Current Electricity

Chapter 3

1 ELECTRIC CURRENT

Current through a given area is net charge passing per unit time through the area.

- Current may not always be steady. We define current in general

$$I = \lim_{\Delta t \to 0} \left(\frac{\Delta Q}{\Delta T} \right)$$

- Its SI unit is ampere (A)
- A cell can maintain a steady current

2 DRIFT VELOCITY

The charge carriers like electrons move with an average velocity which is independent of time, this is phenomenon of drift, and is called drift velocity.

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

τ = relaxation time.

Although collision of electrons don't occur at regular intervals but average time between successive collision is taken as relaxation time.

3 CURRENT DENSITY AND MOBILITY

Current through unit cross-sectional area is called current density.

- It is denoted by J and is a vector.
- SI unit is $A m^{-2}$
- $\vec{J} = \sigma\vec{E} = \left(\frac{ne^2}{m}\tau \right)\vec{E}$

σ = conductivity

E = electric field inside conductor

The relation is Ohm's law in microscopic form.

- Conductivity is due to mobile carriers.
- In metals, charge carriers are electrons.
- In ionised gas, they are electrons and positive charged ions.
- In electrolytes they are positive and negative ions.
- Mobility is magnitude of drift velocity per unit electric field.

$$m = \frac{|v_d|}{E} = \frac{e\tau}{m}$$

- SI units are $m^2 V^{-1} s^{-1}$

4 OHM's LAW

The current flowing through a conductor is proportional to potential difference across it, provided temperature is constant.

$$V \propto I \text{ or } V = RI$$

R is the resistance of substance. SI unit of is ohm ($1\,\Omega = 1\,V A^{-1}$)

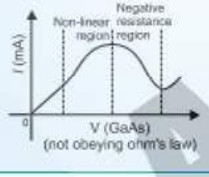
Equivalent form: $\vec{J} = \sigma\vec{E}$ ($\vec{J}$: Current density vector)

Factors affecting R: $R = \frac{\rho l}{A}$

1. Material of conductor
2. Area of cross-section of conductor
3. Length of conductor,

Limitation of ohm's law

- The relation of V and I is not unique in GaAs.
- V ceases to be proportional to I. Material becomes non-ohmic material.
- For a diode, relation of V and I depends on sign of V. This material is used in electronic devices.



5 RESISTIVITY AND ITS TEMPERATURE DEPENDENCE

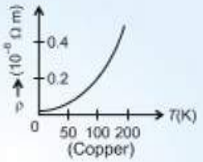
- Materials are classified as conductors, semiconductors and insulators according to their resistivity value.
- Metals have resistivity range $10^{-8}\,\Omega$ m to $10^{-6}\,\Omega$ m.
- Insulators have resistivity range from 10^{5} to $10^{18}\,\Omega$ m.
- For metallic conductor over a limited range, resistivity is approximately given by

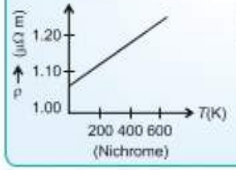
$\rho_T = \rho_0[1 + \alpha(T - T_0)]$

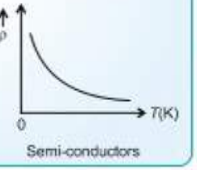
ρ_T = resistivity at temp. T

ρ_0 = resistivity at temp. T_0

α = temperature coefficient of resistivity







6 TYPES AND COLOUR CODING OF RESISTORS

(a) Wire Bound Resistors

- Made of materials which are relatively insensitive to temperature.
- Winding of wires are of alloys viz., manganin, constantan, nichrome etc.
- Range : fraction of an ohm to few hundred ohms.

(b) Carbon Resistors

- Compact, inexpensive and have higher range.
- Colour coding of carbon resistors

Colour	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20

7 CELL AND ITS EMF

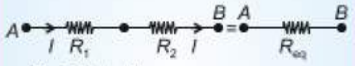
- It is a simple device which can maintain a steady current in electric circuit.
- EMF of cell is potential difference between positive and negative electrode when no current is flowing through the cell.
- $V = \varepsilon - ir$ (discharging)

  $V = \varepsilon + ir$ (charging)
- r is called internal resistance. The actual value of r vary from cell to cell.
- Internal resistance of dry cell is higher than electrolytic cell.

(8) COMBINATION OF RESISTORS

The resistors are sometimes joined together and there are simple rules for calculation of equivalent resistance of such combination.

1. **Series combination:** If only one of their end point is joined.



$R_{eq} = R_1 + R_2$

2. **Parallel combination:** If one end of all the resistors are joined together and similarly other ends joined together. (The potential drop across resistors is same).

$I = I_1 + I_2$

$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

(9) Electrical Energy and Power

Under a potential difference in a conductor charges are moving. These charges suffer collisions with ions and atoms during transit. Energy shared by ions and atoms heats up the conductor. Amount of energy dissipated as heat per unit time is called power loss.

$$P = I^2R = V^2/R = IV$$

R is resistance when current I is flowing through it.

This energy is supplied by source in circuit.

- For long distance transmission, power loss is minimised by transmitting it at high voltage.

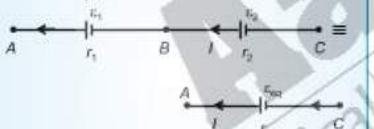
(10) KIRCHHOFF'S RULES

- For complicated electric circuits to determine all the currents and potential differences, Kirchhoff formulated two laws:
  - **Junction rule:** At any junction, sum of currents entering the junction is equal to sum of currents leaving the junction.
  - **Mesh or loop rule:** The algebraic sum of changes in potential around any closed loop involving resistors and cells in the loop is equal to zero.

Note: Binding or reorientation of wire does not change the validity of junction law.

(11) COMBINATION OF CELLS

- Cell can be grouped in series or parallel depending upon current requirements.
- In series: Two cells of emf ε_1 and ε_2 with internal resistances r_1 and r_2 the combination can be considered as one cell of emf ε_{eq} and internal resistance r_{eq}



$(\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2)$ and $(r_{eq} = r_1 + r_2)$

- In parallel combination of two cells

$$\varepsilon_{eq} = \left(\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}\right)$$

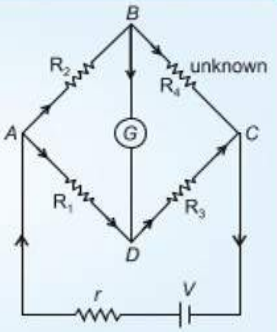
$$r_{eq} = \left(\frac{r_1 r_2}{r_1 + r_2}\right)$$

(12) WHEATSTONE BRIDGE

- Wheatstone bridge in its balanced condition provide a practical method for determination of internal resistance.
- If R_1 and R_2 are two resistances in first and second arm and R_3 in third arm. R_3 is kept on changing till galvanometer shows no deflection. The bridge is then balanced and from balance condition R_4 is known.

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

- The value of one resistance is determined knowing other three resistors.

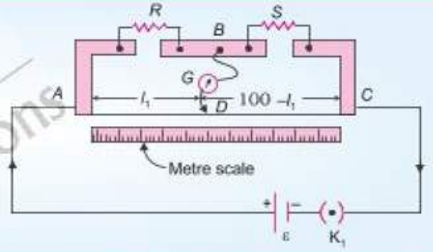


(13) METER-BRIDGE

- It is based on wheatstone bridge.
- With same principle as of Wheatstone bridge it is used to calculate unknown resistance, R, under balance condition.

$$R = S \times \frac{l_1}{100 - l_1}$$

- Percentage error in R is minimised by adjusting balance point near the middle of bridge.



(14) POTENTIOMETER

This is a versatile electric instrument used to compare emf(s) and to determine internal resistance of a cell.

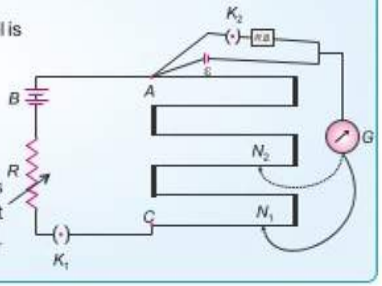
- The method involves condition of no current flow. In this way it can compare emfs of two cells.
- The potentiometer wire has uniform cross-section and homogeneous material so potential drop per unit length of potentiometer wire is constant.
- The formula for internal resistance calculation of cell is

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

l_1 = balancing length without shorting cell

l_2 = balancing length with cell by parallel resistance R

- The potentiometer has the advantage that it draws no current from voltage source being measured. It is not affected by internal resistance of the source. Thus it has high accuracy.



Sharpen Your Understanding

1. Estimate the average drift speed of conduction electrons in a conductor of cross-sectional area 10^{-7} m^2 carrying current of 1.5 A. The number density of conduction electrons is 8.5×10^{28} m^{-3}. [NCERT Pg. 99]

   (1) 2.2 mm s^{-1}

   (2) 1.1 mm s^{-1}

   (3) 3.3 mm s^{-1}

   (4) 0.1 mm s^{-1}

2. Average collision time for electrons in a conductor under a certain potential difference is found to be 10^{-15} s. The mobility of electron in metal conductor is [NCERT Pg. 101]

   (1) 1.5×10^{-3} m^2/V s

   (2) 2.2×10^{-3} m^2/V s

   (3) 2.9×10^{-3} m^2/V s

   (4) 1.75×10^{-4} m^2/V s

3. A charged particle is having drift velocity of 7.5×10^{-4} m s^{-1} in an electric field of 3×10^{-9} V m^{-1}. The electron mobility is [NCERT Pg. 101]

   (1) 2.5×10^{4} m^2 V^{-1} s^{-1}

   (2) 2.5×10^{5} m^2 V^{-1} s^{-1}

   (3) 2.25×10^{-13} m^2 V^{-1} s^{-1}

   (4) 4.1×10^{3} m^2 V^{-1} s^{-1}

4. Arrange following materials in correct order of their conductivity. Nichrome, Copper, Germanium, Silver. [NCERT Pg. 102]

   (1) Silicon > Germanium > Nichrome > Copper

   (2) Silver > Copper > Germanium > Nichrome

   (3) Silver > Copper > Nichrome > Germanium

   (4) Germanium > Nichrome > Copper > Silver

5. The resistivity of alloy manganin [NCERT Pg. 102]

   (1) Increases rapidly with increase of temperature

   (2) Decreases linearly with increase in temperature

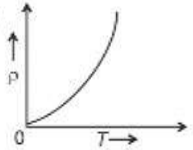
   (3) Increases rapidly with decrease in temperature

   (4) Is nearly independent of temperature

6. The graph of resistivity versus temperature for copper is best represented by graph shown below. The correct graph is [NCERT Pg. 104]

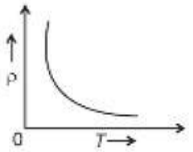
   (1)

   (2)

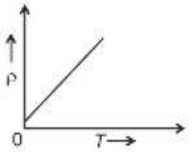


NCERT Based MCQs

   (3)



   (4)



7. A resistor is marked with rings coloured as brown, black, green and gold. The resistance in ohm is [NCERT Pg. 103]

   (1) $(3 \times 10^6 \pm 5\%)\ \Omega$

   (2) $(1.10 \times 10^5 \pm 5\%)\ \Omega$

   (3) $(10^6 \pm 5\%)\ \Omega$

   (4) $(8.5 \times 10^6 \pm 5\%)\ \Omega$

8. Which among the following statements is correct? [NCERT Pg. 104]

   (1) In a metal, number density is independent of temperature

   (2) With increase in temperature, relaxation time in metal decreases

   (3) For semiconductors and insulators number density increases with increase in temperature

   (4) All the above

9. Nichrome has resistance of 75.3 Ω at 30°C. The resistance of nichrome becomes 85.8 Ω when current passes through it, if average temperature coefficient of resistance of

nichrome is 1.7×10^{-4} C^{-1}. The temperature of nichrome now is [NCERT Pg. 105]

(1) 700 °C (2) 750 °C

(3) 850 °C (4) 900 °C

10. The incorrect statement among the following statements is [NCERT Pg. 111]

(1) Emf of a cell is the potential difference between its positive and negative electrodes in an open circuit

(2) Internal resistance of dry cells is much higher than common electrolyte cells.

(3) The terminal potential difference of a cell can be zero

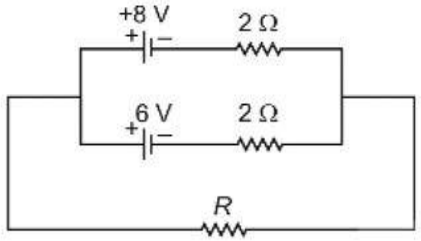
(4) When current passes from positive to negative terminal of a cell inside it, terminal potential difference is less than its emf.

11. When a current of 2 A flows in a battery from its negative to positive terminal, the potential difference across it is 12 V. If a current of 3 A is flowing in opposite direction it produces a potential difference of 15 V, the emf of the battery is [NCERT Pg. 111]

(1) 12.6 V (2) 13.5 V

(3) 14.0 V (4) 13.2 V

12. In the combination of two cells in parallel by joining positive terminals together and similarly two negative ones, the value of $\frac{E_{eq}}{r_{eq}}$ in circuit is [NCERT Pg. 115]



(1) 7 A (2) 10 A

(3) 2 A (4) 8 A

13. When a metal conductor connected to right gap of meter bridge is heated, the balancing point from left end [NCERT Pg. 120]

(1) Shifts towards left

(2) Shifts towards right

(3) Remains unchanged

(4) Shift to zero position

14. Resistance P, Q, S and R are arranged in clockwise cyclic order to form a balanced wheatstone bridge. The ratio of electric power consumed in the branches $(P + Q)$ and $(R + S)$ is [NCERT Pg. 109]

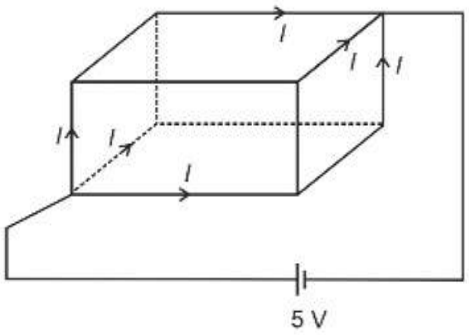
(1) 1 : 1

(2) $R : P$

(3) $R^2 : P^2$

(4) $Q : S$

15. A battery of e.m.f. 5 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors of network each of resistance 1 Ω. The current along one edge of the cube is [NCERT Pg. 116]



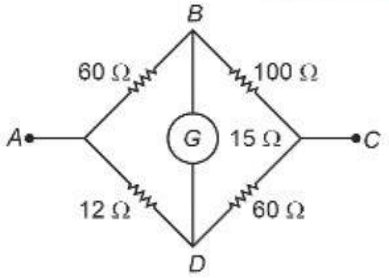
(1) 1 A

(2) 2 A

(3) 3 A

(4) 4 A

16. Four arms of wheat-stone bridge have the following resistances, AB = 60 Ω, BC = 100 Ω, CD = 60 Ω, DA= 12 Ω. A galvanometer of 15 Ω is connected across BD. Calculate the value of additional resistance connected across CD to balance the bridge. [NCERT Pg. 119]

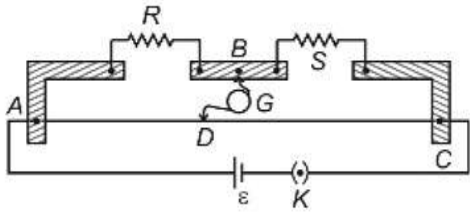


(1) 12 Ω (2) 15 Ω

(3) 18 Ω (4) 30 Ω

17. In a Meter Bridge null point is found to be at 30 cm from end *A*. If now a resistance of 10 Ω is connected in parallel with *S*, the null point occurs at 65 cm, value of *S* is nearly

[NCERT Pg. 121]



(1) 20 Ω

(2) 28 Ω

(3) 33 Ω

(4) 38 Ω

18. In a potentiometer of 8 wires, the balance point is obtained on fifth wire. To shift balance point to 6th wire, we should

[NCERT Pg. 122]

(1) Decrease resistance in main circuit

(2) Increase resistance in main driver circuit

(3) Decrease resistance in series with cell whose emf is to measure

(4) Taking driver battery with higher emf

19. A potentiometer with driver battery of emf 2 V is used for determination of internal resistance of 1.5 V cell. The balance point of the cell in open circuit is 225 cm. When a resistance of 7.0 Ω is used in external circuit across of the cell, the balance point shifts to 210 cm length of potentiometer wire. The internal resistance of the cell is

[NCERT Pg. 131]

(1) 1 Ω (2) 0.5 Ω

(3) 2 Ω (4) 5 Ω

20. Pick out wrong statement about the Kirchhoff's laws of electric circuit.

[NCERT Pg. 116]

(1) Outgoing currents adds up and are equal to incoming currents at a junction

(2) Electric potential in electric circuit is position dependent. Starting with any point if we come back to same point, total potential change must be zero

(3) Junction rule is based on conservation of energy law

(4) Bending or reorienting the wire does not change the validity of Kirchhoff's junction rule.

Thinking in Context

1. Resistance of a conductor depends on material of conductor and also on _____ of conductor. [NCERT Pg. 95]

2. Halving the area of cross-section of a conductor by dividing the conductor into two (by cutting it lengthwise); doubles its resistance. The statement is

[NCERT Pg. 96]

(1) True (2) False

3. Ohm's law is often stated in an equivalent form $\vec{J} = \sigma\vec{E}$ where $\vec{J}$ is current density and $\vec{E}$ the magnitudes of electric field. The statement is [NCERT Pg. 97]

(1) True (2) False

4. In a conductor, when no potential difference is applied, average velocity of all free electrons is _____. [NCERT Pg. 97]

5. In a conductor, collision of electrons don't occur at regular intervals but at random times. The average time between two successive collision is called _____.

[NCERT Pg. 98]

6. Conductivity of conductor has relation with number density of free electrons as $\sigma = \frac{me^2}{n}\tau$. This relation is [NCERT Pg. 99]
   (1) True (2) False
7. The direction of drift velocity of conduction electrons is _____ to the electric field direction. [NCERT Pg. 99]
8. Thermal speed of a copper atom with mass 63.5 u at 300 K is about _____. [NCERT Pg. 99]
9. The ratio of drift speed of an electron to the magnitude of speed of electromagnetic wave along conductor is approximately _____. [NCERT Pg. 99]
10. When electrons drift in a metal from lower to higher potential, it means that all free electrons of metal are moving in same direction. This statement is [NCERT Pg. 100]
    (1) True
    (2) False
11. Between two successive collisions, path of electrons are straight line in the absence of electric field but in the presence of electric field, the paths are in general curved. This statement is [NCERT Pg. 100]
    (1) True
    (2) False
12. SI units of mobility is _____. [NCERT Pg. 100]
13. The relation between potential difference V applied and flowing current I in certain materials depends on sign of V, in other words, if I is current for certain V, then reversing the direction of V keeping its magnitude fixed does not produce current of same magnitude. One such material is _____. [NCERT Pg. 101]
14. The relation between potential difference 'V' applied and current (I) flowing through a conductor is not unique. There is more than one value of voltage V for same current. A material exhibiting such behaviour is _____. [NCERT Pg. 101]
15. Metals have low resistivities in the order of _____ Ω m to _____ Ω m and for semiconductors like graphite and silicon, its order is from _____ to _____ Ω m respectively. [NCERT Pg. 102]
16. Materials like Nichrome, manganin and constantan are widely used in wire bound standard resistors, since their resistance value would change very little with _____. [NCERT Pg. 104]
17. The emf of a cell is potential difference between the positive and negative electrode of a cell when _____. [NCERT Pg. 110]
18. The algebraic sum of changes in potential around any closed loop, involving resistors and cells in a loop, is zero. This rule is a statement of _____ rule. [NCERT Pg. 116]
19. The Wheatstone Bridge and its balance condition provide a practical method of determination of _____. [NCERT Pg. 119]
20. An error in measurement of resistance R, by meter bridge method can be reduced by adjusting balance point on wire near _____. [NCERT Pg. 121]

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