PART – II : CURRENT ELECTRICITY

CHAPTER 3

CURRENT ELECTRICITY

Syllabus

- *Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, electrical resistance, V-I characteristics (linear and nonlinear), electrical energy and power, electrical resistivity and conductivity; temperature dependence of resistance. Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's laws and simple applications, Wheatstone bridge, metre bridge(qualitative ideas only). Potentiometer - principle and its applications to measure potential difference and for comparing EMF of two cells; measurement of internal resistance of a cell (qualitative ideas only)*

Revision Notes

Electric Current, Resistance and Cells

Electric current

- Electric current is defined as the rate of flow of charge, across the cross section of conductor *i.e.*, $I = \frac{dq}{dt}$
- When charge flows at a constant rate, the corresponding electric current can be written as : $I = \frac{q}{t}$
- Conventional current in an external circuit flows from positive terminal to negative terminal.
- Free electrons flow from the negative terminal to the positive terminal in the external circuit.
- 1 ampere current = 6.25×10^{18} electrons flowing per second.
- Direct current is unidirectional flow of electric charge.

Flow of electric charges in metallic conductor

- When an electric field is applied to a metal at certain points, free electrons experience force and start moving.
- Without external applied emf, free electrons will move randomly through metal from one point to other giving zero net current.
- Motion of conducting electrons in electric field is a combination of motion due to random collisions.

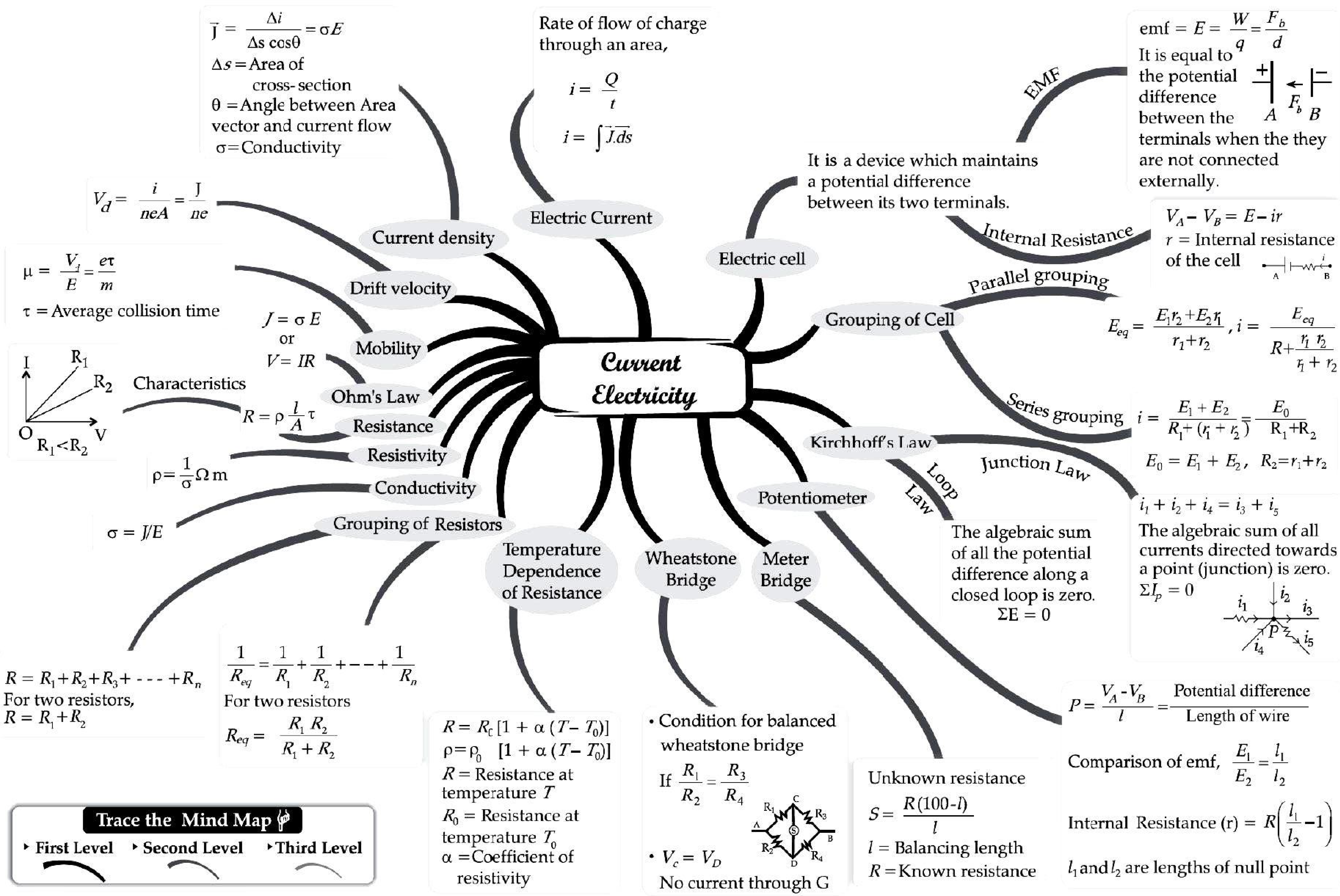
Drift velocity, mobility and their relation with electric current

- Drift Velocity is an average velocity which is obtained by certain particle like electron due to the presence of electric field.
- Drift velocity is written as :

$$\vec{v}_d = -\frac{e\vec{E}}{m}\tau$$

where, relaxation time, $\tau = \frac{\lambda}{v}$, here e = charge, m = mass, λ = mean free path

- When electric current is set up in a conductor, electrons drift through the conductor with velocity v_d, is given as


Current Electricity
Electric Current
Rate of flow of charge through an area,
$i = \frac{Q}{t}$
$i = \int \vec{J}.\vec{ds}$
Current density
$\vec{J} = \frac{\Delta i}{\Delta s \cos\theta} = \sigma E$
Δs = Area of cross-section
θ = Angle between Area vector and current flow
σ = Conductivity
Drift velocity
$V_d = \frac{i}{neA} = \frac{J}{ne}$
Mobility
$\mu = \frac{V_d}{E} = \frac{e\tau}{m}$
τ = Average collision time
Ohm's Law
$J = \sigma E$ or $V = IR$
Characteristics
I, V, O, R_1, R_2, $R_1 < R_2$
Resistance
$R = \rho \frac{l}{A}$
Resistivity
$\rho = \frac{1}{\sigma} \Omega m$
Conductivity
$\sigma = J/E$
Grouping of Resistors
$R = R_1 + R_2 + R_3 + --- + R_n$
For two resistors, $R = R_1 + R_2$
$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + --- + \frac{1}{R_n}$
For two resistors $R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$
Temperature Dependence of Resistance
$R = R_c [1 + \alpha (T - T_0)]$
$\rho = \rho_0 \; [1 + \alpha (T - T_0)]$
R = Resistance at temperature T
R_0 = Resistance at temperature T_0
α = Coefficient of resistivity
Wheatstone Bridge
• Condition for balanced wheatstone bridge
If $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
• $V_c = V_D$
No current through G
A, B, C, D, R_1, R_2, R_3, R_4, G
Meter Bridge
Unknown resistance
$S = \frac{R(100-l)}{l}$
l = Balancing length
R = Known resistance
Potentiometer
$P = \frac{V_A - V_B}{l} = \frac{\text{Potential difference}}{\text{Length of wire}}$
Comparison of emf, $\frac{E_1}{E_2} = \frac{l_1}{l_2}$
Internal Resistance (r) $= R\left(\frac{l_1}{l_2} - 1\right)$
l_1 and l_2 are lengths of null point
Kirchhoff's Law
Loop Law
The algebraic sum of all the potential difference along a closed loop is zero.
$\Sigma E = 0$
Junction Law
$i_1 + i_2 + i_4 = i_3 + i_5$
The algebraic sum of all currents directed towards a point (junction) is zero.
$\Sigma I_p = 0$
i_1, i_2, i_3, i_4, i_5, P
Electric cell
It is a device which maintains a potential difference between its two terminals.
EMF
emf $= E = \frac{W}{q} = \frac{F_b}{d}$
It is equal to the potential difference between the terminals when the they are not connected externally.
+, −, A, B, F_b
Internal Resistance
$V_A - V_B = E - ir$
r = Internal resistance of the cell
A, B, i
Grouping of Cell
Parallel grouping
$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$, $i = \frac{E_{eq}}{R + \frac{r_1 r_2}{r_1 + r_2}}$
Series grouping
$i = \frac{E_1 + E_2}{R_1 + (r_1 + r_2)} = \frac{E_0}{R_1 + R_2}$
$E_0 = E_1 + E_2$, $R_2 = r_1 + r_2$
Trace the Mind Map
First Level
Second Level
Third Level

$$v_d = \frac{I}{neA} \text{ or } I = neAv_d$$

where, I = Electric current through conductor, n = Number of free electrons per unit volume,
A = Area of cross-section, e = Charge of electron

- Drift velocity of electrons under ordinary conditions is of the order of 0.1 mm/s.
- Mobility is the drift velocity of an electron when applied electric field is unity.

Mobility, $$\mu = \frac{v_d}{E}$$

or, $$\mu = \frac{e\tau E / m}{E} = \frac{e\tau}{m}$$

Electrical resistivity and conductivity

- Resistivity is the specific resistance that is given by the conductor having unit length and unit area of cross-section.

$$\rho = \frac{m}{ne^2\tau}$$

- Conductivity is the reciprocal of resistivity shown as :

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$

Ohm's law

- The flow of current through conductor is directly proportional to the potential difference established across the conductor, provided physical conditions remains constant.

or, $$I \propto V$$

or, $$I = GV$$

Here, $$G = \frac{1}{R}$$

or, $$I = \frac{1}{R}V$$

or, $$V = IR$$

where, R = resistance of conductor

Electrical resistance

- It is an obstacle that is shown by the body during the flow of current as :

$$R = \frac{V}{I} = \frac{m}{ne^2\tau}\frac{l}{A}$$

- The resistance of the conductor is given as : $R = \rho\frac{l}{A}$

where, $\rho = \frac{m}{ne^2\tau}$ is specific resistance or resistivity of the material of conductor.

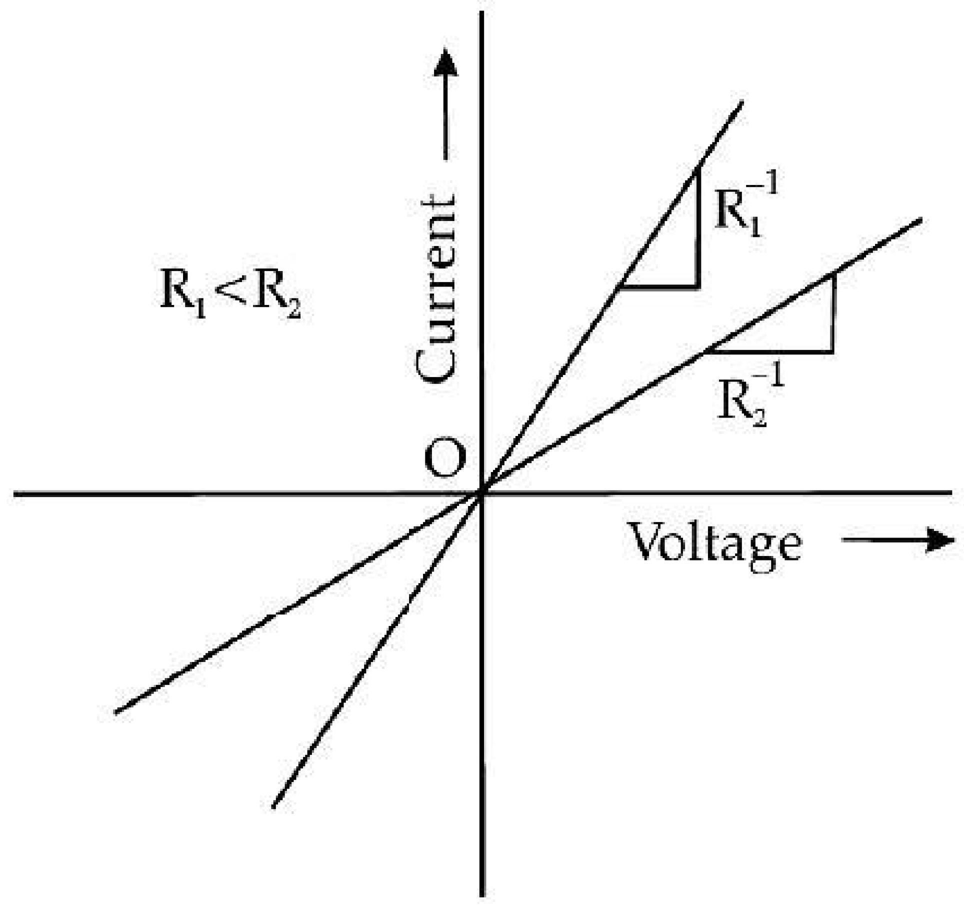
- In the series combination of resistances, the current is same throughout each resistor.
- In the parallel combination of resistances, the potential difference is same across each resistor.

V-I characteristics (linear and non-linear)

- *V-I* characteristic curves show the relationship between the current flowing through an electronic device and applied voltage across its terminals.

Linear *V-I* Characteristics

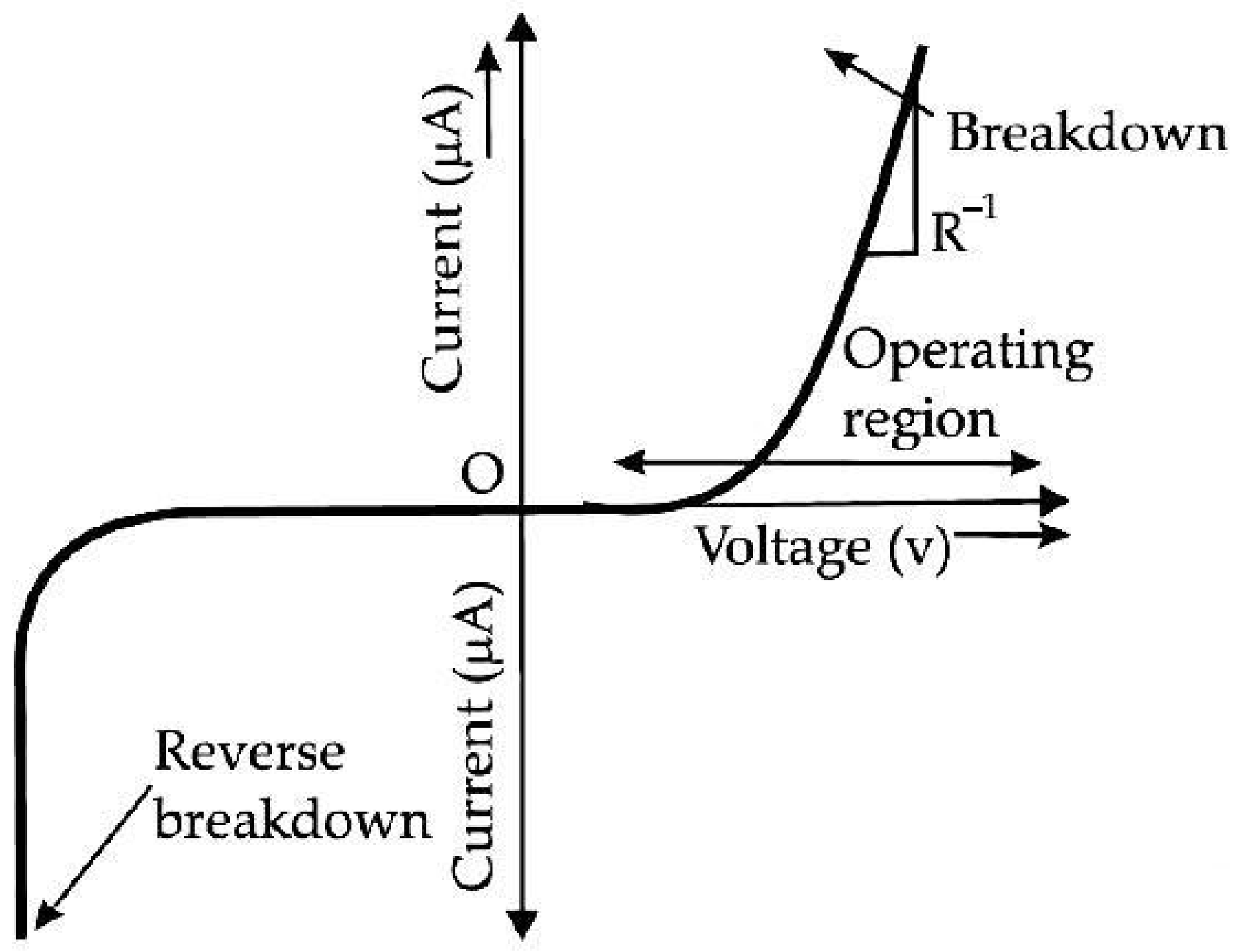
- A linear *V-I* curve has a constant slope and hence a constant resistance. Carbon resistors and metals obey the Ohm's law and have a constant resistance. This means that the *V-I* curve is a straight line passing through the origin.



- An electronic component may exhibit linear characteristic only in a particular region. For example, a resistance shows linear behaviour mostly in its operating region.

Non-linear *V-I* Characteristics

- A circuit component has a non-linear characteristic if the resistance is not constant throughout and is some function of voltage or current. The diode, for example, has varying resistance for different values of voltage.
- However, it has linear characteristic for a narrow operating region. Note that in the graph above, we can also see the maximum forward and reverse voltage in which the diode can be operated without causing breakdown and burning up of the diode.



Electrical energy and power

- Electrical energy is stored in the charged particles in an electric field.

$$E = V \times i \times t = i^2 \times R \times t = \frac{V^2}{R} \times t$$

where, E = Electrical energy, V = Potential difference, t = Time, i = Current, R = Resistance

- Power is the work done per unit time which is the rate of energy consumed in a circuit.

$$P = \frac{W}{t}$$

Since Voltage $V = \frac{W}{q}$,

So, $P = V\frac{q}{t} = VI$ $\left[\text{Here, } I = \frac{q}{t}\right]$

or $P = I^2R$ or $\frac{V^2}{R}$

The unit of power is J/s or W (Watt).

Temperature dependence of resistivity

- With small change in temperature, resistivity varies with temperature as :

$$\rho = \rho_0(1 + \alpha\,\Delta T)$$

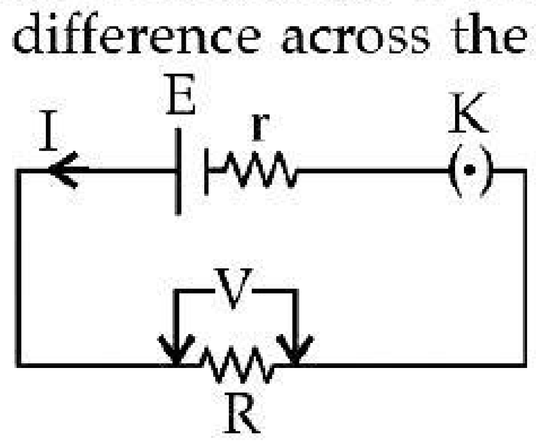
where, α = temperature coefficient of resistivity.

Internal resistance of cell

- Cell is a device that maintains the potential difference that is present between the two electrodes as a result of chemical reaction.
- Internal resistance is the resistance of electrolyte that is present in a battery which resists the flow of current when connected to a circuit.
- Emf E is the potential difference between the electrodes of cell, when no current flows through it.

Potential difference and emf of a cell

- **The emf and terminal potential difference of a cell :** Let emf of a cell be E and its internal resistance, r. If an external resistance R be connected across the cell through a key, then $IR = V$ = potential difference across the external resistance R. This is equal to the terminal potential difference across the cell.



$$E = V + Ir$$

$\Rightarrow$ $I = \frac{E - V}{r}$

So $V = E - Ir$

$\therefore$ $V < E$. (if there is flow of current)

When current is drawn from a cell, its terminal potential difference is less than the emf.

Combination of cells in series and parallel

- **(i) Series combination of cells :** This combination is used when an external resistance (R) of the circuit is much larger as compared to the internal resistance (r) of the cell. *i.e.,*

$$R >> r$$

Let n cells, each of emf E and internal resistance r are connected in series across an external resistance R, then the current in the circuit will be

$$I_S = \frac{nE}{R + nr}$$

(ii) Parallel combination of cells : This combination is used when the external resistance R is much smaller as compared to the internal resistance (r) of the cell, *i.e.,*

$$R << r$$

When m cells are connected in parallel across a resistance R, then current through the resistance is given by

$$I_P = \frac{E}{R + r/m} = \frac{mE}{mR + r}$$

If m cells of emfs E_1, E_2, E_3,.....E_m and of internal resistances r_1, r_2, r_3,.....r_m are connected in parallel across an external resistance R, then the current through the external resistance is given by

$$I_P = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + \frac{E_3}{r_3} ..... + \frac{E_m}{r_m}}{R + \left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + ... + \frac{1}{r_m}\right)}$$

Kirchhoff's Laws, Wheatstone Bridge and their Applications

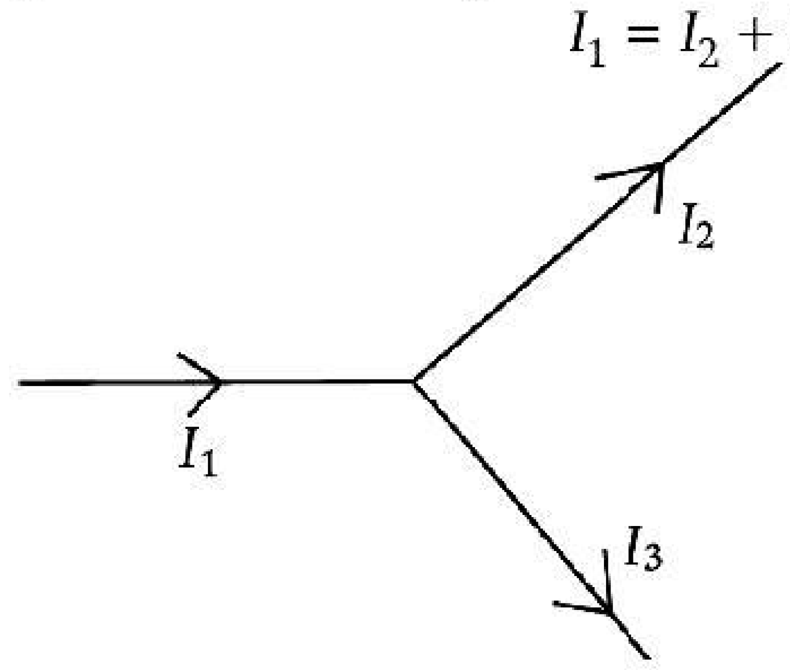
Kirchhoff's Laws

- Kirchhoff's Laws tell us about the relationship between voltages and currents in circuits.

First Law

- Kirchhoff's first law is also known as junction law which states that for a given junction or node in a circuit, sum of the currents entering in a junction will be equal to sum of currents leaving that junction.

$$I_1 = I_2 + I_3$$



OR

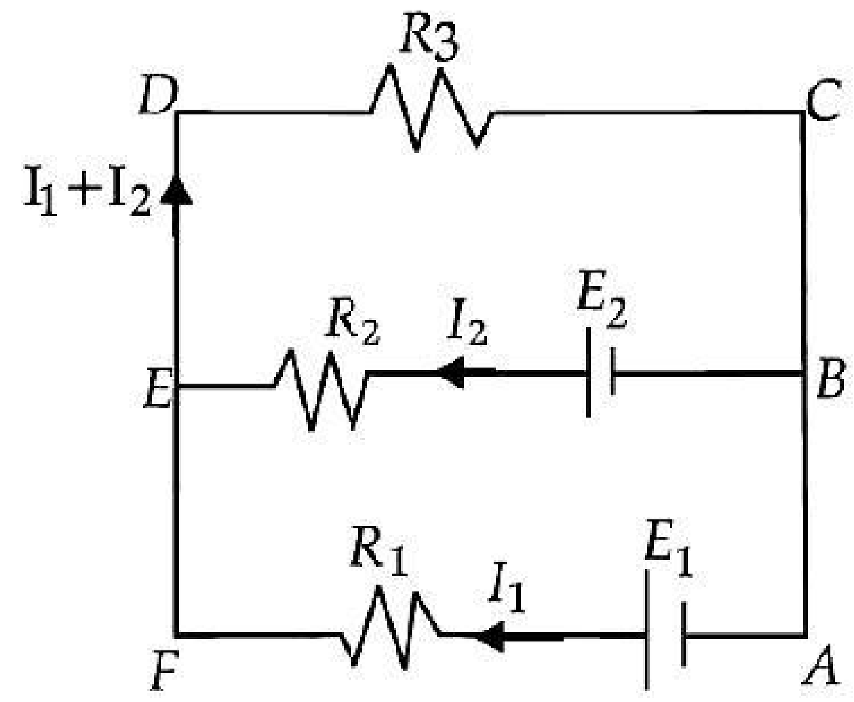
- The algebraic sum of all currents meeting at a junction in a closed circuit is zero. *i.e.,* $\Sigma I = 0$
- This is called the law of conservation of charge.

Second Law

- Kirchhoff's second law is also known as loop law which shows that around any closed loop in a circuit, sum of the potential differences across all elements will be zero.

i.e., $$\Sigma V = 0 \text{ or } \Sigma V = \Sigma IR$$

- This is called the law of conservation of energy.

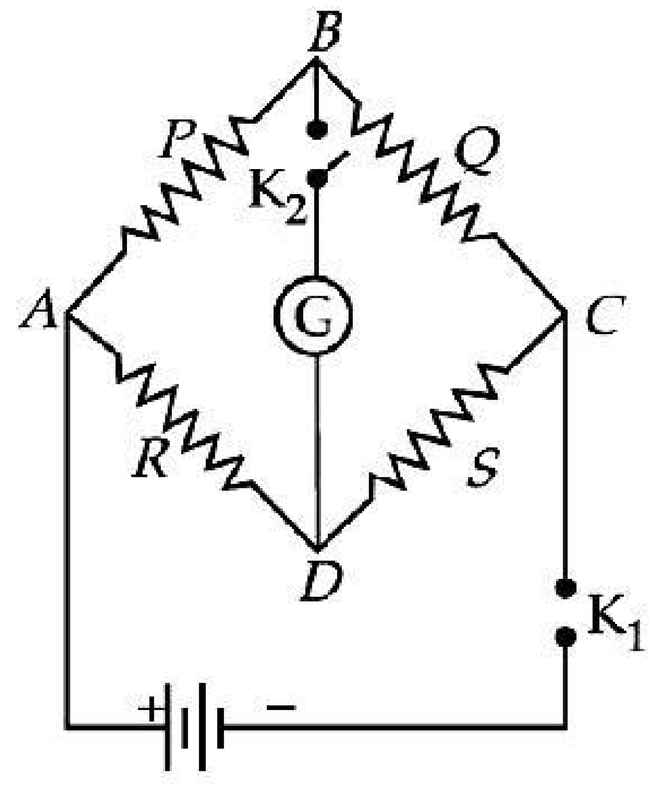


For example : Applying Junction law in loop *AFEBA*,

$$E_1 - E_2 = I_1R_1 - I_2R_2$$

Wheatstone Bridge

- It is a circuit having four resistances *P, Q, R* and *S*, a galvanometer and a battery connected as shown.



Wheatstone Bridge

- **Conductance :** The reciprocal of resistance with unit as siemens, "S."
- **Node :** An end point to any branch of a network or a junction common to two or more branches.
- **Permittivity :** The ability of a material to store electrical potential energy under the influence of an electric field measured by the ratio of the capacitance of a capacitor with the material as dielectric to its capacitance with vacuum as dielectric.
- **Galvanometer :** An instrument for detecting and measuring small electric currents.

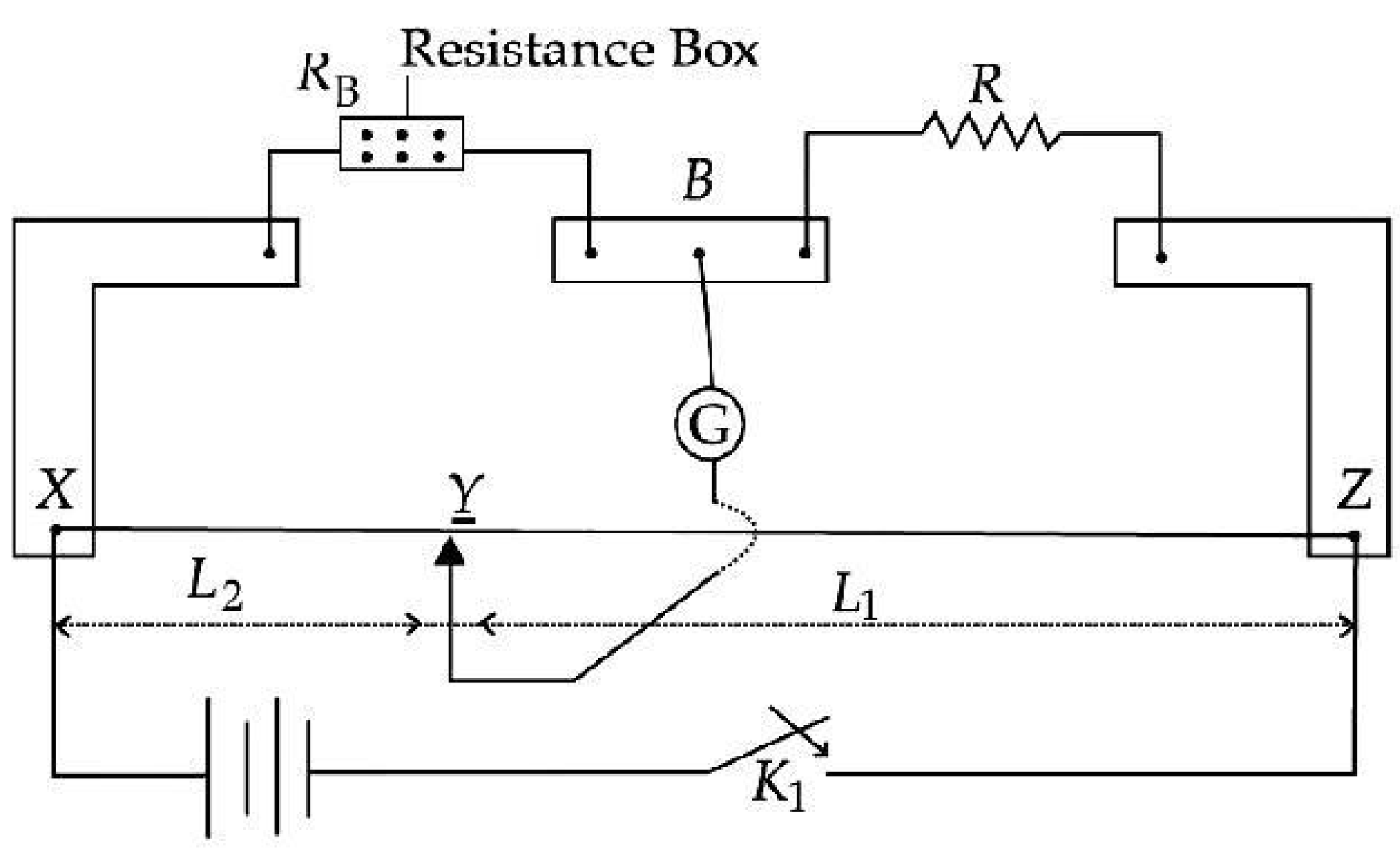
Metre Bridge, Potentiometer and their Applications

Metre Bridge

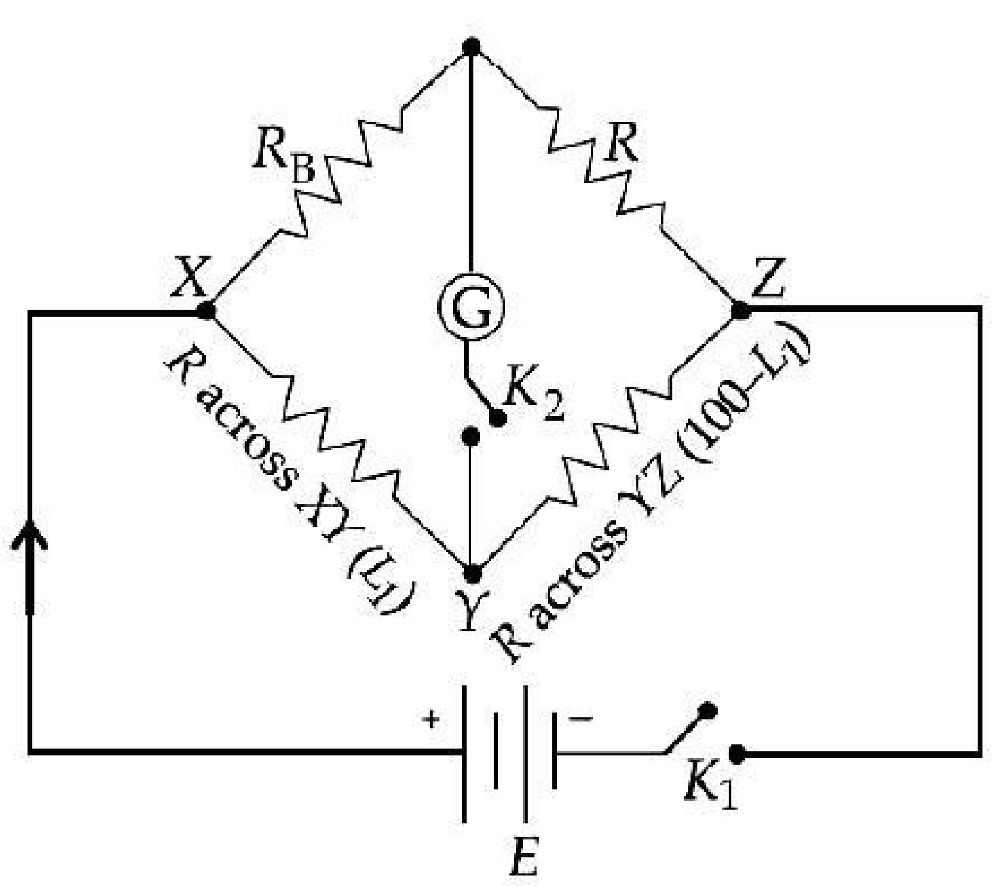
- It is an instrument which is used to find the unknown resistance of a coil or a material connected in a circuit.
- It is also known as slide wire bridge which is an instrument that works on the principle of Wheatstone bridge.
- Metre bridge has two metallic strips which act as holders for the wire that are made of metals like copper.
- In metre bridge :
- Resistance box R_B and unknown resistance *R* are connected across the two gaps of metallic strips.
- One end of galvanometer is connected to the middle lead of metallic strip placed between L shaped strips while other end is connected to a jockey.
- Jockey which is a metal wire having one end as knife edge is used for sliding on the bridge wire.

Measurement from the Metre bridge :

- At negative terminal of galvanometer, there appears zero deflection that makes jockey to connect to negative point on the wire.
- The distance from point *X* to *Y* is taken as L_1 cm while the distance from point *Y* to point *Z* is taken as L_2 cm which can be $(100 - L_1)$ cm.
- Metre bridge can be drawn similar to Wheatstone bridge as :



Metre bridge



Wheatstone bridge

From the above arrangement :

$$\frac{R_B}{\text{Resistance across } XY} = \frac{R}{\text{Resistance across } YZ}$$

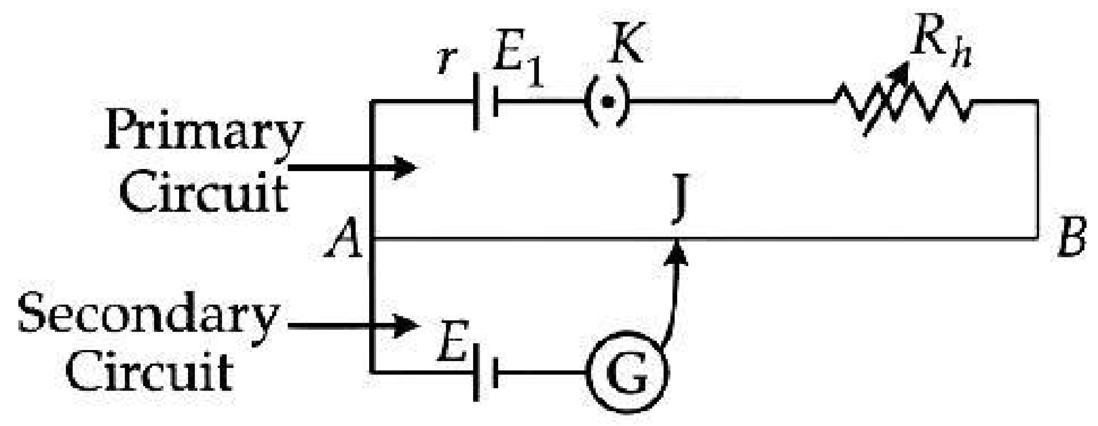
Now, $\dfrac{R_B}{\frac{\rho L_1}{A}} = \dfrac{R}{\frac{\rho L_2}{A}}$ $\quad [\text{As}, R = \frac{\rho L}{A}]$

Further, $\dfrac{R_B}{\frac{\rho L_1}{A}} = \dfrac{R}{\frac{\rho(100 - L_1)}{A}}$ $\quad [\because L_2 = 100 - L_1]$

Hence, $\dfrac{R_B}{L_1} = \dfrac{R}{100 - L_1}$

Potentiometer

- Potentiometer is a device which measures the emf of a particular cell and helps in comparing the emfs of different cells.
- Potentiometer depends on deflection method where zero deflection results in non drawn of current from the cell or circuit.
- It serves as an ideal instrument of infinite resistance for measuring the potential difference.
- Potentiometer comprises of long resistive wire AB of length L (about 6 m to 10 m long) made up of manganin or constantan.
- In this, a battery of known voltage E and internal resistance r forms the primary circuit.
- In the potentiometer circuit, one terminal of other cell is connected at one end of main circuit while other terminal is connected at any point on the resistive wire through galvanometer G which forms the secondary circuit.



where, J = Jockey, K = Key, R_h = Variable resistance which controls the current through the wire AB

In the circuit :

- Specific resistance (ρ) of wire is high while its temperature coefficient of resistance is low.
- At point A, all high potential points of primary and secondary circuits are connected together, while all low potential points are connected to point B or jockey.
- Value of known potential difference is more than the value of unknown potential difference that is to be measured.
- The current in primary circuit should remain constant and jockey should not slide with the wire.

Principle of potentiometer

- Potentiometers are displacement sensors that produce electrical output in proportion to the mechanical displacement.
- It can be used to measure the internal resistance and emf of a cell which cannot be measured by voltmeter.
- The basic principle of potentiometer is that the potential drop along any length of the wire is directly proportional to its length. So, when a constant current flows through a wire of uniform cross-section and composition then,

$$V \propto l.$$

- When there is zero potential difference between two points, there will be no flow of electric current.
- **Applications of potentiometer :** In measuring potential difference and comparing emf of cells in measuring potential difference.
- In a potentiometer, auxiliary circuit comprises of battery of emf E connected across terminals A and B with rheostat R_h, resistance box and key K in series where resistance R_1 is connected to terminal A and jockey J through galvanometer with cell E_1 and key K_1 in series, then if key K_1 is closed, current will flow through resistance R_1 where a potential difference is developed.
- If J is the position of jockey on potentiometer wire which gets adjusted in such a way that galvanometer shows no deflection, then AJ will be the balancing length l on potentiometer wire.
- Here, the galvanometer will show no deflection as potential is same if key K is potential gradient of potentiometer wire, then potential difference across resistance R_1 will result as :

$$V = Kl$$

➢ If r is the resistance of potentiometer of length L, then current through potentiometer will be :

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

➢ Potential drop across potentiometer wire will be :

$$Ir \text{ or } \left(\frac{E}{R+r}\right)\times r$$

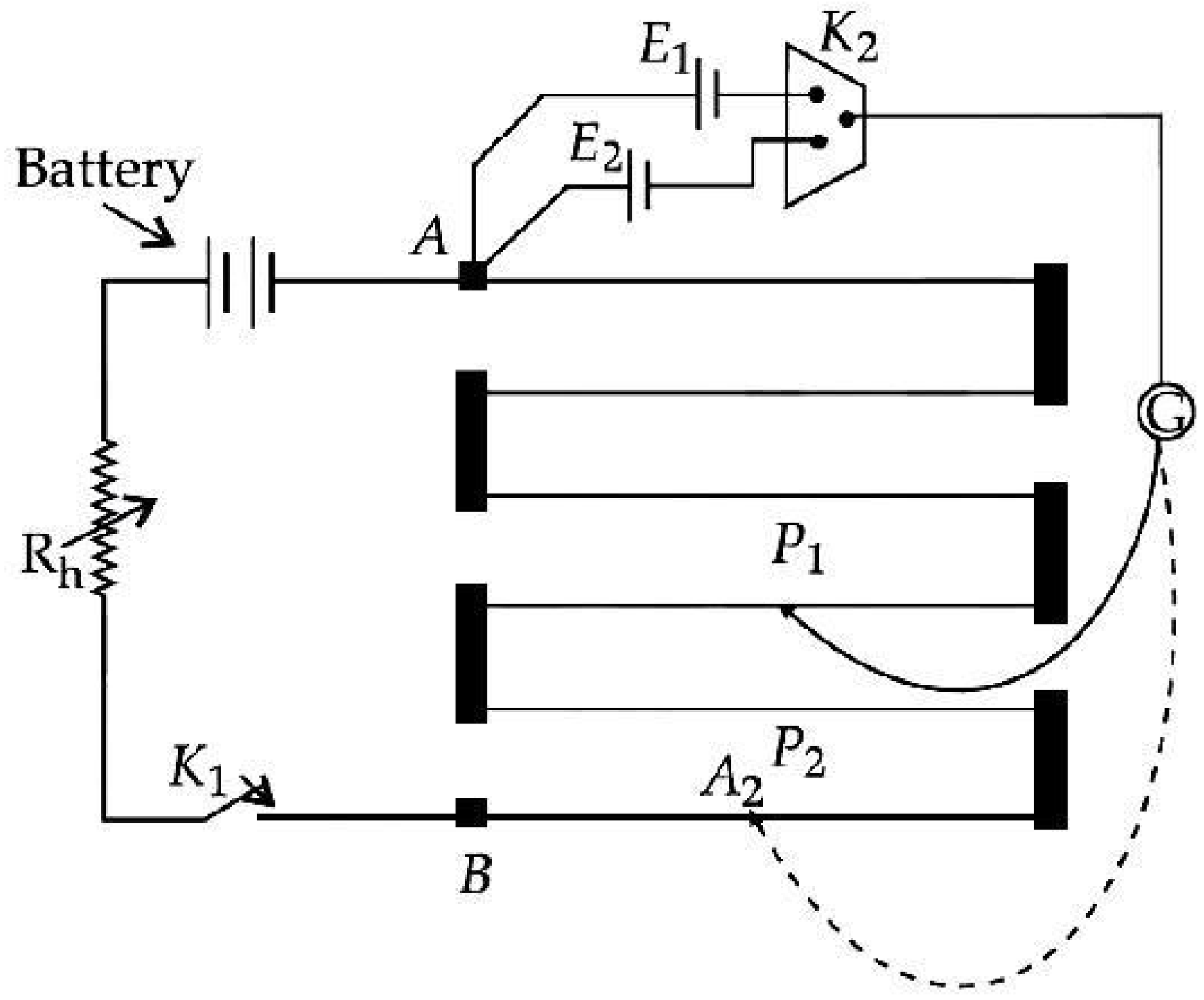
➢ Now potential gradient of potentiometer wire which is potential per unit length is :

$$K = \left(\frac{E}{R+r}\right)\times\frac{r}{L}$$

$$\therefore \quad V = \left(\frac{E}{R+r}\right)\times\frac{rl}{L}$$

Application of potentiometer comparing emf of cells

➢ If a positive terminal of the cell of emf E_1 is connected to terminal A while negative terminal is connected to jockey by galvanometer, then by closing the key, jockey will move along the wire AB and null point is obtained where galvanometer shows no deflection.



➢ When the length of wire AP as l_1 is measured, then potential difference across it, will balance the emf E_1, So $E_1 = Kl_1$, where K is potential gradient of the wire.

➢ When cell of emf E_1 is disconnected while cell of emf E_2 is connected, then $E_2 = Kl_2$.

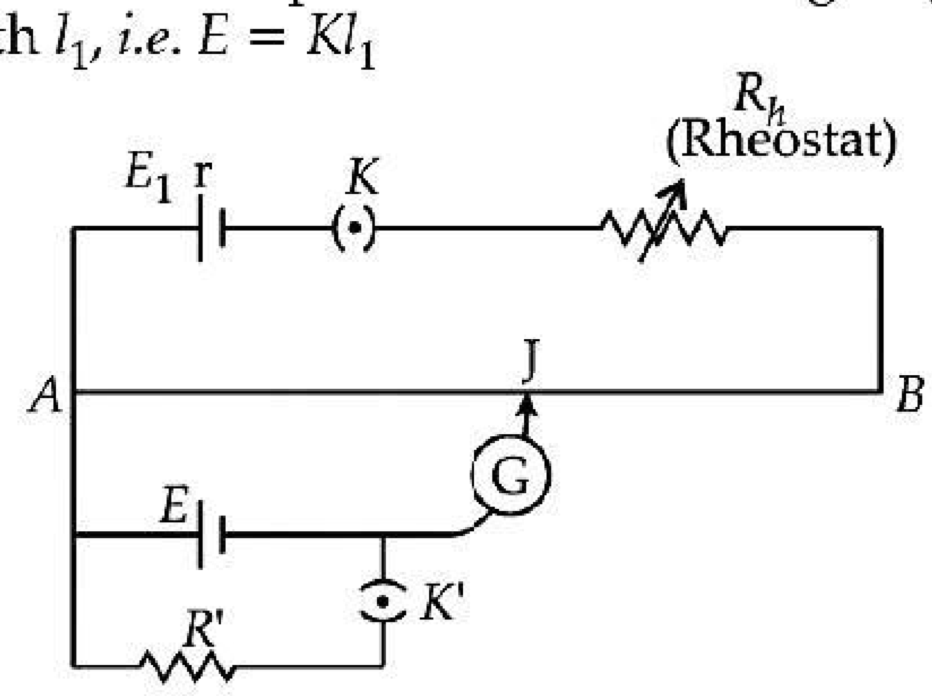
➢ On comparing and dividing, we get an expression :

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

➢ By knowing the values of l_1 and l_2, the emf of two cells can be compared.

Applications of potentiometer in measurement of internal resistance of cell

(i) Initially, in secondary circuit, key K' remains open and the balancing length (l_1) is obtained. Since, cell E is in open circuit so its emf balances on length l_1, *i.e.* $E = Kl_1$ ...(a)



(ii) Now key K' is closed, so cell E comes in closed circuit. If the process is repeated again, then the potential difference V balances on length l_2, *i.e.*, $V = Kl_2$ ...(b)

(iii) By using formula, internal resistance, $r = \left(\frac{E}{V} - 1\right).R'$

$$r = \left(\frac{l_1 - l_2}{l_2}\right).R' \qquad \text{[Using eqns. (a) and (b)]}$$

Know the Terms

- **Conductors :** These are materials, which develop electric currents in them, when an electric field is applied to them.
- **Conventional current :** The current that flows from a point at higher (positive) potential to a point at lower (negative) potential.
- **Relaxation time :** The short time for which a free electron accelerates before it undergoes a collision with positive ion in the conductor.
- **Conductance :** It is reciprocal of the resistance of a conductor. *i.e.,*

$$G = \frac{1}{R}$$

  Unit : ohm^{-1} (Ω^{-1})/siemen (S)/mho.
- **Conductivity :** It is the reciprocal of the resistivity of the material of a conductor *i.e.,*

$$\sigma = \frac{1}{\rho}$$

- **Superconductivity :** The phenomenon due to which a substance loses all signs of its resistance, when cooled to its critical temperature.
- **Temperature coefficient of resistance :** It is defined as the measure of change in electrical resistance of any substance per degree of temperature change.

Know the Formulae

- Electric current, $I = \frac{q}{t}$
- Drift velocity v_d with electric field, $v_d = \frac{-e\vec{E}\tau}{m}$
- Current I with drift velocity v_d, $I = neAv_d$
- Mobility of charge, $\mu = \frac{v_d}{E} = \frac{q\tau}{m}$
- Mobility and drift velocity, $v_d = \mu_e E$
- Current and mobility, $I = neA\,\mu_e E$
- Resistance, potential difference and current, $R = \frac{V}{I}$
- Resistance R with specific resistivity, $R = \rho\frac{l}{A}$
- Resistivity with electrons , $\rho = \frac{m}{ne^2\tau}$
- Current density, $\vec{J} = \frac{I}{\vec{A}}$
- Conductance, $G = \frac{1}{R}$
- Conductivity, $\sigma = \frac{1}{\rho}$
- Microscopic form of Ohm's law, $\vec{J} = \sigma\vec{E}$
- Temperature coefficient of resistance, $\alpha = \frac{R_t - R_0}{R_0 \times (t_t - t_0)}$
- In a cell, emf and internal resistance, $I = \frac{E}{R+r}$
- n cells of emf E in series, $E_{emf} = nE$

- Resistance of n cells in series, (where R is external resistance) $nr + R$
- Current in circuit with n cells in series, $I = \frac{nE}{R+nr}$
- n cells in parallel, then emf $=$ E
- Resistance of n cells in parallel, $R + \frac{r}{n}$
- Internal resistance of a cell, $r = \left(\frac{E-V}{V}\right) \times R$
- Power of a circuit, $P = VI = I^2R = \frac{V^2}{R}$
- Energy consumed, $E = IVt$
- Kirchhoff's Law (Junction law), $\Sigma I = 0$

  Kirchhoff's Law (Loop law), $\Sigma V = 0$

  Wheatstone Bridge, $\Delta V_{BD} = 0$ or $\frac{P}{Q} = \frac{R}{S}$

Note : All symbols have their usual meanings.

- Potential gradient (K) : $K = \frac{V}{L} = \frac{iR}{L} = \left(\frac{E}{R+R_h+r}\right) \times \frac{R}{L}$
- Internal resistance of a cell : $r = \left(\frac{E}{V} - 1\right) \times R = \left(\frac{l_1 - l_2}{l_2}\right) \times R$
- Comparison of emf's of two cells $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

STAND ALONE MCQs (1 Mark each)

Q. 1. Consider a current carrying wire (current I) in the shape of a circle. Note that as the current progresses along the wire, the direction of j (current density) changes in an exact manner, while the current I remain unaffected. The agent that is essentially responsible for is

(A) source of emf.

(B) electric field produced by charges accumulated on the surface of wire.

(C) the charges just behind a given segment of wire which push them just the right way by repulsion.

(D) the charges ahead.

Ans. Option (B) is correct.

> ***Explanation:*** As we know that current density (J) depends on
>
> (i) conductivity [$\sigma = 1/\rho = 1/R.A$]
>
> (ii) Electric field [$J = \sigma E$]
>
> (iii) current, length and area of cross-section
>
> But in the given options only B, that is, electric field can be varied by the charges accumulated on the surface of wire.

Q. 2. Which of the following characteristics of electrons determines the current in a conductor?

(A) Drift velocity alone

(B) Thermal velocity alone

(C) Both drift velocity and thermal velocity

(D) Neither drift nor thermal velocity.

Ans. Option (A) is correct.

> ***Explanation:*** As we know that,
>
> $I = AneV_d$
>
> So current,
>
> $I \propto V_d$
>
> And, current (I) also depend on n, the number of free electrons which increases on increasing temperature which makes more collision between electrons and increases resistance or decrease current.

Q. 3. A metal rod of length 10 cm and a rectangular cross-section of 1 cm $\times \frac{1}{2}$ cm is connected to a battery across opposite faces. The resistance will be

(A) maximum when the battery is connected across 1 cm $\times \frac{1}{2}$ cm faces.

(B) maximum when the battery is connected across 10 cm × 1 cm faces.

(C) maximum when the battery is connected across 10 cm × $\frac{1}{2}$ cm faces.

(D) same irrespective of the three faces.

Ans. Option (A) is correct.

> ***Explanation:*** As we know that,
>
> $$R = \rho\left(\frac{l}{A}\right)$$
>
> The maximum resistance will be achieved when the value of $\frac{l}{A}$, is maximum, so that 'A' must be minimum and it is minimum when area of cross section is 1 cm × $\frac{1}{2}$ cm.

Q. 4. When cell of e.m.f. E is connected with an external resistance R, the p.d. across the cell becomes V. The expression for the internal resistance of the cell is]

(A) $\frac{E-V}{V}R$ **(B)** 10^{23}

(C) $\frac{V-E}{V}R$ **(D)** $\frac{V-E}{E}R$

Ans. Option (A) is correct.

> ***Explanation:*** Current in the circuit = I = V/R
> If r = internal resistance of the cell, then V = E – Ir
>
> $$\therefore r = \frac{E-V}{I} = \frac{E-V}{V/R} = \frac{E-V}{V}R$$

Q. 5. The current density (number of free electrons per m^3) in metallic conductor is of the order of

(A) 10^{28} **(B)** 10^{23}

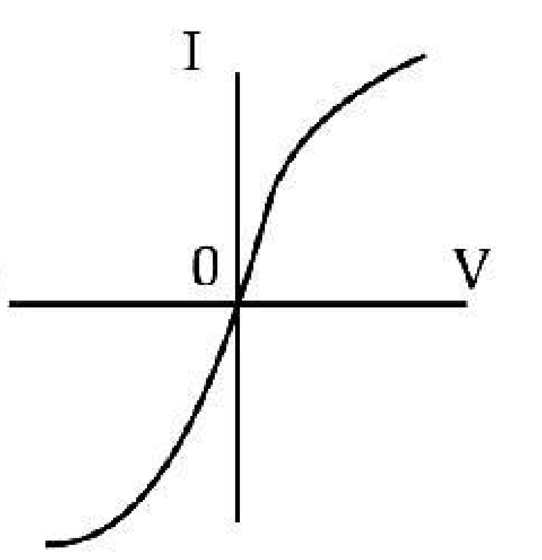
(C) 10^{20} **(D)** 10^{15}

Ans. Option (A) is correct.

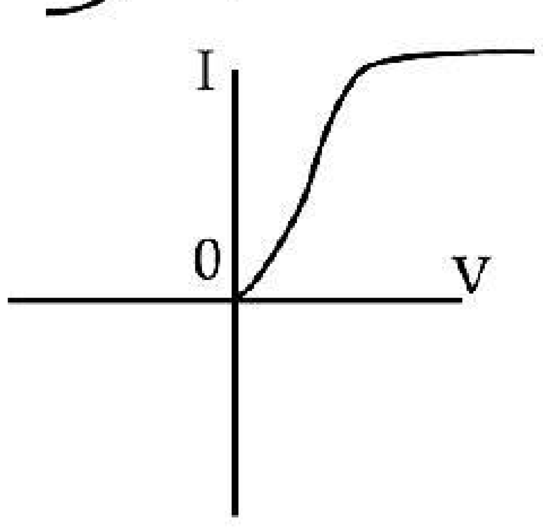
> ***Explanation:*** The current density (number of free electrons per m^3) in metallic conductor is of the order of 10^{28}.

Q. 6. Which of the following I-V characteristic represent the characteristic of a Ohmic conductor?

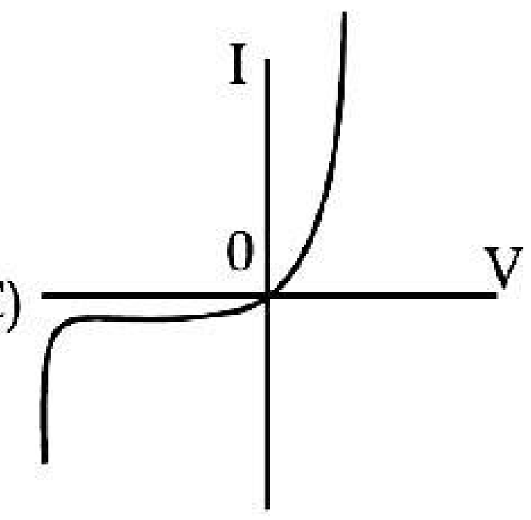
(A)



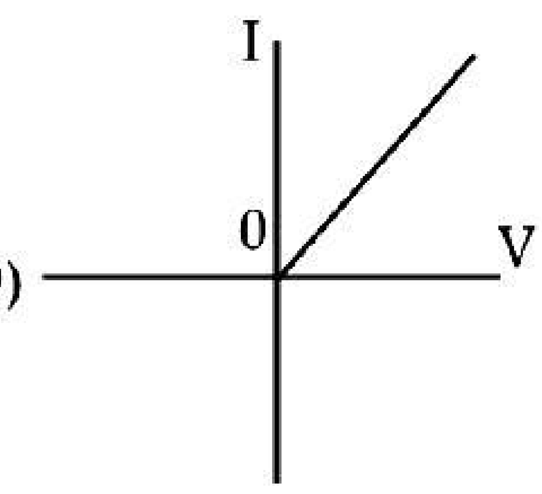
(B)



(C)



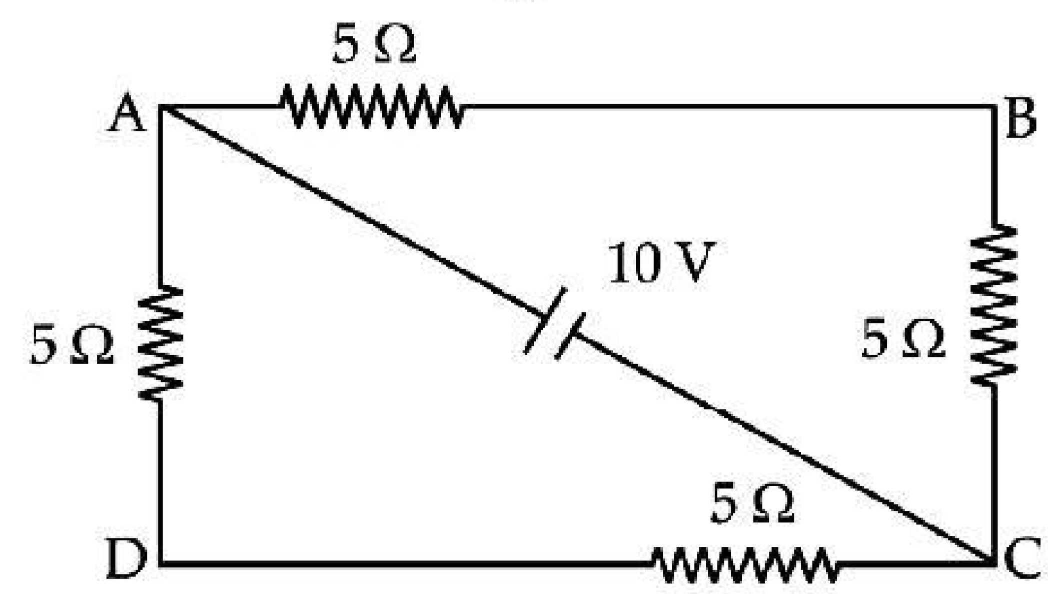
(D)



Ans. Option (D) is correct.

> ***Explanation:*** Slope of I-V characteristic of an Ohmic conductor remains constant throughout.

Q. 7. What is the potential difference between points A and B in the following circuit?



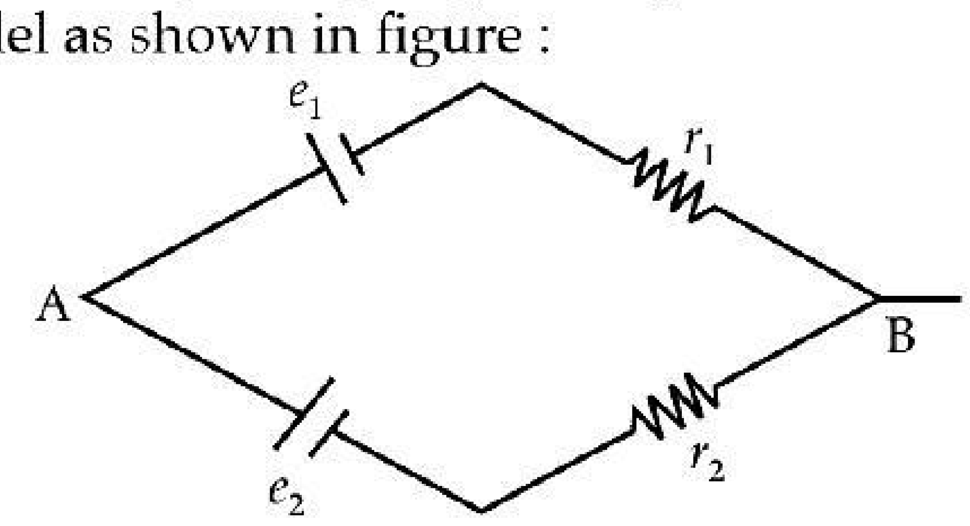
(A) 10 V **(B)** 5 V

(C) 2.5 V **(D)** 20 V

Ans. Option (B) is correct.

> ***Explanation:*** Equivalent resistance of the circuit = (5 + 5) || (5 + 5) = 5 Ω
> Total circuit current = 10/5 = 2 A
> Current in each branch is 1A
> So, potential difference between points A and B i.e. across the 5Ω resistor is 1 × 5 = 5 V.

Q. 8. Two batteries of emf ε_1 and ε_2 ($\varepsilon_2 > \varepsilon_1$) and internal resistances r_1 and r_2 respectively are connected in parallel as shown in figure :



(A) The equivalent emf ε_{eq} of the two cells is between ε_1 and ε_2, *i.e.* $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$.

(B) The equivalent emf ε_{eq} is smaller than ε_1.

(C) The ε_{eq} is given by $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$ always.

(D) ε_{eq} is independent of internal resistances r_1 and r_2.

Ans. Option (A) is correct.

> *Explanation:* As we know that the equivalent emf in parallel combination of cells is :
>
> $$\varepsilon_{eq} = \frac{(\varepsilon_1 r_2 + \varepsilon_2 r_1)}{(r_1 + r_2)}$$
>
> so, it is clear that part '*c*' and '*d*' are incorrect by formula. According to this formula only option (A), is correct.

Q. 9. A resistance R is to be measured using a meter bridge. Student chooses the standard resistance S to be 100 Ω. He finds the null point at l_1 = 2.9 cm. He is told to attempt to improve the accuracy. Which of the following is a useful way?

(A) He should measure l_1 more accurately.

(B) He should change S to 1000 Ω and repeat the experiment.

(C) He should change S to 3 Ω and repeat the experiment.

(D) He should give up hope of a more accurate measurement with a meter bridge.

Ans. Option (C) is correct.

> *Explanation:* To calculate resistance, R
>
> $$R = S\left[\frac{l_1}{(100 - l_1)}\right]$$
>
> $$= 100\left[\frac{2.9}{97.1}\right]$$
>
> $$= 2.98\ \Omega$$
>
> So to get balance point near to 50 cm (middle) we have to take S = 3 Ω, as here R : S =2.9 : 97.1 implies that S is nearly 33 times to R.
>
> In order to make ratio R and S = 1 : 1, we must take the resistance S = 3 Ω, which verifies options (C).

Q. 10. Two cells of emf's approximately 5 V and 10 V are to be accurately compared using a potentiometer of length 400 cm :

(A) The battery that runs the potentiometer should have voltage of 8 V.

(B) The battery of potentiometer can have a voltage of 15 V and R adjusted so that the potential drop across the wire slightly exceeds 10 V.

(C) The first portion of 50 cm of wire itself should have a potential drop of 10 V.

(D) Potentiometer is usually used for comparing resistances and not voltages.

Ans. Option (B) is correct.

> *Explanation:* Given that,
> emf of primary cells are 5 V and 10 V
> The potential drop across potentiometer wire must be slightly more than that larger emf 10 V. So, the battery should be of 15 V and about 4 V potential is dropped by using rheostat or resistances. So option (B) is correct.

Q. 11. Kirchhoff's current law is based on the law of conservation of

(A) charge. **(B)** energy.

(C) mass. **(D)** (B) and (C)

Ans. Option (A) is correct.

> *Explanation:* Kirchhoff's current law is based on the law of conservation of charge.

Q. 12. Kirchhoff's voltage law is based on the law of conservation of

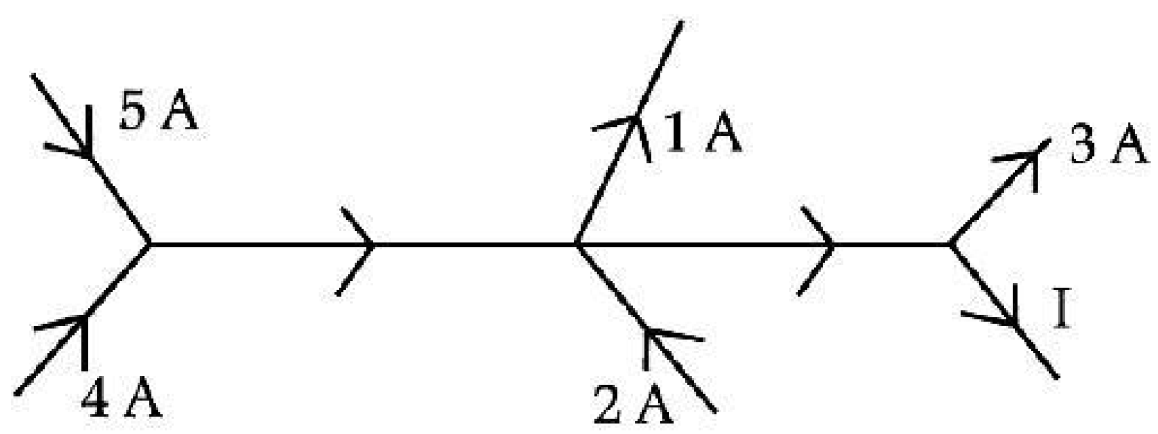
(A) charge **(B)** energy

(C) mass **(D)** (B) and (C)

Ans. Option (B) is correct.

> *Explanation:* Kirchhoff's current law is based on the law of conservation of energy.

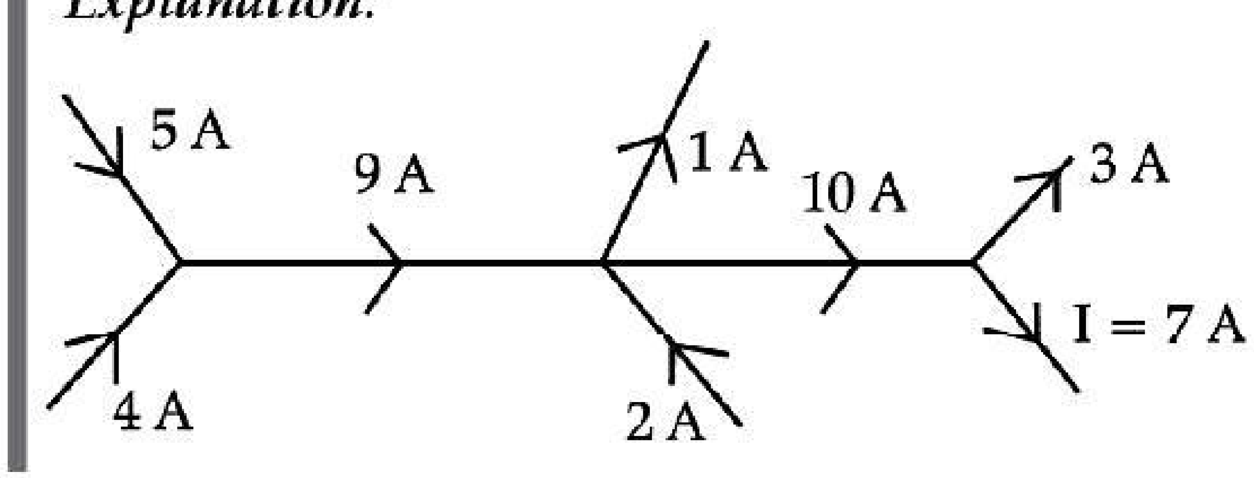
Q. 13. Apply Kirchhoff's law to find the current I in the part of the following circuit.



(A) 5 A **(B)** 3 A

(C) 7 A **(D)** 1 A

Ans. Option (C) is correct.

> *Explanation:*
>
> 
>

Q. 14. Wheatstone Bridge is not suitable for measurement of

(A) very high value resistances.

(B) very low value resistances.

(C) both (A) and (B).

(D) medium value resistances.

Ans. Option (C) is correct.

> *Explanation:* Wheatstone bridge is suitable for measurement of medium value resistances because to ensure sensitivity, other resistors must be of comparable values.

Q. 15. Kirchhoff's laws are valid for _______.

(A) only passive circuits

(B) only linear circuits

(C) only non-linear circuits

(D) both (B) and (C).

Ans. Option (D) is correct.

> *Explanation:* Kirchhoff's laws are valid for both linear and non-linear circuits.

Q. 16. Two resistances are connected in two gaps of Meter Bridge. The balance is 10 cm from the zero end. A resistance of 20 Ω is connected in series with the smaller of the two. The null point shifts to 20 cm. What is the value of the bigger resistance?

(A) 89 Ω (B) 144 Ω

(C) 100 Ω (D) None of the above

Ans. Option (B) is correct.

> *Explanation:* **Case 1:** P/Q = 10/90 = 1/9 ...(i)
> **Case 2:** (P+20)/Q = 20/80 = ¼ ...(ii)
> Dividing equation (i) by (ii)
> P/(P+20) = 4/9
> ∴ P = 16 Ω
> Putting in equation (i)
> Q = 144 Ω

Q. 17. In a metre bridge, what is the effect on null deflection of galvanometer, when the radius of the meter bridge wire is doubled?

(A) There will be no change

(B) Null point will shift to $L_1/2$ point

(C) Null point will shift to $2L_1$ point

(D) Null point will not be available

Ans. Option (A) is correct.

> *Explanation:* For a balanced Meter Bridge $P/Q = L_1/(100 - L_1)$.
> There is no parameter related to the radius of the wire. So, the null deflection of galvanometer does not depend on the radius of the wire. So, even if the radius of the wire is doubled, the null deflection of the galvanometer will not be changed.

Q. 18. Consider a metre bridge whose length of wire is 2m. A resistance of 10 Ω is connected across one gap of the meter bridge and an unknown resistance is connected across the other gap. When these resistances are interchanged, the balance point shifts by 50 cm. What is the value of the unknown resistance?

(A) 250 Ω (B) 10 Ω

(C) 16.7 Ω (D) None of the above

Ans. Option (C) is correct.

> *Explanation:* Say, the unknown resistance = X
> **Case 1:** $10/X = L_1/(200-L_1)$
> Or, $xL_1 = 2000 - 10L_1$ ...(i)
> **Case 2:** $X/10 = (L_1 + 50)/(150-L_1)$
> Or, $xL_1 = 150X - 10L_1 - 500$ ...(ii)
> Comparing equation (i) and (ii)
> X = 2500/150 = 16.7 Ω

Q. 19. Which error of meter bridge is removed when the known and unknown resistances are interchanged?

(A) End error (B) Measurement error

(C) Percentage error (D) Parallex error

Ans. Option (A) is correct.

> *Explanation:* End error of metre bridge is removed when the known and unknown resistances are interchanged.

Q. 20. In a potentiometer of 5 wires, the balance point is obtained on the 3rd wire. To shift the balance point to the 4th wire,

(A) current of the main circuit is to be decreased.

(B) current of the main circuit is to be increased.

(C) the shifting is not possible

(D) None of the above

Ans. Option (A) is correct.

> *Explanation:* To shift the balance point of a potentiometer to a higher length, the potential gradient of the wire is to be decreased. This can also be achieved by decreasing the current of the main circuit. So, this is a true statement.

Q. 21. Which one of the following statements is correct?

(A) Potentiometer is used to measure the current in a circuit.

(B) Potentiometer is used to measure the internal resistance of a cell.

(C) Potentiometer is used to measure the resistance of a circuit.

(D) Potentiometer is used to measure the potential difference across a resistor.

Ans. Option (B) is correct.

> *Explanation:* Potentiometer is used to measure internal resistance of a cell, e.m.f. of a cell and to compare the e.m.f.s of

ASSERTION AND REASON BASED MCQs (1 Mark each)

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A

(B) Both A and R are true but R is NOT the correct explanation of A

(C) A is true but R is false

(D) A is false and R is true

Q. 1. Assertion (A): Fuse wire has high resistance and low melting point.

Reason (R): Fuse wire is for small current flow only.

Ans. Option (C) is correct.

> *Explanation:* Fuse wire should melt and disconnect the circuit from mains supply if the current increases beyond a rated value. For this reason, its resistance should be high for more heat generation and melting point should be low for fast melting. So assertion is correct.
>
> Fuse wire is not for small current flow. Fuse wire may be of various current rating depending on the type of appliance being used and the capacity of the wiring. So, the reason is false. 1

Q. 2. Assertion (A): Electric appliance with metal body has three electrical connections. But an electrical bulb has two electrical connection.

Reason (R): Three pin connection reduces chances of electrical shocks.

Ans. Option (A) is correct.

> *Explanation:* The metallic body of electrical appliance is connected to the 3rd pin which is an earth pin.
>
> By any chance if the metallic body gets connected to the LIVE line, current flows to earth through this pin without giving any shock to the user.
>
> Hence assertion is true.
>
> Electric bulb does not have any metallic encloser and hence there is no requirement of earth pin. So, the reason is also true and properly explains the assertion.

Q. 3. Assertion (A): The resistance of superconductor is zero.

Reason (R): Super conductors are used for electrical power transmission.

Ans. Option (B) is correct.

> *Explanation:* Resistance of superconductor falls to zero at critical temperature.
>
> This property is very useful for power transmission without any loss.
>
> Assertion and reason both are true but reason does not explain the assertion.

Q. 4. Assertion (A): The same amount of current flows through the filament and line wire. But more heat is produced in filament.

Reason (R): Filament is made of material having high resistance and high melting point.

Ans. Option (A) is correct.

> *Explanation:* Heat produced = $H = i^2Rt$
>
> $H \propto R$
>
> Since resistance of filament >> Resistance of wire so more heat is produced in filament. Therefore, Assertion is true. Filament is made of material having high resistance like tungsten so that heat produced is more.
>
> Melting point of the material also should be high so that it can sustain more heat. Hence reason is also true. Reason properly explains the assertion.

Q. 5. Assertion (A): Power rating of resistance is not so important when used in a circuit.

Reason (R): The resistance value changes with temperature.

Ans. Option (D) is correct.

> *Explanation:* Power rating describes the heat dissipation capability of the resistor. If the heat generated is more than the power rating of the resistor, it will burn. So assertion is false. Resistance value is temperature dependent. So, the reason is true, But reason does not explain the assertion.

Q. 6. Assertion (A): Kirchhoff's junction rule is applicable for any number of lines meeting at a point in an electrical circuit.

Reason (R): When there is a flow of steady current, then there is no accumulation of charge at the junction.

Ans. Option (A) is correct.

> *Explanation:* Kirchhoff's junction rule is applicable at any point of an electrical circuit and there is no limitation of number of lines meeting at that point. So the assertion is true.
>
> While steady current is flowing there is no accumulation of charge at the junction. Total incoming charge = total outgoing charge. So the reason is also true and explains the assertion.

Q. 7. Assertion (A): Kirchhoff's voltage law indicates that the electric field is conservative.

Reason (R): Potential difference between two points in a circuit does not depend on the path.

Ans. Option (A) is correct.

Explanation: Kirchhoff's voltage law says that the sum of the voltages around any closed loop is zero. A closed loop starts from a node, traces a path through the circuit and returns to the same node. Since the total work done in moving a charge around this close path the zero, hence the electric field is conservative. So, the assertion is true.

Potential difference between two points in a circuit does not depend on the path. This is true for conservative field. Hence the reason is also true and it explains the assertion.

Q. 8. Assertion (A): In balanced condition, if the galvanometer and the voltage source is interchanged, the balanced condition remains same.

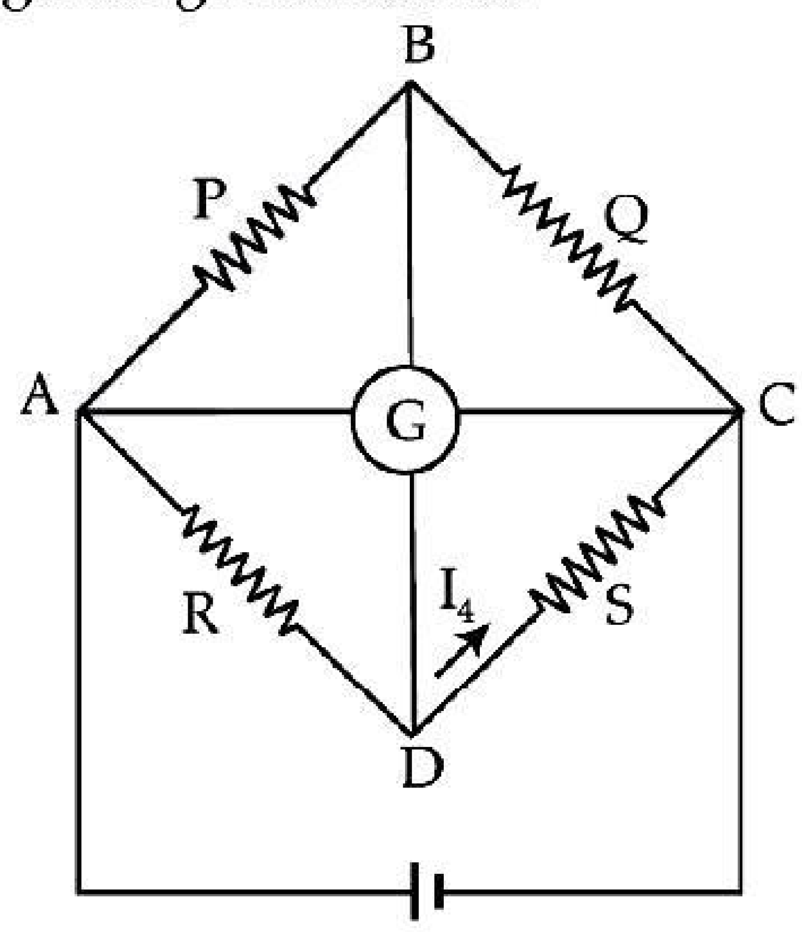
Reason (R): The balanced condition of Wheatstone bridge does not depend on the value of the resistances.

Ans. Option (C) is correct.

Explanation: In balanced condition, if the galvanometer and the voltage source are interchanged, the balanced condition remains same since in both the cases R_1R_4 remains equal to R_2R_3 . The assertion is true.

The balanced condition of Wheatstone bridge depends on the value of the resistances. R_1R_4 should be equal to R_2R_3. So, if the resistance values are changed, the balanced condition also gets disturbed. So, the reason is false.

Q. 9. Assertion (A): In balanced condition of a Wheatstone bridge, there is no current flow through the galvanometer.



Reason (R): The potential of point B and D are same.

Ans. Option (A) is correct.

Explanation: In balanced condition of a Wheatstone bridge, there is no current flow through the galvanometer. This is also called null condition. So, the assertion is true.

When the potential of point B and D are same then only there is no current flow through the galvanometer. Hence the reason is also true and explains the assertion.

Q. 10. Assertion (A): A high resistance is connected in series with the galvanometer of meter bridge.

Reason (R): As resistance increases, the current also increases.

Ans. Option (C) is correct.

Explanation: Resistance of galvanometer is low. So, to protect it from damage a high resistance is connected in series with it which limits the flow of current through it. So the assertion is true.

From Ohms law, I = V/R. So as resistance increases, the current decreases. Hence the reason is false.

Q. 11. Assertion (A): Meter bridge wire is generally made of Constantan.

Reason (R): Constantan has a very low temperature coefficient of resistance.

Ans. Option (A) is correct.

Explanation: Meter bridge wire is generally made of Constantan. The assertion is true.

Temperature coefficient of resistance of Constantan is very low. So, its resistance variation is negligible even after long use. This is the requirement of an ideal meter bridge. So the reason is true and properly explains the assertion.

Q. 12. Assertion (A): The balancing point of a meter bridge is obtained at L = 40 cm. When the area of cross-section of the wire of is doubled, the balancing point shifts to L = 60cm.

Reason (R): Resistance of wire is directly proportional to its area of cross-section .

Ans. Option (D) is correct.

Explanation: For a meter bridge, at the balancing point $\frac{R}{X} = \frac{L}{100-L}$ which is independent of the area of cross section. So, the assertion is false.

Resistance of wire is inversely proportional to its area of cross-section since R = $R = \rho\frac{L}{A}$. So reason is also false.

Q. 13. Assertion (A): Potentiometer is used to measure the e.m.f. of a cell.

Reason (R): Potentiometer is preferred over voltmeter to measure the e.m.f. a cell since it does not draw any net current from the cell.

Ans. Option (A) is correct.

Explanation: Potentiometer is used to measure the e.m.f. of a cell. The assertion is true. Voltmeter draws certain amount of current from the cell. So, V = E – iR. The measured value by the voltmeter is less than the actual e.m.f. of the cell. But potentiometer draws no net current at balance point, hence it measures the actual e.m.f. of the cell. So, the reason is also true and explains the assertion properly.

CASE-BASED MCQs

Attempt any 4 sub-parts out of 5. Each sub-part carries 1 mark.

I. Read the following text and answer the following questions on the basis of the same:

Electric Toaster : Small Industries Service Institute Takyelpat Industrial Estate Imphal has designed an Electric toaster which is operated at 220 volts A.C., single phase and available in four different rated capacity such as 600 W, 750 W, 1000 W and 1250 W. The heating element is made of nichrome 80/20 (80% nickel, 20% chromium), since Nichrome does not get oxidise readily at high temperature and have higher resistivity, so it produces more heat.

The element is wound separately on Mica sheets and fitted with body of toaster with the help of ceramic terminals.

Q. 1. Heating element of the toaster is made of :

(A) copper. **(B)** nichrome.

(C) chromium. **(D)** nickel.

Ans. Option (B) is correct.

Explanation: The heating element is made of nichrome 80/20 (80% nickel, 20% chromium).

Q. 2. What is meant by 80/20 Nichrome?

(A) 80% Chromium and 20% Nickel

(B) 80% Nickel and 20% Chromium

(C) Purity 80%, Impurity 20%

(D) It is a mixture of Chromium and Nickel

Ans. Option (B) is correct.

Explanation: Nichrome 80/20 means an alloy of 80% nickel, 20% chromium.

Q. 3. Which one will consume more electricity?

(A) 600 W **(B)** 750 W

(C) 1000 W **(D)** 1200 W

Ans. Option (D) is correct.

Explanation: Electricity consumption is measured by kWH. So, 1200W toaster will consume more electricity.

Q. 4. Operating voltage of the device is :

(A) 220 V AC, single phase

(B) 220 V AC, three phase

(C) 220 V DC

(D) 220 V AC/DC

Ans. Option (A) is correct.

Explanation: The designed electric toaster is operated at 220 volts A.C., single phase.

Q. 5. Insulating materials used in the device are :

(A) Mica

(B) Ceramic

(C) Mica, ceramic, Nichrome

(D) Mica, ceramic

Ans. Option (D) is correct.

Explanation: The element is wound separately on Mica sheets and fitted with body of toaster with the help of ceramic terminals.

II. Read the following text and answer the following questions on the basis of the same:

Shunt resistance:

The ammeter shunt is the device which provides the low resistance path to the flow of current. It is connected in parallel with the ammeter. In some ammeter the shunt is inbuilt inside the instrument while in others it is externally connected to the circuit.

Ammeters are designed for measurement of low current. For measuring high current, the shunt is connected in parallel to the ammeter. The significant portion of the current passes to the shunt because of the low resistance path and little amount of current passes through the ammeter.

The shunt is connected in parallel to the ammeter because of which the voltage drops across the meter and shunt remain the same. Thus, the movement of the pointer is not affected by the shunt.

Let us consider that the current to be measured is I. The circuit has ammeter and shunt connected parallel to each other. The ammeter is designed for measurement of small current say, I_m. The magnitude of the current I passes through the meter is very high, and it will burn the meter. So, for measuring the current I the shunt is required in the circuit.

As the shunt connects in parallel with the ammeter, thus the same voltage drops occur between them:

$I_{Sh}R_{SH} = I_mR_m$

$\therefore \quad R_{SH} = I_mR_m/I_{SH}$

Shunt current $I_{SH} = I - I_m$

So, $\quad R_{SH} = I_mR_m/(I - I_m)$

$\therefore \quad I/I_m = 1 + (R_m/R_{SH})$

The ratio of the total current to the current required for the movement of the ammeter coil is called the multiplying power of the shunt.

$\therefore$ The multiplying power $= m = I/I_m$

$R_{SH} = R_m / (m - 1)$

The following are the requirements of the shunt.

- The resistance of the shunt should remain constant with time.
- The temperature of the material should remain same even though substantial current flows through the circuit.

Q. 1. Manganin and Constantan are used for making the shunt of DC and AC ammeter respectively.

What is multiplying power of the shunt?

(A) $\dfrac{\text{Total current}}{\text{Current required by the movement of ammeter coil}}$

(B) $\dfrac{\text{Current required by the movement of ammeter coi}}{\text{Total current}}$

(C) Current required by the movement of ammeter coil X Total current

(D) None of the above

Ans. Option (A) is correct.

Q. 2. Materials used for making shunt of DC and AC ammeter are respectively

(A) Manganin and Manganin

(B) Manganin and Copper

(C) Manganin and Constantan

(D) Constantan and Manganin

Ans. Option (C) is correct.

Q. 3. Current through shunt is

(A) greater than current through ammeter coil.

(B) less than current through ammeter coil.

(C) equal to the current through ammeter coil.

(D) may be greater than or equal to or less than current through ammeter coil.

Ans. Option (A) is correct.

Q. 4. How shunt is connected with a ammeter?

(A) In series when connected externally

(B) In parallel when connected externally

(C) In parallel when connected internally

(D) Both (B) and (C)

Ans. Option (D) is correct.

Q. 5. What will be the value of the shunt resistance if the ammeter coil resistance is 1Ω and multiplying power is 100?

(A) 1/99Ω **(B)** 99Ω

(C) 101Ω **(D)** 1/101Ω

Ans. Option (A) is correct.

> ***Explanation:*** $R_{SH} = R_m / (m - 1) = 1/(100 - 1) = 1/99\Omega$

III. Read the following text and answer the following questions on the basis of the same:

Types of resistors

Most common type of resistor is Carbon Composition Resistors. Carbon resistors are a cheap, general purpose resistor used in electrical and electronic circuits. Their resistive element is manufactured from a mixture of finely ground carbon dust or graphite and a non-conducting ceramic powder to bind it all together.

The ratio of carbon dust to ceramic (conductor to insulator) determines the resistive value of the resistor. Higher the ratio of carbon, lower the overall resistance.

Film Type Resistors consist of Metal Film, Carbon Film and Metal Oxide Film .Such resistors are generally made by depositing pure metals, such as nickel, or an oxide film, such as tin-oxide, on an insulating ceramic rod or substrate.

The resistive value of the resistor is controlled by increasing the desired thickness of the deposited film giving them the names of either "thick-film resistors" or "thin-film resistors".

Film type resistors can achieve much higher ohmic value compared to other types.

Another type of resistor, called a Wirewound Resistor, is made by winding a thin metal alloy wire (Nichrome) or similar wire on an insulating ceramic former in the form of a spiral helix.

These types of resistors are generally only available in very low ohmic value with high precision .

They are able to handle much higher electrical currents than other resistors of the same ohmic value with much excessive power ratings. These high power resistors are moulded into an aluminium heat sink body with fins attached to increase their overall surface area to promote heat loss and cooling.

Q. 1. Carbon composition resistors are made from a mixture of

(A) finely ground metal dust and ceramic powder.

(B) finely ground carbon dust or graphite and ceramic powder.

(C) finely ground carbon dust or graphite and copper powder.

(D) finely ground carbon dust or graphite.

Ans. Option (B) is correct.

Explanation: Carbon Composition Resistors are manufactured from a mixture of finely ground carbon dust or graphite and a non-conducting ceramic powder to bind it all together.

Q. 2. In carbon composition resistors, ______ the ratio of carbon, _____ the overall resistance.

(A) Higher, lower (B) Lower, higher

(C) Lower, lower (D) Higher, higher

Ans. Option (A) is correct.

Explanation: The ratio of carbon dust to ceramic (conductor to insulator) determines the resistive value of the resistor. Higher the ratio of carbon, lower the overall resistance.

Q. 3. Metal Film Type Resistors are generally made by depositing pure ______, on ______ rod or substrate.

(A) Ceramic, metal (B) Carbon, ceramic

(C) Metal, ceramic (D) Carbon, metal

Ans. Option (C) is correct.

Explanation: Metal Film Type Resistors are generally made by depositing pure metals, such as nickel on an insulating ceramic rod or substrate.

Q. 4. Wirewound Resistors are made by winding a thin _____ or similar wire on an ____ former in the form of a spiral helix.

(A) Nichrome, copper (B) Nichrome, ceramic

(C) Copper, ceramic (D) Copper, Nichrome

Ans. Option (B) is correct.

Explanation: Wirewound Resistor, is made by winding a thin metal alloy wire (Nichrome) or similar wire on an insulating ceramic former in the form of a spiral helix.

Q. 5. Wire wound resistors are available in very ____ ohmic high precision values with ______ power rating.

(A) High, high (B) Low, low

(C) High, Low (D) Low, high

Ans. Option (D) is correct.

Explanation: Wire-wound Resistors are generally only available in very low ohmic high precision values. They are able to handle much higher electrical currents than other resistors of the same ohmic value with much excessive power ratings. These high power resistors are moulded into an aluminium heat sink body with fins attached to increase their overall surface area to promote heat loss and cooling.