Current and circuits

B.5 · SL and HL

Why does a phone battery go flat?

> A circuit moves energy from a source to components, one coulomb at a time.

- Invented battery model: 50 kJ of stored energy.
- Used hard, the battery warms up: some energy is wasted inside it.
- This unit: emf $\rightarrow$ current and pd $\rightarrow$ resistance $\rightarrow$ power $\rightarrow$ circuits $\rightarrow$ **internal resistance**.

Emf and sources

- A 1.5 V cell gives 1.5 J to every coulomb.
- Chemical cells are portable; solar cells need no fuel but no light means no output.

$$\varepsilon = \frac{W}{q}$$

Emf is energy given to each coulomb by the source.

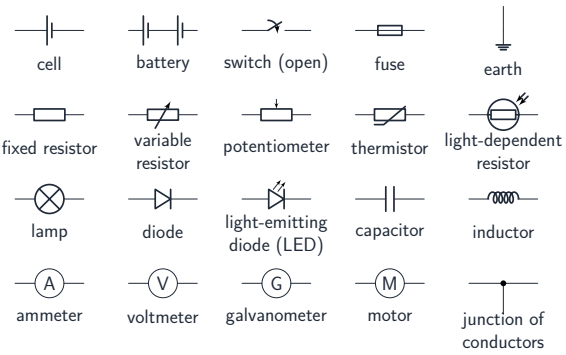
Current and potential difference

- 3.0 C in 1.5 s is 2.0 A, 1.25×10^{19} electrons per second.
- 12 J transferred by 2.0 C in a lamp means 6.0 V across it.

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

Ammeters go in series; voltmeters go in parallel.

The circuit symbols



Draw them exactly as in the data booklet

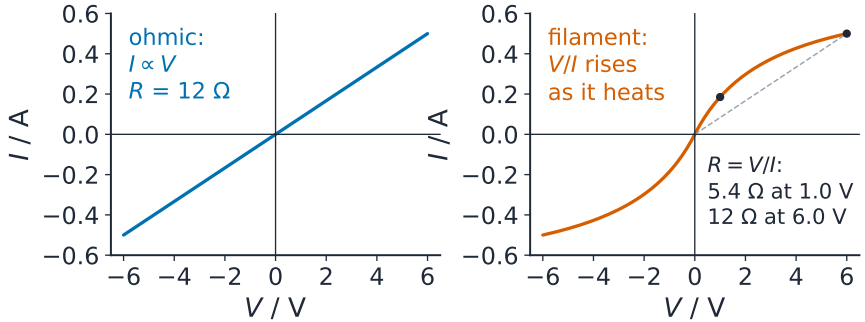
Resistance and resistivity

- Electrons collide with vibrating lattice ions, transferring energy.
- 2.0 m of 0.50 mm copper wire is 0.17 Ω; nichrome would be 11 Ω.

$$R = \frac{V}{I} \qquad R = \frac{\rho L}{A}$$

Double the length doubles R; double the area halves R.

Ohmic and non-ohmic



- **Ohm's law** holds at constant temperature.
- A heating filament collides electrons more often, so R rises.

Measuring an I–V characteristic

1. **Connect.** Ammeter in series; voltmeter across the component; variable low-voltage dc supply.
2. **Measure.** Change the pd in steps; record both V and I at each setting.
3. **Reverse.** Reverse polarity when the component permits; plot I against V.
4. **Control.** Limit current and switch off between readings to reduce unwanted heating.

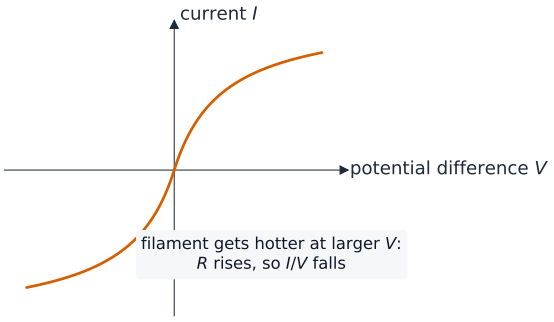
Decision

Keep an **ohmic** wire at constant temperature.

Variable resistors

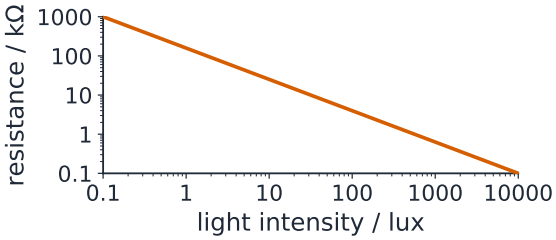
Component	Response
NTC **thermistor**	Resistance falls as temperature rises.
LDR	Resistance falls as light gets brighter.
potentiometer	Slider changes track segments; full-track resistance can stay fixed.

The filament lamp is non-ohmic



$R = V/I$ at a point, not the gradient

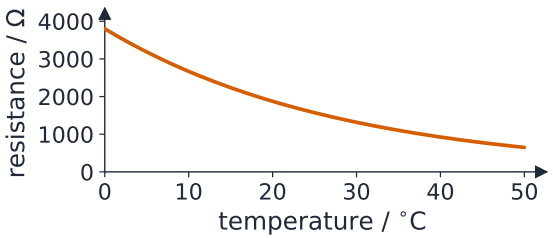
An LDR in light and dark



LDR: more light $\Rightarrow$ lower R

Both axes are logarithmic

An NTC thermistor



NTC: R falls as T rises

Resistance falls steeply as it warms

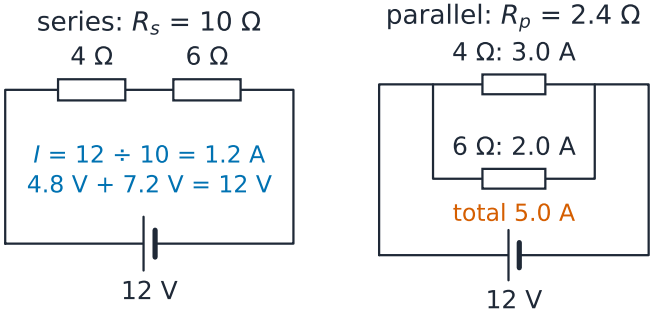
Electrical power

- Kettle: 2.3 kW on 230 V draws 10 A; its element is 23 Ω.
- Halving the current in a cable quarters the energy wasted.

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

Use the form that contains the quantities you know.

Series and parallel



- Current rule is conservation of charge; pd rule is conservation of energy.
- A parallel total is less than the smallest resistor.

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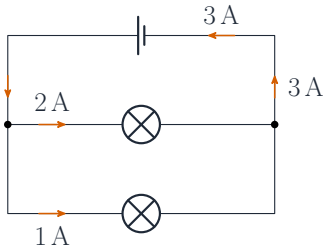
Worked example: a combined circuit

1. **Known.** Ideal 12 V supply; 2.0 Ω in series with a parallel pair of 6.0 Ω and 3.0 Ω.
2. **Parallel.** $1/R_p = 1/6.0 + 1/3.0$, so $R_p = 2.0$ Ω; total 4.0 Ω.
3. **Supply.** $I = 12/4.0 = 3.0$ A; 6.0 V across each part.
4. **Branches.** $6.0/6.0 = 1.0$ A and $6.0/3.0 = 2.0$ A.

Decision

1.0 A + 2.0 A = 3.0 A, as charge is conserved

Current divides at a junction



at each junction: $3\,\mathrm{A} = 2\,\mathrm{A} + 1\,\mathrm{A}$

Charge is conserved at every junction

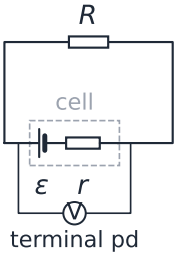
Internal resistance

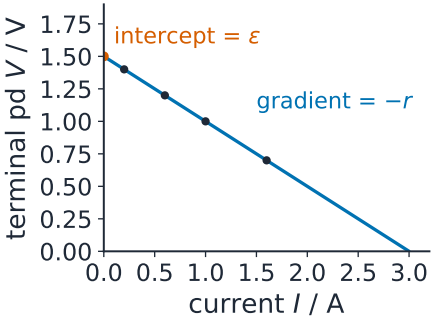
- $\varepsilon = 6.0$ V, $r = 0.50\ \Omega$, $R = 2.5\ \Omega$ gives $I = 2.0$ A.
- Terminal pd 5.0 V; 1.0 V is lost inside the cell.

$$\varepsilon = I(R + r) = V + Ir$$

The lost volts Ir warm the cell.

Measuring emf and internal resistance





- Plot terminal pd V against current I.
- Intercept ε; gradient $-r$.

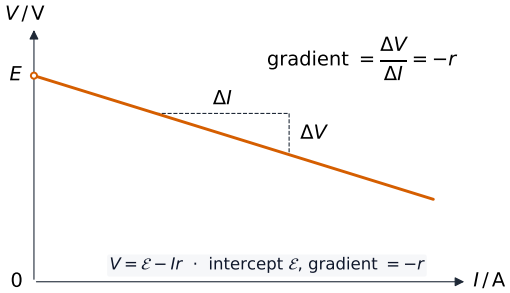
Check: a cell and a resistor

Your turn

A discharging cell has emf 1.5 V and internal resistance 0.40 Ω, with an external 2.6 Ω resistor. What is its terminal pd?

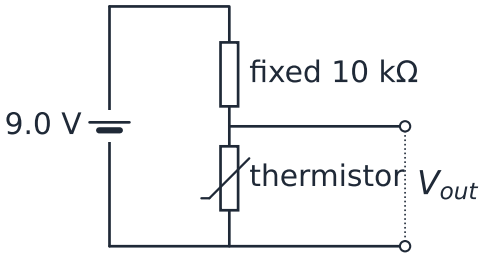
A. 0.20 V
B. 1.1 V
C. 1.3 V
D. 1.5 V

Measuring e.m.f. and internal resistance



$$V = E - Ir$$

Potential dividers



$$V_{out} = 9.0 \times \frac{R_{th}}{R_{th} + 10\ \text{k}\Omega}$$

cold: $R_{th} = 20\ \text{k}\Omega \rightarrow V_{out} = 6.0\ \text{V}$

warm: $R_{th} = 5\ \text{k}\Omega \rightarrow V_{out} = 3.0\ \text{V}$

- With negligible output load, the larger series resistor takes the larger share.
- A **thermistor** or LDR makes a sensor circuit.

Exam tips

> For a **non-ohmic** component, find $R = V/I$ at a point, never from the gradient.

- Emf is energy given; pd is energy transferred.
- Convert diameters to radii and mm^2 to m^2.
- Terminal pd falls as current rises.

Check yourself

Try these

Find the resistivity of a 1.5 m wire of area 2.0×10^{-7} m^2 and resistance 0.13 Ω.

Find the total resistance of three 12 Ω resistors, two in parallel and one in series.

An ideal 9.0 V supply has a fixed upper 10 kΩ resistor and a lower 10 kΩ thermistor. Find the unloaded output across the thermistor.