Cambridge IGCSE · Physics 0625 · Notes

Electric circuits

Read online at **pastopic.com/cambridge/physics-0625/notes/electric-circuits**

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Read first: Electrical quantities

What you need to know

This topic is about how components are joined into circuits, and what the current and potential difference (p.d.) do in them. It builds on current, p.d., resistance and $V = IR$ from the electrical quantities topic. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

1. **Draw and read circuit diagrams** containing cells, batteries, power supplies, generators, potential dividers, switches, fixed and variable resistors, heaters, NTC thermistors, light-dependent resistors (LDRs), lamps, motors, bells, ammeters, voltmeters, magnetising coils, transformers, fuses and relays, and know what each one does in a circuit.
2. **Extended only:** do the same for diodes and light-emitting diodes (LEDs).
3. **Know that the current is the same at every point in a series circuit.**
4. **Build and use series and parallel circuits.**
5. **Work out the combined e.m.f. of several cells or other sources in series.**
6. **Work out the combined resistance of two or more resistors in series.**
7. **State that in a parallel circuit the current from the source is larger than the current in any one branch.**
8. **State that two resistors in parallel have a combined resistance less than either resistor on its own.**
9. **State the advantages of wiring lamps in parallel** in a lighting circuit.
10. **Extended only:** recall and calculate with three rules: the currents going into a junction add up to the currents coming out; the p.d.s across components in series add up to the total p.d.; and every branch of a parallel arrangement has the same p.d. across it.
11. **Extended only:** explain why the current into a junction equals the current out of it.
12. **Extended only:** calculate the combined resistance of two resistors in parallel.
13. **Know that, for the same current, a conductor with more resistance has a larger p.d. across it.**
14. **Extended only:** describe how a variable potential divider works.
15. **Extended only:** recall and use the potential divider equation $\dfrac{R_1}{R_2} = \dfrac{V_1}{V_2}$.

Understand it

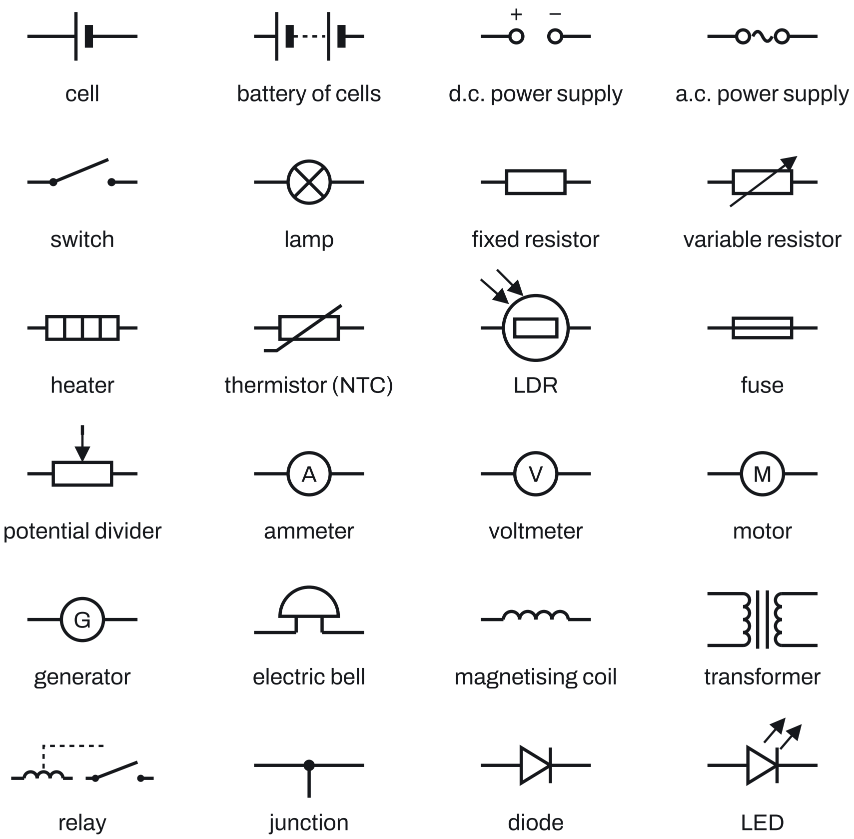
A circuit is a complete loop

A current is a flow of charge (in metal wires, electrons). Charge only flows if there is a **complete loop** of conductors from one terminal of the supply, through the components, and back to the other terminal. Any gap, such as an open switch, a broken filament or an insulator, stops the current in that whole loop.

The cell or power supply pushes the charge round: its **e.m.f.** is the energy it gives each coulomb. The components take that energy from the charge: the **p.d.** across a component is the energy each coulomb transfers there.

Circuit symbols

Circuit diagrams use standard symbols, drawn with straight wires and square corners. You must be able to draw each one and recognise it.



Tips for telling similar symbols apart:

- **Cell and battery.** The long thin line is the positive (+) terminal and the short thick line is the negative (−). A **battery** is two or more cells joined in series; a dashed line between two cells means "more cells here".
- **Circles with a letter:** A ammeter, V voltmeter, M motor, G generator. A circle with a cross is a **lamp**.

- **Rectangles:** a plain rectangle is a **fixed resistor**. With an arrow through it, a **variable resistor**. With a line through it lengthwise (the wire runs right through), a **fuse**. Divided into sections, a **heater**. With a bent line through it, a **thermistor**. Inside a circle with two arrows pointing **in** (light arriving), an **LDR**. With an arrow pointing at its side (the slider), a **potential divider**.
- **Diode and LED (Extended only):** a triangle pointing at a bar. An LED has two arrows pointing **out** (light leaving).
- A **junction** where wires join is shown with a dot. Wires that cross without a dot are not joined.

What each component does

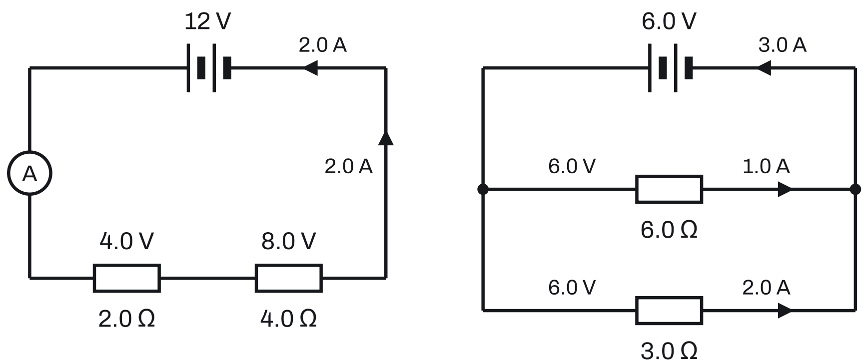
Component	What it does in a circuit
Cell, battery, power supply	Provides the e.m.f. that drives the current. A d.c. supply pushes one way; an a.c. supply keeps reversing
Generator	Produces an e.m.f. when it is turned (electromagnetic induction)
Switch	Open: a gap, no current. Closed: completes the loop
Fixed resistor	Limits the current; its resistance does not change
Variable resistor	Its resistance can be changed, to control the current (for example, to dim a lamp or slow a motor)
Lamp	Lights when there is a current; the bigger the current, the brighter
Heater	Transfers electrical energy to thermal energy
Motor	Turns when there is a current
Bell	Rings when there is a current
Thermistor (NTC)	Its resistance **falls** as its temperature **rises**; used as a temperature sensor
LDR	Its resistance **falls** as the light on it gets **brighter**; used as a light sensor
Ammeter	Measures current. Connected **in series**, so the current flows through it
Voltmeter	Measures p.d. Connected **in parallel**, across the component
Fuse	A thin wire that melts if the current gets too big, breaking the circuit
Magnetising coil	Becomes an electromagnet when there is a current in it
Relay	A coil that, when it has a current, pulls a switch closed (or open). A small current in one circuit switches a second circuit, often one with a larger current
Transformer	Changes the size of an alternating p.d.
Potential divider	Two resistances (or one resistor with a slider) that share out the supply p.d.
Extended only: diode	Lets current through in one direction only (the way the triangle points)

Component	What it does in a circuit
Extended only: LED	A diode that gives out light when current passes through it forwards

Series circuits

In a **series** circuit the components are one after another in a single loop, so there is only one path. The same charge goes through every component, so:

- **The current is the same at every point.** Ammeters anywhere in the loop give the same reading. No current is "used up" by a component; it is energy that is transferred.
- **Resistances add:** $R = R_1 + R_2 + R_3 + \ldots$ Each extra resistor makes the current smaller.
- **Cells in series add their e.m.f.s:** four 1.5 V cells make a 6.0 V battery. A cell turned the wrong way round subtracts its e.m.f. instead.
- **Extended only:** the p.d.s add up to the supply p.d. Each coulomb gets its energy from the battery and hands it all over along the loop.
- Because the current is the same in each part, $V = IR$ says that **the component with the larger resistance has the larger p.d.** across it.



series: same current, p.d.s add

parallel: same p.d., currents add

In the series circuit above, $R = 2.0 + 4.0 = 6.0\ \Omega$, so $I = \dfrac{12}{6.0} = 2.0$ A. The p.d.s are $2.0 \times 2.0 = 4.0$ V and $2.0 \times 4.0 = 8.0$ V, and $4.0 + 8.0 = 12$ V.

Parallel circuits

In a **parallel** circuit the current splits at a junction into two or more **branches**, then joins up again. So:

- **The current from the source is bigger than the current in any one branch**: it is the sum of the branch currents. **Extended only:** at a junction, the current in equals the total current out. Charge is not made or destroyed at a junction, and it does not pile up there, so every coulomb that arrives each second must leave each second.

- **Extended only:** each branch has the **same p.d.** across it, equal to the p.d. across the whole parallel arrangement. With nothing else in the circuit, that is the supply p.d.
- **The combined resistance is less than the smallest single resistance.** Adding a branch gives the charge an extra path, so more current flows for the same p.d.

In the parallel circuit above, each branch has 6.0 V across it, so the currents are $\frac{6.0}{6.0} = 1.0$ A and $\frac{6.0}{3.0} = 2.0$ A, and the battery supplies $1.0 + 2.0 = 3.0$ A. The combined resistance is $\frac{6.0}{3.0} = 2.0\ \Omega$, less than either resistor.

Extended only: for two resistors in parallel,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}, \qquad \text{or} \qquad R = \frac{R_1 R_2}{R_1 + R_2} \ \ \text{(product over sum)}.$$

For $6.0\ \Omega$ and $3.0\ \Omega$: $R = \frac{6.0 \times 3.0}{6.0 + 3.0} = 2.0\ \Omega$, the same answer. Two **identical** resistors in parallel give half of one: two $10\ \Omega$ resistors give $5.0\ \Omega$.

Why lamps in a house are in parallel

- Each lamp gets the **full supply p.d.**, so it works at its proper brightness.
- If one lamp **fails** (its filament breaks), the others stay on, because their loops are still complete. In series, one broken lamp puts them all out.
- Each lamp can have its own switch, so it can be **switched on and off on its own**.

Potential dividers

Two resistors in series across a supply share the supply p.d. between them. The same current is in both, so the bigger resistance gets the bigger share. This arrangement is a **potential divider**, and the p.d. across one of the resistors is its output.

Extended only: because $V = IR$ with the same I, the p.d.s are in the same ratio as the resistances:

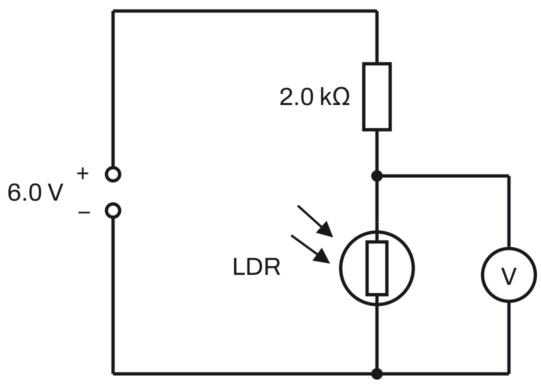
$$\frac{R_1}{R_2} = \frac{V_1}{V_2}, \qquad \text{so} \qquad V_2 = \frac{R_2}{R_1 + R_2} \times V_{\text{supply}}.$$

With $R_1 = 1.0$ kΩ and $R_2 = 3.0$ kΩ across 8.0 V, the p.d.s are in the ratio $1 : 3$, so $V_1 = 2.0$ V and $V_2 = 6.0$ V.

Extended only: a **variable potential divider** is one resistor with a sliding contact. The output is taken between one end and the slider. With the slider at that end, the output is 0 V; sliding it to the other end raises the output smoothly up to the full supply p.d. That is how it can vary the p.d. across a lamp all the way from 0 V, which a variable resistor in series cannot do.

Sensors in a potential divider

Put an LDR or a thermistor in a potential divider and its changing resistance makes the output p.d. change.



light	LDR	*V*
dark	10 kΩ	5.0 V
bright	0.40 kΩ	1.0 V

- In the dark the LDR has the larger resistance (10 kΩ against 2.0 kΩ), so it takes most of the 6.0 V: $\frac{10}{12} \times 6.0 = 5.0$ V.
- In bright light its resistance falls to 0.40 kΩ, so it takes a small share: $\frac{0.40}{2.4} \times 6.0 = 1.0$ V. The p.d. across the fixed resistor rises from 1.0 V to 5.0 V, because the two always add up to 6.0 V.

A thermistor behaves the same way with temperature: hotter means lower resistance, a smaller share of the p.d. and a larger current. The output can switch on a **relay**, which then switches a lamp, heater, fan or alarm in a second circuit: a night light (LDR, lamp comes on in the dark), a fire alarm (thermistor, bell rings when hot), a frost alarm.

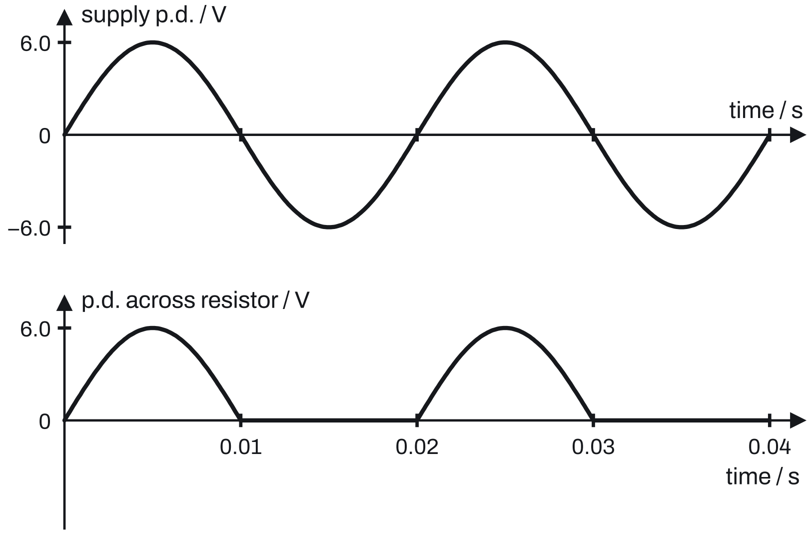
In a simple **series** loop with a lamp, the same idea gives: brighter light on an LDR (or a hotter thermistor) → less resistance → bigger current → brighter lamp and a bigger ammeter reading.

Diodes and rectification

Extended only: a **diode** lets current flow only in the direction its triangle points (it has a very high resistance the other way). Connected the wrong way round in a series loop, it stops the current: an LED in that loop does not light, and the ammeter reads 0.

On a current–p.d. graph a diode shows almost no current for reverse (negative) p.d.s and a current that rises steeply once the forward p.d. is big enough. You may be asked to name a diode from this graph.

With an **a.c.** supply, a diode in series with a resistor passes only the half-cycles that go the right way. The output is current in **one direction only**: d.c. that comes in pulses. This is **rectification**, and turning a.c. into d.c. is the diode's main use. A "bridge" of four diodes lets both halves through, all in the same direction (full-wave rectification).



An **LED** is a diode that lights when current passes through it forwards. Each colour of LED has its own current–p.d. graph. In parallel, LEDs all have the same p.d. across them, so read each LED's current off its own graph at that p.d. and **add** them to get the total.

Key facts and formulas

The 0625 papers have no formula sheet, so learn every equation.

Formula	Status
$V = IR$ (p.d. = current × resistance)	Learn it
$P = IV$ and $E = IVt$ (power in W, energy in J, t in s)	Learn it
$Q = It$ (charge in C)	Learn it
Series: same current everywhere	Learn it
Series resistances: $R = R_1 + R_2 + \dots$	Learn it
Series cells: e.m.f.s add (a reversed cell subtracts)	Learn it
Parallel: source current $>$ current in any branch	Learn it
Parallel: combined resistance $<$ the smallest resistor	Learn it
Extended only: junction: $I = I_1 + I_2$ (total in = total out)	Learn it
Extended only: series: $V = V_1 + V_2 + \dots$	Learn it
Extended only: parallel: same p.d. across every branch	Learn it
Extended only: two in parallel: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$, or $R = \frac{R_1 R_2}{R_1 + R_2}$	Learn it
Extended only: potential divider: $\frac{R_1}{R_2} = \frac{V_1}{V_2}$	Learn it
Units: 1 kΩ $= 1000\ \Omega$; 1 mA $= 0.001$ A; energy in kWh = power in kW × time in hours	Learn it

How to do it

In the Paper 1–4 questions we have tagged for this topic (218 questions, 178 of them different, 2021–2025), the types came up this often. 60 of the different questions mix types (a long structured question often has five or more), so the counts add up to more than 178.

Question type	Questions
Draw, complete or read circuit diagrams and symbols	60
Use $V = IR$, $P = IV$, $E = IVt$ or $Q = It$ for one component	49
Combined resistance of series or parallel resistors	44
The p.d. rules and potential dividers	37
LDR and thermistor circuits	34
The current rules	31
Effect of a variable resistor, slider or extra branch	19
Diodes and LEDs	17
Which switches to close, which lamps light	15
Cells in series	11
Advantages of lamps in parallel	8

1. Draw, complete or read circuit diagrams and symbols (60 questions)

1. **Use the standard symbol for every part**, exactly as in the symbol grid above. A lamp is a circle with a cross, not a drawing of a bulb.
2. **Draw wires as straight lines** with square corners, and leave **no gaps**: every component must be in a complete loop.
3. **Put ammeters in series** (in the loop, so the current passes through) and **voltmeters in parallel** (connected from one side of the component to the other, on their own separate wires).
4. For "in series", draw one single loop. For "in parallel", give each component its own branch between the same two junctions.

Variations you will meet:

- **Draw a circuit from a photo, sketch or list** ("a battery, a lamp and a switch in series"). Marks go to each correct symbol, then one for the correct connection.
- **Complete a part-drawn circuit**: add a missing voltmeter across a component, a cell, a switch, or a second lamp. A second lamp that makes the ammeter reading **bigger** must go **in parallel**.
- **Name a component from its symbol**, match symbols to names, or pick the diagram that contains a named part (a fuse, an LDR, a thermistor and a heater, a diode in series with a resistor).
- **Count the parts**: how many cells, lamps and switches a diagram has.

- **Say what a meter measures**: an ammeter measures current, a voltmeter p.d. Write the quantity ("current"), not "ammeter reading".
- **Extended only:** draw the symbol for a potential divider, a diode or an LED; draw a battery with the right number of cells for a given e.m.f.

2. Use $V = IR$, $P = IV$, $E = IVt$ or $Q = It$ for one component (49 questions)

1. **Pick out the values for that one component**: the current through it and the p.d. across it (from the meters, or from the rules in types 4 and 6).
2. **Write the equation**, rearranged if needed: $R = \frac{V}{I}$, $I = \frac{V}{R}$, $P = IV$, $E = IVt$.
3. **Convert units first**: minutes and hours to seconds, kΩ to Ω, mA to A.
4. Substitute, calculate, and give the unit.

For example, a lamp with 6.0 V across it and 0.50 A through it: $R = \frac{6.0}{0.50} = 12\ \Omega$, $P = 0.50 \times 6.0 = 3.0$ W, and in 2.0 minutes $E = 3.0 \times 120 = 360$ J.

Variations you will meet:

- **Energy in kWh**: use the power in kW and the time in hours. A 2.0 kW heater on for 3.0 hours uses $2.0 \times 3.0 = 6.0$ kWh. If you work out the power in W, divide by 1000 first.
- **Current from a power rating**: $I = \frac{P}{V}$, for example $\frac{1150}{230} = 5.0$ A for a 1150 W kettle on 230 V.
- **Charge**: $Q = It$, so 0.50 A for 60 s moves 30 C.
- Include the unit if the answer line has none: Ω for resistance, W for power, J for energy.

3. Combined resistance of series or parallel resistors (44 questions)

1. **Series: add them.** $3.0\ \Omega$ and $5.0\ \Omega$ in series make $8.0\ \Omega$.
2. **Parallel (Core): the answer is less than the smallest resistor.** If you are asked to "suggest a value", any value between 0 and the smallest resistor is right. Two identical resistors in parallel give half of one.
3. **Extended only, parallel: calculate.** Use $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$, then **turn it upside down** at the end, or use $R = \frac{R_1 R_2}{R_1 + R_2}$. $3.0\ \Omega$ and $6.0\ \Omega$ in parallel: $R = \frac{18}{9.0} = 2.0\ \Omega$.
4. **Extended only, mixtures:** replace each parallel group by its combined value first, then add the series parts.

Variations you will meet:

- **Find the unknown resistor from the total.** Series: subtract. Parallel: $\frac{1}{R_2} = \frac{1}{R} - \frac{1}{R_1}$. A resistor in parallel with $12\ \Omega$ giving $4.0\ \Omega$: $\frac{1}{R_2} = \frac{1}{4} - \frac{1}{12} = \frac{1}{6}$, so $R_2 = 6.0\ \Omega$.
- **Which arrangement gives a set total?** Try each option. With identical $10\ \Omega$ resistors, $15\ \Omega$ comes from one resistor in series with two in parallel ($10 + 5.0 = 15\ \Omega$).

- **Which formula is right?** $R = R_1 + R_2$ is for series only; $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ is for parallel.
- **The total from meter readings**: $R = \frac{V_{\text{supply}}}{I_{\text{supply}}}$.
- **Removing a branch** makes the combined resistance bigger, so the supply current falls.

4. The p.d. rules and potential dividers (37 questions)

1. **Parallel branches:** each has the same p.d. With nothing in series with them, that is the supply p.d.
2. **Series components (Extended only):** the p.d.s add up to the supply. So the p.d. across one component is **supply minus the others**: with 9.0 V across a resistor and an LDR and 2.5 V across the LDR, the resistor has $9.0 - 2.5 = 6.5$ V.
3. **Share the p.d. in the ratio of the resistances (Extended only)**: $V_2 = \frac{R_2}{R_1 + R_2} \times V_{\text{supply}}$. With $4.0\ \Omega$ and $8.0\ \Omega$ across 12 V, the $8.0\ \Omega$ resistor has $\frac{8.0}{12} \times 12 = 8.0$ V.
4. **Or go through the current**: find I from the total resistance, then $V = IR$ for each part.
5. **Core:** the bigger resistance in series always has the bigger p.d.

Variations you will meet:

- **Find an unknown resistor** from p.d.s: the ratio $\frac{R_1}{R_2} = \frac{V_1}{V_2}$, or find the current through the known resistor and use it for the other. A $5.0\ \Omega$ resistor in series with R on 9.0 V, with 1.5 V across R: the $5.0\ \Omega$ has 7.5 V, so $R = 5.0 \times \frac{1.5}{7.5} = 1.0\ \Omega$.
- **Series–parallel circuits:** the p.d. across a parallel group is the supply minus the p.d. across the series resistor (see Example 3).
- **A voltmeter across a switch, or across a gap**: an open switch in a series loop has the whole supply p.d. across it; a closed one has 0 V.
- **Read p.d.s from graphs**: for components in series, read each p.d. at the shared current, then add them.
- **Explain why one resistor heats more:** a bigger p.d. means more work is done on each coulomb passing through it (and more current means more coulombs each second).

5. LDR and thermistor circuits (34 questions)

1. **State the resistance change.** LDR: brighter → lower resistance; darker → higher. NTC thermistor: hotter → lower resistance; colder → higher.
2. **Series loop with a lamp or ammeter:** lower resistance → bigger current → brighter lamp, bigger ammeter reading.
3. **Potential divider (Extended only):** the component whose resistance goes **up** takes a **bigger share** of the supply p.d.; the other component's p.d. goes down by the same amount, because they add to the supply.
4. Give the chain in full: the change in the surroundings, the resistance change, then the effect on the p.d. or current.

Variations you will meet:

- **Choose the sensor** for a job: temperature → thermistor (a fire alarm, a fan that turns on when hot); light → LDR (a night light, street lights).
- **Which pair of components makes the output p.d. rise** when it gets hotter? The output must be across the fixed resistor if the thermistor's resistance falls, since the fixed resistor's share then grows.
- **A relay circuit**: the sensor controls the current in the relay coil, and the relay switches the lamp or heater. Work out when the coil current is large enough to close the switch.
- **Sketch resistance against light intensity** for an LDR: a curve falling steeply at first, then levelling off, never reaching zero.
- **Calculate** the sensor's resistance from the p.d.s (type 4) or from its current and p.d. (type 2).

6. The current rules (31 questions)

1. **Series:** the same current everywhere. Every ammeter in a single loop reads the same.
2. **Parallel:** the current from the supply (the main line, before the junction) is bigger than each branch current. **Extended only:** it equals the sum: $I = I_1 + I_2$.
3. **Extended only:** find each branch current with $I = \dfrac{V}{R}$, using the branch p.d., then add. For 0.30 A and 0.45 A in two branches, the supply gives 0.75 A.

Variations you will meet:

- **Which ammeter reads most?** The one in the main line, before the current splits.
- **Which set of readings is possible?** Check that currents in match currents out at every junction.
- **Identical branches** have identical currents, because they have the same p.d. and the same resistance.
- **A branch switched on** adds its current to the supply current; the other branches are not affected (they still have the same p.d.).
- **Why the currents add (Extended only):** charge is conserved; none is stored at the junction.

7. Effect of a variable resistor, slider or extra branch (19 questions)

1. **More resistance in a loop → less current → dimmer lamp** (and a smaller ammeter reading). Less resistance → more current.
2. A longer length of resistance wire in the loop has more resistance, so moving a sliding contact to include more wire dims the lamp.
3. The **purpose of a variable resistor** is to change the current in the circuit (and so the brightness, or the p.d. across a component).

Variations you will meet:

- **Which component controls a lamp's brightness?** Only one in the same loop as that lamp. A lamp in its own parallel branch straight across the supply is not affected by a variable resistor in a different branch.

- **Adding a parallel branch** lowers the combined resistance, so the supply current and power go up; the other branches keep their current.
- **Extended only, variable potential divider:** moving the slider towards the supply end raises the output p.d. from 0 V up to the full supply; the lamp connected across the output gets brighter.
- **Extended only, a sketch of current against the variable resistance:** the current is largest when the variable resistance is 0 (equal to $\frac{V}{R_{\text{fixed}}}$) and falls as it increases, curving but never reaching zero.

8. Diodes and LEDs (17 questions, Extended only)

1. **Find the direction:** current flows the way the triangle points, from the + side of the supply round to the −.
2. **Check every diode in a loop.** If any diode in a series loop is the wrong way round, there is **no current** in that loop and its LEDs do not light.
3. **Reversing the supply** stops the current through a diode, so the ammeter reads 0.

Variations you will meet:

- **Which LEDs light?** Trace each loop from + to −; an LED lights only if it and every diode in its loop point the same way as the current.
- **Rectification:** a diode turns a.c. into d.c. For a sketch of the p.d. across the resistor, keep the positive half-cycles the same as the supply and draw zero for the negative ones; mark the peak and the times. For a 50 Hz supply, one cycle takes $\frac{1}{50} = 0.020$ s.
- **Four-diode bridge:** both halves come out in the same direction (full-wave); the current in the resistor always goes the same way.
- **Name the component from its I–V graph:** current only for one direction of p.d. means a diode.
- **LEDs in parallel with a known p.d.:** read each LED's current off its graph at that p.d., then add them for the ammeter reading. Convert mA to A if needed.
- **Which device converts a.c. to d.c.?** A diode.

9. Which switches to close, which lamps light (15 questions)

1. **Trace each lamp's path** from one terminal of the supply, through the lamp, back to the other terminal.
2. A lamp lights only if **every switch on its path is closed**.
3. A lamp is out if its path has an open switch, **or** if a closed switch gives the current a route with no resistance round it (a short circuit across it).

Variations you will meet:

- **Light only chosen lamps** (or ring the bell without lighting the lamp): close exactly the switches on their paths and keep open any switch that would complete another path.
- **Which switch turns off only one lamp?** One in that lamp's own branch, not in the main line.

- **Testing materials:** put the sample in a gap in the loop. A conductor completes the circuit, so the lamp lights (or the ammeter reads); an insulator leaves a gap. An insulator in parallel with a resistor changes nothing.

10. Cells in series (11 questions)

1. **Add the e.m.f.s** of cells joined $+$ to $-$ in a row. Five 1.5 V cells give 7.5 V.
2. **Number of cells** for a battery $= \frac{\text{battery e.m.f.}}{\text{one cell's e.m.f.}}$: a 4.5 V torch needs $\frac{4.5}{1.5} = 3$ cells.
3. **A cell turned round** (its $+$ facing the other cells' $+$) subtracts its e.m.f.

11. Advantages of lamps in parallel (8 questions)

Give any of these:

- if one lamp breaks, the others **stay lit**;
- each lamp can be **switched on and off on its own**;
- each lamp has the **full supply p.d.**, so each is at full brightness.

A multiple-choice version asks which statement is **not** true: identical lamps in parallel carry the **same** current, not different currents.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A student builds a series circuit with a battery made of 1.5 V cells, a $10\ \Omega$ resistor, a $20\ \Omega$ resistor, an ammeter and a switch. The battery's e.m.f. is 9.0 V.

(a) State the number of cells in the battery. **[1]**

(b) Calculate the combined resistance of the two resistors. **[1]**

(c) Calculate the reading on the ammeter. **[3]**

(d) Calculate the p.d. across the $20\ \Omega$ resistor. **[3]**

(e) State how the student should connect a voltmeter to measure this p.d. **[1]**

(a) $9.0 \div 1.5 = 6$ cells. **B1**

(b) $10 + 20 = 30\ \Omega$. **B1**

(c) Current $=$ p.d. ÷ resistance **C1** $= 9.0 \div 30$ **C1** $= 0.30$ A **A1**.

(d) The current is 0.30 A everywhere in a series circuit. $V = IR$ **C1** $= 0.30 \times 20$ **C1** $= 6.0$ V **A1**. (The $10\ \Omega$ resistor has 3.0 V, and $6.0 + 3.0 = 9.0$ V, the battery's e.m.f.)

(e) In parallel with the $20\ \Omega$ resistor, joined to both of its ends. **B1**

Example 2

Extended only. A 12 V supply is connected across an $8.0\ \Omega$ resistor and a $24\ \Omega$ resistor in parallel. An ammeter measures the current from the supply.

(a) Calculate the current in each resistor. **[2]**

(b) Determine the reading on the ammeter. **[1]**

(c) Calculate the combined resistance of the two resistors, and show that it agrees with (b). **[2]**

(d) Calculate the energy transferred by the $8.0\ \Omega$ resistor in 5.0 minutes. **[3]**

(a) Each branch has the full 12 V across it. $I = \dfrac{12}{8.0} = 1.5$ A and $I = \dfrac{12}{24} = 0.50$ A. **B1 B1**

(b) The currents add at the junction: $1.5 + 0.50 = 2.0$ A. **B1**

(c) $R = \dfrac{8.0 \times 24}{8.0 + 24}$ **C1** $= 6.0\ \Omega$ **A1**. Check: $\dfrac{12}{2.0} = 6.0\ \Omega$.

(d) $E = IVt$ **C1**, with $t = 5.0 \times 60 = 300$ s **C1**: $E = 1.5 \times 12 \times 300 = 5400$ J **A1**.

Example 3

Extended only. A 6.0 V battery is connected to a $4.0\ \Omega$ resistor in series with a parallel pair: a $6.0\ \Omega$ resistor and a $12\ \Omega$ resistor.

(a) Show that the combined resistance of the parallel pair is $4.0\ \Omega$. **[2]**

(b) Calculate the current from the battery. **[2]**

(c) Determine the p.d. across the parallel pair. **[2]**

(d) Calculate the current in the $12\ \Omega$ resistor. **[1]**

(a) $\dfrac{1}{R} = \dfrac{1}{6.0} + \dfrac{1}{12} = \dfrac{3}{12}$ **C1**, so $R = \dfrac{12}{3} = 4.0\ \Omega$ **A1**.

(b) Total resistance $= 4.0 + 4.0 = 8.0\ \Omega$ **C1**, so $I = \dfrac{6.0}{8.0} = 0.75$ A **A1**.

(c) P.d. across the series $4.0\ \Omega$ resistor $= 0.75 \times 4.0 = 3.0$ V **C1**. The rest of the 6.0 V is across the pair: $6.0 - 3.0 = 3.0$ V **A1**.

(d) $I = \dfrac{3.0}{12} = 0.25$ A. **B1** (The $6.0\ \Omega$ resistor carries 0.50 A, and $0.25 + 0.50 = 0.75$ A, as it should.)

Example 4

Extended only. A frost alarm uses a potential divider made of a fixed 2.0 kΩ resistor in series with an NTC thermistor, across a 9.0 V supply. A voltmeter is connected across the thermistor.

(a) At 5 °C the thermistor's resistance is 4.0 kΩ. Calculate the voltmeter reading. **[2]**

(b) The temperature rises to 25 °C. State and explain what happens to the voltmeter reading. **[3]**

(c) On a frosty night the voltmeter reads 7.2 V. Calculate the resistance of the thermistor. **[3]**

(a) $V = \dfrac{4.0}{2.0 + 4.0} \times 9.0$ **C1** $= 6.0$ V **A1**.

(b) The reading **decreases B1**. The thermistor's resistance falls as it gets warmer **B1**, so it takes a smaller share of the supply p.d. (the p.d.s are in the ratio of the resistances) **B1**.

(c) The fixed resistor has $9.0 - 7.2 = 1.8$ V **C1**. $\dfrac{R}{2.0} = \dfrac{7.2}{1.8}$ **C1**, so $R = 2.0 \times 4 = 8.0$ kΩ **A1**.

Common mistakes

- **Wrong or home-made symbols.** Examiners regularly see thermistors, variable resistors, d.c. supplies and fuses drawn wrongly, or a lamp drawn as a bulb. Learn the symbol grid, and check the details: the arrow direction on an LDR (in) and an LED (out), the bent line on a thermistor.
- **Voltmeter in series, ammeter in parallel.** A voltmeter goes across the one component, on its own wires; the ammeter goes in the loop. Don't draw a wire running through the middle of a meter's circle.
- **Gaps in circuit diagrams.** A circuit with a break is not complete and loses the connection mark. Join every wire.
- **Adding parallel resistances.** $6\ \Omega$ and $3\ \Omega$ in parallel are **not** $9\ \Omega$. Parallel always gives **less** than the smallest.
- **Forgetting to turn $\frac{1}{R}$ upside down.** $\frac{1}{6} + \frac{1}{3} = \frac{1}{2}$ gives $R = 2\ \Omega$, not $0.5\ \Omega$.
- **Thinking current gets used up.** The current is the same before and after a lamp in series; it is energy that is transferred.
- **Using the supply p.d. for one series component.** In a series circuit, each component has only part of the p.d.; find the current first or subtract the other p.d.s.
- **Getting sensor behaviour backwards.** An NTC thermistor's resistance **falls** as it heats; an LDR's resistance **falls** in bright light. Then in a potential divider the **bigger** resistance takes the **bigger** p.d.; say this, rather than just "the voltage changes".

- **Writing "ammeter reading" or "voltmeter reading" as a quantity.** Write "current" and "potential difference" (or "voltage").
- **Mixing up variable resistor and potential divider.** A variable resistor in series cannot bring a lamp's p.d. down to 0 V; a potential divider can.
- **Diodes pointing the wrong way.** Check the direction in every loop before saying a lamp or LED lights.
- **Units.** kΩ and mA must be converted before $V = IR$ unless you keep them together consistently; minutes must be turned into seconds for $E = IVt$, and kWh needs kW and hours.

How to get the marks

- **Calculations:** Paper 3 marks are usually **C1** for the equation (in symbols or words), **C1** for the numbers substituted, **A1** for the answer. Write all three lines, so a slip in the arithmetic still leaves you two marks.
- **Show your working** when asked to "determine" a reading: "current in lower branch $= 0.16$ A, total $= 0.24$ A". The method marks are for each branch current and the sum.
- **"Show that"** gives the answer: write the calculation that reaches it, such as $12 - 3.0 = 9.0$ V, and don't just repeat the given value.
- **"State and explain"** needs the effect (increases, decreases, no change) **and** a reason linked to resistance and p.d. or current. The statement mark usually needs the explanation to be right too.
- **Circuit drawings:** each correct symbol earns credit (often A2 for all correct, C1 for some), and a separate mark is for the correct connection. Draw neatly with a ruler.
- **"Suggest a value"** for two resistors in parallel: any value less than the smaller resistor scores. For a calculation, give 2 or 3 significant figures, matching the data.
- **Units:** if the answer line has no unit printed, the unit is part of the answer.
- **Error carried forward:** a wrong value from an earlier part, used correctly later, still earns the later marks. Keep going.

Quick check

1. Four 1.5 V cells are placed in a row, but one of them is turned the wrong way round. What is the combined e.m.f.?
2. A $5.0\ \Omega$ resistor and a $20\ \Omega$ resistor are connected in parallel. (a) Is the combined resistance more or less than $5.0\ \Omega$? (b) **Extended only:** calculate it.
3. **Extended only.** A current of 0.60 A enters a junction and splits into two branches. One branch carries 0.25 A. What is the current in the other branch?
4. **Extended only.** A 1.0 kΩ resistor and a 2.0 kΩ resistor are in series across a 6.0 V supply. Calculate the p.d. across the 2.0 kΩ resistor.
5. A lamp and an LDR are in series with a battery. The room gets darker. What happens to the resistance of the LDR, the current and the brightness of the lamp?

Answers

1. Three cells add (4.5 V) and the reversed one subtracts: $4.5 - 1.5 = 3.0$ V.
2. (a) Less than $5.0\ \Omega$: parallel resistances are always less than the smallest one. (b) $R = \frac{5.0 \times 20}{5.0 + 20} = \frac{100}{25} = 4.0\ \Omega$.
3. The current in equals the current out: $0.60 - 0.25 = 0.35$ A.
4. $V = \frac{2.0}{1.0 + 2.0} \times 6.0 = 4.0$ V. (The 1.0 kΩ resistor has the other 2.0 V.)
5. The LDR's resistance increases, so the total resistance increases, the current decreases and the lamp gets dimmer.

Past questions to try

- **0625/31/M/J/25 Q8**: combined resistance and current in a series circuit, and where to draw a voltmeter.
- **0625/41/M/J/25 Q7**: a diode's I–V graph and symbol, then two heaters in parallel on the mains.
- **0625/41/O/N/24 Q6**: a potential divider made of an LDR and a thermistor.
- **0625/43/O/N/22 Q9**: the period of a 50 Hz supply and sketching the rectified output of a diode.