A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 9 · ~7 MIN READ

Electricity

Current as a flow of charge carriers, quantised charge, Q = It and I = Anvq, potential difference and power, resistance and Ohm's law, I–V characteristics of a wire, diode and filament lamp, resistivity, and LDRs and thermistors.

Charge carriers | Q = It | I = Anvq | Potential difference | Power | Resistance | Ohm's law | I–V characteristics

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Current** is the rate of flow of charge: I = Q/t. In metals the charge carriers are free electrons. Charge is quantised: it comes in multiples of e = 1.60 × 10^{-19} C.
- **I = Anvq** links the current to the number density n of carriers and their drift speed v.
- **Potential difference** is energy transferred per unit charge: V = W/Q. Power P = VI = I^2R = V^2/R.
- **Resistance** R = V/I at any point. **Ohm's law** applies only when I ∝ V, e.g. a metal wire at constant temperature.
- **Resistivity** is a property of the material: R = ρL/A.

BY THE END YOU CAN

- Explain current as a flow of charge carriers and use Q = It and I = Anvq.
- Define potential difference and use V = W/Q and the three power equations.
- Define resistance, state Ohm's law, and sketch and explain I–V characteristics.
- Use R = ρL/A, and describe how LDR and thermistor resistances change.

1 Current and charge

Definitions

Electric current — the rate of flow of charge, I = ΔQ/Δt.

The coulomb — the charge that passes a point when a current of 1 A flows for 1 s (1 C = 1 A s).

- **Charge is quantised:** any charge is a whole-number multiple of the elementary charge e = 1.60 × 10^{-19} C.

WORKED EXAMPLE

A current of 2.5 A flows for 3.0 minutes. Find the charge and the number of electrons.

1. Q = It = 2.5 × 180 = **450 C** C1 A1
2. **N = 450/1.60 × 10^{-19} = 2.8 × 10^{21} electrons** A1

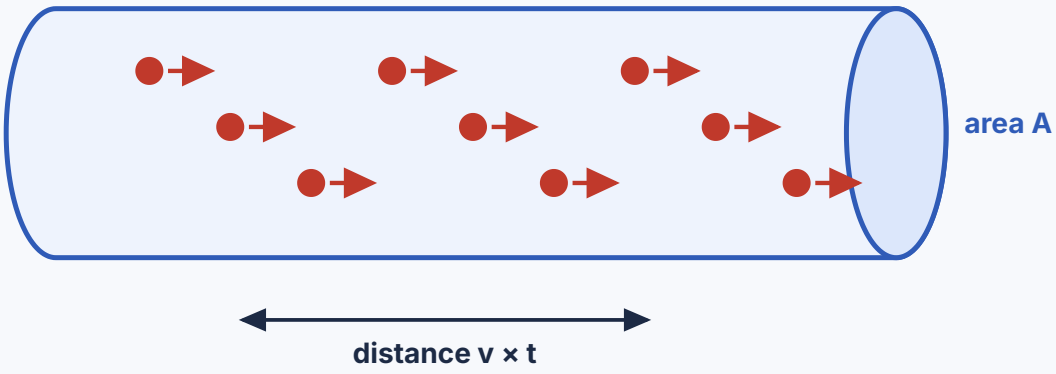
COMMON MISTAKE

Forgetting to convert minutes to seconds, or not converting coulombs to a number of e (2024 Paper 1).

I = Anvq

I = Anvq

n carriers per m^3, drift speed v, charge q



In time t, the carriers in a length vt of wire pass through the cross-section.

- **Derivation:** in time t, carriers move a distance vt. The volume Avt contains nAvt carriers with total charge nAvtq. So I = Q/t = Anvq.

$$I = Anvq$$ DATA & FORMULAE

n = number of charge carriers per unit volume; v = mean drift speed; q = charge on each carrier

WORKED EXAMPLE

A copper wire of cross-sectional area 1.0 mm^2 carries 2.0 A. Copper has 8.5×10^{28} free electrons per m^3. Find the drift speed.

1. $v = I/(Anq) = 2.0/(1.0 \times 10^{-6} \times 8.5 \times 10^{28} \times 1.60 \times 10^{-19})$ C1
2. **$= 1.5 \times 10^{-4}$ m s^{-1}** A1 **(very slow: the signal travels fast, the electrons don't)**

- **Same current, thinner section ⇒ faster drift** ($v \propto 1/A$). A semiconductor has a much smaller n, so its carriers drift much faster for the same current.

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2 Potential difference and power

Definitions

Potential difference — the energy transferred from electrical energy to other forms per unit charge passing between two points, V = W/Q.

The volt — one joule per coulomb.

$$P = VI = I^2R = V^2/R$$ LEARN IT

the last two use V = IR

WORKED EXAMPLE

A kettle is rated 2.0 kW at 230 V. Find the current and the resistance of its element.

1. $I = P/V = 2000/230 =$ **8.7 A** A1
2. **$R = V^2/P = 230^2/2000 = 26\ \Omega$** A1

3 Resistance

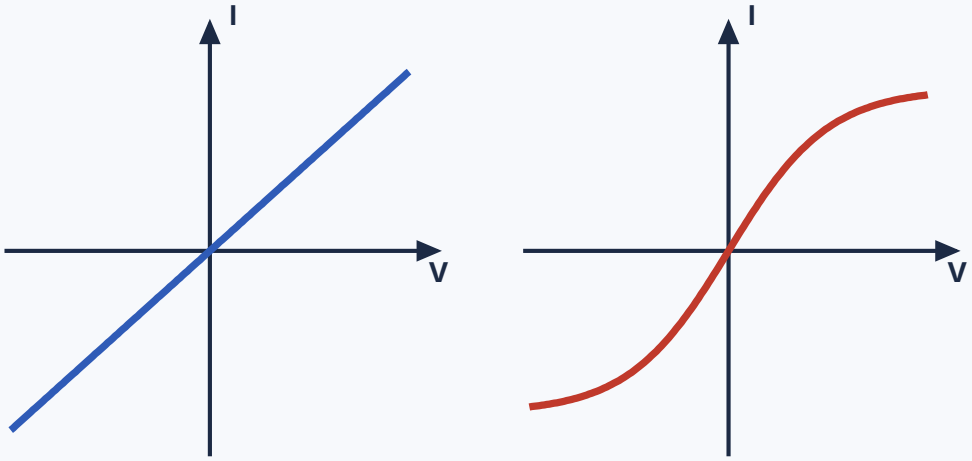
Definitions and Ohm's law

Resistance — the ratio of the potential difference across a component to the current in it, R = V/I.

The ohm — the resistance of a component when a p.d. of 1 V drives a current of 1 A through it.

Ohm's law — the current in a metallic conductor is proportional to the potential difference across it, provided the temperature (and other physical conditions) remain constant.

I–V characteristics



ohmic resistor:
straight line through origin

filament lamp: R rises
as it heats up (non-ohmic)

An ohmic conductor gives a straight line through the origin; a filament lamp's resistance rises with current.

Component	I–V graph	Explanation
Metal wire at constant temperature	straight line through the origin	R constant: obeys Ohm's law
Filament lamp	curve, gradient decreasing as V increases	higher current ⇒ hotter filament ⇒ ions vibrate more ⇒ more collisions ⇒ R increases
Semiconductor diode	almost zero current in reverse; current rises sharply above about 0.6 V forward	very high resistance in reverse, low resistance once forward-biased

- **Resistance at a point = V/I at that point,** not the gradient of the graph. The 2024 Paper 4 report also warns against confusing the inverse of the gradient with resistance.

WORKED EXAMPLE

From a lamp's I–V graph, I = 0.25 A when V = 6.0 V. Find its resistance at this point.

1. **R = V/I = 6.0/0.25 = 24 Ω** A1

Resistivity

Resistivity — a property of a material defined by ρ = RA/L; numerically the resistance of a sample of unit length and unit cross-sectional area (Ω m).

$$R = \rho L/A$$ LEARN IT

L = length, A = cross-sectional area

WORKED EXAMPLE

A nichrome wire (ρ = 1.1 × 10^{-6} Ω m) is 0.80 m long with diameter 0.30 mm. Find its resistance.

1. $A = \pi(0.15 \times 10^{-3})^2 = 7.07 \times 10^{-8}$ m² C1
2. **$R = 1.1 \times 10^{-6} \times 0.80/7.07 \times 10^{-8} = 12$ Ω** A1

COMMON MISTAKE

Confusing resistance and resistivity (2024 Paper 1). Resistance depends on the shape of the sample; resistivity depends only on the material (and temperature).

LDRs and thermistors

- **Light-dependent resistor (LDR):** resistance decreases as light intensity increases (more charge carriers are released).
- **Thermistor (NTC):** resistance decreases as temperature increases. Assume a negative temperature coefficient in this syllabus.
- They are used in potential dividers to make sensing circuits: see D.C. circuits.

LINKING QUESTION

Circuits and potential dividers build on this in D.C. circuits; charge flow is quantised as in Particle physics; and the Hall effect uses I = Anvq in Magnetic fields.

Test yourself — cover the answers first

QUICK CHECK

1. Define potential difference.
2. State Ohm's law.
3. A wire is stretched to twice its length at constant volume. By what factor does R change?
4. How does the resistance of an NTC thermistor change as it warms?
5. Find the energy transferred by a 3.0 Ω heater on 12 V for 5.0 minutes.

EXAM-STYLE

6. Explain why the resistance of a filament lamp increases as the current increases.
7. Two wires of the same material carry the same current. Wire X has twice the diameter of wire Y. Find the ratio of drift speeds $v_X : v_Y$.
8. Show that the ohm is equivalent to kg m^2 s^{-3} A^{-2}.

Show answers

1. energy transferred from electrical to other forms per unit charge
2. $I \propto V$ for a metallic conductor at constant temperature
3. ×4 (L doubles, A halves)
4. it decreases
5. P = 48 W; E = 14 400 J
6. more current ⇒ higher temperature ⇒ lattice ions vibrate with greater amplitude ⇒ electrons collide more often ⇒ resistance rises
7. $A_X = 4A_Y$, so $v_X : v_Y = 1 : 4$
8. $V = W/Q$ = kg m^2 s^{-2}/(A s) = kg m^2 s^{-3} A^{-1}; $\Omega = V/A$ = kg m^2 s^{-3} A^{-2}

Stuck on a question?

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