Electricity

Current as a flow of charge carriers, quantised charge, I = Anvq, potential difference and power, resistance, I-V characteristics, Ohm's law, resistivity, LDRs and thermistors.

Electric current

Electric current is a flow of charge carriers. In a metal the carriers are free electrons, and in a salt solution they are positive and negative ions.

$$Q = It$$

Current is the rate of flow of charge, so 1 coulomb is the charge that passes when 1 A flows for 1 s.

Charge is **quantised**: it comes in whole-number multiples of the elementary charge $e = 1.60 \times 10^{-19}$ C. You can never have half an electron's charge on a free particle.

The transport equation

For a conductor of cross-section A, with n charge carriers per unit volume, each carrying charge q and moving with mean drift speed v:

$$I = Anvq$$

In a volume Avt there are $Avtn$ carriers, with total charge $Avtnq$. Dividing by the time t gives the current.

> TRY IT
>
> **A copper wire of area 1.0×10^{-6} m² carries 2.0 A, with $n = 8.5 \times 10^{28}$ m⁻³. Find the drift speed.** $v = I/(Anq) = 2.0/(1.0 \times 10^{-6} \times 8.5 \times 10^{28} \times 1.6 \times 10^{-19}) = 1.5 \times 10^{-4}$ m/s. That is slow: under a millimetre per second.

A thinner section of the same wire has the same current but a smaller area, so the electrons drift faster.

Potential difference and power

The **potential difference** across a component is the energy transferred per unit charge passing through it:

$$V = \frac{W}{Q}$$

So 1 V is 1 J/C.

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Electrical power

Power is the rate of energy transfer. Since $W = VQ$ and $Q = It$:

$$P = VI = I^2R = \frac{V^2}{R}$$

Use whichever form has the quantities you know. Energy transferred is $W = VIt$.

> TRY IT
>
> **A 2.0 kW heater runs on 230 V. Find the current and the resistance.** $I = P/V = 8.7$ A. $R = V^2/P = 230^2/2000 = 26\ \Omega$.

Resistance and resistivity

Resistance is the ratio of the potential difference across a component to the current through it:

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

The unit is the ohm, where $1\ \Omega = 1$ V/A.

I–V characteristics

- **Metallic conductor at constant temperature:** a straight line through the origin, so the resistance is constant.
- **Filament lamp:** an S-shaped curve. As the current increases, the filament gets hotter. Its ions vibrate more, the electrons collide with them more often, and the **resistance increases**.
- **Semiconductor diode:** almost no current in reverse. In the forward direction, the current rises sharply above about 0.6 V, so the resistance falls.

Resistance at a point on a curve is V/I at that point, **not** the gradient of the tangent.

Ohm's law

> **For a metallic conductor at constant temperature, the current is proportional to the potential difference across it.**

Resistivity

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

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where ρ is the **resistivity** of the material (Ω m), L is the length and A is the cross-sectional area. Resistivity is a property of the material, and resistance is a property of a particular sample.

TRY IT

A wire has resistance 12 Ω. It is stretched to twice its length with its volume unchanged. What is its new resistance? Its area halves as its length doubles, so R becomes $\rho(2L)/(A/2) = 4\rho L/A = 48\ \Omega$.

LDRs and thermistors

- **Light-dependent resistor (LDR):** resistance **decreases** as light intensity increases.
- **Thermistor (negative temperature coefficient):** resistance **decreases** as temperature increases.

In both, more energy frees more charge carriers, and that outweighs other effects. Chapter 10 shows how these are used in sensors.

NOTE

Exam tip: a voltmeter is taken to have infinite resistance, and an ammeter zero resistance, unless the question says otherwise.

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