2.6 Current, resistance and circuits

Name: _____ Class: _____ Date: _____ **Total: 27 marks**

KEY WORDS Current • Potential difference • Ohm's law • Charge conservation • Energy conservation • Electrical power • Resistivity • drift velocity

Objective

Build the methods for WPH12 statements 64–73: current, resistance and circuits. These are original teaching questions, not copied past-paper items.

1 Key knowledge and worked examples

Current is the rate of charge flow. Conventional current follows the direction positive charges would move. In a metal, electrons drift in the opposite direction.

$$I = \frac{\Delta Q}{\Delta t} \qquad V = \frac{W}{Q} \qquad R = \frac{V}{I}$$

One ampere is one coulomb per second. **Potential difference** V is energy transferred per unit charge between two points. Resistance R is defined by the ratio V/I at an operating point. **Ohm's law** is the extra condition $I \propto V$ when temperature and other physical conditions stay constant. Not every resistor or component obeys it.

Worked example. A current of 0.40 A flows for 30 s. Find the number of electrons passing a point.

$$Q = It = 0.40\ \text{A} \times 30\ \text{s} = 12\ \text{C}$$

$$N = \frac{Q}{e} = \frac{12\ \text{C}}{1.60 \times 10^{-19}\ \text{C}} = 7.5 \times 10^{19}$$

■ Conservation gives the circuit rules

Charge conservation means charge does not build up at a steady-current junction. Total current entering equals total current leaving. Current is not used up by a resistor.

Energy conservation means the total energy supplied per coulomb around a complete loop equals the energy transferred per coulomb. The sum of voltage rises equals the sum of voltage drops.

For series resistors, the same current passes through each and their potential differences add:

$$V = V_1 + V_2 = IR_1 + IR_2 \quad \Rightarrow \quad R_{\text{series}} = R_1 + R_2$$

For parallel resistors, each has the same p.d. and the branch currents add:

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} \quad \Rightarrow \quad \frac{1}{R_{\text{parallel}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

A parallel combination has smaller resistance than its smallest branch resistance. A voltmeter connects in parallel across a component; an ideal voltmeter has infinite resistance. An ammeter connects in series; an ideal ammeter has zero resistance.

Worked example. A 6.0 Ω resistor is parallel to 3.0 Ω. The combination is in series with 4.0 Ω across 12 V.

- Known: circuit arrangement. Reduce the parallel section first, then apply the series rule.

$$R_p = \left(\frac{1}{6.0} + \frac{1}{3.0}\right)^{-1} \ \Omega = 2.0 \ \Omega$$

$$I = \frac{V}{R_p + R_s} = \frac{12 \text{ V}}{(2.0 + 4.0) \ \Omega} = 2.0 \text{ A}$$

$$V_p = IR_p = 2.0 \text{ A} \times 2.0 \ \Omega = 4.0 \text{ V}$$

$$I_6 = \frac{V_p}{6.0 \ \Omega} = 0.67 \text{ A} \qquad I_3 = \frac{V_p}{3.0 \ \Omega} = 1.33 \text{ A}$$

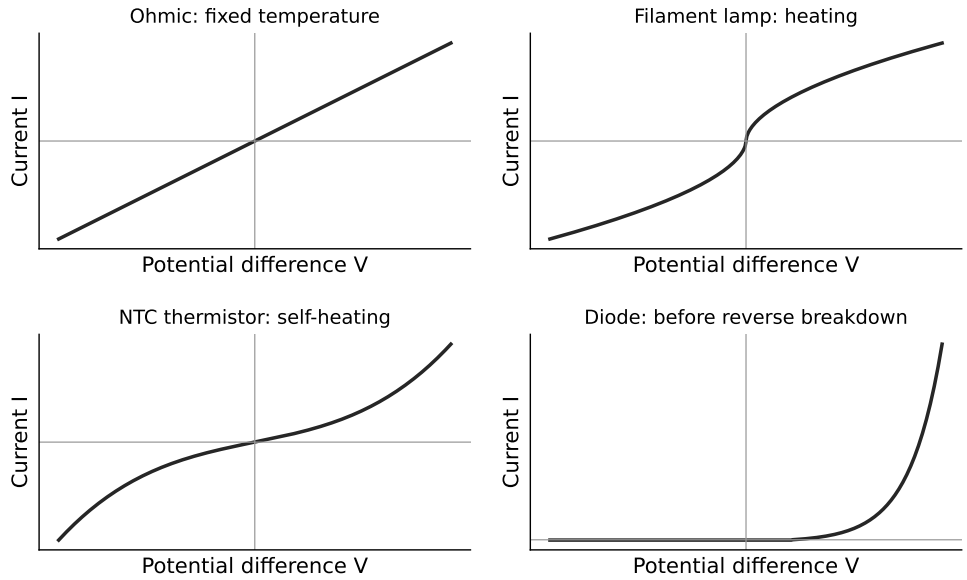
- Check: branch currents add to 2.0 A. The remaining series resistor has an 8.0 V drop.

■ Power and component graphs

Electrical power is energy transferred each second. Substituting $V = IR$ into $P = VI$ gives the other forms:

$$P = VI = I^2R = \frac{V^2}{R} \qquad W = Pt = VIt$$

Use voltage across, and current through, the same component. The resistance forms apply to its operating-point resistance; do not assume a heating lamp has constant resistance.



Axes and temperature conditions matter when interpreting these schematic curves.

- Ohmic conductor at constant temperature: straight line through the origin. On an I-vertical, V-horizontal graph its gradient is $1/R$.
- Filament lamp: as voltage magnitude rises, heating increases resistance. The I–V curve becomes less steep.
- NTC thermistor: heating lowers resistance. If current heats it sufficiently, the curve becomes steeper. At a controlled fixed temperature its behaviour over a suitable range can be approximately ohmic. Do not claim every thermistor curve must bend under every measurement condition.
- Diode: very small reverse current before breakdown; forward current rises rapidly after a characteristic knee. It conducts mainly in one direction. A real diode does not have one constant resistance.

For a curved graph, $R = V/I$ uses a line from the origin to the operating point. The tangent gradient is not generally $1/R$.

Resistivity and core practical 7

Resistivity ρ is a material property at a stated temperature:

$$R = \frac{\rho l}{A} \qquad A = \frac{\pi d^2}{4}$$

Lengthening a uniform wire increases resistance. Increasing cross-sectional area decreases it. Doubling diameter gives four times the area and one-quarter the resistance, if material, length and temperature stay unchanged.

For CP7, connect a uniform wire, ammeter, power supply, switch and current-limiting resistor in series. Connect a voltmeter across the measured wire length. Measure several lengths and find $R = V/I$ for each. Plot R against l: gradient $= \rho/A$, so $\rho = A \times$ gradient.

Measure diameter with a micrometer at several positions and orientations; check its zero. Measure length between the actual electrical contacts. Use a small current and switch off between readings to limit heating. Keep contacts secure. A non-zero intercept may indicate contact or lead resistance. Repeating readings reduces scatter but does not remove a diameter zero error. Because area depends on d^2, a small percentage diameter uncertainty contributes about twice that percentage to area uncertainty.

Worked example. A wire diameter is 0.40 mm. An R–l graph has gradient $3.5\ \Omega\,\mathrm{m}^{-1}$.

$$A = \frac{\pi d^2}{4} = \frac{\pi(0.40 \times 10^{-3}\ \mathrm{m})^2}{4} = 1.26 \times 10^{-7}\ \mathrm{m}^2$$

$$\rho = A \times \text{gradient} = 1.26 \times 10^{-7}\ \mathrm{m}^2 \times 3.5\ \Omega\,\mathrm{m}^{-1} = 4.4 \times 10^{-7}\ \Omega\,\mathrm{m}$$

The charge-carrier model

The **drift velocity** v is the small mean directed velocity of charge carriers, not their random thermal speed:

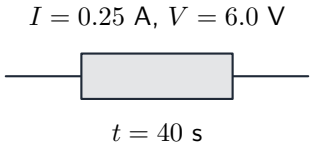
$$I = nqvA$$

Here n is the number of mobile carriers per unit volume, q is charge magnitude per carrier, and A is cross-sectional area. A larger carrier density allows the same current with a smaller drift speed. In series wires the current is the same; changing n or A changes v.

Materials have different resistivities because their carrier densities and the ease of carrier motion differ. More scattering reduces drift speed for the same applied potential gradient. Carrier density alone does not explain every difference between materials.

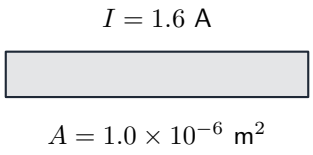
2 Practice

2.1 A 0.25 A current flows for 40 s through a component with p.d. 6.0 V. Calculate charge, transferred energy and power. [3]



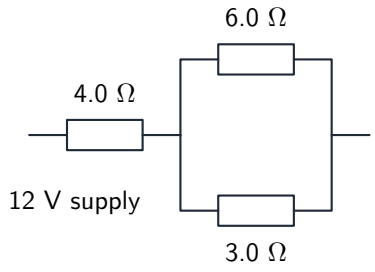
2.2 Derive the effective resistance of two parallel resistors from charge conservation. Explain why the effective resistance is smaller than either branch resistance. [4]

2.3 A metal wire has $n = 8.0 \times 10^{28}$ m^{-3}, area 1.0×10^{-6} m^2 and current 1.6 A. Calculate electron drift speed. Use $e = 1.60 \times 10^{-19}$ C. [3]

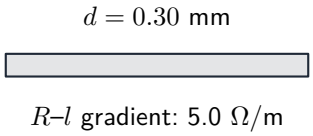


3 Exam-style questions

3.1 A 4.0 Ω resistor is in series with a parallel combination of 6.0 Ω and 3.0 Ω, supplied by an ideal 12 V source. Calculate total current and power in the 3.0 Ω branch. Explain why using $12^2/3.0$ for that branch is wrong. [5]



3.2 Plan a resistivity measurement using a uniform wire. An R–l best-fit line has gradient $5.0\ \Omega\,\mathrm{m}^{-1}$ and intercept $0.20\ \Omega$. Diameter is 0.30 mm. Calculate resistivity and suggest the origin of the intercept. [6]



3.3 On current–voltage axes, sketch an ohmic conductor, a filament lamp and a diode. State the relevant temperature condition for the ohmic graph. Explain why the tangent gradient of a curved graph does not generally give the reciprocal of V/I. [6]