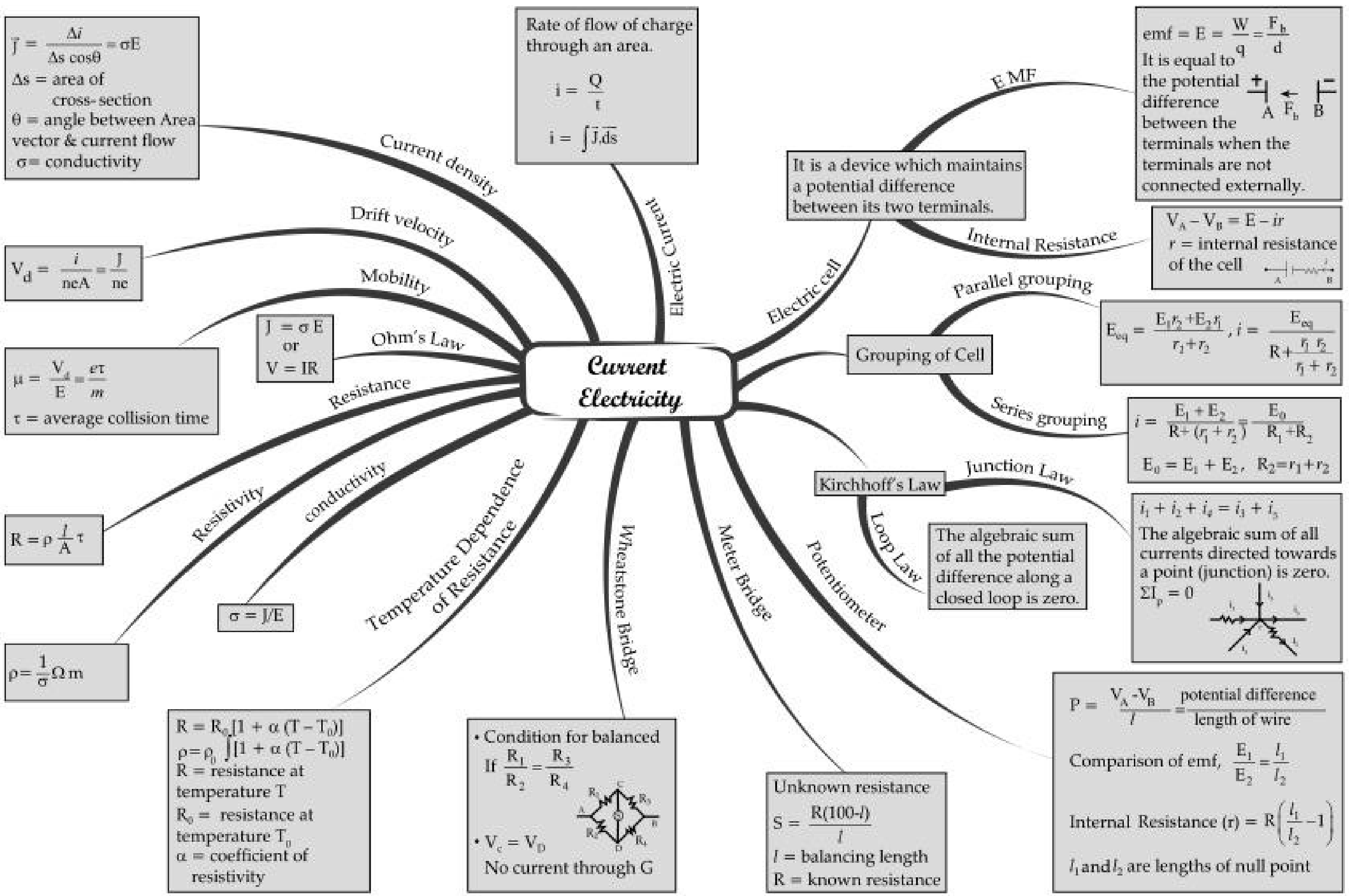


Current Electricity
Electric Current
Rate of flow of charge through an area.
$i = \frac{Q}{t}$
$i = \int \vec{J}.\vec{ds}$
Current density
$\vec{J} = \frac{\Delta i}{\Delta s \cos\theta} = \sigma E$
Δs = area of cross-section
θ = angle between Area vector & current flow
σ = conductivity
Drift velocity
$V_d = \frac{i}{neA} = \frac{J}{ne}$
Mobility
$\mu = \frac{V_d}{E} = \frac{e\tau}{m}$
τ = average collision time
Ohm's Law
$J = \sigma E$ or $V = IR$
Resistance
$R = \rho \frac{l}{A} \tau$
Resistivity
$\rho = \frac{1}{\sigma} \Omega m$
conductivity
$\sigma = J/E$
Temperature Dependence of Resistance
$R = R_0[1 + \alpha (T - T_0)]$
$\rho = \rho_0 [1 + \alpha (T - T_0)]$
R = resistance at temperature T
R_0 = resistance at temperature T_0
α = coefficient of resistivity
Wheatstone Bridge
• Condition for balanced
If $\frac{R_1}{R_2} = \frac{R_3}{R_4}$
• $V_c = V_D$
No current through 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
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.
$\Sigma I_p = 0$
Loop Law
The algebraic sum of all the potential difference along a closed loop is zero.
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
$i = \frac{E_1 + E_2}{R + (r_1 + r_2)} = \frac{E_0}{R_1 + R_2}$
$E_0 = E_1 + E_2$, $R_2 = r_1 + r_2$
Electric cell
It is a device which maintains a potential difference between its two terminals.
E MF
$emf = E = \frac{W}{q} = \frac{F_b}{d}$
It is equal to the potential difference between the terminals when the terminals are not connected externally.
A F_b B
Internal Resistance
$V_A - V_B = E - ir$
r = internal resistance of the cell

UNIT – 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 non-linear), 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.*
- *Potentiometer—principle and its applications to measure potential difference and for comparing emf of two cells; measurement of internal resistance of a cell.*

Chapter Analysis

List of Concepts Name	2017		2018	2019	
	D	OD	D/OD	D	OD
Electric Current, Resistance and Cells	1 Q (5 marks)	1 Q (1 mark) 1 Q (3 marks)	1 Q (2 marks) 1 Q (3 marks) 1 Q (4 marks)	1 Q (1 marks) 1 Q (2 marks)	1 Q (3 marks)
Kirchhoff's laws, Wheatstone Bridge and their Applications	1 Q (5 marks)	1 Q (3 marks)	–	1 Q (3 marks)	
Meter Bridge, Potentiometer and their Applications	2 Q (3 marks)	–	–	1 Q (3 mark) or 1 Q (3 marks)	1 Q (5 marks)

TOPIC-1

Electric Current, Resistance and Cells

Revision Notes

Electric current

- Electric current is defined as the rate of flow of charge, across the corss-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

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

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, 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

Scan to know more about this topic

Ohm's law

Electrical resistance

- It is an obstacle that is shown by the a 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.

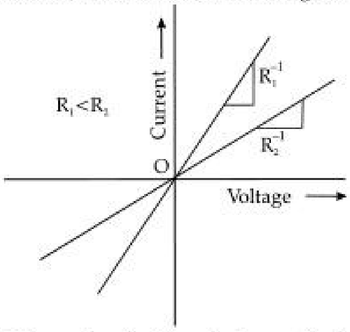
- In the series combination of resistances, the current is same throughout each resistor.
- In the parallel combination of resistances, the potential difference is same across each resistor.

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

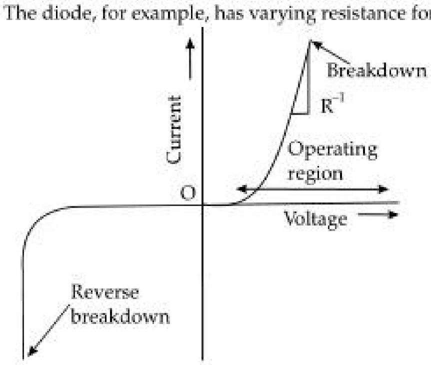
- A linear V-I curve has a constant slope and hence a constant resistance. Carbon resistors and metals obey the Ohm's law and have a constant resistance. This means that the V-I curve is a straight line passing through the origin.



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

Nonlinear 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 $\quad V = \frac{W}{q},$

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

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

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

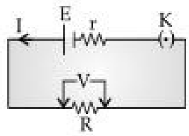
➢ Cell is a device that maintains the potential difference that is present between the two electrodes as a result of chemical reaction.

➢ 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.



$$E = V + Ir$$

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

$$\text{So} \qquad V = E - Ir$$

$$\therefore \qquad V < E. \qquad \text{(if there is flow of current)}$$

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

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

Scan to know more about this topic

Electric Current, Resistance and Cells

(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 $E_1, E_2, E_3,\ldots..E_m$ and of internal resistances $r_1, r_2, r_3,\ldots..r_m$ are connected in parallel across an external resistance R, then the current through the external resistance is given by

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

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, P. D., 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 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 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 $E = IVt$

Note : All symbols have their usual meanings.

Objective Type Questions (1 mark each)

(I) MULTIPLE CHOICE QUESTIONS

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. [NCERT Exemplar]

Ans. Correct option : (b)

Explanation : As we know that current density (*J*) depends on

Conductivity [$\sigma = 1/\rho = l/RA$]

Electric field [$J = \sigma E$]

Current and 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. [NCERT Exemplar]

Ans. Correct option : (a)

Explanation : As we know that,

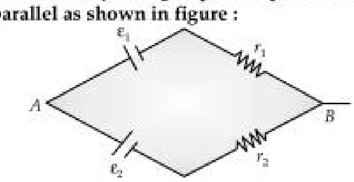
$$I = Anev_d$$

So current,

$$I \propto v_d$$

And, current (*I*) also depends on *n*, the number of free electrons which increase on increasing temperature which make more collisions between electrons thereby increase resistance or decrease current.

Q. 3. 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. [NCERT Exemplar]

Ans. Correct option : (a)

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. 4. A wire of resistance R is divided in 10 equal parts. These parts are connected in parallel, the equivalent resistance of such connection will be [A]

(a) 0.01 R **(b) 0.1 R**

(c) 10 R **(d) 100 R**

Ans. Correct option : (a)

Explanation : A wire of resistance R is cut into 10 equal parts.

Let new resistance = *r*

r = R/10

They are joined in parallel.

the resistance = R'

1/R' = 1/(R/10) + 1/(R/10) + 1/(R/10) + ... (10 times)

1/R' = 10 × 10/R

1/R' = 100/R

R' = R/100 = 0.01 R

Equivalent resistance = R/100

(II) FILL IN THE BLANKS

Q. 1. The unit of conductance is .... [R]

Ans. mho or seimen(s).

Q. 2. The drift velocity inside a conductor .... with the increase in the current flowing. [U]

Ans. increases.

Q. 3. When more than two resistors are connected in parallel, ... remains same for all the resistors. [R]

Ans. potential difference.

(III) VERY SHORT ANSWER TYPE QUESTIONS

Q. 1. Define the conductivity of a conductor. Write its SI unit. [R] **[O.D. Compt I, II, III 2017]**

Ans. Definition ½

SI Unit ½

Conductivity is reciprocal of resistivity

$$\sigma = \frac{1}{\rho}$$ ½

SI unit : S/m (siemens per metre) ½

[CBSE Marking Scheme, 2017]

Detailed Answer :

Conductivity of a conductor is the reciprocal of its resistivity *i.e.*,

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m} \qquad ½$$

SI unit of conductivity is siemens per metre and is represented as (S/m). ½

Q. 2. Define temperature coefficient of resistivity.
R **[SQP 2018-19]**

Ans. Fractional change in resistivity per unit change in temperature. 1
[CBSE Marking Scheme, 2018-19]

AI **Q. 3. Nichrome and copper wires of same length and same radius are connected in series. Current *I* is passed through them. Which wire gets heated up more ? Justify your answer.** R **[O.D. I, II, III 2017]**

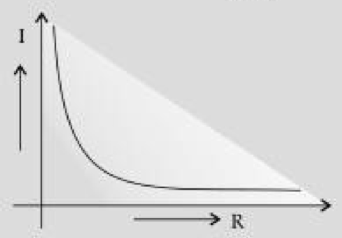
Ans. (i) Nichrome ½
(ii) $R_{Ni} > R_{Cu}$ (or Resistivity$_{Ni}$ > Resistivity$_{Cu}$)
Justification : Conduction of electrons ½
[CBSE Marking Scheme, 2017]

Detailed Answer :

Two wires having similar length and radius, Nichrome wire gets heated up more as compared to copper wire since resistivity of Nichrome is more than that of Copper. 1

AI **Q. 4. Plot a graph showing the variation of current *I* versus resistance *R*, connected to a cell of emf *E* and internal resistance *r*.** U **[CBSE SQP 2017-18]**

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



1
[CBSE Marking Scheme, 2017]

Q. 5. Give an example of a material each for which temperature coefficient of resistivity is (i) positive, (ii) negative. U **[CBSE SQP 2015-2016]**

Ans. (i) Cu (metals, alloys). ½
(ii) Si (semiconductor). ½
[CBSE Marking Scheme, 2016]

AI **Q. 6. Write the expression for the drift velocity of charge carriers in a conductor of length *l* across which a potential difference *V* is applied.**
R **[O.D. Comptt. I, II, III 2014]**

Ans. $$v_d = \frac{-eV}{ml}\tau \qquad 1$$
[CBSE Marking Scheme, 2014]

Detailed Answer :

Since drift velocity, $v_d = \dfrac{-eE}{m}\tau$ ...(i)

But, $E = \dfrac{V}{l}$ ...(ii)

Now, from equation (i) and (ii),

Drift velocity, $v_d = \dfrac{-eV}{ml}\tau$ 1

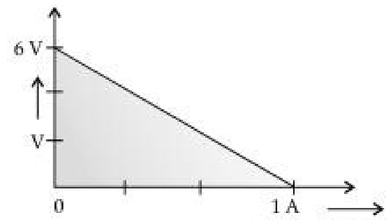
AI **Q. 7. How does one explain increase in resistivity of a metal with increase in temperature ?**
U **[O.D. Comptt. I, II, III 2014]**

Ans. With increase in temperature, the relaxation time (average time between successive collisions) decreases and hence resistivity increases.

Alternatively,

Resistivity, $\rho = \left(\dfrac{m}{ne^2\tau}\right)$ increases as τ decreases with increase in temperature. 1
[CBSE Marking Scheme, 2014]

Q. 8. The plot of the variation of potential difference across a combination of three identical cells in series, versus current is shown below. What is the emf and internal resistance of each cell ?



R **[O.D. I, II, III 2016]**

Ans. Voltage across cell combination

$V = E - Ir$

When current $I = 0 \Rightarrow V = E$

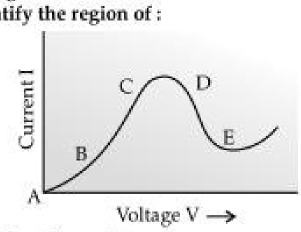
From graph, when $I = 0$, $V = 6$ V $\Rightarrow$ emf $E = 6$ V

As $I = 1$ A, at $V = 0$ (from graph)

$\therefore V = E - Ir \Rightarrow 0 = 6 - Ir \Rightarrow -6 = -Ir$

$r = 6\,\Omega.$ 1

Q. 9. Graph showing the variation of current versus voltage for a material GaAs is shown in the figure, identify the region of :



(i) Negative resistance
(ii) Where Ohm's law is obeyed.
U **[Delhi I, II, III 2015]**

Ans. From the graph :

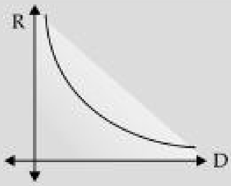
(i) *DE* shows negative resistance region ½

(ii) AB region obeys Ohm's law ½

[CBSE Marking Scheme, 2015]

Q. 10. Draw a graph to show the variation of resistance of a metal wire as a function of its diameter keeping its length and material constant. U **[CBSE SQP, 2016]**

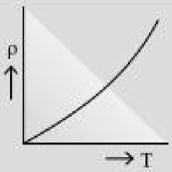
Ans.



[CBSE Marking Scheme, 2016] 1

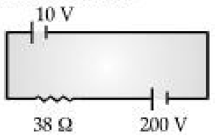
AI **Q. 11. Show variation of resistivity of copper as a function of temperature in a graph.** U

Ans.



[CBSE Marking Scheme, 2014] 1

Q. 12. A 10 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 38 Ω as shown in the figure. Find the value of the current in the circuit.



U **[Delhi 2018]**

Ans. From the circuit we see that, the two batteries are joined together with positive terminal, so equivalent emf of both the batteries will result as :

$$I = \frac{E}{R} = \frac{190}{38} = 5\text{ A.} \qquad 1$$

[CBSE Marking Scheme 2013, 2018]

Alternatively :

$$E_{net} = E_1 - E_2$$
$$= (200 - 10) = 190\text{ V}$$

$$\text{Current in circuit, } I = \frac{E_{net}}{R}$$
$$= \frac{190}{38} = 5\text{A}$$

Q.13. What is the value of the current corresponding to a point charge moving in a circle with constant speed and frequency 'f' ? A

Ans. The current flowing through a circuit can be calculated by the rate of charge flow through the circuit. The current is given by $\frac{dQ}{dt}$.

If current is steady, then $I = \frac{Q}{t} = \frac{ne}{t}$

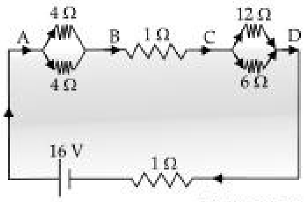
If a point charge q is moving in circle with constant speed and frequency f, then corresponding current.

$I = fq = —q$.

Short Answer Type Questions

(2 marks each)

Q. 1. A network of resistors is connected to a 16 V battery with internal resistance of 1 Ω, as shown in the following figure. Compute the equivalent resistance of the network.



U **[CBSE SQP 2018-19]**

Ans. Equivalent Resistance

$$= \frac{R_1 . R_2}{(R_1 + R_2)} + R_3 + \frac{R_4 . R_5}{(R_4 + R_5)} \qquad 1$$

$$= \left[\frac{(4 \times 4)}{(4+4)}\right] + 1 + \frac{[(12 \times 6)]}{(12+6)}\Omega \qquad ½$$

$$= 7\,\Omega \qquad ½$$

[CBSE Marking Scheme, 2018-2019]

Q. 2. A 9 V battery is connected in series with a resistor. The terminal voltage is found to be 8 V. Current through the circuit is measured as 5 A. What is the internal resistance of the battery?

A **[CBSE SQP 2018-19]**

Ans.

$$r = \frac{E - V}{I} \qquad 1$$

$$= \frac{9\text{V} - 8\text{V}}{5\text{A}} \qquad ½$$

$= 0.2\,\Omega$ ½

[CBSE Marking Scheme, 2018]

AI Q. 3. Two electric bulbs P and Q have their resistances in the ratio of 1 : 2. They are connected in series across a battery. Find the ratio of the power dissipation in these bulbs. A **[Delhi O.D. 2018]**

Sol. **Formula** ½

Stating that currents are equal ½

Ratio of powers 1

Power $= I^2R$ ½

The current, in the two bulbs, is the same as they are connected in series. ½

$$\therefore \quad \frac{P_1}{P_2} = \frac{I^2R_1}{I^2R_2} = \frac{R_1}{R_2} \qquad ½$$

$$= \frac{1}{2} \qquad ½$$

[CBSE Marking Scheme, 2018]

Detailed Answer :

Since, in series combination of resistance, the current flowing is same but voltage is different, therefore power dissipation is given by

$$P = I^2R \Rightarrow P \propto R \Rightarrow \frac{P_1}{P_2} = \frac{R_1}{R_2} \qquad ½+½$$

Now for two bulbs P and Q, we have

$$\frac{P_1}{P_2} = \frac{R_1}{R_2} = \frac{1}{2} \qquad 1$$

(Since $R_1 : R_2 = 1 : 2$ given).

$\Rightarrow$ Ratio of Power dissipation, $P_1 : P_2 = 1 : 2$ ½

Ans. Given $R_P : R_Q = 1 : 2$

Let the ratio be K

$\Rightarrow R_P = K \times 1 = K$

$R_Q = K \times 2 = 2K$

Now, as in a series circuit current remains same in both the bulbs.

Power$_P$: Power$_Q$

$I^2R_P : I^2R_Q$

$= R_P : R_Q$

$= K : 2K$

$= \underline{1 : 2}$

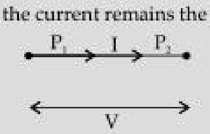
[Topper's Answer, 2018]

Q. 4. Two metallic wires P_1 and P_2 of the same material and same length but different cross-sectional areas A_1 and A_2 are joined together and then connected to a source of emf. Find the ratio of the drift velocities of free electrons in the wires P_1 and P_2, if the wires are connected (i) in series, and (ii) in parallel. U **[Foreign II 2017]**

Ans. Ratio of drift velocities in series 1

Ratio of drift velocities in parallel 1

In series, the current remains the same



$$I = neA_1v_{d_1} = neA_2v_{d_2} \qquad ½$$

$$\therefore \quad \frac{v_{d1}}{v_{d2}} = \frac{A_2}{A_1} \qquad ½$$

In parallel, potential difference is same but currents are different.

$$V = I_1R_1$$

$$= neA_1v_{d1}\frac{\rho l}{A_1}$$

$$= ne\rho v_{d1}l$$

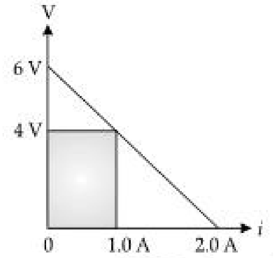
Similarly, $V = I_2R_2 = ne\rho v_{d2}l$ ½

$$I_1R_1 = I_2R_2$$

$$\therefore \quad \frac{v_{d1}}{v_{d2}} = 1 \qquad ½$$

[CBSE Marking Scheme, 2017]

Q. 5. The figure shows a plot of terminal voltage 'V' versus the current 'i' of a given cell. Calculate from the graph (i) emf of the cell and (ii) internal resistance of the cell.



U [O.D. Comptt. I, II, III 2017]

Ans. Emf of cell 1

Internal resistance 1

(i) $E = V$ for $I = 0$

$\therefore$ $E = 6\text{ V}$ ½

(ii) $E = V + ir$ ½

$\therefore$ $6 = 4 + r$ ½

$r = 2\,\Omega$ ½

[CBSE Marking Scheme, 2017]

Q. 6. Two cells of emf E_1 and E_2 have internal resistance r_1 and r_2. Deduce an expression for equivalent emf of their parallel combination. U **[SQP II 2017]**

Ans.

$$I = I_1 + I_2 \quad ½$$

$$= \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

$$I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$I = \frac{E_1 r_2 + E_2 r_1}{r_1 r_2} - V\left(\frac{r_1 + r_2}{r_1 r_2}\right) \quad ½$$

or
$$V = \left(\frac{E_1 r_2 + E_2 r_1}{r_1 r_2}\right) \times \left(\frac{r_1 r_2}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad ½$$

or
$$V = \left(\frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad ½$$

Comparing above with

$$V = E_{eq} - I_{eq} \times R_{eq} \quad ½$$

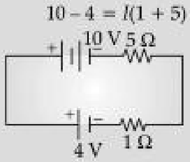
We get
$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} \quad ½$$

AI **Q. 7. A cell of emf 4 V and internal resistance 1 Ω is connected to a d.c. source of 10 V through a resistor of 5 Ω. Calculate the terminal voltage across the cell during charging.** U **[O.D. III 2017]**

Ans. Calculation of Current 1

Calculation of Terminal Voltage 1

$$10 - 4 = I(1 + 5) \quad ½$$



$\therefore$ $I = 1\text{ A}$ ½

$\therefore$ Terminal voltage across cell

$= (4 + 1 \times 1)\text{ V}$ ½

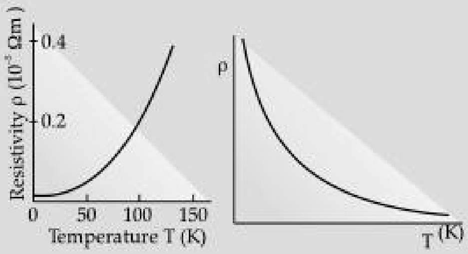
$= 5\text{ V}$ ½

[CBSE Marking Scheme, 2017]

Q. 8. Draw a plot showing the variation of resistivity of a (i) conductor and (ii) semiconductor, with the increase in temperature.

How does one explain this behaviour in terms of number density of charge carriers and the relaxation time ? U **[Delhi Comptt. I, II, III 2014]**

Ans. (i) Conductor **(ii)** Semiconductor



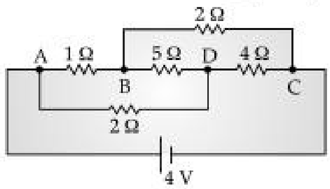
$$\rho = \frac{m}{ne^2\tau} \quad ½+½$$

In conductors, average relaxation time decreases with increase in temperature, resulting in an increase in resistivity. ½

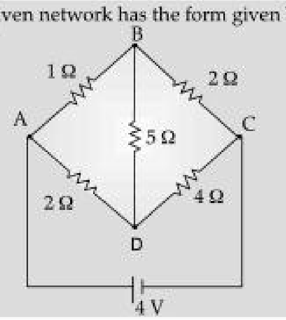
In semiconductors, the increase in number density (with increase in temperature) is more than the decrease in relaxation time; the net result is, therefore, a decrease in resistivity. ½

[CBSE Marking Scheme, 2014]

AI **Q. 9. Calculate the current drawn from the battery by the network of resistors shown in the figure.** A **[O.D. I, II, III 2015]**



Ans. The given network has the form given below :



It is a balanced Wheatstone Bridge. ½

Its equivalent resistance, R is given by

$$\frac{1}{R} = \frac{1}{1+2}+\frac{1}{2+4} \quad ½$$

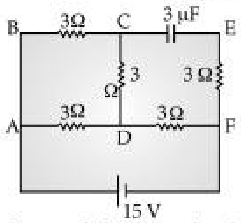
$$= \frac{1}{2}$$

$$R = 2\,\Omega$$

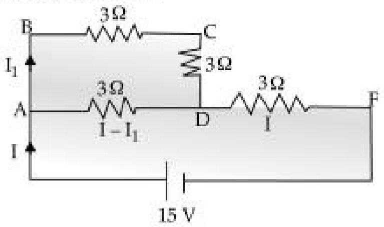
$$\therefore \quad \text{Current drawn} = \frac{4V}{2} = 2\text{ A} \quad 1$$

[CBSE Marking Scheme, 2015]

Q. 10. In the circuit shown in the figure, find the total resistance of the circuit and the current in the arm *CD*. A **[Foreign Set II 2014]**



Ans. In a steady state (when capacitor is fully charged no current flows through branch *CEF* and the given circuit reduced to



$$\frac{1}{R_{eq(AD)}} = \frac{1}{6}+\frac{1}{3}$$

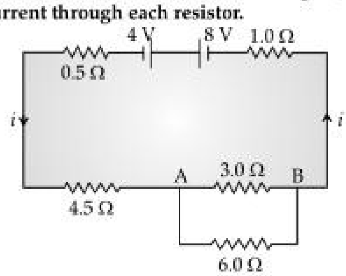
$$\Rightarrow \quad R_{eq(AD)} = 2\,\Omega \quad ½$$

Total resistance, $R_{AF} = 2 + 3 = 5\,\Omega$

Hence $I = \frac{15}{5}\text{A} = 3\text{A}$ ½

Current through, CD, $I_1 = \frac{3}{9}\times I = 1\text{A}$ 1

AI Q. 11. In the circuit shown in the figure, find the current through each resistor.



A **[Delhi I, II, III 2015]**

Ans. Total emf in the circuit = 8 V – 4 V = 4 V ½

Total resistance of the circuit = 8 Ω ½

Hence current flowing in the circuit

$$i = \frac{V}{R} = \frac{4}{8}\text{ A} = 0.5\text{ A} \quad ½$$

Current flowing through the resistors :

Current through 0.5 Ω, 1.0 Ω and 4.5 Ω is 0.5 A

Current through 3.0 Ω is $\frac{2}{3}\text{I} = \frac{1}{3}\text{A}$

Current through 6.0 Ω is $\frac{1}{3}\text{I} = \frac{1}{6}\text{A}$ ½

Q.12. Two bulbs are rated (P_1, V) and (P_2, V). If they are connected (i) in series and (ii) in parallel across a supply V, find the power dissipated in the two combinations in terms of P_1 and P_2. [Delhi I 2019]

Ans. Calculation of Power dissipation in two combinations **1 + 1**

$$R_1 = \frac{V^2}{P_1}, R_2 = \frac{V^2}{P_2}, \quad ½$$

$$P_s = \frac{V^2}{R_s} = \frac{P_1P_2}{P_1+P_2} \quad ½$$

$$\frac{1}{P_s} = \frac{1}{P_1}+\frac{1}{P_2} \quad ½$$

$$\frac{1}{R_p} = \frac{1}{R_1}+\frac{1}{R_2} = \frac{P_1+P_2}{V^2} \quad ½$$

$$\therefore P_p = \frac{V^2}{R_p} = P_1 + P_2 \quad ½$$

[CBSE Marking Scheme, 2019]

Detailed Answer :

Power dissipation is given by $P = \frac{V^2}{R}$

Resistance across two bulbs are

$$R_1 = \frac{V^2}{P_1} \text{ and } R_2 = \frac{V^2}{P_2}$$

Total resistance of combination in series,

$$R = R_1 + R_2 = \frac{V^2}{P_1}+\frac{V^2}{P_2} = V^2\left(\frac{1}{P_1}+\frac{1}{P_2}\right)$$

⇒ Total power dissipated,

$$P = \frac{V^2}{R} = \frac{V^2}{V^2\left(\frac{1}{P_1}+\frac{1}{P_2}\right)} = \frac{P_1P_2}{P_1+P_2}$$

For a parallel combination

$$\frac{1}{R} = \frac{1}{R_1}+\frac{1}{R_2} = \frac{P_1+P_2}{V^2}$$

$$\text{or } R = \frac{V^2}{(P_1+P_2)}$$

⇒ Power dissipated

$$P = \frac{V^2}{V^2/(P_1+P_2)} = (P_1+P_2)$$

Long Answer Type Questions-I (3 marks each)

AI Q. 1. Derive the expression for the current density of a conductor in terms of the conductivity and applied electric field. Explain, with reason how the mobility of electrons in a conductor changes when the potential difference applied is doubled, keeping the temperature of the conductor constant. A **[Delhi Comptt. I, II, III 2017]**

Ans. Derivation of current density **2**

Explanation with reason the change in mobility of electrons **1**

Using Ohm's law,

$$V = IR = \frac{I\rho l}{A} \quad ½$$

Potential difference (V), across the ends of a conductor of length 'l', where field 'E' is applied is given by

$$V = El$$

$$\therefore \quad El = \frac{I\rho l}{A} \quad ½$$

But current density,

$$J = \frac{I}{A}$$

$$El = J\rho l = \frac{Jl}{\sigma} \quad \left[\because \frac{1}{\rho} = \sigma\right] \quad ½$$

$$\Rightarrow \quad J = \sigma E \quad ½$$

No change

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

and $v_d = \dfrac{eV\tau}{ml}$ ½

As potential is doubled, drift velocity also gets doubled, therefore, no change in mobility. ½

[CBSE Marking Scheme, 2017]

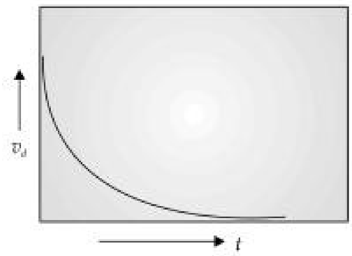
Q. 2. What is relaxation time ? Derive an expression for resistivity of a wire in terms of number density of free electrons and relaxation time. A**[SQP I 2017-18]**

Ans. Definition and Derivation. **3**

[CBSE Marking Scheme, 2017]

Detailed answer :

(i) Relaxation time shows the effect of collisions among the electrons and ions or impurities on electrical conduction in a metal. It is the time taken for the drift velocity to decay $1/e$ of its initial value. As drift velocity increases, relaxation time decreases since the electrons move the distance in which they frequently collide faster. **1**



(ii) When a potential difference V is applied across conductor of length l, then drift speed of electron will result as :

$$v_d = \frac{eE\tau}{m}$$

$$= \frac{eV\tau}{lm} \quad \because \left[E = \frac{V}{l}\right]$$

The electric current through the conductor and drift speed are linked as $I = neAv_d$

where,

n = number density of electrons

e = electronic charge

A = area of cross section

v_d = electron drift speed

$$\therefore \quad I = neA\left(\frac{eV\tau}{lm}\right) \quad ½$$

So, $$\frac{V}{I} = \frac{ml}{ne^2\tau A} \quad ½$$

At constant temperature :

$$\frac{V}{I} = R$$

Hence, $$R = \left(\frac{m}{ne^2\tau}\right) \times \frac{l}{A} \quad ½$$

Comparing above expression with

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

where, ρ = specific resistance

$$\rho = \frac{m}{ne^2\tau} \quad ½$$

Q. 3. Two cells of emfs E_1 & E_2 and internal resistances r_1 & r_2 respectively are connected in parallel. Obtain expressions for the equivalent.

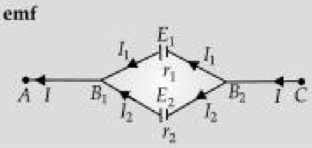
(i) resistance and

(ii) emf of the combination U **[CBSE Comptt. 2018]**

Sol. Obtaining Expression for the equivalent

(i) resistance **1**

(ii) emf **2**



$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\therefore \quad r = \frac{r_1 r_2}{r_1 + r_2} \qquad ½$$

$$I = I_1 + I_2$$

$$V = E_1 - I_1 r_1 \text{ and } V = E_2 - I_2 r_2$$

$$\therefore \quad I = \left(\frac{E_1 - V}{r_1}\right) + \left(\frac{E_2 - V}{r_2}\right) \qquad ½$$

$$V = \left(\frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \qquad 1$$

also $\quad V = E_{eq} - Ir_{eq} \qquad ½$

(i) $\quad r_{eq} = \dfrac{r_1 r_2}{r_1 + r_2} \qquad 1$

(ii) $\quad E_{eq} = \dfrac{E_1}{r_1} + \dfrac{E_2}{r_2}$

[CBSE Marking Scheme, 2018]

Q. 4. First a set of n equal resistors of R each is connected in series to a battery of emf E and internal resistance R. A current I is observed to flow. Then the n resistors are connected in parallel to the same battery. It is observed that the current becomes 10 times. What is n ? A **[SQP I 2017]**

Ans.

$$I = \frac{E}{(R + nR)} \qquad 1$$

$$10I = \frac{E}{R + \frac{R}{n}} \qquad 1$$

$$\frac{1+n}{\left(1 + \frac{1}{n}\right)} = 10 \Rightarrow \frac{1+n}{(n+1)}n = 10$$

$$n = 10 \qquad 1$$

[CBSE Marking Scheme, 2017]

Detailed Answer :

It is observed that an equivalent resistance of series combination is in series with internal resistance of a battery. Equivalent resistance of parallel combination will also be in series with internal resistance of battery.

Hence in series combination of resistors, current I will be : ½

$$I = \frac{E}{(R + nR)} \qquad \text{...(i) ½}$$

In case of parallel combination, current 10 I will be :

$$\frac{E}{\left(R + \frac{R}{n}\right)} = 10I \qquad \text{...(ii) ½}$$

From the equations (i) and (ii),

$$\frac{1+n}{\left(1 + \frac{1}{n}\right)} = 10 \qquad ½$$

So, $\quad 10 = \dfrac{1+n}{(n+1)}n \qquad ½$

Hence, $\quad n = 10 \qquad ½$

Q. 5. The following table gives the length of three copper wires, their diameters and the applied potential difference across their ends. Arrange the wires in increasing order according to the following :

(i) The magnitude of the electric field within them,

(ii) The drift speed of electrons through them, and

(iii) The current density within them.

R **[CBSE SQP 2017-18]**

Wire No.	Length	Diameter	Potential Difference
1	L	$3d$	V
2	$2L$	d	V
3	$3L$	$2d$	$2V$

Ans. (i) $\quad E_1 = \dfrac{V}{L},\ E_2 = \dfrac{V}{2L},\ E_3 = \dfrac{2V}{3L} \qquad ½$

$E_2 < E_3 < E_1 \qquad ½$

(ii) $\quad v_d \propto E \qquad ½$

$v_{d2} < v_{d3} < v_{d1} \qquad ½$

(iii) $\quad I = neAv_d \qquad ½$

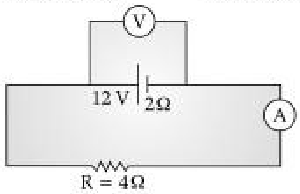
$J = nev_d$

$J_2 < J_3 < J_1 \qquad ½$

[CBSE Marking Scheme, 2017]

Q. 6. (i) The potential difference applied across a given resistor is altered so that the heat produced per second increases by a factor of 9. By what factor does the applied potential difference change ?

(ii) In the figure shown, an ammeter A and a resistor of 4 Ω are connected to the terminals of the source. The emf of the source is 12 V having an internal resistance of 2 Ω. Calculate the voltmeter and ammeter readings. R **[O.D. I, II, III 2017]**



Ans. (i) The factor by which the potential difference changes 1

(ii) Ammeter Reading 1

(iii) Voltmeter Reading 1

(i) $\quad H = \dfrac{V^2}{R} \qquad ½$

$\therefore$ V increases by a factor of $\sqrt{9} = 3 \qquad ½$

(ii) Ammeter Reading, $I = \dfrac{V}{R+r}$ ½

$= \dfrac{12}{4+2} A = 2A$ ½

(iii) Voltmeter Reading, $V = E - Ir$ ½

$= [12 - (2 \times 2)]\, V = 8\, V$ ½

(**Alternatively,** $V = iR = 2 \times 4\, V = 8\, V$)

[CBSE Marking Scheme, 2017]

Detailed Answer :

(i) Let the original potential difference be V volts with heat generated as H.

Now heat generated will be :

$$H = \frac{V^2 t}{R} \quad ...(1)\ ½$$

Take the new potential difference as V' and change in heat produced be H', so,

Change in heat produced :

$$H' = \frac{V'^2 t}{R} \quad ...(2)\ ½$$

But from the question, if the heat produced by a factor of 9, so

$$H' = 9H$$

Now,

$$\frac{V'^2 t}{R} = 9 \times \frac{V^2 t}{R} \quad ½$$

$$V'^2 = 9V^2$$

$$V' = 3V \quad 1½$$

Hence, it is clear that the applied potential difference increases by factor 3.

(ii) Considering voltmeter and ammeter to be ideal. Then Ammeter reading will be,

$I = \dfrac{12}{4+2}$

$= 2A$

Voltmeter reading will be,

$V = 12 - I \times 2$

$= 12 - 2 \times 2$

$= 8V$

Q. 7. Two material bars A and B of equal area of cross-section, are connected in series to a DC supply. A is made of usual resistance wire and B of an n-type semiconductor.

(i) In which bar is drift speed of free electrons greater?

(ii) If the same constant current continues to flow for a long time, how will the voltage drop across A and B be affected?

Justify each error. A&E **[CBSE Comptt. 2018]**

Sol. (a) Drift speed in B (n-type semiconductor) is higher

Reason : $I = neAv_d$ is same for both ½

n is much lower in semiconductors. ½

(b) Voltage drop across A will increase as the resistance of A increases with increase in temperature. ½+½

Voltage drop across B will decrease as resistance of B will decrease with increase in temperature. ½+ ½

[CBSE Marking Scheme, 2018]

AI **Q. 8. (a) Define the term 'conductivity' of a metallic wire. Write its SI unit.**

(b) Using the concept of free electrons in a conductor, derive the expression for the conductivity of a wire in terms of current density and relaxation time. Hence obtain the relation between current density and the applied electric field E.

R&U **[Delhi & O.D. 2018]**

Ans. (a) Definition and SI unit of conductivity ½ + ½

(b) Derivation of the expression for conductivity 1½

Relation between current density and electric field ½

(a) The conductivity of a material equals the reciprocal of the resistance of its wire of unit length and unit area of cross-section. ½

[Alternatively :

The conductivity (σ) of a material is the reciprocal of its resistivity (ρ)]

(Also accept $\sigma = \dfrac{1}{\rho}$)

Its SI unit is

$\left(\dfrac{1}{\text{ohm-metre}}\right)$ / ohm^{-1}m^{-1} / (mho m^{-1}) / siemen m^{-1} ½

(b) The acceleration, $\vec{a} = -\dfrac{e}{m}\vec{E}$

The average drift velocity, v_d, is given by

$$v_d = -\frac{eE}{m}\tau$$

(τ = average time between collisions/relaxation time)

If n is the number of free electrons per unit volume, the current I is given by ½

$$I = neA|v_d| = \frac{e^2 A}{m}\tau n|E| \quad ½$$

But $I = |j|A$ (j = current density)

We, therefore, get

$$|j| = \frac{ne^2}{m}\tau|E|,$$

The term $\dfrac{ne^2}{m}\tau$ is conductivity

$$\therefore \quad \sigma = \frac{ne^2\tau}{m} \quad ½$$

$$\Rightarrow \quad J = \sigma E \quad ½$$

[CBSE Marking Scheme, 2018]

Detailed Answer :

(a) We know that $V = IR$

$$V = \rho \frac{l}{A} I$$

$$\sigma V = \frac{l}{A} I$$

$$\sigma = \frac{I}{V} \cdot \frac{l}{A}$$

Conductivity of metallic wire may be defined as ability to allow electric current to pass through. Its SI unit is $\Omega^{-1} m^{-1}$

(b) Consider a conductor of length l and cross section area A.

Now, we know that

$$I = nAev_d$$

$$I = \frac{nAe^2E\tau}{m} \qquad \because v_d = \frac{eE\tau}{m}$$

$$= \frac{nAe^2(E l)\tau}{ml}$$

$$I = \frac{nAe^2\tau V}{ml}$$

$$V = \frac{ml}{nAe^2\tau} \times I$$

$$\text{or } R = \frac{ml}{nAe^2\tau}$$

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

$$\Rightarrow \frac{\rho l}{A} = \frac{ml}{ne^2\tau A}$$

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

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

$$\Rightarrow \boxed{\sigma = \frac{ne^2\tau}{m}}$$

Now, $V = IR$

$$V = \frac{I\rho l}{A}$$

$$V = J\rho l$$

$$\frac{V}{l} = \frac{J}{\sigma}$$

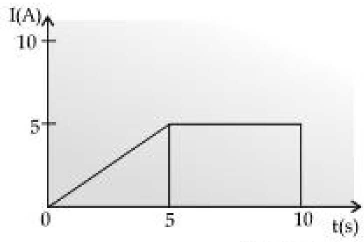
$$E = \frac{J}{\sigma}$$

$$\Rightarrow \boxed{J = \sigma E}$$

[Topper's Answer, 2018]

AI **Q. 9. (i)** Deduce the relation between current I flowing through a conductor and drift velocity v_d of the electrons.

(ii) Figure shows a plot of current 'I' flowing through the cross-section of a wire versus the time 't'. Use the plot to find the charge flowing in 10 s through the wire.

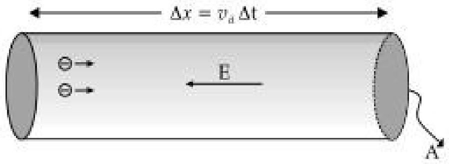


U [O.D. I, II, III 2015]

Ans. (i) According to the figure,

$$\Delta x = v_d \, \Delta t \qquad ½$$

Hence, amount of charge crossing area A in time Δt



½

$$\therefore \qquad \Delta Q = I\Delta t = neA|v_d|\Delta t \qquad ½$$

$$\therefore \qquad I = neAv_d \qquad ½$$

(ii) Charge flowing $= \sum I\Delta t$

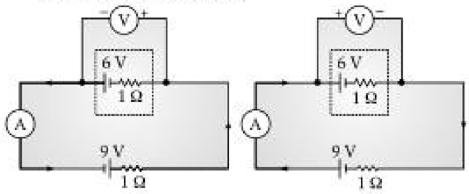
$= $ area under the curve

$$= \left[\frac{1}{2} \times 5 \times 5 + 5(10-5)\right] \text{C}$$

½

$= 37.5$ C ½

AI Q. 10. In the two electric circuits shown in the figure, determine the readings of ideal ammeter (A) and the ideal voltmeter (V).



(a) (b)

A [Delhi I, II, III 2015]

Ans. In circuit (a),

Total emf $= 15$ V

Total Resistance $= 2\,\Omega$

Current $i = (15/2)$ A $= 7.5$ A ½

Potential difference between the terminals of 6 V battery

$$V = E - ir$$
$$= [6 - (7.5 \times 1)] \text{ V}$$
$$V = -1.5 \text{ V}$$

In circuit (b),

Effective emf $= (9 - 6)$ V 1

$= 3$ V

Total resistance $= 2\,\Omega$

Current, $i = \left(\frac{3}{2}\right)$ A $= 1.5$ A ½

Potential difference across 6 V cell

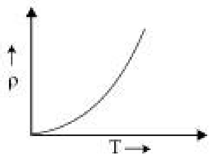
$$V = E + ir$$
$$= 6 + 1.5 \times 1$$
$$= 7.5 \text{ V} \qquad 1$$

Q. 14. (i) Show, on a plot, variation of resistivity of (i) a conductor, and (ii) a typical semiconductor as a function of temperature.

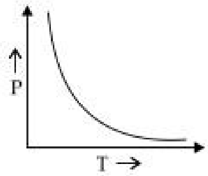
(ii) Using the expression for the resistivity in terms of number density and relaxation time between the collisions, explain how resistivity in the case of a conductor increases while it decreases in a semiconductor, with the rise of temperature. [O.D. I 2019]

Ans. (i) Characteristic curve between resistivity and temperature.

(i) For a conductor



(ii) For semiconductor



For conductor, resistivity is given as

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

Here, all alphabets are in their usual meanings.

$$\rho = \rho_0 [1 + \alpha(T - T_0)]$$

Hence, ρ increases with the increase in temperature and decrease in its relaxation time 'τ' and number density 'n'

For semiconductor, resistivity is given as

$$\rho = \rho_0 e^{-Eg/KT}$$

Here, E_g is the Band gap energy, K is Boltzmann constant.

Hence, ρ decreases with the increase in temperature and decrease in 'τ' and 'n'

Long Answer Type Questions - II

(5 marks each)

AI Q. 1. (i) Derive an expression for drift velocity of electrons in a conductor. Hence deduce Ohm's law.

(ii) A wire whose cross-sectional area is increasing linearly from its one end to the other, is connected across a battery of V volts. Which of the following quantities remain constant in the wire ?

(a) drift speed

(b) current density

(c) electric current

(d) electric field

Justify your answer. A **[Delhi I, II, III 2017]**

Ans. (i) Derivation of the expression for drift velocity 2

Deduction of Ohm's law 2

(ii) Name of quantity and justification ½+½

(i) Let an electric field E be applied to the conductor. Acceleration of each electron is

$$a = -\frac{eE}{m} \qquad ½$$

Velocity gained by the electron

$$v = -\frac{eE}{m}t \qquad ½$$

Let the conductor contain n electrons per unit volume. The average value of time 't', between their successive collisions, is the relaxation time, 'τ'. ½

Hence average drift velocity, $v_d = \frac{-eE}{m}\tau$ ½

The amount of charge, crossing area A, in time Δt, is $= neAv_d\Delta t = I\Delta t$ ½

Substituting the value of v_d, we get

$$I\Delta t = neA\left(\frac{eE\tau}{m}\right)\Delta t$$

$$\therefore \quad I = \left(\frac{e^2A\tau n}{m}\right)E$$

$$\therefore \quad \frac{I}{A} = \left(\frac{e^2\tau n}{m}\right)E$$

$$= \sigma E \quad \left(\sigma = \frac{e^2\tau n}{m} \text{ is the conductivity}\right)$$

But $I = JA$, where, J is the current density, ½

$$\Rightarrow \quad J = \left(\frac{e^2\tau n}{m}\right)E \qquad ½$$

$$\Rightarrow \quad J = \sigma E \qquad ½$$

This is Ohm's law

[Note : Credit should be given if the student derives the alternative form of Ohm's law by substituting $E = \frac{V}{l}$]

(ii) (b) Current density will remain constant in the wire. ½

All other quantities, depend on the cross sectional area of the wire. ½

[CBSE Marking Scheme, 2017]

Detailed Answer :

(ii) Out of these, current density remains constant in a wire whose cross-sectional area increases linearly from its one end to other as current density is :

$$J = \frac{I}{A} \text{ and } I = \frac{V}{R}$$

$$\therefore \quad J = \frac{V}{RA} \text{ and } R = \rho\frac{l}{A}$$

$$\therefore \quad = \frac{VA}{\rho l A} = \frac{V}{\rho l} = \text{constant}$$

It is current per unit area that depends on area of cross-section. ½

Drift speed is given as :

$$v_d = \frac{I}{Ane}$$

Electric field $= \frac{J}{\sigma}$; where σ is electrical conductivity

½

AI Q. 2. (i) Why do the 'free electrons', in a metal wire, 'flowing by themselves', not cause any current flow in the wire ?

Define 'drift velocity' and obtain an expression for the current flowing in a wire, in terms of the 'drift velocity' of the free electrons.

(ii) Use the above expression to show that the 'resistivity', of the material of a wire, is inversely proportional to the 'relaxation time' for the 'free electrons' in the metal. R&U **[Foreign Comptt. 2016]**

Ans. (i) The free electrons, in a metal, (flowing by themselves), have a random distribution of their velocities. Hence the net charge crossing any cross section, in unit time, is zero. ½

The 'drift velocity' equals the average (time dependant) velocity acquired by free electrons, under the action of an applied (external) electric field. 1

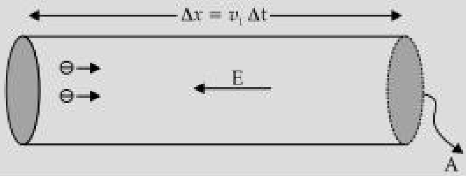
We have, for an applied electric field $\vec{E}$

$$\vec{a} = -\frac{e\vec{E}}{m} \qquad ½$$

$$\therefore \vec{v}_d = (\vec{v}_i)_{\text{average}} = -\frac{e\vec{E}}{m}(t)_{\text{average}} \qquad ½$$

The average time, between successive collisions, is called the 'Relaxation time' and is denoted by τ

$$\therefore \quad \vec{v}_d = -\left(\frac{e\vec{E}}{m}\right)\tau \qquad ½$$



Because of the drift, we can write

$$I\Delta t = +\ neA\,|\vec{v}_d|\,\Delta t$$

$$= \frac{ne^2A}{m}\tau\Delta t\,|\vec{E}| \qquad ½$$

But $\quad I = |\vec{J}|A$

$$\therefore \quad |\vec{J}| = \frac{ne^2}{m}\tau|\vec{E}|$$

But $\quad |\vec{J}| = \sigma|\vec{E}| \qquad ½$

$$\therefore \sigma = \text{conductivity} = \frac{ne^2}{m}\tau$$

Also we can write,

Also we can write,

$$I = neAv_d \qquad ½$$

(ii) We have

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

$$\therefore \quad \rho \propto \frac{1}{\tau} \qquad ½$$

[CBSE Marking Scheme, 2016]

TOPIC-2
Kirchhoff's Laws, Wheatstone Bridge and their Applications

Revision Notes

Scan to know more about this topic

Kirchhoff's Laws, Wheatstone Bridge and their Applications

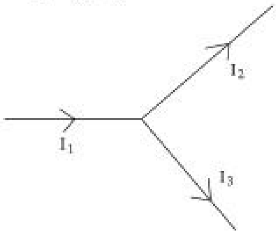
Kirchhoff's Laws

- 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

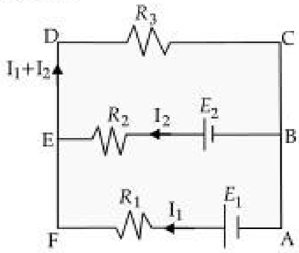
- The algebraic sum of all currents meeting at a junction in a closed circuit is zero. *i.e.*, $\Sigma I = 0$
- This is called the law of conservation of charge.

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., $\Sigma V = 0$ or $\Sigma V = \Sigma IR$

- This is called the law of conservation of energy.

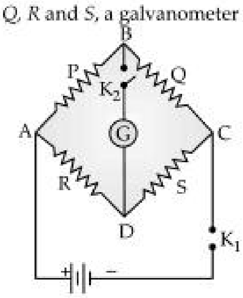


For example : Applying Junction law in loop *AFEBA*

$$E_1 - E_2 = I_1R_1 - I_2R_2$$

Wheatstone Bridge

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



Wheatstone Bridge

- It is a balanced bridge when there is no current through the galvanometer and potential at node *B* will be equal to potential at node *D* resulting as :

$$V_B \sim V_D = 0 \text{ or } \frac{P}{Q} = \frac{R}{S}$$

- **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.

Know the Formulae

- Kirchhoff's Law (Junction law) $\Sigma I = 0$

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

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

Objective Type Questions (1 mark each)

(I) MULTIPLE CHOICE QUESTIONS

Q. 1 By using the variations on a Wheatstone bridge we can U

(a) measure quantities such as voltage, current and power

(b) measure high resistance values

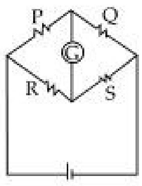
(c) measure quantities such as complex power

(d) measure quantities such as capacitance, inductance and impedance.

Ans. Correct option : (d)

Explanation : A Wheatstone bridge consists of resistive arms. It is used for the measurement of quantities such as capacitance, inductance and impedance by making use of the variations because the ratio can be applied to these quantities as well.

Q. 2. The given figure shows the Wheatstone bridge method for measurement of unknown resistance R. The balanced equation for Wheatstone bridge is given by : U



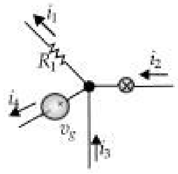
(a) $\frac{P}{R}=\frac{Q}{S}$ (b) $\frac{P}{S}=\frac{Q}{R}$

(c) $\frac{P}{R}=\frac{S}{Q}$ (d) $\frac{R}{P}=\frac{Q}{S}$

Ans. Correct option : (a)

Explanation : A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit. It is said to be balanced when the ratio of two resistances on the left is equal to the ratio of two resistances on the right.

Q. 3. Consider the following figure and chose the correct option



(a) $i_4 + i_1 = i_3 + i_2$ (b) $i_3 + i_1 = i_4 + i_2$

(c) $i_4 + i_1 = i_3 - i_2$ (d) $i_4 - i_1 = i_3 + i_2$ A

Ans. Correct option : (a)

Explanation : Kirchhoff's First Law states that the total current entering a junction is equal to the total current leaving the junction. Thus, the algebraic sum of currents at a junction is zero.

(II) FILL IN THE BLANKS

Q. 1. The point at where the terminals of two or more circuit elements meet is known as .... R

Ans. Node.

Q. 2. When the variable resistor is adjusted and the Wheatstone bridge is balanced, then the current in the galvanometer becomes...... . U

Ans. Zero.

Q. 3. Kirchoff's voltage law is also known as .... R

Ans. Kirchoff's loop rule.

(III) VERY SHORT ANSWER TYPE QUESTIONS

Q. 1. What do you mean by sensitivity of the meter bridge? R

Ans The Wheatstone bridge is more sensitive when all their resistances are equal, or their ratio is unity. Their sensitivity decreases when their ratio is less than unity.

Q. 2. What is the significance of junction rule? U

Ans Conservation of charge because the total incoming current for a junction is equal to the total outgoing current.

Q. 3. What is the principle of the Wheatstone bridge? R

Ans. The Wheatstone bridge works on the principle of null deflection, *i.e.* the ratio of their resistances are equal, and no current flows through the galvanometer.

Short Answer Type Questions (2 marks each)

Q. 1. State Kirchhoff's rules. Explain briefly how these rules are justified. R **[Delhi I, II, III 2014]**

Ans. Kirchhoff's first law is known as junction rule which states that for a given junction or node in a circuit, sum of the currents entering will be equal to sum of currents leaving. ½

Kirchhoff's second law is also known as loop rule which shows that around any closed loop in a circuit, sum of the potential differences across all elements will be zero. ½

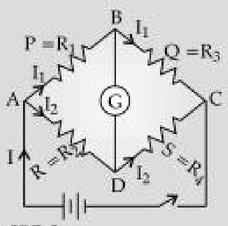
Justification : The junction rule is in accordance with the conservation of charge that serves as basis of current rule while loop rule is based on law of conservation of energy. 1

[CBSE Marking Scheme, 2014]

AI **Q. 2. Use Kirchhoff's rules to obtain conditions for the balance condition in a Wheatstone bridge.** A **[Delhi I, II, III 2015]**

Ans. Applying Kirchhoff's loop rule to closed loop *ADBA*

$-I_1R_1 + I_gR_G + I_2R_2 = 0 \ (I_g = 0)$ ...(i) ½



For loop *CBDC*,

$-I_2R_4 + I_gR_G + I_1R_3 = 0 \quad (I_g = 0)$ ...(ii)

from equation (i)

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$ ½

From equation (ii)

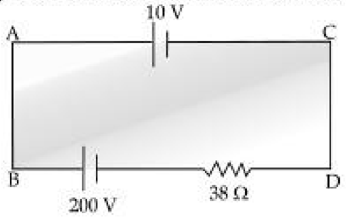
$$\frac{I_1}{I_2} = \frac{R_4}{R_3} \qquad ½$$

$$\therefore \qquad \frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad ½$$

$$\text{or,} \qquad \frac{P}{Q} = \frac{R}{S} \qquad ½$$

[CBSE Marking Scheme, 2015]

Q. 3. A 10 V cell of negligible internal resistance is connected in parallel across a battery of emf 200 V and internal resistance 38 Ω as shown in the figure. Find the value of current in the circuit.



A **[Delhi & O.D. 2018]**

Ans. Writing the equation 1

Finding the current 1

By Kirchhoff's law, we have, for the loop *ACDBA*,

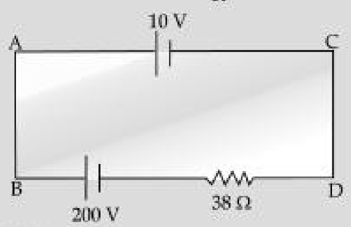
$$+200 - 38i - 10 = 0 \qquad 1$$

$$\therefore \qquad i = \frac{190}{38}\text{ A} = 5\text{A} \qquad 1$$

Alternatively :

Finding the Net emf 1

Stating that $\quad I = \dfrac{V}{R}$ ½



Calculating I ½

The two cells being in 'opposition',

$$\therefore \text{ net E.M.F.} = 200 - 10\text{ V} = 190\text{ V}$$

Now

$$I = \frac{V}{R}$$

$$\therefore \qquad I = \frac{190\text{ V}}{38\ \Omega} = 5\text{ A}$$

[**Note :** Some students may use the formulae

$$\frac{E}{r} = \frac{E_1}{r_1} + \frac{E_2}{r_2},$$

and

$$r = \frac{(r_1 r_2)}{(r_1 + r_2)}$$

For two cells connected in parallel

Then we can say that $r = 0$;

E is indeterminate and hence I is also indeterminate

Award full marks (2)

to students giving this line of reasoning.]

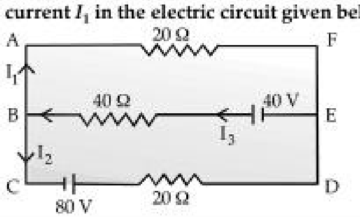
[CBSE Marking Scheme, 2018]

Long Answer Type Questions-I

(3 marks each)

AI **Q. 1.State Kirchhoff's laws of current distribution in an electrical network.**

Using these rules determine the value of the current I_1 in the electric circuit given below :



R&A

Ans. (i) Kirchhoff's laws 1

(ii) Finding value of current I_1 in electric circuit 2

Detailed Answer :

(i) Try yourself Similar to Q. 1, Short Answer Type Questions 1

(ii) Now from the given figure,

$$I_1 + I_2 = I_3 \qquad \text{...(i)}$$

$$I_2 = I_3 - I_1 \qquad \text{...(ii)}$$

For *ABEFA*

$$-20I_1 - 40I_3 = -40$$

$$-20(I_1 + 2I_3) = -40$$

$$I_1 + 2I_3 = 2 \qquad \text{...(iii)}$$

For *BCDEB*

$$40I_3 + 20I_2 = 80 + 40$$

$$20(2I_3 + I_2) = 120$$

$$2I_3 + I_2 = 6$$

$$2I_3 + (I_3 - I_1) = 6 \qquad \text{using eq. (i)}$$

$$2I_3 + I_3 - I_1 = 6$$

$$3I_3 - I_1 = 6 \qquad \text{...(iv)}$$

Now solving eqns. (iii) and (iv),

$$\text{We get} \qquad I_3 = \frac{8}{5} = 1.6\text{ A} \qquad 1$$

$$\text{and} \qquad I_1 = -\frac{6}{5}\text{ A} = -1{\cdot}2\text{ A}$$

Now, from equation (ii),

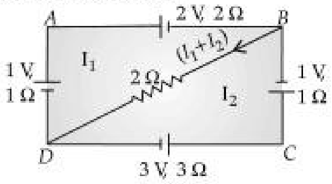
$$I_2 = I_3 - I_1$$

$\Rightarrow \qquad = 1.6 - (-1.2)$

$\Rightarrow \qquad = 1.6 + 1.2$

$\Rightarrow \qquad = 2.8 \text{ A}$ **1**

AI Q. 2. Using Kirchhoff's rules, calculate the potential difference between *B* and *D* in the circuit diagram as shown in the figure.



A **[CBSE-2018 Comptt.]**

Sol. Writing the two loop equations ½+½

Finding the current through DB 1½

Finding the p.d. between B and D ½

Using Kirchhoff's voltage rule, we have :

For loop *DABD*

$(1 \times I_1 + (1) + (-2) + 2I_1 + 2(I_1 + I_2) = 0$

Or $5I_1 + 2I_2 = 1$ ...(i) ½

For loop *DCBD*

$+ I_2 \times 3 + (3) + (-1) + 1 \times I_2 + 2(I_1 + I_2) = 0$

Or $2I_1 + 6I_2 = -2$ ...(ii) ½

Solving (i) and (ii), we get

$$I_1 = \frac{5}{13} \text{A}$$ ½

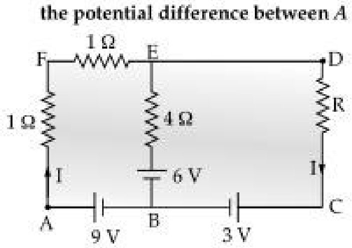
$$I_2 = \frac{-6}{13} \text{A}$$ ½

$\therefore$ Current through $DB = I_1 + I_2 = \frac{-1}{13}$A ½

$\therefore$ P.D. between *B* and *D* = 0.154 A ½

[CBSE Marking Scheme, 2018]

AI Q. 3. Using Kirchhoff's rules determine the value of unknown resistance *R* in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between *A* and *D*.



A

Ans. Apply Kirchhoff's Voltage rule

For loop *ABEFA*

$$-9 + 6 + 4 \times 0 + 2I = 0$$ ½

$$2I - 3 = 0$$

$$I = \frac{3}{2} \text{A}$$ ½

$$I = 1{\cdot}5 \text{ A}$$

For loop *BCDEB*

$3 + IR + 4 \times 0 - 6 = 0$ ½

$\therefore \qquad IR = 3$

Substituting the value of current I,

$$\frac{3}{2} \times R = 3$$

$\therefore \qquad R = 2 \, \Omega$ ½

Potential difference between *A* and *D* through path *ABCD* :

$$+9 - 3 - IR = V_{AD}$$

$$+9 - 3 - \frac{3}{2} \times 2 = V_{AD}$$

$\Rightarrow \qquad V_{AD} = 3 \text{ V}$ **1**

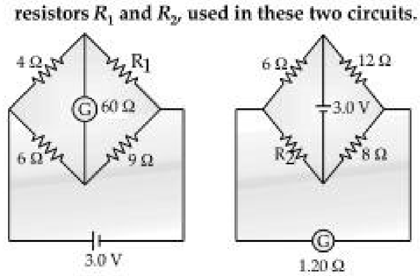
[Alternatively through path *AFD*]

$$\frac{3}{2} \times 2 = V_{AD}$$

$\Rightarrow \qquad V_{AD} = 3\text{V}$

[CBSE Marking Scheme, 2012]

Q. 4. The galvanometer, in each of the two given circuits, does not show any deflection. Find the ratio of the resistors R_1 and R_2, used in these two circuits.



A **[CBSE SQP 2013]**

Ans. For circuit 1, we have, (from the Wheatstone bridge balance condition),

$$\frac{4}{R_1} = \frac{6}{9}$$ ½

$$R_1 = 6 \, \Omega$$ ½

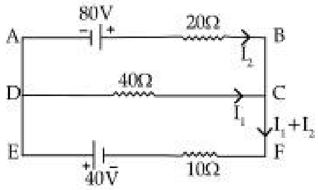
In circuit 2, the interchange of the positions of the battery and the galvanometer, does not change the (Wheatstone Bridge) balance condition. ½

$\therefore \qquad \frac{R_2}{8} = \frac{6}{12}$ ½

or $\qquad R_2 = 4 \, \Omega$ ½

$\therefore \qquad \frac{R_1}{R_2} = \frac{6}{4} = \frac{3}{2}$ ½

Q. 5. Using Kirchhoff's rules, calculate the current through the 40 Ω and 20 Ω resistors in the following circuit :



[Delhi I 2019]

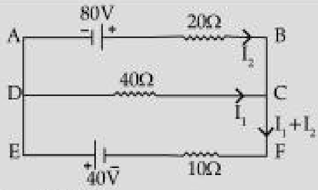
Ans. (a) Writing two loop equations **1 + 1**

(b) Calculation of currents through 40 Ω and 20 Ω resistors **1**

In loop ABCFA

$+80 - 20I_2 + 40I_1 = 0$

$4 = I_2 - 2I_1$ **1**



In loop FCDEA

$-40I_1 - 10(I_1 + I_2) + 40 = 0$

$-50I_1 - 10I_2 + 40 = 0$

$5I_1 + I_2 = 4$ **1**

Solving these two equations

$I_1 = 0$ A ½

$I_2 = 4$ A ½

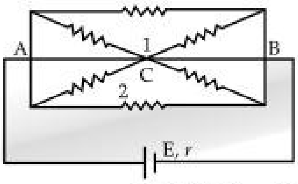
[CBSE Marking Scheme, 2019]

Long Answer Type Questions - II

(5 marks each)

AI Q. 1. (i) State the two Kirchhoff's laws. Explain briefly how these rules are justified.

(ii) The current is drawn from a cell of emf E and internal resistance r connected to the network of resistors each of resistance r as shown in the figure. Obtain the expression for (i) the current drawn from the cell and (ii) the power consumed in the network.



R [Delhi Compt I, II, III 2017]

Ans. (i) Try yourself Similar to Q. 1, Short Answer Type Questions **3**

(ii) Equivalent resistance of the loop

$$R = \frac{r}{3} \qquad ½$$

Hence current drawn from the cell

$$I = \frac{E}{\frac{r}{3}+r} = \frac{3E}{4r} \qquad ½$$

Power consumed, $P = I^2R$ ½

$$= \frac{9E^2}{16r^2} \times \frac{4r}{3}$$

$$= \frac{3E^2}{4r} \qquad ½$$

[**Note :** Award the last 1½ marks for this part, if the calculation, for these parts, are done by using (any other) value of equivalent resistance obtained by the student.] **[CBSE Marking Scheme, 2017]**

Detailed Answer :

(ii) Consider the circuit :

Since the resistances and internal resistance in the above circuit having similar resistance 'r', so we use horizontal symmetry criteria to find the current.

Now taking mesh 1, then resistance will be :

$$\frac{1}{R_1} = \frac{1}{r} + \frac{1}{2r}$$

$$\frac{1}{R_1} = \frac{2+1}{2r}$$

$$\therefore \quad R_1 = \frac{2r}{3} \qquad ½$$

Further since both mesh 1 and 2 are similar,

$$\therefore \quad R_2 = \frac{2r}{3} \qquad ½$$

Now combining resistances R_1 and R_2, we get :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (\text{As } R_1 \,||\, R_2)$$

$$\therefore \quad \frac{1}{R} = \frac{1}{\frac{2r}{3}} + \frac{1}{\frac{2r}{3}} \qquad 1$$

$$\therefore \quad R = \frac{r}{3} \qquad 1$$

As the circuit is in series with internal resistance, then resultant resistance will be :

$$r' = r + \frac{r}{3} = \frac{4r}{3} \qquad ½$$

Hence the current drawn from the cell will be :

$$I = \frac{E}{r'} = \frac{3E}{4r} \qquad 1$$

Now power consumed by the network :

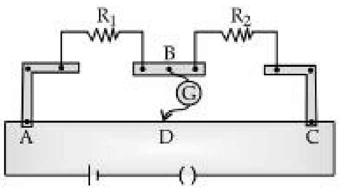
$$P = I^2 r' \qquad ½$$

$$= \left(\frac{3E}{4r}\right)^2 \times \frac{4r}{3}$$

$$\therefore \text{ Power,} \quad P = \frac{3E^2}{4r} \qquad 1$$

AI Q. 2. (i) State Kirchhoff's rules for an electric network. Using Kirchhoff's rules, obtain the balance condition in terms of the resistances of four arms of Wheatstone bridge.

(ii) In the meter bridge experimental set up, shown in the figure, the null point 'D' is obtained at a distance of 40 cm from end A of the metre bridge wire. If a resistance of 10 Ω is connected in series with R_1, null point is obtained at AD = 60 cm. Calculate the values of R_1 and R_2.



R A

Ans. (i) Try yourself Similar to Q. 1, Short Answer Type Questions **2**

Try yourself Similar to Q. 2, Short Answer Type Questions **1**

(ii)
$$\frac{R_1}{R_2} = \frac{40}{60} = \frac{2}{3} \qquad \tfrac{1}{2}$$

$$\frac{R_1+10}{R_2} = \frac{60}{40} = \frac{3}{2} \qquad \tfrac{1}{2}$$

$$\frac{R_1}{R_2} + \frac{10}{R_2} = \frac{3}{2}$$

$$\Rightarrow \quad \frac{2}{3} + \frac{10}{R_2} = \frac{3}{2}$$

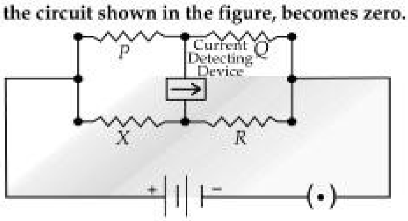
$$\Rightarrow \quad R_2 = 12\ \Omega \qquad \tfrac{1}{2}$$

Substituting for R_2 and finding the value of R_1

$$R_1 = 8\ \Omega \qquad \tfrac{1}{2}$$

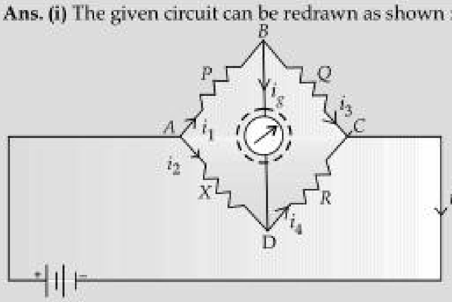
[CBSE Marking Scheme, 2013]

AI Q.3. (i) Obtain the condition under which the current flowing, in the current detecting device, used in the circuit shown in the figure, becomes zero.



(ii) Describe briefly the device, based on the above question. Draw a circuit diagram for this device and discuss, in brief, how it is used for finding an unknown resistance. U **[Foreign Comptt. 2016]**

Ans. (i) The given circuit can be redrawn as shown :



½

It is, therefore, a Wheatstone Bridge. ½

Using Kirchhoff's laws, we get (when $i_g = 0$)

$$i_1 = i_3$$

and $$i_2 = i_4$$

For the loop ABDA, we have ½

$$-i_1P + i_2X = 0 \text{ or } i_1P = i_2X$$

For the loop BCDB we have,

$$-i_3Q + i_4R = 0 \text{ or } i_3Q = i_4R$$

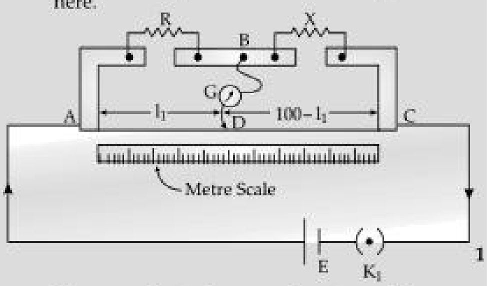
Dividing we get,

$$\frac{i_1P}{i_3Q} = \frac{i_2X}{i_4R}$$

or $$\frac{P}{Q} = \frac{X}{R} \qquad (\because i_1 = i_3 \text{ and } i_2 = i_4)\ \tfrac{1}{2}$$

(ii) A simple device, based on the above condition, is the metre bridge. It has a (uniform cross-section) wire of length 1 m stretched out between two thick metallic clamps. It has two gaps for connection a resistance box and the unknown resistance. ½

The circuit diagram, for the metre bridge, is shown here.



1

We move the jockey, on the wire of the meter bridge, till we find a point at which the deflection in G, is zero. we can have

$$\frac{R}{l_1} = \frac{X}{l_2} \qquad \tfrac{1}{2}$$

or $$S = R\left(\frac{l_2}{l_1}\right) \qquad \tfrac{1}{2}$$

Knowing R, and finding l_1 and $l_2 = (100 - l_1)$, we can easily calculate X. ½

[CBSE Marking Scheme, 2016]

TOPIC-3
Metre Bridge, Potentiometer and their Applications

Revision Notes

Metre Bridge

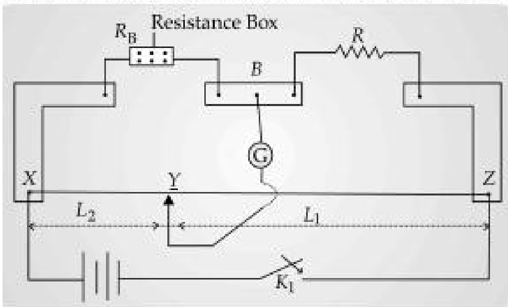
- It is an instrument which is used to find the unknown resistance of a coil or a material connected in a circuit.
- It is also known as slide wire bridge which is an instrument that works on the principle of Wheatstone bridge.
- Metre bridge has two metallic strips which act as holders for the wire 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.

Scan to know more about this topic

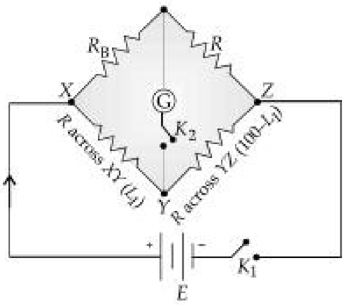
Metre Bridge

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



Wheastone bridge

From the above arrangement :

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

Now, $$\frac{R_B}{\frac{\rho L_1}{A}} = \frac{R}{\frac{\rho L_2}{A}} \qquad \left[\text{As, } R = \frac{\rho L}{A}\right]$$

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

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

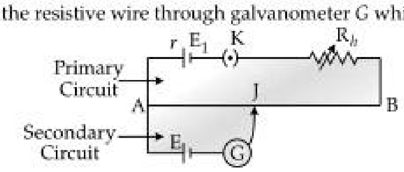
Potentiometer

- 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.

Scan to know more about this topic

Potentiometer and their Applications

- 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 :

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

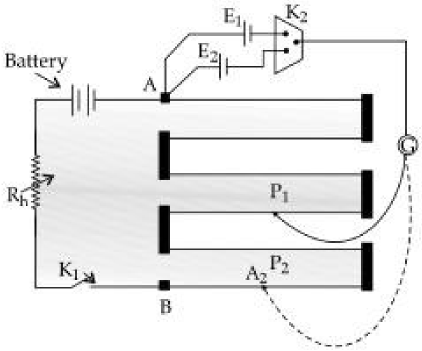
- Now potential gradient of potentiometer wire which is potential per unit length is :

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

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

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.



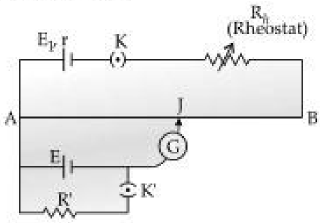
- When the length of wire AP as l_1 is measured, then potential difference across it, will balance the emf E_1, So $E_1 = Kl_1$, where K is potential gradient of the wire.
- When cell of emf E_1 is disconnected while cell of emf E_2 is connected, then $E_2 = Kl_2$.
- On comparing and dividing we get 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, $r = \left(\frac{E}{V} - 1\right).R'$

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

Know the Formulae

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

Objective Type Questions

(1 mark each)

(I) MULTIPLE CHOICE QUESTIONS

Q. 1. 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.

[NCERT Exemplar]

Ans. Correct option : (c)

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.

Q. 2. The resistance in 2 gaps of meter bridge are 10 ohm and 30 ohm if the resistance are interchanged the balancing point shifts by : A

(a) 33.3 cm (b) 66.67 cm

(c) 25 cm (d) 50 cm

Ans. Correct option : (d)

Explanation :

$$S = \left(\frac{100-l}{l}\right).R \text{ Initially,}$$

$$30 = \left(\frac{100-l}{l}\right)\times 10 \Rightarrow l = 25\text{cm}$$

Finally,

$$10 = \left(\frac{100-l}{l}\right)\times 30 \Rightarrow l = 75\text{cm}$$

So, shift = 50 cm.

Q. 3. In order to achieve high accuracy, the slide wire of a potentiometer should be R

(a) As long as possible (b) As short as possible

(c) Neither too small not too large (d) Very thick

Ans. Correct option : (a)

Explanation : The potentiometer is based on the principle that the potential drop is directly proportional to length of the wire. So, for longer length, the potential gradient would be smaller. Thus, the distance of the null position is increased which helps in the precise measurement.

Q. 4. For the measurement of potential difference, a potentiometer is preferred over voltmeter because : U

(a) potentiometer is more sensitive than voltmeter

(b) the resistance of potentiometer is less than voltmeter

(c) potentiometer is cheaper than voltmeter

(d) potentiometer does not take any current from the circuit.

Ans. Correct option : (d)

Explanation : When a voltmeter draws a small current from the cell for its operation, it measures the terminal potential difference in a closed circuit which is less than the electromotive force of a cell. That is why a potentiometer is preferred over a voltmeter for measuring the emf of a cell.

(II) FILL IN THE BLANKS

Q. 1 The material used for the potentiometer wire is .... R

Ans. Constantan or Manganin.

Q. 2. The connecting resistors in a meter bridge are made of.......... . R

Ans. Thick copper strips.

Q. 3. If E_1 and E_2 are the emfs of two cells, then the ratio of E_1 and E_2 in terms of the balancing lengths is equal to .... U

Ans. $\frac{l_1}{l_2}$.

(III) VERY SHORT ANSWER TYPE QUESTIONS

AI **Q. 1. Why is potentiometer preferred over a voltmeter for determining the emf of a cell ?**

U [Delhi Comptt., 2016]

Ans. Potentiometer does not draw any (net) current from the cell. Voltmeter draws some current from cell, when connected across it, hence it measures terminal voltage. 1

[CBSE Marking Scheme, 2016]

Detailed Answer :

Potentiometer is preferred over voltmeter because voltmeter needs a current to pass through it so as to measure the potential difference. The potential difference being measured by the voltmeter is given as $V = E - IR$ ½

Hence the voltage V measured is less than emf of a battery E. Potentiometer does not draw any current from the cell and hence will not cause such problem and can measure the emf directly. ½

Q. 2. Give the formula to determine the internal resistance of the cell using potentiometer. A

Ans.

$$r = R\left[\frac{l_1}{l_2} - 1\right]$$

where l_1 and l_2 are the balancing lengths without and with the external resistance respectively.

Q. 3. How the error in finding the resistance in a meter bridge can be minimized? U

Ans. The error in finding the resistance in a meter bridge can be minimized by adjusting the balancing point near middle of the bridge (close to 50 cm) by suitable choice of standard resistance S.

Q. 4 The resistivity of a potentiometer wire is given as 5×10^{-6} Ωm. The area of cross section of the wire is given as 6×10^{-4} m². Find the potential gradient if a current of 1 A is flowing through the wire. A

Ans. The potential gradient $k = \frac{V}{L}$

$= \frac{IR}{L}$

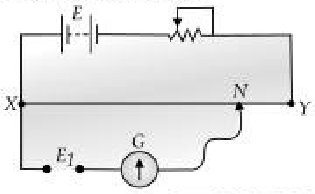
$= \frac{(I\rho L / A)}{L}$

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

Substituting the values we get $k = 1 \times 5 \times 10^{-6} / 6 \times 10^{-4}\,m^2 = 0.83 \times 10^{-2}$ V/m

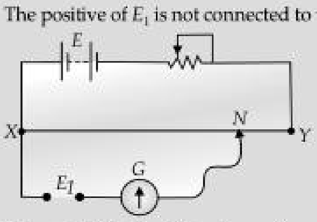
Short Answer Type Questions (2 marks each)

AI **Q. 1. The diagram below shows a potentiometer set up. On touching the jockey near to the end X of the potentiometer wire, the galvanometer pointer deflects to left. On touching the jockey near to end Y of the potentiometer, the galvanometer pointer again deflects to left but now by a larger amount. Identify the fault in the circuit and explain, using appropriate equations or otherwise, how it leads to such a one-sided deflection.**



A & E **[CBSE S.Q.P. 2018-19]**

Sol. The positive of E_1 is not connected to terminal X. ½



In loop $PGJX$, $E_1 - V_G + E_{XN} = 0$

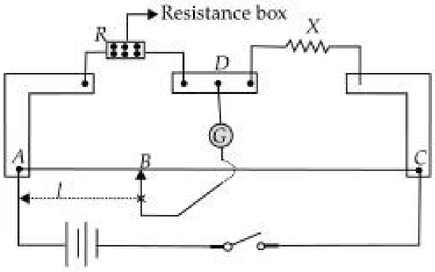
$V_G = E_1 + E_{XN}$ ½

$V_G = E_1 + k\,l$ ½

So, V_G (or deflection) will be maximum when l is maximum *i.e.*, when jockey is touched near and Y. Also, V_G (or deflection) will be minimum when l is minimum *i.e.*, when jockey is touched near end X.

[CBSE Marking Scheme, 2018]

Q. 2. Following circuit was set up in a meter bridge experiment to determine the value X of an unknown resistance.



(a) Write the formula to be used for finding X from the observations.

(b) If the resistance R is increased, what will happen to balancing length? R&U **[CBSE SQP 2018-19]**

Sol. (a) $X = (100 - l)\,R/l$ 1

(b) Balancing length will increase in increase of resistance R. 1

[CBSE Marking Scheme, 2018]

Q. 3. In a potentiometer arrangement for determining the emf of a cell, the balance point of the cell in open circuit is 350 cm. When a resistance of 9 Ω is used in the external circuit of the cell, the balance point shifts to 300 cm. Determine the internal resistance of the cell. A **[Delhi & O.D. 2018]**

Sol. Stating the formula 1

Calculating r 1

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

$\therefore \quad r = \left(\frac{350 - 300}{300}\right) \times 9\,\Omega$ ½

$= \frac{50}{300} \times 9\,\Omega = 1.5\,\Omega$ ½

[CBSE Marking Scheme, 2018]

Detailed Answer :

9) Given, balancing point in open circuit = 350 cm

balancing point in closed circuit = 300 cm

where R (external resistance) = 9 Ω

Let K be the potential gradient

In ~~closed~~ open circuit, potentiometer measures Emf

$\Rightarrow E = Kl_1 = 350K$ —①

In closed circuit, potentiometer measures Voltage

$\Rightarrow V = Kl_2 = 300K$ —②

Now, $\dfrac{E}{R+r} = \dfrac{V}{R}$

$(E-V)R = Vr$

or $r = \left(\dfrac{E}{V} - 1\right)R$

$\Rightarrow r = \left(\dfrac{350\cancel{K}}{300\cancel{K}} - 1\right) \times 9$

$= \dfrac{350-300}{300} \times 9$

$= \dfrac{5\cancel{0}}{30\cancel{0}} \times 9$

$= \dfrac{9}{6} = \dfrac{3}{2} = 1.5\ \Omega$

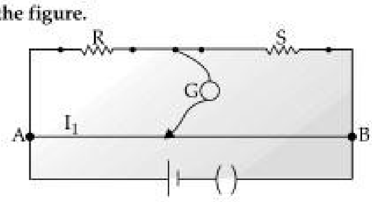
[Topper's Answer, 2018]

Long Answer Type Questions-I

(3 marks each)

Q. 1. (i) Write the principle of working of a metre bridge.

(ii) In a metre bridge, the balance point is found at a distance l_1 with resistances R and S as shown in the figure.



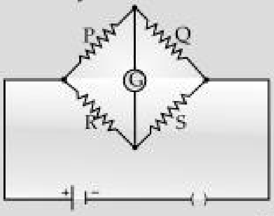
An unknown resistance X is now connected in parallel to the resistance S and the balance point is found at a distance l_2. Obtain a formula for X in terms of l_1, l_2 and S. A [O.D. I, II, III 2017]

Ans. (i) Principle of metre bridge 1

(ii) Relation between l_1, l_2 and S 2

(i) The principle of working of a metre bridge is same as that of a balanced Wheatstone bridge.

Alternatively :



1

When $i_G = 0$, then $\frac{P}{Q} = \frac{R}{S}$ ½

(ii) $\frac{R}{S} = \frac{l_1}{100 - l_1}$ ½

When X is connected in parallel :

$$\frac{R}{\left(\frac{XS}{X+S}\right)} = \frac{l_2}{100 - l_2}$$

On solving we get, $X = \frac{l_1 S(100 - l_2)}{100(l_2 - l_1)}$ 1

[CBSE Marking Scheme, 2017]

Detailed Answer :

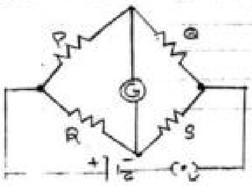
Principle of working of a metre bridge

The principle is Wheatstone principle

If four resistances P, Q, R and S are connected in the Wheatstone bridge in the following manner, then at balanced condition, current in the galvanometer is zero, the

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

The unknown resistance can be found:



$$\frac{l_1 S + l_1 x}{100x - xl_1} = \frac{l_2}{100 - l_2}$$

$$(l_1 S + l_1 x)(100 - l_2) = l_2(100x - xl_1)$$

$$100 l_1 S - l_1 l_2 S + l_1 x 100 - l_1 l_2 x = l_2 100 x - x l_1 l_2$$

$$x = \frac{100 l_1 S - l_1 l_2 S + 100 l_1}{100 l_2}$$

$$100 l_1 x - 100 l_2 x = l_1 l_2 S - 100 l_1 S$$

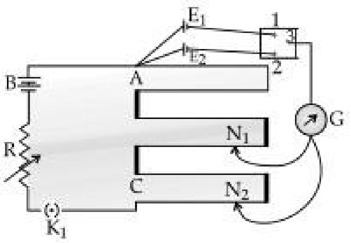
$$x[100 l_1 - 100 l_2] = l_1 l_2 S - 100 l_1 S$$

$$x = \frac{l_1 l_2 S - 100 l_1 S}{100[l_1 - l_2]}$$

[Topper's Answer, 2017]

AI Q. 2. Draw a circuit diagram of a potentiometer. State its working principle. Derive the necessary formula to describe how it is used to compare the emfs of the two cells. U **[O.D. I, II, III 2015]**

Ans. The circuit diagram of the potentiometer, is as shown here :



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Working Principle :

The potential drop, V, across a length l of a uniform wire, is proportional to the length l of the wire. ½

or, $V \propto l$ (for a uniform wire)

Derivation : From the figure, connect points 1 and 3 together with balance point at point N_1 where $AN_1 = l_1$ Now connect points 2 and 3 together with balance point at point N_2 where $AN_2 = l_2$. ½

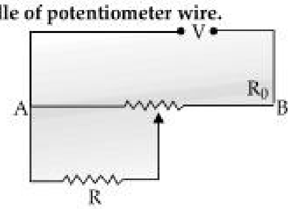
We have,

So, $E_1 = kl_1$ ½

and $E_2 = kl_2$

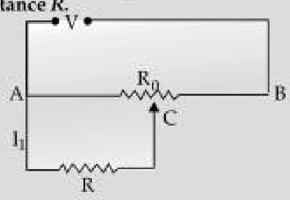
$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$ ½

Q. 3. A resistance of R draws current from a potentiometer. The potentiometer wire, AB, has a total resistance of R_0. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of potentiometer wire.



U **[Delhi I, II 2017]**

Ans. Derivation of expression of voltage across resistance R. 3



Resistance between points A and C

$$\frac{1}{R_1} = \frac{1}{R} + \frac{1}{\left(\frac{R_0}{2}\right)}$$ ½

Effective resistance between points A and B

$$R_2 = \left(\frac{R\frac{R_0}{2}}{R + \frac{R_0}{2}}\right) + \frac{R_0}{2}$$ ½

Current drawn form the voltage source,

$$I = \frac{V}{R_2}$$

$$I = \frac{V}{\left(\frac{R\frac{R_0}{2}}{R + \frac{R_0}{2}}\right) + \frac{R_0}{2}}$$ ½

Let current through R be I_1

$$I_1 = I\frac{\left(\frac{R_0}{2}\right)}{R + \frac{R_0}{2}}$$ ½

Voltage across R

$$V_1 = I_1 R$$

$$= \frac{IR_0}{2\left(R + \frac{R_0}{2}\right)} \cdot R$$

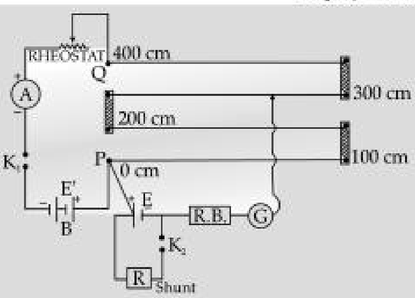
$$= \frac{RR_0}{2\left(R + \frac{R_0}{2}\right)} \cdot \frac{V}{\left(\frac{RR_0}{2R + R_0}\right) + \frac{R_0}{2}}$$ ½

$$= \frac{2RV}{R_0 + 4R}$$ ½

[CBSE Marking Scheme, 2017]

Q. 4. Draw a circuit for determining internal resistance of a cell using a potentiometer. Explain the principle on which this method is based. U **[SQP II 2017]**

Ans.



1

(ii) If key K_2 is open and key K_1 is closed and null point is obtained at a distance l_1 from Q,

$E = Kl_1$ ...(i) ½

If key K_2 is closed and key K_1 is open and null point is obtained at a distance l_2 from Q,

$V = Kl_2$ ...(ii) ½

On dividing equation (i) by (ii)

$$\frac{E}{V} = \frac{l_1}{l_2}$$ ½

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

Hence, $r = \left(\frac{l_1 - l_2}{l_2}\right)R$ ½

where,

R = shunt resistance in parallel with the cell,

l_1 and l_2 = balancing length without and with shunt

r = internal resistance of the cell

[CBSE Marking Scheme, 2017]

AI **Q. 5. A potentiometer wire of length 1 m has a resistance 10 Ω. It is connected to 6 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm.** A

Ans. Current flowing in potentiometer wire,

$$I = \frac{V}{R + R'}$$ ½

where, R is the resistance of potentiometer wire and $R' = 5\ \Omega$

$$I = \frac{6}{10+5}\ \text{A} = 0.4\ \text{A}$$ ½

Potential drop across the potentiometer wire

$$V = IR$$

$$= 0.4 \times 10\ \text{V} = 4.0\ \text{V}$$ ½

Potential gradient $k = V/l = 4.0$ V/m ½

∴ Unknown emf of the cell $(E) = kl'$ ½

$$= 4.0 \times 0.4\ \text{V}$$

$$= 1.6\ \text{V}$$ ½

[CBSE Marking Scheme, 2014]

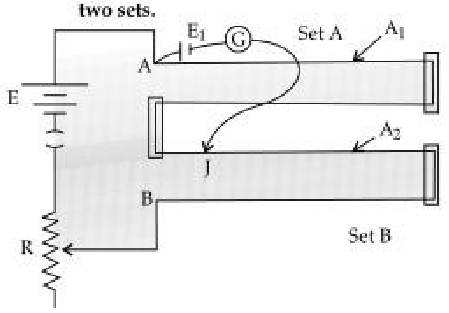
Q. 6. You are given two sets of potentiometer circuit to measure the emf E_1 of a cell.

Set A : consists of a potentiometer wire of a material of resistivity ρ_1, area of cross-section A_1 and length l.

Set B : consists of a potentiometer of two composite wires of equal lengths l_2 each, of resistivity ρ_1, ρ_2 and area of cross-section A_1, A_2 respectively.

(i) Find the relation between resistivity of the two wires with respect to their area of cross section, if the current flowing in the two sets is same.

(ii) Compare the balancing length obtained in the two sets. U



Ans. (i) $I = \dfrac{E}{R + \dfrac{\rho_1 l}{A_1}}$ (for Set A) ½

$$I = \frac{E}{R + \dfrac{\rho_1 l}{2A_1} + \dfrac{\rho_2 l}{2A_2}}$$ (for Set B) ½

Equating the above two expressions and simplifying

$$\frac{\rho_1}{A_1} = \frac{\rho_2}{A_2}$$ ½

(ii) Potential gradient of the potentiometer wire for Set A,

$$K = I\frac{\rho_1}{A_1}$$

Potential drop across the potentiometer wire in Set B

$$V = I\left(\frac{\rho_1 l}{2A_1} + \frac{\rho_2 l}{2A_2}\right)$$

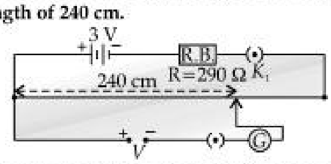
$$V = \frac{I}{2}\left(\frac{\rho_1}{A_1} + \frac{\rho_2}{A_2}\right)l$$ ½

$K' = \dfrac{I}{2}\left(\dfrac{\rho_1}{A_1} + \dfrac{\rho_2}{A_2}\right)$, using the condition obtained in part (i) ½

$K' = I\dfrac{\rho_1}{A_1}$, which is equal to K

Therefore, balancing lengths obtained in the two sets are same. ½

Q. 7. Calculate the value of the unknown potential V for the given potentiometer circuit. The total length (400 cm) of the potentiometer wire has a resistance of 10 Ω and the balance point is obtained at a length of 240 cm. A



Ans. The current through the potentiometer wire

$$= \frac{3\ \text{V}}{(290+10)\ \Omega} = 10^{-2}\ \text{A}$$ 1

∴ Potential drop per unit length of the potentiometer wire,

$$\phi = \frac{10^{-2}\text{A} \times 10\Omega}{400\ \text{cm}}$$

$$= \frac{1}{4} \times 10^{-3}\ \text{V/cm}$$ 1

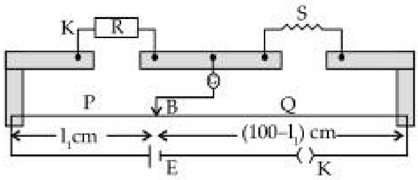
$$\therefore \quad V = \phi l = \frac{1}{4} \times 10^{-3} \times 240\ \text{volt}$$

$$= 6\ \text{V} \times 10^{-2}\ \text{V}$$

$$= 60\ \text{millivolt}$$

$$= 60\ \text{mV}$$ 1

Q. 8. What is end error in a metre bridge ? How is it overcome ? The resistances in the two arms of the metre bridge are R = 5 Ω and S respectively. When the resistance S is shunted with an equal resistance, the new balance length found to be 1.5 l_1 where l_1 is the initial balancing length. Calculate the value of S.



[Delhi I 2019]

End error, overcoming ½
Formula for metre bridge ½
Calculation of value of S 2

The end error, in a metre bridge, is the error arising due to :

(i) Ends of the wire not coinciding with the 0 cm / 100 cm marks on the metre scale. ½

(ii) Presence of contact resistance at the joints of the meter bridge wire with the metallic strips.

It can be reduced/overcome by finding balance length with two interchanged positions of R and S and taking the average value of 'S' from two readings. ½

(**Note :** Award this ½ make even if student just writes only the point (i) or point (ii) given above.)

For a metre bridge

$$\frac{R}{S} = \frac{l}{100-l}$$ ½

For the two given conditions,

$$\frac{5}{S} = \frac{l_1}{100-l_1}$$

$$\frac{5}{S/2} = \frac{1.5l_1}{100-1.5l_1}$$ ½

Dividing the two

$$2 = \frac{1.5l_1}{(100-1.5l_1)} \times \frac{(100-l_1)}{l_1}$$ ½

$$200 - 3l_1 = 150 - 1.5l_1$$

$$l_1 = \frac{100}{3} \text{ cm}$$

Putting the value of l_1 in any one of the two given conditions.

$S = 10\,\Omega$ ½

[CBSE Marking Scheme, 2019]

Detailed Answer :

The end error in metre bridge is due to the following reasons :

(1) The zero mark on the scale that is provided along the length of bridge wire may not start from the position where the bridge wire leaves the copper strip and 100 cm mark of scale may not be at the position, where the copper strip touches the bridge wire function.

(2) The resistance of connecting wire and copper strips not taken into consideration.

This error can be rectified by repeating the experiment by interchanging the known and unknown resistances and by taking the mean of resistances determined.

Initially at balance point

$$\frac{l_1}{(100-l_1)} = \frac{5}{S} \quad ...(1)$$

by shunting S with equal resistance, the new resistance

$$\frac{1}{S'} = \frac{1}{S} + \frac{1}{S} \Rightarrow S' = \frac{S}{2}$$

Now at balance point

$$\frac{1.5l_1}{(100-1.5l_1)} = \frac{5}{S'} \quad ...(2)$$

Dividing eqn. (1) by eqn. (2),

$$\frac{l_1}{100-l_1} \times \frac{(100-1.5\,l_1)}{1.5l_1} = \frac{5}{S} \times \frac{S}{2\times 5}$$

$$2\,(100-1.5l_1) = (100-l_1)\,1.5$$

$$200 - 3l_1 = 150 - 1.5$$

or $\quad 1.5l_1 = 50$

$\Rightarrow \quad l_1 = \frac{50}{1.5}$ cm

Putting this value of l_1 in eqn. (1) gives

$$\frac{50/1.5}{(100-50/1.5)} = \frac{5}{S} \Rightarrow S = 10\,\Omega$$

Long Answer Type Questions - II (5 marks each)

Q. 1. (i) State the working principle of a potentiometer with help of the circuit diagram, explain how the internal resistance of a cell is determined.

(ii) How are the following affected in the potentiometer circuit when (i) the internal resistance of the drive cell increases and (ii) the series resistor connected to the driver cell is reduced ? Justify your answer.

A [Delhi Compt. I, II, III 2017]

Ans. (i) Statement of working principle 1
Circuit diagram and determination of internal resistance 3
(ii) (a) Effect of internal resistance ½
(b) Series resistance ½

[CBSE Marking Scheme, 2017]

Detailed Answer :

(i) Working principle : Try yourself Similar to Q. 2 (i) Long Answer Type Questions-I

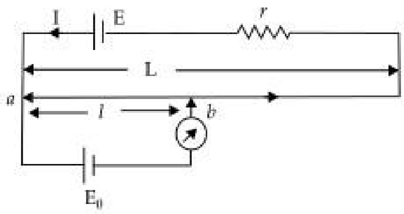
Circuit Diagram and determination : Try yourself Similar to Q. 2(i) Long Answer Type Questions-I

(ii) Current in the circuit when null point is attained is

$$I = \frac{E}{r + (L \times r_0)}$$

E_0 = Potential drop across ab

resistance per unit length of the wire = r_0



$$E_0 = I \times r_{ab}$$

$$E_0 = \frac{E}{(r + Lr_0)} \times (r_0 \times l) = \frac{El}{(\frac{r}{r_0} + L)}$$

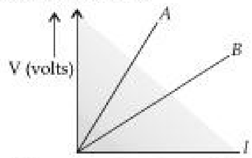
$$I = \frac{E_0(\frac{r}{r_0} + L)}{E}$$

(a) When r increases, than, l that is balancing length will increase

(b) When series resistance with driver cell reduced, equivalent to say that r decreases than l, also decreases.

AI Q. 2. (i) (a) State the principle on which a potentiometer works. How can a given potentiometer be made more sensitive ?

(b) In the graph shown below for two potentiometers, state with reason which of the two potentiometers, A or B, is more sensitive.



(ii) Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (i) in series, and (ii) in parallel.

A **[Foreign I, II, III 2017]**

Ans. (i) (a)	Principle of potentiometer	1
	How to increase sensitivity	½
(b)	Name of potentiometer	½
	Reason	½
(ii)	Formula	½
(a)	Ratio of drift velocities in series	1
(b)	Ratio of drift velocities in parallel	1

[CBSE Marking Scheme, 2017]

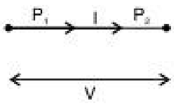
Detailed Answer :

(i) (a) Principle : Similar to Q. 2 Long Answer Type Questions-I 1

It can be made more sensitive by decreasing current in the main circuit/decreasing potential gradient/increasing resistance put in series with the potentiometer wire. ½

(b) Potentiometer B has smaller value $\frac{V}{l}$ ½+½

(ii) In series, the current remains the same ½



$$I = neA_1V_{d1} = neA_2V_{d2} \quad ½$$

$$\therefore \quad \frac{V_{d1}}{V_{d2}} = \frac{A_2}{A_1} \quad ½$$

In parallel, potential difference is same but currents are different.

$$V = I_1R_1 = neA_1V_{d1}\frac{\rho l}{A_1} \quad ½$$

$$= ne\rho V_{d1}l$$

Similarly, $V = I_2R_2 = ne\rho V_{d2}l$ ½

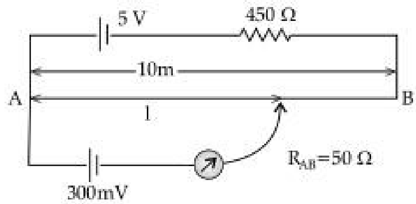
$$I_1R_1 = I_2R_2$$

$$\therefore \quad \frac{V_{d1}}{V_{d2}} = 1 \quad ½$$

Q. 3. (a) Describe briefly, with the help of a circuit diagram, the method of measuring the internal resistance of a cell.

(b) Give reason why a potentiometer is preferred over a voltmeter for the measurement of emf of a cell.

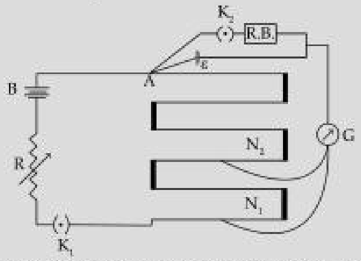
(c) In the potentiometer circuit given below, calculate the balancing length l. Give reason, whether the circuit will work, if the driver cell of emf 5 V is replaced with a cell of 2 V, keeping all other factors constant. 5



[Delhi III, 2019]

Ans. Circuit diagram and describing the method to measure internal resistance of cell by potentiometer	1+½
Reason	1
Calculating balancing length and reason (circuit works or not)	1½ +1

(a) Circuit diagram :



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Brief description : Plug in the key K_1 and keep K_2 unplugged and the find the balancing length l_1 such that : 1 E = Kl_1 ...1 ½

With the key K_2 also plugged in find out balancing length l_2 again such that:

$$V = Kl_2 \quad ...2\,½$$

$$r = \left(\frac{E}{V} - 1\right)R$$

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

(b) The potentiometer is preferred over the voltmeter for measurement of e.m.f. of a cell because potentiometer draws no current from the voltage source being measured. ½

(c) V = 5 V, R_{AB} = 50 Ω, R = 450 Ω

$$I = \frac{5}{450 + 50} = \frac{1}{100} = 0.01\text{A} \quad ½$$

$$V_{AB} = 0.01 \times 50 = 0.5 \text{ V}$$

$$K = \frac{0.5}{10} = 0.05 \text{ Vm}^{-1} \quad ½$$

$$l = \frac{V}{K} = \frac{300 \times 10^{-3}}{0.05} = 6\text{m} \quad ½$$

With 2 V driver cell current in the circuit is

$$I = \frac{2}{450 + 50} = 0.04\text{A}. \quad ½$$

Potential difference across

AB = 0.004 × 50 = 200 mV. Hence the circuit will not work. ½

[CBSE Marking Scheme, 2019]

Detailed Answer :

(a) If key K_2 is open and key K_1 is closed and null point is obtained at a distance l_1 from A,

$$E = Kl_1 \quad ...(i)$$

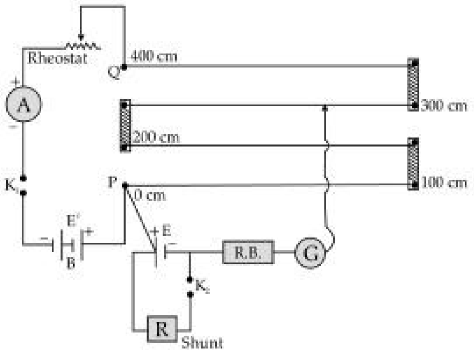
If key K_2 is closed and key K_1 is open and null point is obtained at a distance l_2 from A,

$$V = Kl_2 \quad ...(ii)$$

On dividing equation (i) by (ii)

$$\frac{E}{V} = \frac{l_1}{l_2}$$

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



Hence, $r = \left(\frac{l_1 - l_2}{l_2}\right)R$

where,

R = shunt resistance in parallel with the cell,

l_1 and l_2= balancing length without and with shunt

r = internal resistance of the cell

(b) Potentiometer is preferred over voltmeter because voltmeter needs a current to pass through it so as to measure the potential difference. The potential difference being measured by the voltmeter is given as

$$V = E - IR$$

where,

V = voltage measured,

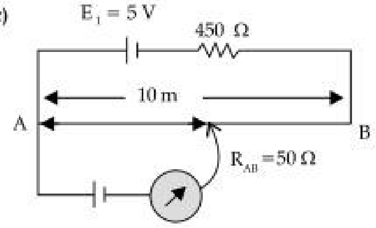
E = emf of battery,

R = resistance of voltmeter,

I = current passing through voltmeter,

Hence the voltage V measured is less than emf of a battery E. Potentiometer does not draw any current from the cell and hence will not cause such problem and can measure the emf directly.

(c) E_1 = 5 V



E_2 = 300 mV

Resistance of potentiometer wire, R_{AB} = 50 Ω

Length of the potentiometer wire, AB = 10 m

Emf of cell E_1 = 5 V

Emf of cell E_2 = 300 mV = 0.3 V

Let the balancing length be 'l'

Now, the circuit current

$$I = \frac{E_1}{450+50} = \frac{5\text{ V}}{500\ \Omega}$$

$$I = 10^{-2}\text{ A}$$

The voltage across wire AB,

$$V_{AB} = R_{AB} \times I$$
$$= 50\ \Omega \times 10^{-2}\text{ A}$$
$$= 0.50\text{ V}$$

Now, $E_2 = K \times l$

$0.3\text{ V} = Kl$

or, $$K = \frac{0.3}{l} \quad ...(i)$$

But $$K = \frac{V_{AB}}{AB} = \frac{0.50\text{ V}}{10\text{ m}} \quad ...(ii)$$

Now, from equation (i) and (ii),

$$\frac{0.3}{l} = \frac{0.50}{10}$$

or, $$l = \frac{0.3 \times 10}{0.5}$$
$$= \frac{3.0}{0.5}$$
$$l = 6\text{ m}$$

If the voltage driver is 2.0 V, then the circuit current

$$I = \frac{2.0}{450+50} = 0.004\text{ A}$$

Hence, the potential difference across AB,

$$V_{AB} = 0.004 \times 50 = 200\text{ mV}$$

Since 200 mV < E_2. Hence, the circuit will not work.

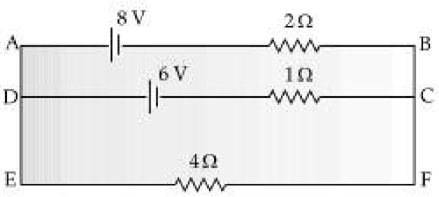
Q. 4. (a) State the working principle of a meter bridge which is used to measure an unknown resistance.

(b) Give reason :

(i) why the connections between the resistors in a metre bridge are made of thick copper strips,

(ii) why is it generally preferred to obtain the balance length near the mid-point of the bridge wire.

(c) Calculate the potential difference across the 4 W resistor in the given electrical circuit, using Kirchhoff's rules.



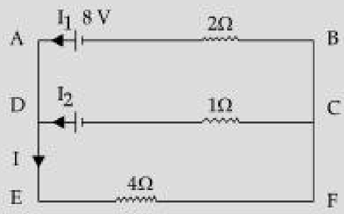
- **State the working principle of metre bridge** 1
- **Reasons** ½ + ½
- **Calculation of potential difference using Kirchhoff's rules** 3

(a) Meter bridge is based on the principle of balanced Wheat stone bridge. **1**

(b) (i) Thick copper strips are used to minimize resistance of connections which are not accounted for in the bridge formula. ½

(ii) Balance point is preferred near midpoint of bridge wire to minimize percentage error in resistance (R). ½

(c)



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$I = I_1 + I_2$ (1)

In loop ABCDA,

$-8 + 2I_1 - 1 \times I_2 + 6 = 0$ (2)**1**

In loop DEFCD,

$-4I - 1 \times I_2 + 6 = 0$

$4I + I_2 = 6$

$4(I_1 + I_2) + I_2 = 6$

$4I_1 + 5I_2 = 6$ (3) ½

From equations (1) and (2), we get

$$I_1 = \frac{8}{7}\text{ A},\ I_2 = \frac{2}{7}\text{ A},\ I = \frac{10}{7}\text{ A}$$

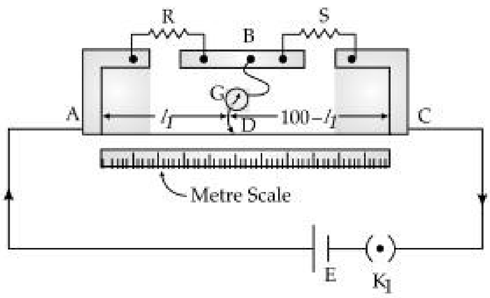
Potential difference across resistor 4 Ω is :

$$V = \frac{10}{7} \times 4 = \frac{40}{7}\text{ volt}$$

[CBSE Marking Scheme, 2019]

Detailed Answer :

(a) The circuit diagram of the metre bridge is as shown below :

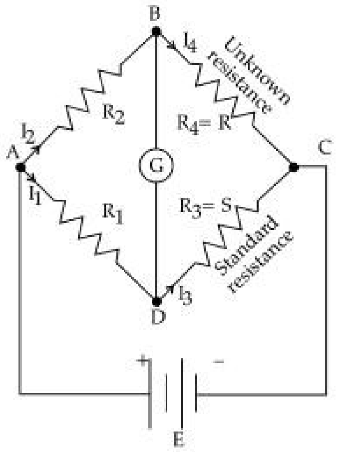


Working Principle : The working principle of the meter bridge is same as that of a Wheatstone bridge. The Wheatstone bridge gets balanced when :

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

For the metre bridge, circuit shown above, this relation takes the form

$$\frac{R}{S} = \frac{l_1}{(100 - l_1)}$$



Determination of unknown Resistance (R) : In the circuit diagram shown above, S is taken as a known standard resistance.

We find the value of the balancing length l_1, corresponding to a given value of S. We then use the relation :

$$\frac{R}{S} = \frac{l_1}{(100 - l_1)}$$

to calculate R.

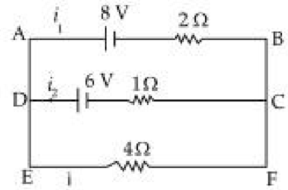
By choosing (at least three) different values of S, we calculate R each time. The average of these values of R gives the value of the unknown resistance.

(b) **(i)** This is to ensure that the connections do not contribute any extra, unknown, resistances in the circuit.

(ii) This is done to minimize the percentage error in the value of the unknown resistance.

This is done to have a better "balancing out" of the effects of any irregularity or non-uniformity in the metre bridge wire.

(c) This can help in increasing the sensitivity of the metre bridge circuit.



Apply the current junction rule of Kirchhoff's Law at point D

$$i = i_1 + i_2 \quad \text{...(i)}$$

Apply Kirchhoff's Voltage rule for the mesh AEFBA

$$4i + 2i_1 = 8$$

or $\quad 2i + i_1 = 4 \quad$ ...(ii)

Apply Kirchhoff's voltage rule for mesh DEFCD

$$4i + 1i_2 = 6$$

or, $\quad 4i + i_2 = 6 \quad$ ...(iii)

Adding equation (ii) and (iii), we get

$$6i + i_1 + i_2 = 10$$

or, $\quad 6i + i = 10 \quad$ [using equation (i)]

or $\quad i = \frac{10}{7}$ A

Now, the potential difference across resistor 4 W

$$V_{EF} = i \times 4$$

$$= \frac{10}{7} \times 4$$

$$= 5\frac{5}{7} \text{ V}$$