Class 12 Physics · Chapter 3: Current Electricity

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. The SI unit of resistivity is [1]

(a) S m^{-1} (b) Ω m^{-1}

(c) Ω m^{-2} (d) Ω m

Answer: (d) From R = ρl/A, ρ = RA/l, with unit Ω m^2 / m = Ω m. S m^{-1} is the unit of conductivity.

2. A heater is rated 1.0 kW at 220 V. Assuming its resistance does not change, the power it draws when connected to a 110 V supply is [1]

(a) 125 W (b) 500 W

(c) 1000 W (d) 250 W

Answer: (d) R = V^2/P is fixed, so P ∝ V^2. Halving V gives P = 1000 × $(110/220)^2$ = 250 W. Taking P ∝ V gives the wrong 500 W.

3. A steady current of 2.0 A flows through a wire of uniform cross-section 0.50 mm^2. The magnitude of the current density in the wire is [1]

(a) 8.0 × 10^6 A m^{-2} (b) 1.0 × 10^6 A m^{-2}

(c) 0.25 × 10^6 A m^{-2} (d) 4.0 × 10^6 A m^{-2}

Answer: (d) j = I/A = 2.0 A / (0.50 × 10^{-6} m^2) = 4.0 × 10^6 A m^{-2}.

4. In a conductor placed in a uniform electric field of 0.60 V m^{-1}, the charge carriers drift at 0.30 mm s^{-1}. Their mobility is [1]

(a) 500 cm^2 V^{-1} s^{-1} (b) 0.050 cm^2 V^{-1} s^{-1}

(c) 5.0 cm^2 V^{-1} s^{-1} (d) 0.20 cm^2 V^{-1} s^{-1}

Answer: (c) μ = v_d/E = (0.30 × 10^{-3} m s^{-1})/(0.60 V m^{-1}) = 5.0 × 10^{-4} m^2 V^{-1} s^{-1}. Since 1 m^2 V^{-1} s^{-1} = 10^4 cm^2 V^{-1} s^{-1}, μ = 5.0 cm^2 V^{-1} s^{-1}.

5. A steady potential difference is maintained across a metal wire. The drift velocity of its free electrons is [1]

(a) along the field, and increases steadily with time

(b) opposite to the field, and constant in time

(c) opposite to the field, and equal to the electrons' thermal speed

(d) zero, since the random velocities of the electrons average to zero

Answer: (b) v_d = −(eE/m)τ: the minus sign puts it opposite to E, and it does not depend on time even though each electron accelerates between collisions. The random velocities average to zero, so the drift is due to the field alone and is far smaller than the thermal speed.

6. Ohm's law is not a fundamental law of nature. State two different ways in which a device can depart from it, naming a device or material for each. [2]

(i) V stops being proportional to I, or the relation depends on the sign of V, as in a diode (rectifier), where reversing V does not give the same magnitude of current. (ii) The relation is not unique, more than one V for the same I, as in GaAs.

- one departure with an example (diode: non-linear or sign-dependent) (1)
- a second departure with an example (GaAs: non-unique relation) (1)

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7. State the condition for balance of a Wheatstone bridge with arms P, Q, R and S. Why does the balance point not depend on the resistance of the galvanometer? [2]

Balance: P/Q = R/S (with P, Q in one pair of adjacent arms and R, S in the other). At balance no current flows through the galvanometer, so its resistance carries no potential drop and does not enter the condition.

- P/Q = R/S (1)
- $I_g = 0$ at balance, so the galvanometer's resistance plays no part (1)

8. A copper wire (resistivity $1.7 \times 10^{-8}\ \Omega$ m) carries a current density of 2.0×10^{6} A m^{-2}. Find the electric field inside the wire and state its direction relative to the current density. [2]

$E = \rho j = 1.7 \times 10^{-8} \times 2.0 \times 10^{6} = 3.4 \times 10^{-2}$ V m^{-1}. Since $j = \sigma E$ with σ positive, E points along j.

- $E = \rho j = 3.4 \times 10^{-2}$ V m^{-1} (1)
- E is along the current density (1)

9. Three identical cells, each of emf 2.0 V and internal resistance 0.60 Ω, are joined in parallel across a 1.8 Ω resistor. (a) Find the emf and internal resistance of the equivalent cell. (b) Find the current in the resistor and in each cell. (c) Find the current in the resistor if the three cells are instead joined in series. [3]

(a) $1/r_{eq} = 3/0.60$, $r_{eq} = 0.20\ \Omega$; $\varepsilon_eq/r_{eq} = 3 \times 2.0/0.60$, $\varepsilon_eq = 2.0$ V. (b) $I = 2.0/(1.8 + 0.20) = 1.0$ A, so each cell gives 1/3 A. (c) Series: $\varepsilon = 6.0$ V, $r = 1.8\ \Omega$, $I = 6.0/3.6 = 1.67$ A.

- $\varepsilon_eq = 2.0$ V and $r_{eq} = 0.20\ \Omega$ (1)
- 1.0 A in the resistor, 1/3 A in each cell (1)
- series: 6.0/3.6 = 1.67 A (1)

10. A coil of metal X (temperature coefficient of resistivity $5.0 \times 10^{-3}\ ^\circ\text{C}^{-1}$, referred to 20 °C) and a manganin coil Y each have a resistance of 10.0 Ω at 20 °C. Treat the resistance of Y as constant and ignore changes in dimensions. (a) At what temperature is the resistance of X 1.5 times that of Y? (b) What is the resistance of X and Y in parallel at that temperature? [3]

(a) $R_X = 10.0[1 + 5.0 \times 10^{-3}(T - 20)] = 15.0\ \Omega$ gives $T - 20 = 100$, so $T = 120$ °C. Y stays at 10.0 Ω because manganin's resistivity depends very little on temperature. (b) $15.0 \times 10.0/25.0 = 6.0\ \Omega$.

- $R_T = R_0[1 + \alpha(T - T_0)]$ set to 15.0 Ω (1)
- T = 120 °C (1)
- parallel resistance 6.0 Ω (1)

11. Electrons in a conductor of cross-section A, with n free electrons per unit volume and relaxation time τ, are in a uniform field E. Starting from the drift velocity, show that the conductivity is $\sigma = ne^2\tau/m$. [3]

Each electron has acceleration $-eE/m$; averaging over electrons, with average time τ since the last collision and zero average random velocity, $v_d = -eE\tau/m$. In time Δt the electrons within $|v_d|\Delta t$ of an area A cross it: charge $neA|v_d|\Delta t$, so $I = neA|v_d| = (e^2A\tau n/m)E$. Then $j = I/A = (ne^2\tau/m)E$; comparing with $j = \sigma E$, $\sigma = ne^2\tau/m$.

- $v_d = -eE\tau/m$ from averaging (1)
- $I = neAv_d$ leading to $I = (ne^2\tau A/m)E$ (1)
- $j = (ne^2\tau/m)E$ compared with $j = \sigma E$ (1)

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