Electric Current and Ohm's Law

Charge and Current

Charge is a fundamental property of matter and can be positive or negative. The SI unit of charge is the Coulomb (C). Electric current is the rate of flow of electric charge through a conductor and is measured in amperes (A). It is a scalar quantity.

Static and Current Electricity

Static electricity refers to electric charges at rest, while current electricity involves charges in motion through a conductor.

Electric Circuit and Conventional Current

An electric circuit is a closed path through which electric current flows. Conventionally, current is considered to flow from the positive terminal to the negative terminal, opposite to the actual flow of electrons.

Ammeter and Voltmeter

An ammeter is a low resistance galvanometer connected in series to measure current. A voltmeter is a high resistance galvanometer connected in parallel to measure potential difference.

Electric Potential and Potential Difference

Electric potential at a point is the electric potential energy per unit charge. Potential difference between two points is the work done to move a unit charge between them, measured in volts (V).

Ohm's Law

Ohm's Law states that the current through a conductor between two points is directly proportional to the potential difference across the conductor, provided external conditions remain constant. Mathematically, $V = IR$, where V is voltage, I is current, and R is resistance.

Resistance and Resistivity

Resistance is the property of a conductor that opposes the flow of current, measured in ohms (Ω). It depends on the length, cross-sectional area, temperature, and material of the conductor. Resistivity (ρ) is the resistance of a unit length and unit cross-sectional area conductor, measured in ohm-metre (Ω m).

Combination of Resistors

Resistors can be connected in series or parallel. In series, resistances add up: $R_s = R_1 + R_2 + \dots$. In parallel, the reciprocal of total resistance is the sum of reciprocals: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$.

Heating Effect and Electric Power

Electric current produces heat in a conductor, given by Joule's law: $H = I^2Rt$. Electric power is the rate of energy consumption: $P = VI = I^2R = \frac{V^2}{R}$, measured in watts (W).

Solved Examples

Example 1: Calculate the current flowing through a conductor if 10 Coulombs of charge pass through it in 2 seconds.

Solution:

Given, $Q = 10$ C, $t = 2$ s

Current, $I = \frac{Q}{t} = \frac{10}{2} = 5$ A

Therefore, the current is 5 amperes.

Example 2: A resistor of resistance 4 Ω is connected across a 12 V battery. Find the current flowing through the resistor.

Solution:

Given, $V = 12$ V, $R = 4\,\Omega$

Using Ohm's Law, $I = \frac{V}{R} = \frac{12}{4} = 3$ A

Therefore, the current flowing is 3 amperes.

Example 3: Two resistors of 3 Ω and 6 Ω are connected in series. Find the total resistance.

Solution:

In series, total resistance $R_s = R_1 + R_2 = 3 + 6 = 9\,\Omega$

Therefore, the total resistance is 9 ohms.

Practice Set

Conceptual Questions

- **Level 1:** Define electric current and state its SI unit.
- **Level 2:** Explain why the conventional current direction is opposite to the electron flow.

Application-based Question

- **Level 3:** A 9 V battery is connected to a resistor of 18 Ω. Calculate the current flowing through the resistor and the power dissipated.

Answer Key

Conceptual Questions

- **Level 1:** Electric current is the rate of flow of electric charge through a conductor. Its SI unit is ampere (A).
- **Level 2:** Conventional current is considered the flow of positive charges from positive to negative terminal, opposite to the actual electron flow which is from negative to positive terminal.

Application-based Question

- **Level 3:** Given, $V = 9$ V, $R = 18\,\Omega$
- Current, $I = \frac{V}{R} = \frac{9}{18} = 0.5$ A
- Power, $P = VI = 9 \times 0.5 = 4.5$ W
- Therefore, current is 0.5 A and power dissipated is 4.5 watts.

Resistance and Resistivity

Definition of Resistance

Resistance is the property of a conductor that opposes the flow of electric current. It is measured in ohms (Ω).

Factors Affecting Resistance

Resistance depends on the length (directly proportional), cross-sectional area (inversely proportional), temperature, and the material of the conductor.

Resistivity

Resistivity is the resistance of a conductor of unit length and unit cross-sectional area. It is a material property and does not depend on the dimensions of the conductor. Its SI unit is ohm-metre (Ω m).

Resistivity of Metals, Alloys, and Insulators

Metals have low resistivity, alloys have higher resistivity than their constituent metals, and insulators have the highest resistivity.

Solved Examples

Example 1: Calculate the resistance of a wire 2 m long and 0.5 mm² in cross-sectional area if its resistivity is 1.7×10^{-8} Ω m.

Solution:

Given, $l = 2$ m, $A = 0.5 \times 10^{-6}$ m², $\rho = 1.7 \times 10^{-8}$ Ω m

Resistance, $R = \rho \frac{l}{A} = 1.7 \times 10^{-8} \times \frac{2}{0.5 \times 10^{-6}} = 0.068\,\Omega$

Therefore, the resistance is 0.068 ohms.

Practice Set

Conceptual Questions

- **Level 1:** What is resistivity and what are its units?
- **Level 2:** How does the resistance of a wire change if its length is doubled and cross-sectional area is halved?

Application-based Question

- **Level 3:** A wire of length 1 m and cross-sectional area 1 mm² has a resistance of 2 Ω. Find the resistivity of the material.

Answer Key

Conceptual Questions

- **Level 1:** Resistivity is the resistance of a conductor of unit length and unit cross-sectional area. Its SI unit is ohm-metre (Ω m).
- **Level 2:** Resistance is directly proportional to length and inversely proportional to area. Doubling length doubles resistance; halving area doubles resistance. Overall resistance becomes four times.

Application-based Question

- **Level 3:** Given, $R = 2$ Ω, $l = 1$ m, $A = 1$ mm² = 1×10^{-6} m²
- Resistivity, $\rho = R\frac{A}{l} = 2 \times \frac{1\times10^{-6}}{1} = 2 \times 10^{-6}$ Ω m
- Therefore, resistivity is 2×10^{-6} ohm-metre.

Resistor Combinations, Power, and Heating

Resistors in Series

Resistors connected end to end so that the same current flows through each are in series. Total resistance is the sum of individual resistances: $R_s = R_1 + R_2 + \ldots$.

Resistors in Parallel

Resistors connected across the same two points providing separate current paths are in parallel. Reciprocal of total resistance is sum of reciprocals: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$.

Heating Effect of Electric Current

Electric current produces heat in a conductor, given by Joule's law: $H = I^2Rt$, where H is heat produced, I current, R resistance, and t time.

Electric Power

Power is the rate of energy consumption: $P = VI = I^2R = \frac{V^2}{R}$, measured in watts (W). Commercial energy unit is kilowatt-hour (kWh).

Electric Fuse

A fuse is a safety device made of copper-tin alloy with low melting point, connected in series to protect appliances from overcurrent by melting and breaking the circuit.

Solved Examples

Example 1: Find the total resistance of two resistors 5 Ω and 10 Ω connected in parallel.

Solution:

$$\frac{1}{R_p} = \frac{1}{5} + \frac{1}{10} = \frac{2}{10} + \frac{1}{10} = \frac{3}{10}$$

$$R_p = \frac{10}{3} = 3.33\,\Omega$$

Therefore, total resistance is 3.33 ohms.

Example 2: Calculate the heat produced when a current of 2 A flows through a resistor of 4 Ω for 3 minutes.

Solution:

Given, $I = 2$ A, $R = 4\,\Omega$, $t = 3 \times 60 = 180$ s

Heat produced, $H = I^2Rt = 2^2 \times 4 \times 180 = 16 \times 180 = 2880$ J

Therefore, heat produced is 2880 joules.

Example 3: A 12 V battery is connected to a resistor of 6 Ω. Find the power consumed.

Solution:

Current, $I = \frac{V}{R} = \frac{12}{6} = 2$ A

Power, $P = VI = 12 \times 2 = 24$ W

Therefore, power consumed is 24 watts.

Practice Set

Conceptual Questions

- **Level 1:** What is the difference between resistors connected in series and parallel?
- **Level 2:** Explain the principle of an electric fuse and its importance.

Application-based Question

- **Level 3:** Calculate the total resistance of three resistors 2 Ω, 3 Ω, and 6 Ω connected in series and find the power dissipated if connected to a 12 V battery.

Answer Key

Conceptual Questions

- **Level 1:** In series, resistors are connected end to end with the same current flowing through each; total resistance is sum of resistances. In parallel, resistors are connected across the same two points; total resistance is less than any individual resistance.
- **Level 2:** A fuse is a safety device that melts and breaks the circuit when current exceeds a safe limit, protecting appliances from damage.

Application-based Question

- **Level 3:** Total resistance in series: $R_s = 2 + 3 + 6 = 11$ Ω
- Current, $I = \frac{V}{R} = \frac{12}{11} = 1.09$ A
- Power, $P = VI = 12 \times 1.09 = 13.08$ W
- Therefore, total resistance is 11 Ω and power dissipated is approximately 13.08 watts.

Quick Reference Table

Common Mistakes and Misconceptions

Glossary