IB DP PHYSICS · THEME B THE PARTICULATE NATURE OF MATTER · B.5 · ~8 MIN READ

B.5 Current and circuits

Charge and current, potential difference, resistance and resistivity, Ohm's law and I–V graphs, electrical power, series and parallel circuits, potential dividers, emf and internal resistance.

Current | Potential difference | Resistance & resistivity | Ohm's law & I–V graphs | Power | Series & parallel | Potential dividers | emf & internal resistance

RS by Riyaz Sir
mentorriyaz.in

No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 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 = Δq/Δt. **Potential difference** is the energy transferred per unit charge, V = W/q.
- **Resistance** R = V/I comes from charge carriers colliding with the lattice. For a wire, **R = ρL/A**.
- **Series:** same current, voltages add, resistances add. **Parallel:** same voltage, currents add, 1/R adds.
- A real cell has **emf ε** and **internal resistance r**: ε = I(R + r), so the terminal voltage V = ε − Ir drops as the current rises.
- **B.5 is the same at SL and HL.**

BY THE END YOU CAN

- Use I = Δq/Δt, V = W/q and R = V/I, and describe conductors and insulators.
- Use resistivity, and interpret I–V graphs for ohmic and non-ohmic components.
- Calculate power and energy in circuits.
- Analyse series and parallel combinations and potential dividers.
- Use emf and internal resistance, and interpret V–I graphs for a cell.

1 Charge, current and potential difference

$$I = \frac{\Delta q}{\Delta t}$$ DATA BOOKLET

current in amperes; conventional current flows + to −

$$V = \frac{W}{q}$$ DATA BOOKLET

potential difference in volts (J C^{-1})

- **Conductors** have many mobile charge carriers (free electrons in metals, ions in solutions); **insulators** have almost none. Semiconductors sit in between, and their carrier number rises with temperature.
- **Cells** are sources of emf: chemical cells convert chemical energy, solar cells convert light energy into electrical energy.

WORKED EXAMPLE

A current of 0.25 A flows for 2.0 minutes. Find the charge and the number of electrons.

1. q = It = 0.25 × 120 = **30 C** A1
2. **N = 30/(1.60 × 10^{-19}) = 1.9 × 10^{20} electrons** A1

2 Resistance

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

resistance in ohms (Ω)

$$\rho = \frac{RA}{L}$$ DATA BOOKLET

resistivity in Ω m: a property of the material

- **Why resistance:** electrons are accelerated by the field but keep colliding with the vibrating ions of the lattice, transferring energy to them (the wire heats up). Heating makes the ions vibrate more, so resistance usually rises with temperature in metals.

WORKED EXAMPLE

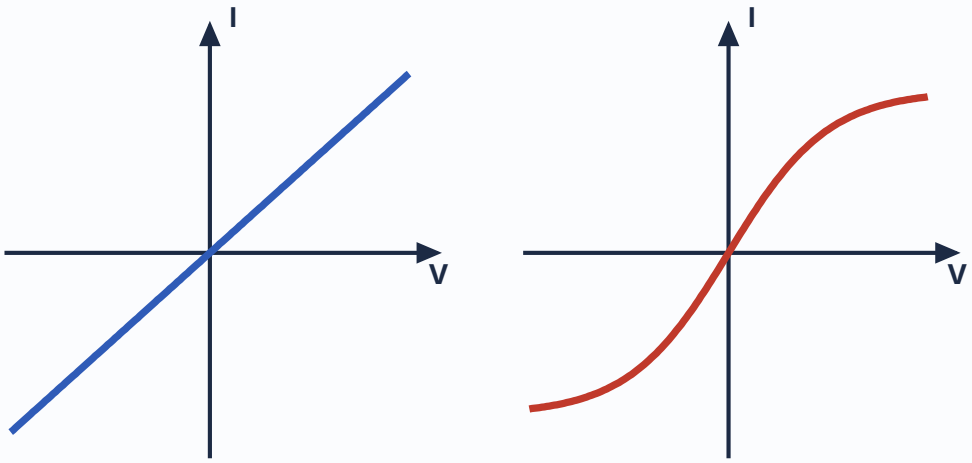
A copper wire is 2.0 m long with diameter 0.50 mm ($\rho = 1.7 \times 10^{-8}$ Ω m). Find its resistance.

1. $A = \pi(0.25 \times 10^{-3})^2 = 1.96 \times 10^{-7}$ m^2 M1
2. $R = \rho L/A = 1.7 \times 10^{-8} \times 2.0/1.96 \times 10^{-7}$ M1
3. **= 0.17 Ω** A1

COMMON MISTAKE

Using the diameter instead of the radius in $A = \pi r^2$. Halving the diameter quarters the area and **quadruples** the resistance.

Ohm's law and I–V graphs



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 curves because its resistance rises as it gets hotter.

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

- **R at a point is V/I**, not the gradient of the I–V graph. For a curved graph, read V and I at that point.

$$P = IV = I^2R = \frac{V^2}{R}$$ DATA BOOKLET

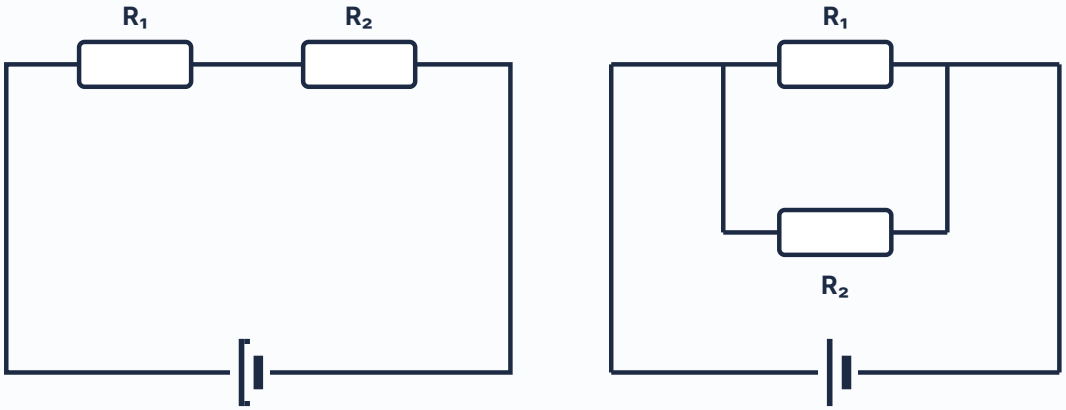
electrical power; energy = Pt

WORKED EXAMPLE

A lamp is rated 60 W, 230 V. Find the current and its resistance when lit.

1. $I = P/V = 60/230 =$ **0.26 A** A1
2. **$R = V^2/P = 230^2/60 = 880\ \Omega$** A1

3 Series and parallel



series: same I

$R = R_1 + R_2$

parallel: same V

$1/R = 1/R_1 + 1/R_2$

In series the charge has one path; in parallel it splits between branches.

	Series	Parallel
current	the same everywhere: $I = I_1 = I_2$	adds: $I = I_1 + I_2$
voltage	adds: $V = V_1 + V_2$	the same: $V = V_1 = V_2$
resistance	$R_s = R_1 + R_2 + \ldots$	$1/R_p = 1/R_1 + 1/R_2 + \ldots$

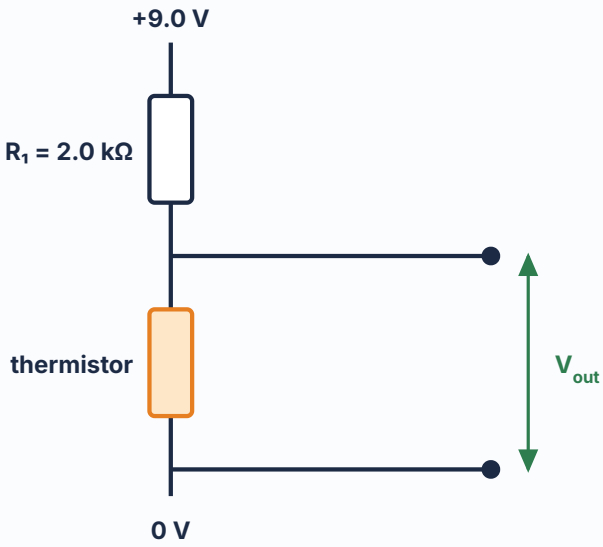
- All of these are in the data booklet DATA BOOKLET. Adding a resistor **in parallel** always **lowers** the total resistance.

WORKED EXAMPLE

A 6.0 Ω resistor is in series with a parallel pair of 4.0 Ω and 12 Ω, across an 18 V supply. Find every current.

1. parallel pair: 1/R = 1/4 + 1/12 = 1/3, so R_p = 3.0 Ω M1
2. total 9.0 Ω, so I = 18/9.0 = **2.0 A** through the 6.0 Ω A1
3. V across the pair = 2.0 × 3.0 = 6.0 V M1
4. **$I_{4\Omega}$ = 6.0/4.0 = 1.5 A, $I_{12\Omega}$ = 6.0/12 = 0.50 A (they add to 2.0 A ✓)** A1

Potential dividers and variable resistors



$V_{out} = V \times R_2/(R_1 + R_2)$

thermistor at 1.0 kΩ:

V_{out} = 9.0 × 1/3 = 3.0 V

warmer ⇒ R_2 falls

⇒ V_{out} falls

Two resistors share the supply voltage in proportion to their resistances.

$$V_{out} = V \times \frac{R_2}{R_1 + R_2}$$

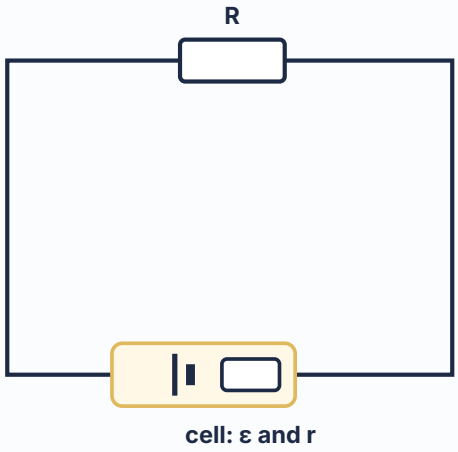
potential divider (derive it from I = V/(R_1 + R_2))

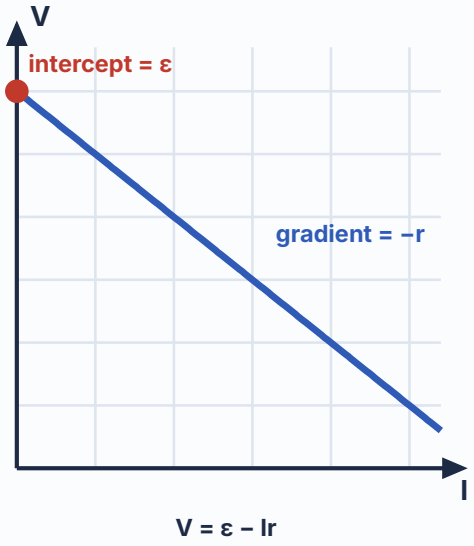
- **Sensors:** a thermistor's resistance falls as temperature rises; a light-dependent resistor's falls as light intensity rises. Put one in a divider to make a voltage that tracks temperature or light.
- **Variable resistor (rheostat) vs potentiometer:** a rheostat in series changes the current; a potentiometer (three terminals) used as a divider can give any voltage from 0 to the full supply.

4 emf and internal resistance

$$\varepsilon = I(R + r)$$ DATA BOOKLET

emf = energy per unit charge given by the cell; r = internal resistance





Measuring terminal voltage at different currents gives a straight line: intercept ε, gradient −r.

- **Terminal voltage** V = IR = ε − Ir. The "lost volts" Ir are dissipated inside the cell, which is why cells warm up at high current.

WORKED EXAMPLE

A cell of emf 12 V and internal resistance 0.50 Ω drives current through a 5.5 Ω resistor. Find the current, terminal voltage and power in the resistor.

1. I = ε/(R + r) = 12/6.0 = **2.0 A** M1 A1
2. V = ε − Ir = 12 − 1.0 = **11 V** A1
3. **P = I^2R = 4.0 × 5.5 = 22 W** A1

COMMON MISTAKE

Thinking the emf is the voltage across the terminals. They are equal only when no current flows (an open circuit or an ideal voltmeter).

EXAM TIP

"Explain why the terminal voltage falls when more lamps are added in parallel": total R falls → I rises → lost volts Ir rise → V = ε − Ir falls.

LINKING QUESTION

Moving charges in conductors connect to D.3 (force on a current in a magnetic field) and to D.4, where a changing magnetic flux becomes the source of emf.

IDEA FOR YOUR IA / EXPLORATION

Determine the emf and internal resistance of a fruit cell or a solar cell from a V–I graph, and investigate how the internal resistance depends on electrode separation or light intensity.

Test yourself — cover the answers first

QUICK CHECK

1. Define potential difference.
2. What is the unit of resistivity?
3. A wire's length doubles and its diameter doubles. What happens to R?
4. Three 6 Ω resistors are in parallel. Total resistance?
5. What does the gradient of a V–I graph for a cell give?
6. When does the terminal voltage equal the emf?

EXAM-STYLE

7. A 9.0 V battery with internal resistance 1.0 Ω is connected to two 4.0 Ω resistors in parallel. Find the current from the battery and the power dissipated inside the battery.

8. A heater draws 8.0 A from a 230 V supply. How much does it cost to run for 3.0 hours at ₹8 per kWh?

Show answers

1. work done (energy transferred) per unit charge between two points
2. Ω m
3. $R \propto L/d^2$: × 2/4, so it halves
4. 2 Ω
5. −r (minus the internal resistance)
6. when no current flows
7. R_p = 2.0 Ω; I = 9.0/(2.0 + 1.0) = **3.0 A**
   power in r = I^2r = 9.0 × 1.0 = **9.0 W**
8. P = 230 × 8.0 = 1840 W = 1.84 kW
   energy = 1.84 × 3.0 = 5.52 kWh
   cost = 5.52 × 8 ≈ **₹44**

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Want regular help? Send this to your parent →

Share with a friend

Ask Riyaz Sir