied in a closed loop of electrical network is zero.

i.e. $\Sigma IR + \Sigma E = 0$ .....(1)

Sign Convention : While tracing a circuit,

i) Potential difference taken in the direction of conventional current is negative and P.D. taken against the direction of conventional current is positive. OR If the direction of tracing is same as that of conventional current flow then potential difference across the resistances is considered as negative otherwise it is positive.

ii) E.M.F. is positive if we traverse from negative terminal to the positive terminal inside the cell and e.m.f. is negative if we traverse from the positive terminal to the negative terminal.

Let us assume that current flows from A to B i.e. from higher potential point A to lower potential point B and applying Kirchoff's second law.

(I) For loop 'ACDFA',

$\therefore -I_1R_2 + I_2R_4 - E_2 + I_2R_5 - I_1R_1 + E_1 = 0$

i.e. $E_1 - E_2 - I_1(R_2+R_1) + I_2(R_4+R_5) = 0$

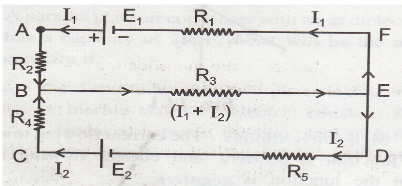
(II) For the loop 'ABEFA',

$-I_1R_2 - (I_1+I_2)R_3 - I_1R_1 + E_1 = 0$

i.e. $E_1 - I_1(R_2+R_1+R_3) - I_2R_3 = 0$

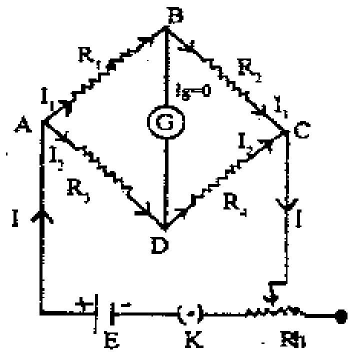
(III) For the loop 'BCDEB'

$I_2R_4 - E_2 + I_2R_5 + (I_1+I_2)R_3 = 0$



By definition of P.D. (ΣIR) represents the total energy spend in sending a unit charge round the circuit again ΣE represents the total energy supplied by the sources of e.m.f. in that circuit for sending a unit charge. Kirchhoff's second law is in accordance with the law of conservation of energy.

Wheatstone Bridge



Simple method of finding unknown resistance is a bridge circuit designed by scientist Wheatsstone. Wheat - Stone bridge consists of an arrangement of four resistance R_1, R_2, R_3 and R_4 in such a way that as to from quadrilateral ABCD. A cell is connected across any digonal say AC and galvanometer is connected across other digonal say BD bridge is said to be balanced when there is no flow of current through galvanometer.

Let I be the current delivered by the cell. At point 'A' there will be branching of the current. Let current I_1 flows through resistance R_1 and current I_2 flows through resistance R_3. In balance condition R_1, R_2, R_3 and R_4 are adjusted such a that there is no flow of current through the galvanometer. Hence current I_1 flows through resistance R_2 and current I_2 flows hrough resistance R_4

Proof for Balance Condition : When the bridge is balance, there is no flow of current through galvanometer i.e. potential at B equal to potential at D i.e.

$V_B = V_D$ $\qquad$ $V_A - V_B = V_A - V_D$

$\therefore \; I_1R_1 = I_2R_3$ $\qquad$ ----------------- (1)

again, $V_B = V_D$

$V_B - V_C = V_D - V_C$

$\therefore \; I_1R_2 = I_2R_4$ $\qquad$ ------------------- (2)

Dividing (1) by (2)

$$\frac{I_1R_1}{I_1R_2} = \frac{I_2R_3}{I_2R_4} \qquad | \qquad \frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Out of four resistance, if three are known, fourth can be calculated by using above formula.

II Method

Proof for balance condition by applying Kirchhoff's Voltage Law

Applying Kirchhoff's Voltage Law for closed ABDA, we get

$0 = I_1R_1 + G \text{ x } 0 - I_2R_3$

$I_1R_1 = I_2R_3$ $\qquad$ -------------- (1)

Also applying Kirchhoff's Law for closed circuit BCDB

$$0 = I_1R_2 - I_2R_4 + G \times 0$$

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

dividing (1) By (2)

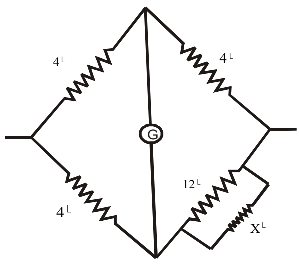
$$\frac{I_1R_1}{I_1R_2} = \frac{I_2R_3}{I_2R_4} \qquad | \qquad \frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Out of four resistance, if three are known, fourth can becalculated by using above formula.

Ex. 6 Four resistances 4, 4, 4 and 12Ω form a Wheatstone's network. Find the resistance which when connected across the 12Ω resistance, will balance the network.

Soln : $R_1 = 4\ \Omega$, $R_2 = 4\ \Omega$

$R_3 = 4\Omega$, $R_4 = 12\ \Omega$



To find X, we first find equivalent resistance in parallel combination

$$\frac{1}{Rp} = \frac{1}{X} + \frac{1}{12} = \frac{12 + X}{12X}$$

$$\therefore \quad Rp = \frac{12\ X}{12 + X}$$

In balancing condition

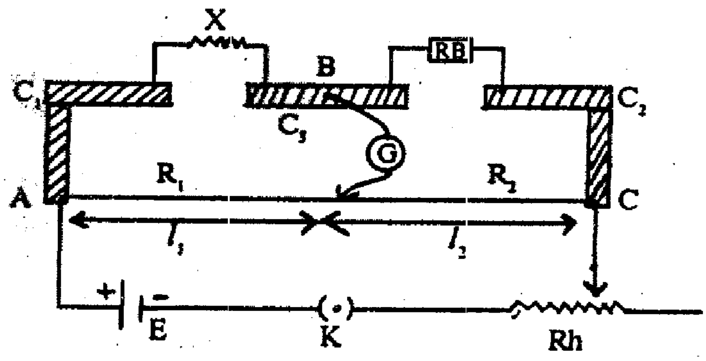
$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \frac{4}{4} = \frac{4}{\frac{12X}{12 + X}}$$

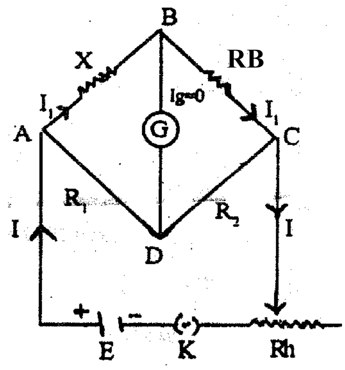
$$1 = \frac{4(12 + X)}{12X} \qquad 12X = 48 + 4X$$

$$8X = 48 \qquad \boxed{\therefore \ X = 6\Omega}$$

Metre Bridge :

Metre Bridge is simple form of Wheatstone bridge. It consist of thin uniform wire AC of one meter long stretched on wooden board between two thick metal strips C_1 and C_2. There is one more metal strip C_3 so placed between C_1 and C_2 that it forms two equal gaps between C_1 and C_2.





Known resistance in the form of resistance box (RB) is conected in right gap and unknown resistance (X) is placed in left gap of meter bridge. A cell (E), Key (K) and Rheostat (Rh) are connected across the wire AC as shown in above circuit diagram. One end of galvanometer is connected at point B and other end is connected to Jockey which Slides on AC. Adjust the resistance R from resistance box (RB) Jockey is outched at different points on the wire AC and Point D is obtained at which galvanometer shows zero deflection is determined. The point D is called as null point.

let $l(AD) = l_1$ and $l(DC) = l_2$

If R_1 is resistance of wire AD and R_2 is resistance of wire DC

$$R_1 = \frac{\rho l_1}{A} \quad ---------- \left[\therefore R \propto \frac{l}{A} \therefore R = \frac{Sl}{A}\right] \quad \text{and} \quad R_2 = \frac{\rho l_2}{A}$$

Where ρ is specific resistance of material of wire and A is area of cross section of wire AC, Applying balance condition to above metre bridge we get

$$\frac{x}{R} = \frac{R_1}{R_2} \qquad | \qquad X = \frac{R_1}{R_2} R$$

Putting the value of R_1 and R_2

$$X = \frac{\rho l_1/A}{\rho l_2/A} \text{ x } R \qquad | \qquad X = \frac{\rho l_1}{A} \text{x} \frac{A}{\rho l_2} \text{ x } R$$

$$X = \frac{l_1}{l_2} R \; ; \qquad l_2 = 100\text{-}l_1 \qquad X = \left(\frac{l_1}{100 - l_1}\right) R$$

Knowing l_1, l_2 and R, unknown resistance X can be calculated by using above formula.

Precaution OR Sources OR Error :

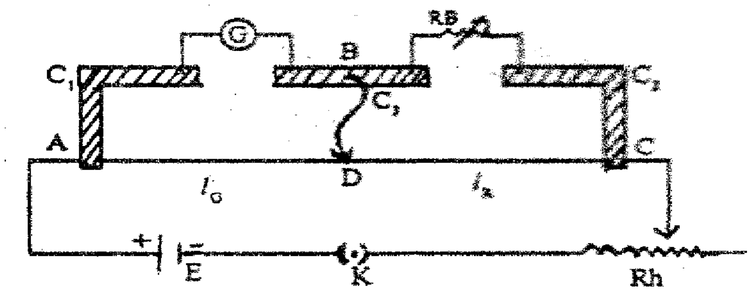
1) **Error due to non-uniformity of wire :** The wire may be non-uniform to eliminates this error unknown resistance X and known resistance R are interchanged in the gap and null point is found again. The average value of X is then calculated.

2) **Error due to contact resistance :** If contact between copper strip and bridge wire at A and C are not contact resistance. The error due to contact resistance becomes minimum when l_1 and l_2 are maximum. i.e. when null point is obtained at centre of the wire. This is done by adjusting the resistance R.(i.e. null point is obtained at middle one third portion of wire).

3) **Error due to Joules heating effect :** To avoid error due to Joules heating effect continuous current should not be passed through the wire.

Determination of Resistance of Galvanometer by Kelvin's Method :

Electrical circuit diagram for Kelvin's method is as shown in above circuit. Galvanometer G whose resistance is to be determined is connected is one gap of meter bridge and resistance box (RB) is connected in other gap. A cell (E), a key (K) and Rehostat (Rh) are connected across wire AC as shown in above circuit diagram. A point B is connected to jockey. A suitable resistance R is introduced in resistance box and current is put on. Current passes through the galvanometer gives some deflection (θ).



Now touch the Jockey to different point of wire AC and D is obtained at which galvanometer shows same deflection as before (θ) is determined. Galvanometer shows same deflection with or without contact point D. Point D is called null point or balance pont. In Kelvin's mentod Galvanometer deflection remains same. Hence it is also called "Constant Delfection Method".

Let length of segment of wire opposite to the galvanometer is l_g length of segment of wire opposite to the resistance box be l_R. Let G be the resistance of galvanometer since bridge is balanced applying balance condition we get,

$$\frac{G}{R} = \frac{R_1}{R_2}$$

But $R_1 = \frac{\rho l_g}{A}$

ρ	----------	Specific resistance of wire
A	----------	Area of cross section of wire

$$R_2 = \frac{\rho l_R}{A}$$

Hence, putting the value of R_1 and R_2 in (1), we get

$$\frac{G}{R} = \frac{l_g}{l_R}$$

$$G = \frac{l_g}{l_R} R \; ; \qquad l_R = 100 - l_g \quad \text{OR} \quad G = \left(\frac{l_g}{100 - l_g}\right) R$$

Knowing l_g, l_R and R unknown resistance of galvanometer can be calculated.

Precaution :

1) **Error due to non-uniformity of wire :** The wire may be non-uniform to eliminate these error unknown resistance G and known resistance R are interchanged in the gap and null point is found again. The average value of G is then calculated.

2) **Error due to contact resistance :** If contact between copper strip and bridge wire at A and C are not perfect then some resistance is introduced A and C. This resistance is called contact resistance. The error due to contact resistance becomes minimum when l_g and l_R are maximum i.e. when null point is obtained at centre of the wire. This is done by adjusting the resistance R. (ie null point is obtained at middle one third portion of wire).

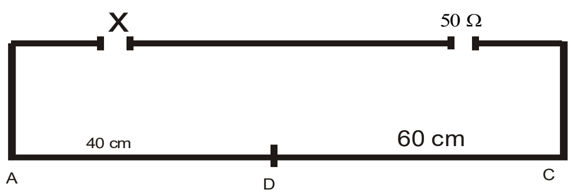
3) **Error due to Joules heating effect :** To avoid error due to Joules heating effect continuous current should not be passed through the wire.

Ex. 7 An unknown resistance x is placed in the left gap & known resistance 50Ω is placed in right gap of mater bridge. The null point is obtained at 40 cm from the left end of the bridge. Find the unknown resistance.

Sol^n : Given : - $R_1 = x$, $R_2 = 50\Omega$

$l_1 = 40\text{cm}$, $l_2 = 60$ cm

To find - x



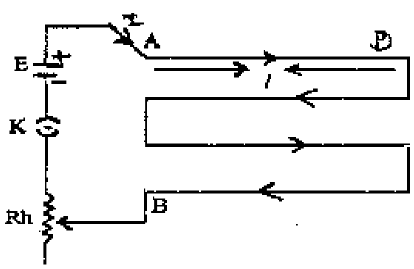
Since bridge is balanced

$$\frac{x}{50\Omega} = \frac{40\text{cm}}{60\text{cm}} \qquad \therefore \; x = 33.33\Omega$$

Potentiometer :

Q. Explain the princile of Potentiometer

Potentiometer is a device which can be measure potential difference between two point in an electric circuit. It consist of uniform resistance wire stretched on wooden board between two terminal. The length of wire may be form 2m to 10 m.



Let L ---- Length of potentiometer wire.

R ---- Resistance of potentiometer wire.

l ----- Balancing length

Resistance per unit length of wire (r') = $\frac{R}{L}$

If I is a steady current flowing through the potentiometer wire, then, Potential difference per unit length of wire = I r' Potential difference per unit length of wire os also called as potential gradient. If D is any point on the potentiometer wire at a distance l from A then, Potential difference between A and D = (Ir')l For steady current (I r') is constant Hence Potential difference between A and D = Kl i.e. Potential difference between A and D $\propto l$

Potential different per unit length of wire = Ir' = I (R/L) = V/L (Volt/M)

Principle of Potentiometer : For a steady current flowing through potentiometer wire potential difference across any length of wire is directly proportional to length of wire.

Ex. 8 A potentiometer wire has a length of 2 m and resistance $10\ \Omega$. It is connected in series with resistance $990\ \Omega$ and a cell of e.m.f. 2 V. Calculate the potential gradient along the wire.

Soln : $L = 2\,m,\ r = 10\ \Omega,\ R = 990\ \Omega,\ E = 2\,V$

Sol^n : The current in the circuit is

$$I = \frac{E}{r+R} = \frac{2}{10+990} = \frac{2}{1000} = 2\times10^{-3}\ A$$

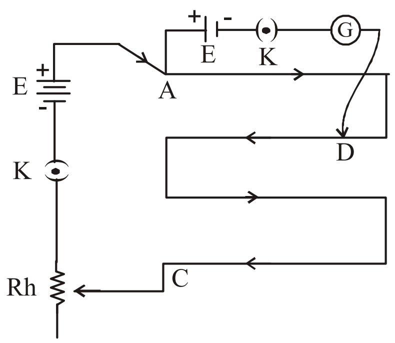
The potential difference across the wire is

$$V = Ir = 2\times10^{-3}\times10 \qquad \therefore\ V = 2\times10^{-2}\ V$$

$$\therefore \text{ Potential gradient along the wire} = \frac{V}{L} = \frac{2\times10^{-2}}{2}$$

$$\frac{V}{L} = 10^{-2}\ V/m$$

Q.No. 1 : Determination of emf of cell by potentiometer.



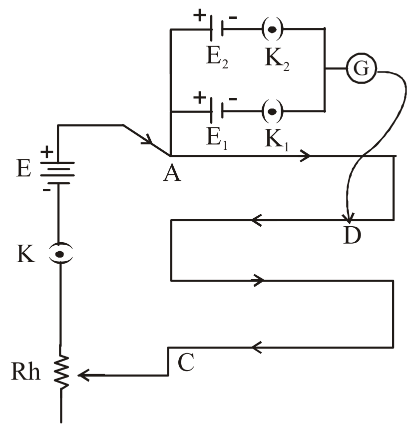
Connections are made as shown in above circuit diagram. Positive terminal of cell is connected to that end of potentiometer where positive terminal of battery is connected. Negative terminal of cell is connected to jockey through galvanometer.

Negative terminal of battery is connected to point C through rheostat. Adjust the position of rehostat, so that deflection at two ends of potentiometer is on opposite side closed, K_1 so that cell of emg E_1 is in the circuit. Find balancing length with the help of Jockey i.e. a point (D) where galvanometer will not show any deflection. Let it be l_1 cm then by principle of potentiometer we have,

$E_1 = (Ir')l_1$ ----------- (1)

Knowing potential gradient, emf (E_1) of cell can be calculated.

Q.2 To compare emf of two cell by Potentiometer OR $\frac{E_1}{E_2}$ by Potentiometer.



Connections are made as shown in above circuit diagram. Positive terminal of two cells are connected to that end of potentiometer where positive terminal of battery is connected. Negative terminal of cells are connected to Jockey through galvanometer by using two way key. Negative terminal of battery is connected to point C through rheostat. Adjust the position of rehostat,so that deflection at two ends of potentiometer is on opposite side. Closed K_1 and open K_2 so that cell of emg E_1 is in the circuit. Find balancing length with the help of a Jockey i.e. a point (D) where galvanometer will not show any deflection. Let it be l_1 cm than by principle of potentiometer, we have,

$E_1 = (Ir')l_1$ ----------- (1)

Where I r' is potential gradient.

Now closed K_2 and open K_1 so that cell of emf E_2 is in the circuit, find the balancing length. Let it be $l_2$cm. they by principle of potentiometer we have,

$E_2 = (Ir')l_2$ ----------- (2)

dividing (1) by (2) we get

$\frac{E_1}{E_2} = \frac{l_1}{l_2}$ change the position of rheostat and each case find out l_1 and l_2

hence, Find out $\frac{E_1}{E_2}$.

Ex. 9 Resistance of potentiometer wire is $0.1\Omega/\text{cm}$. A cell of e.m.f. 1.5 V balances at 300 cm on this potentiometer wire. Find the balancing length for another cell of e.m.f. 1.4 Volts on the same potentiometer wire.

Sol^n : Given : - $r' = 0.1\ \Omega/\text{cm}$

$r' = 10\ \Omega/\text{m}$

$E_1 = 1.5\,\text{V}$

$E_2 = 1.4\,\text{V}$

$l_1 = 300\,\text{cm} = 3\,\text{m}$

To find - l_2

We know that - $\dfrac{E_1}{E_2} = \dfrac{l_1}{l_2}$

$\therefore \dfrac{1.5}{1.4} = \dfrac{3}{l_2}$ $\qquad \therefore 1.5\,l_2 = 1.4 \times 3$

$\boxed{\therefore \ l_2 = 2.8\,\text{m}}$

Ex. 10 In potentiometer experiment, the balancing length is found to be 1.8 m for a cell of e.m.f. 1.5 V. Find the balancing length for a cell of e.m.f . 1 V

Sol^n : Given : - $l_1 = 1.8\,\text{m}$

$E_1 = 1.5\,\text{V}$

$E_2 = 1\,\text{V}$

To find - l_2

We know that - $E_1 = (Ir')\,l_1$

$\therefore \ Ir' = \dfrac{E_1}{l_1} = \dfrac{1.5}{1.8}$

$\therefore \ Ir' = 0.8333$ amp.

Now, $\qquad E_2 = (Ir')\,l_2$

$\therefore \ l_2 = \dfrac{E_2}{(Ir')} = \dfrac{1}{0.8333}$

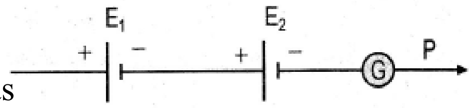
$\boxed{\therefore \ l_2 = 1.2\ \text{m.}}$

Precaution :

1) Positive terminal of battery in primary circuit should be connected to that end of potentiometer wire where positive terminal of cells are connected.
2) EMF of battery connected in primary circuit must be greater than emf of cell $E>E_1$, $E>E_2$
3) Continuous current should not be passed through potentiometer wire.
4) Potentiometer wire must be uniform.
5) Resistance of potentiometer wire must be high.

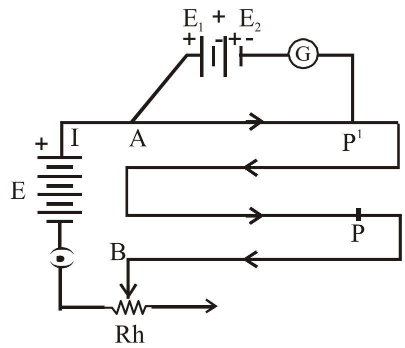
Q. Comparision of emf of two cells by potentiometer by sum and difference method.

OR $\frac{E_1}{E_2}$ sum and difference method.



(a) Cells assist to each other

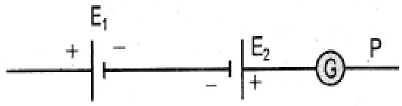
Comparision of emf of two cell can also be made by using both cells together in circuit as shown in above circuit diagram. When two cell are connected together as shown in fig. (1). The combination acts as a signal cell having emf $E = E_1 + E_2$. These cell are said to be assisting each other. The balancing length l_3 is found on potentiometer wire i.e., point D where galvanometer will show no deflection, they by theory of potentiometer, we have,



$E_1 + E_2 = (Ir')l_3$ ----------- (3)

Where Ir' is potential gradient

Now, cells are connected as shown in figure (II) The combination acts as single cell having emf $E = E_1 - E_2$. These cell are said to be opposite each other. The balancing length l_4 is again found then by principle of potentiometer.

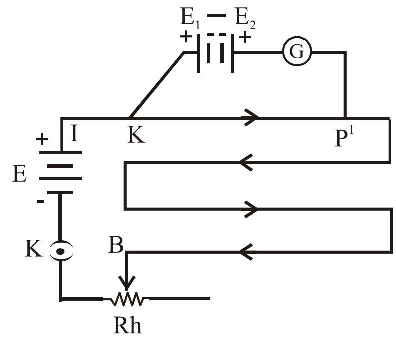


(b) Cells oppose to each other.

$E_1 - E_2 = (Ir')\, l_4$ ----------- (3)

$$\frac{E_1}{E_2} = \frac{l_3 + l_4}{l_3 - l_4}$$

Knowing l_3 and l_4, $\frac{E_1}{E_2}$ can be calculated.



Precaution :

1) Positive terminal of battery in primary circuit should be connected to that end of potentiometer wire where positive terminal of cell are connected.
2) Emf of barrery connected in parimary circuit must be greater than emf of cell.
3) Continuous current should not be passed through potentiometer wire.

Ex. 11 In potentiometer experiment to compare the emf of two cells by sum & difference method, balancing length is found to be 250 cm & 50 cm respectively. Determine ratio of two emf.

Soln : Gven : - $l_3 = 250\,\text{cm} = 2.5\,\text{m}$

$l_4 = 50\,\text{cm} = 0.5\,\text{m}$

To find : - E_1 / E_2

By sum & difference method -

$$\frac{E_1}{E_2} = \frac{l_3 + l_4}{l_3 - l_4} \qquad \therefore \frac{E_1}{E_2} = \frac{2.5 + 0.5}{2.5 - 0.5} = \frac{3.0}{2.0}$$

$$\boxed{\therefore \frac{E_1}{E_2} = \frac{3}{2}}$$

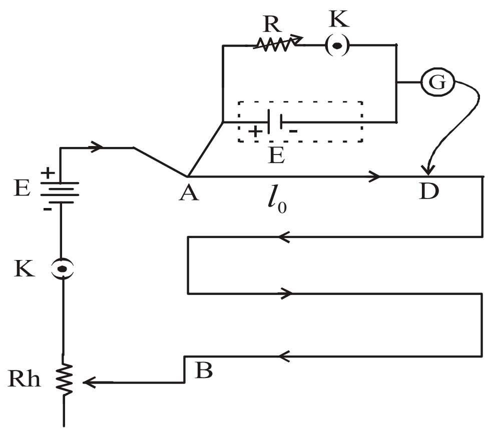
Determination of Internal Resistance of Cell by potentiometer.

Connection are made as shown in above fig. positive terminal of cell (E) is connected to that end of potentiometer wire where positive terminal of battery is connected. Negative terminal of cell is connected to jockey through galvanometer. Resistance box along with key are connected across the cell as shown in the above circuit diagram. initially, key (K) is kept open. By sliding the jockey along the wire, point D is obtained where galvanometer will not show any deflection. Let length of wire AD be l_0 cm then by principle of potentiometer.

$E = (Ir')l_0$ ------------- (1)

Now suitable resistance R is introduced in resistance box and key (K) is closed then, current in the circuit containing cell of emf E and resistance R is given by

$$I = \frac{E}{R + r}$$



Where r is the internal resistance of cell to be calculatd.

Potential difference across R is given by

$$V = IR, \text{ But } I = \frac{E}{R + r}$$

$$V = \left(\frac{E}{R + r}\right) R$$

Corresponding to this potential null point is obtained with the help of jockey. Let this balancing length be ℓ cm then by principle of Potentiometer.

$V = (Ir')l$

$$\text{But } V = \left(\frac{E}{R + r}\right)R \qquad \left(\frac{E}{R + r}\right) R = (Ir')l \quad \text{--------------- (2)}$$

$$\text{dividing (1) by (2)} \quad \frac{R + r}{R} = \frac{l_0}{l} \qquad r = \left(\frac{l_0}{l} - 1\right)R$$

Knowing l_0, l and R the internal resistance of cell (r) can be calculated by using above formula.

Precaution :

1) Positive terminal of battery in primary circuit should be connected to that end of potentiometer wire where positive terminal of cell are connected.
2) Emf of battery connected in primary circuit must be greater than emf of cell. $E>E_1+E_2$
3) Continuous current should not be passed through potentiometer wire.
4) Potentiometer wire must be uniform.
5) Resistance and potentiometer wire must be high.

Use of Potentiometer :

(i) To measure e.m.f. of a cell.

(ii) To compare e.m.f.s of two cells.

(iii) To determine internal resistance of a cell.

Ex. 12 Emf of cell is balanced by a fall of potentiometer along 281 cm of potentiometer wire. If resistance of 8Ω is connected across the cell, balancing length is found to be 151 cm. Calculate internal resistance of cell.

Soln : Given : - $l_0 = 281$ cm

$R = 8\Omega$

$l = 151$cm

To find : - r

$$\text{Internal resistance } (r) = \left(\frac{l_0}{l} - 1\right) R$$

$$\therefore r = \left(\frac{281}{151} - 1\right) 8$$

$$\therefore r = \left(\frac{130}{151}\right) 8$$

$$\therefore \quad r = 6.887\Omega$$

Q. Write down advantages of potentiometer related in voltmeter OR Difference between voltmeter and potentiometer.

1) Voltmeter can measure potential difference only but potentiometer can be measure potential difference as well as emf of cell.

2) Potentiometer can measure very small potential difference and it can be used to calibrate the voltmeter.

3) Measurement of Potentiometer is more accurated than that of voltmeter.

4) The accuracy of potentiometer can be easily increased by increasing the length of wire.

5) A small P.D. can be measured accurately with the help of potentiometer. The resistance of voltmeter is high but not infinity to work as an ideal voltmeter.

6) Potentiometer can measure internal resistance of cell voltmeter can not measure internal resistance of cell.

Disadvantages of potentiometer

1) Voltmeter is portable but potentiometer is not protable

2) Voltmeter gives direct reading potentiometer do not give direct reading.

QUESTION BANK

1. State & explain Kirchhoff's laws for electrical circuit.

2. Obtain balancing condition in case of wheatstone's network.

3. Explain with neat circuit diagram, how will you determine the unknown resistance by using a meter bridge.

4. Describe Kelvin's method to determine the resistance of galvanometer by using meter- bridge.

5. State any two sources of errors in meter-bridge experiment. Explain how they can be minimized.

6. Explain : In Wheatstone's meter-bridge experiment the null point is obtained in middle one third portion of wire.

7. Explain the principle of potentiometer.

8. Describe how potentiometer is used to compare the e.m.f.s of two cells by
   a) direct method   b) combination method.

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

10. State the precautions which must be taken while performing experiment with potentiometer.

11. State the advantages of potentiometer over voltmeter.

ASSIGNMENT

1) Two coils are connected in series in one gap of a meterbridge and the null point is obtained in the middle of the wire by putting $75\,\Omega$ in the other gap. Two coils are then connected in parallel and the null point is obtained again in the middle of the wire, the resistance in the other gap is changed by $57\,\Omega$. Find the resistance of each coil.
Ans : $45\,\Omega$ and $30\,\Omega$)

2) Two resistances X and Y are connected in the left and right gap of meter bridge. A null point was found on the bridge wire such that ratio of lengths of two segments of wire is 2:3. The distance of the null point was measured from the left end of the wire. When the value of X is changed by 20Ω, the position of null point divides the wire into segments of length in the ratio 1:4. Determine X and Y.
(Ans : X = 32 Ω and Y = 48 Ω)

3) A cell balances against a length of 250 cm on potentiometer wire when it is shunted by a resistance of 10Ω. The balancing length reduces by 50 cm.when it is shunted by a resistance of 5Ω. Calculate the balancing length when the cell is in open circuit and the internal resistance of the cell. (Ans : r = 3.333Ω)

4) A cell of emf 3V and internal resistance 4Ω is connected to two resistances of 10Ω and 24 Ω joined in parallel. Find the current through each resistance using Kirchoff's laws. (Ans : I = 0.2713 Amp)

5) The current flowing through an external resistance of 2Ω is 0.5A when it is connected to the terminals of a cell. This current reduces to 0.25 A when the external resistance is 5Ω. Use Kirchoff's laws to find emf of a cell. (Ans : r = 1Ω and E = 1.5V)

6) Four resistances 5Ω, 10Ω, 15Ω and an unknown resistance X Ω are connected in series so as to form Wheatstone network. Determine the unknown resistance X, if the network is balanced by these numerical values of resistances. (Ans : X = 7.5Ω)

7) Two equal resistances are introduced in two gaps of meter bridge. Find shift in null point, if an equal resistances is connected in series with the resistance in left gap
(Ans : $l = 66.66$)

8) Two cells having unknown emf's E_1 and E_2 ($E_1 > E_2$) are connected in potentiometer circuit so as to assist each other. The null point is obtained at 8.125 m from the higher potential end. When cell E_2 is connected so as to oppose E_1, the null point is obtained at 1.25 m from same end. Compare the emf's of two cells. (Ans : $\frac{E_1}{E_2} = 1.364$)

9) A potentiometer wire has a length 10 m and a resistance 20 Ω . Its terminals are connected to a battery of emf 4V and internal resistance 5Ω. What are the distances at which null points are obtained when two cells of emf 1.5 V and 1.3V are connected so as to (a) assist and (b) oppose each other ? (Ans : (a) 8.75 m (b) 0.625 m)

10) An unknown resistance is placed in the left gap and resistance of 50 ohm is placed in the right gap of a meter bridge. The null point is obtained at 40 cm from the left end. Determine the unknown resistance. **(Ans :**33.33 ohm) **(March - 2017)**

11) A potentiometer wire has resistance of per unit length of $0.1\Omega/m$. A cell of e.m.f. 1.5 volt balances against 300 cm length of the wire. Find the current in the potentiometer wire. (Ans : $\therefore \quad I = 5A$) **(October - 2015)**

12) A potentiometer wire has a length of 4m and a resistance of 5 Ω. What resistance should be connected in series with a potentiometer wire and a cell of e.m.f. 2 V having internal resistance 1 Ω to get a potential gradient of 10^{-3} V/cm? (Ans : $\therefore \ R_1 = 19\Omega$) **(Oct. 2014)**

13) The resistance of 11Ω is connected in right gap. If null point is obtained at a distance of 45 cm from the left end, find the resistance of the ring. (Ans : $\therefore \ x = 36\ \Omega$) **(Feb 2014)**

MULTIPLE CHOICE QUESTION

1 A wire of resistance R is uniformly stretched 'n' times of its original length (l). Its new resistance will be :
a) nRl b) n^2R c) n^2R/l d) n^2R^2

2. When a wire stretched and its radius becomes r/2, then the resistance will be
a) 16R b) 4R c) 2R d) R/2

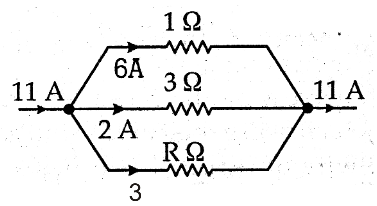
3 The V-I graph for a conductor makes angle θ with y-axis. Here V denotes voltage and I denotes current. The resistance of the conductor is given by
a) sin θ b) cos θ c) tan θ d) cot θ

4 When the potential difference applied across a solid conductor is increased, the rate of flow of electrons
a) decreases b) increases c) remains same d) decreases sharply

5 A series combination of two resistors 1 Ω each is connected a 12 V battery of internal resistance 0.4 Ω. The current flowing through is
a) 12 A b) 6A c) 5A d) 3.2 A

6. Four resistanas 15Ω, 20Ω, 20Ω and X Ω are connected in cyclic order to form wheatstone bridge if bridge is balance value and x 15
a) 15Ω b) 10 Ω c) 30 Ω d) 25 Ω

7 In the circuit shown in figure, the value of R is



a) 1Ω b) 2Ω c) 3Ω d) 4Ω

8. In Wheatstone bridge, the resistances in four arms are 10Ω, 10Ω, 10Ω and 20Ω . To make the bridge balance, resistance connected across 20 Ω is

a) 10 Ω b) 5 Ω c) 20 Ω d) 40Ω

9. A P.D. of V volt is applied to a conductor of length L & diameter D. It ρ is sp. resistance of its material, then its resistance R is :

a) $\rho L / \pi D^2$ b) $2\rho L / \pi D^2$ c) $4\rho L / \pi D^2$ d) $\pi D^2 / 4\rho L$

10. The specific resistance of conductor depends on

a) length b) diameter c) area of crossection d) material

11. In metre bridge the null point divides the wire in ratio 4 : 3. If left gap contains 20 Ω resistance then right gap contains ......

a) 5Ω b) 10 Ω c) 15 Ω d) 20Ω

12. In metre bridge the resistance X in left gap and R in right gap, the null point is obtained at the centre of wire. If the resistances are shunted by an equal resistances then the shift in null point is ....

a) zero b) 10 cm towards left
c) 10 cm towards right d) 5 cm towards left

13. Three resistances each of 4Ω are connected to form a triangle. The effective resistance between any two corners will be

a) 8/3Ω b) 3/8Ω c) 4/3Ω d) 3/4Ω

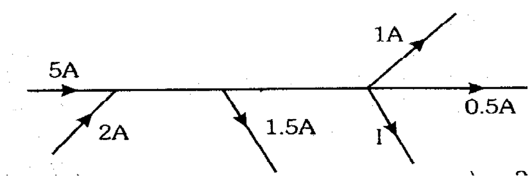
14. Twelve wires each of resistance 12 Ω are connected to form a cube. The effective resistance between two diagonally opposite corners of the cube is

a) 10 Ω b) 12Ω c) 8Ω d) 4Ω

15. Kirchhoff's first law i.e. Σ I = 0 at a junction deals with the conservation of

a) charge b) energy c) momentum d) all of these

16. The adjoining fig. shows current in a part of an electric circuit. The current I will be :



a) 1 A b) 2 A c) 3A d) 4A

17. Kelvins method for determination of resistance of galvanometer by meter bridge is

a) Null deflection method b) equal deflection method
c) equal distance method d) both 'b' and 'c'

18. Two resistances of values 20 Ω and 30 Ω are connected in left and right gap of a meter bridge. Determine the shift in null point when the resistance of 20 Ω is shunted by another resistance of 20 Ω :

a) 15 cm to left b) 15 cm to right
c) 25 cm to left d) 25 cm to right

19. Although a direction is associated with electric current, it is a :
a) scalar quantity b) vectory quantity c) pseudo quantity d) derived quantity

20. A resistor of 5 Ω resistance is connected in series with the parallel combination of 'n' number of resistances each of 6 Ω. If the total resistance of combination is 7 Ω, the value of n is :
a) 7 b) 4 c) 5 d) 3

21. Two diametrically opposite point of a metal ring are connected in left gap of meter bridge and a resistance of 15 Ω in right gap. If null point is obtained at 40 cm from left end, the resistance of metal ring is :
a) 60 Ω b) 80 Ω c) 45 Ω d) 40 Ω

22. In a meter bridge experiment, when a unknown resistance is kept in one gap and a resistance of 60 Ω in other gap, the null point is obtained somewhere on the wire. If the unknown resistance is shunted by a resistance half of its value, the value of known resistance in other gap to obtain the null point of same place as before will be :
a) 40 Ω b) 20 Ω c) 10 Ω d) 60 Ω

23. Kirchhoff's second law is based on the law of conservation of
a) charge b) current c) energy d) momentum

24. Equal length of the wires A & B are connected in the left & right gaps of a meter bridge, the null point is obtained at 40 cm from left end. If the diameter of the wires are in the ratio 2:3, the comparison of specific resistance of the materials of the wires is :
a) 8/27 b) 27/8 c) 5/12 d) 12/5

25. The resistance of potentiometer wire is 1 Ω/m. A Daniel cell of emf 1.08 balances at 216 cm on this wire. The current in the potentiometer wire is :
a) 0.2 A b) 0.3 A c) 0.4 A d) 0.5 A

26. A cell of emf x and internal resistance y is connected to a resistance of y. The terminal P.D. of cell is .....
a) x b) x/2 c) 2x d) y/2

27. A cell balances at 200 cm when the potential gradient along the potentiometer wire is 0.7 V/m. The emf of cell is ......
a) 1 volt b) 1.2 volt c) 1.4 volt d) 2 volt

28. A potentiometer wire of length 5 metre has a resistance of 12 ohm. The resistance per centimeter of the wire is :
a) 2.4×10^{-2} Ω/cm b) 0.25 Ω/cm c) 2.4 Ω/cm d) 0.41 Ωm

29. A potentiometer wire of length 4 m has a resistance of 4 Ω. What resistance must be connceted in series with wire & an accumulator of emf 2 V, so as to get potential drop of 10^{-3} V'/cm along the wire (r = 0)
a) 1.6 Ω b) 32 Ω c) 18 Ω d) 16 Ω

30. A voltmeter has a resistance of 50 Ω. What will be its reading when it is connected across a cell of emf 2 volt & internal resistance 4 Ω.
a) 1.85 volt b) 1.55 volt c) 1.65 volt d) 1.95 volt.