

Electricity and magnetism

IGCSE Physics

Magnetism

A **magnet** can attract some metals. Every magnet has two ends, called **poles**: a **north pole** (N pole) and a **south pole** (S pole).



Like poles repel; unlike poles attract

The rule for two poles is like the rule for charges:

- Poles that are the same (N and N, or S and S) **repel** (push apart): this is **repulsion**.
- Poles that are different (N and S) **attract** (pull together): this is **attraction**.

A magnet attracts a **magnetic material**, such as iron, steel, cobalt and nickel. Materials such as copper, plastic and wood are classed as non-magnetic here: they are not strongly attracted by a stationary bar magnet.

■ Induced magnetism

Put a piece of iron near or touching a magnet, and the iron becomes a magnet itself. This is **induced magnetism**. The end of the iron nearest the magnet gains the opposite pole, so the two then attract.

■ Temporary and permanent magnets

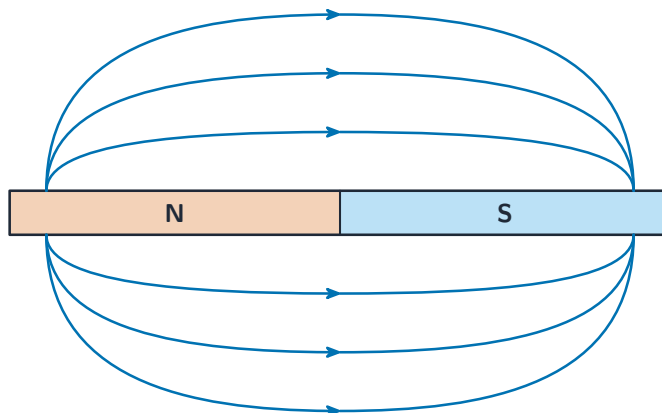
- **Soft iron** is easy to **magnetise** but loses its magnetism quickly. It is used for a **temporary magnet**.
- **Steel** is harder to magnetise but keeps its magnetism. It is used for a **permanent magnet**.

An initially **unmagnetised** soft-iron core is suitable when magnetism should fall quickly after the current stops. Steel is a suitable permanent-magnet material in these examples.

■ Magnetic fields

A **magnetic field** is a **region** where a magnetic pole feels a force. We draw it with **magnetic field lines** :

- The lines come *out of* the N pole and go *into* the S pole.
- The field direction at a point is the direction of the force on the N pole of a small test magnet placed there.
- Where the lines are close together the field is strong; where they are far apart the field is weak.



The field lines of a bar magnet come out of the N pole and go into the S pole

You can show the pattern by sprinkling **iron filings** on paper over a magnet, or by moving a small plotting **compass** around it (the needle points along the field).



Iron filings line up along the field lines, showing the field pattern of a bar magnet

■ Uses of magnets

- **Permanent magnets:** fridge door catches, compass needles, loudspeakers.
- **Electromagnets** (their field is controlled by current): cranes that lift scrap iron, electric bells, relays. Changing the current controls an electromagnet's field; soft iron reduces remaining magnetism when the current stops.

Magnetic forces happen because the fields of the two magnets push and pull on each other.

Static electricity

There are two kinds of **electric charge** : **positive charge** and **negative charge** . The rule is like the rule for poles – same charges repel, different charges attract.



Every hair picks up the same charge from the dome, and like charges repel – so the hairs push apart

■ Charging by friction

When you rub two different materials together, **electrons** (tiny negative particles) move from one to the other. This is **charging by friction** .

- The material that gains electrons becomes negative.
- The material that loses electrons becomes positive.

In charging solids by friction, electrons transfer; positive nuclei do not move between the solids. If a rod gains electrons from a cloth, it becomes negative and the cloth positive. The direction of transfer depends on the pair of materials.

Detecting a charge. A charged rod picks up small pieces of paper, and it bends a thin stream of water from a tap. Hang one charged rod from a thread and bring

another charged rod near it: if the two have the same kind of charge, the hanging rod swings away. Repulsion is the only sure test for a charge, because attraction also happens with uncharged objects.

■ Conductors and insulators

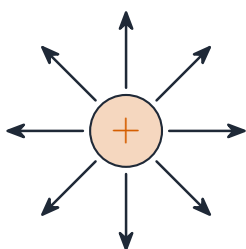
- A **conductor** (copper and other metals) lets charge flow through it easily, because it has free electrons that can move.
- An **insulator** (plastic, rubber, glass) does not let charge flow, because its electrons cannot move freely.

In a supervised low-voltage test, place the sample in a working cell-and-lamp circuit. A lit lamp shows enough current passes. If it does not light, first check the connections and the lamp with a known conductor; a fault or a very small current can also prevent lighting.

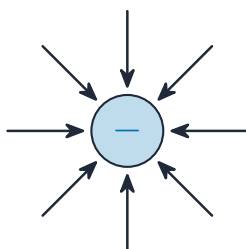
■ Electric fields and ions

Charge is measured in **coulombs** (C). An **electric field** is a region where an electric charge feels a force. Its direction at a point is the direction of the force on a positive charge. Simple field patterns (the arrows show the direction):

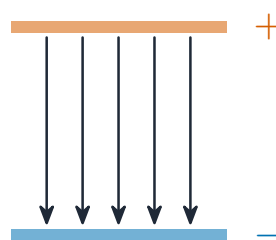
- around a **point charge**: straight lines, pointing away from a positive charge and towards a negative charge;
- around an isolated charged conducting sphere: radial lines, like a point charge outside the sphere;
- between two parallel plates with opposite charges, ignoring edge effects: straight, evenly spaced lines from the positive plate to the negative plate.



positive charge



negative charge



parallel plates

*Electric field lines point away from a positive charge and towards a negative one;
between parallel plates the field is uniform*

An atom is normally neutral. If it loses electrons it becomes a positive **ion**; if it gains electrons it becomes a negative ion.

Electric current

An **electric current** is a flow of electric charge. It is measured in **amperes** (A) with an **ammeter**, joined in series in the circuit.

An **analogue** ammeter has a needle that moves over a scale; a **digital** ammeter shows the reading as a number. Both come with different **ranges**. Start with a range high enough to avoid overloading the meter, then use a suitable lower range that still includes the reading: a 0–1 A range for a current of about 0.4 A, or a 0–100 mA range for a few milliamps.

Current is the charge that passes a point each second:

$$I = \frac{Q}{t}$$

Here I is current (A), Q is charge (C) and t is time (s). Rearranged, $Q = It$.

Worked example. A current of 3.0 A flows through a lamp for 20 s. How much charge passes through it?

Known: $I = 3.0$ A and $t = 20$ s. Current is charge per unit time, so rearrange $I = Q/t$:

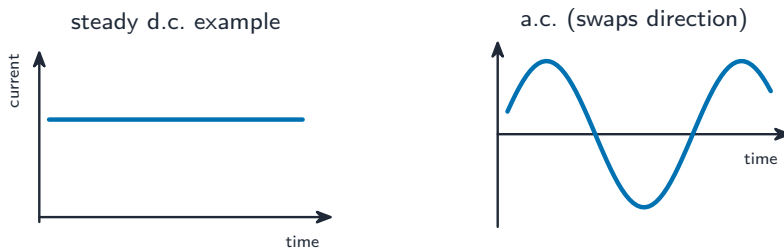
$$Q = It$$

$$Q = (3.0 \text{ A})(20 \text{ s}) = 60 \text{ C}$$

In a metal the current is a flow of **free electrons**. There are two “directions” to know:

- **Conventional current** is taken to flow from + to – round the outside of the cell.
- The free electrons really drift the other way, from – to +.

A **direct current** (d.c.) flows in one direction; its size need not be constant. A steady battery current is one example. An **alternating current** (a.c.) keeps swapping direction many times each second, as from the **mains supply**.



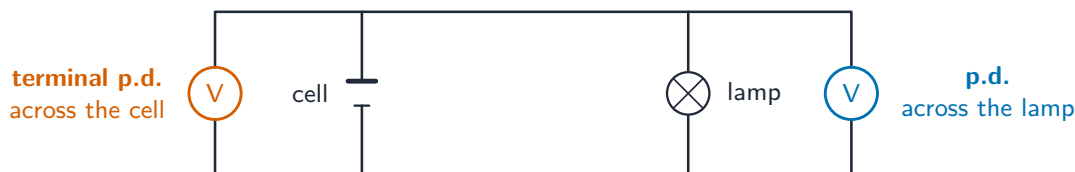
The d.c. example is steady and one-directional; the a.c. example reverses direction

E.m.f. and potential difference

A cell gives **energy** to the charges that move through it. Two quantities describe this, and both are measured in **volts** (V).

- The **electromotive force** (e.m.f.) of a source is the electrical work it does to drive unit charge all the way round a complete **circuit**.
- The **potential difference** (p.d.) across a component is the work done by unit charge as it passes *through that component*.

A **voltmeter** measures e.m.f. or p.d. It is joined in parallel (across the component). Like ammeters, voltmeters are analogue or digital and have different ranges: pick the range just above the largest voltage you expect.



*The voltmeter across the **cell** measures its terminal p.d.; this equals the e.m.f. for the ideal cell assumed here. The meter across the **lamp** measures that component's p.d.*

Both are work done per unit charge:

$$E = \frac{W}{Q}, \quad V = \frac{W}{Q}$$

where W is the energy transferred (J) and Q is the charge (C). For a source giving $W = 120 \text{ J}$ to $Q = 60 \text{ C}$, use work per unit charge:

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

$$E = \frac{120 \text{ J}}{60 \text{ C}} = 2.0 \text{ V}$$

Here E denotes e.m.f. in volts; in the energy section E denotes energy in joules. Read the context and unit.

Resistance

Resistance measures how hard it is for current to flow. At the same p.d., a bigger resistance gives a smaller current. It is measured in **ohms** (Ω).

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

Measuring resistance. Connect the component in series with a cell, a switch, an ammeter and a **variable resistor** , and connect a voltmeter across the component. Close the switch, read I and V , then change the variable resistor to get several more pairs of readings. For a resistor held at constant temperature, repeated $R = V/I$ values can be compared and averaged. A V -against- I graph has gradient R ; an I -against- V graph has gradient $1/R$. For a heating filament, resistance changes, so averaging across different operating temperatures would hide the change.

Worked example. A 12 V battery drives a current of 0.50 A through a lamp. Find the lamp’s resistance.

Use the p.d.-to-current ratio at this operating point:

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

$$R = \frac{12\text{ V}}{0.50\text{ A}} = 24\text{ }\Omega$$

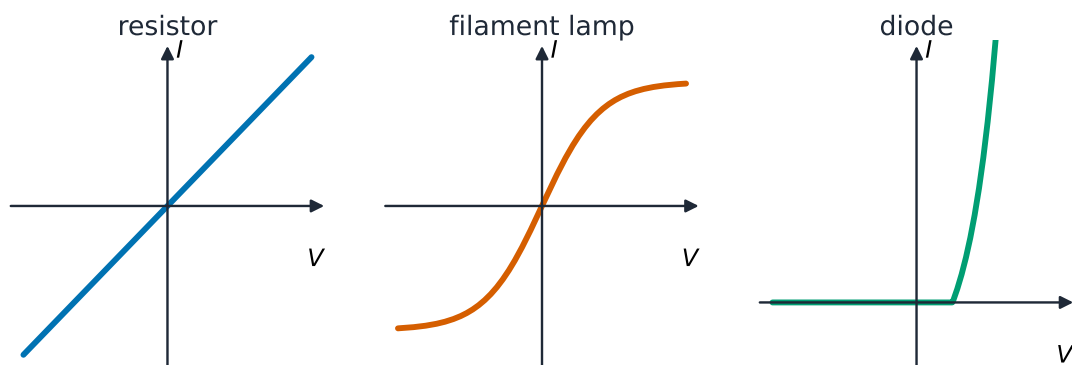
For wires of the same metal at constant temperature:

- a longer wire has a bigger resistance – resistance is **directly proportional** to length, $R \propto l$;
- a thicker wire has a smaller resistance – resistance is **inversely proportional** to **cross-sectional area** , $R \propto \frac{1}{A}$.

So doubling the length doubles the resistance; doubling the area halves it. (Area depends on the diameter squared, so a small change in diameter changes the resistance a lot.)

Current–voltage graphs show how three components behave:

Component	Shape of the I–V graph	What it tells you
resistor (fixed)	straight line through the origin	resistance is constant, so $I \propto V$
filament lamp	S-shaped, getting flatter as V rises	the wire heats up, so its resistance rises
diode	current one way only	very high resistance the “wrong” way



resistor (ohmic): $V = IR$ straight · filament: resistance rises with heat · diode: one-way

A resistor gives a straight line; a filament lamp curves as it heats up; a diode lets current pass only one way

Electrical energy and power

A circuit transfers energy from a source (a cell or the mains) to the components, and then into the surroundings (often as heat, light or sound).

Electrical power is the energy transferred each second, measured in **watts** (W):

$$P = IV$$

The **electrical energy** transferred in a time t , measured in **joules** (J), is:

$$E = IVt$$

Worked example. A 12 V motor draws a current of 2.0 A. Find its power, and the energy it transfers in 30 s.

Power is energy transferred per second. Known: $I = 2.0$ A, $V = 12$ V, $t = 30$ s.

$$P = IV$$

$$P = (2.0 \text{ A})(12 \text{ V}) = 24 \text{ W}$$

$$E = Pt$$

$$E = (24 \text{ W})(30 \text{ s}) = 720 \text{ J}$$

■ The kilowatt-hour

Home electricity bills use a bigger energy unit, the **kilowatt-hour** (kWh).
One kilowatt-hour is the energy used by a 1 kW **appliance** in 1 hour.

$$\text{energy (kWh)} = \text{power (kW)} \times \text{time (h)}$$

$$\text{cost} = \text{energy (kWh)} \times \text{price per kWh}$$

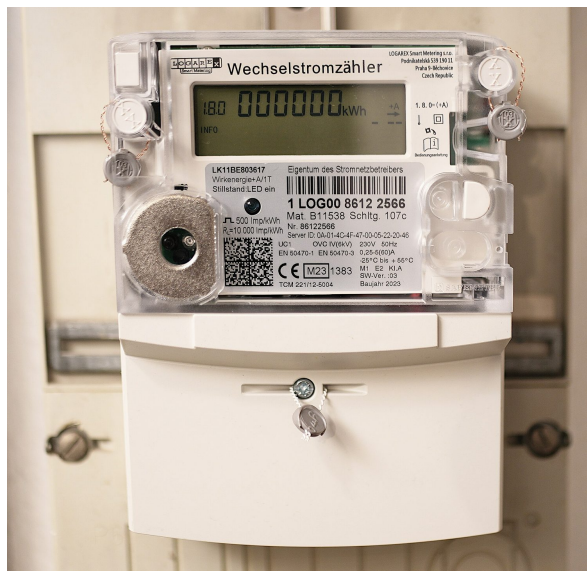
For a 2 kW **heater** used for 3 h at a fictional price of 20 cents per kWh:

$$E = Pt$$

$$E = (2 \text{ kW})(3 \text{ h}) = 6 \text{ kWh}$$

$$\text{cost} = E \times \text{price per kWh}$$

$$\text{cost} = (6 \text{ kWh})(20 \text{ cents/kWh}) = 120 \text{ cents}$$



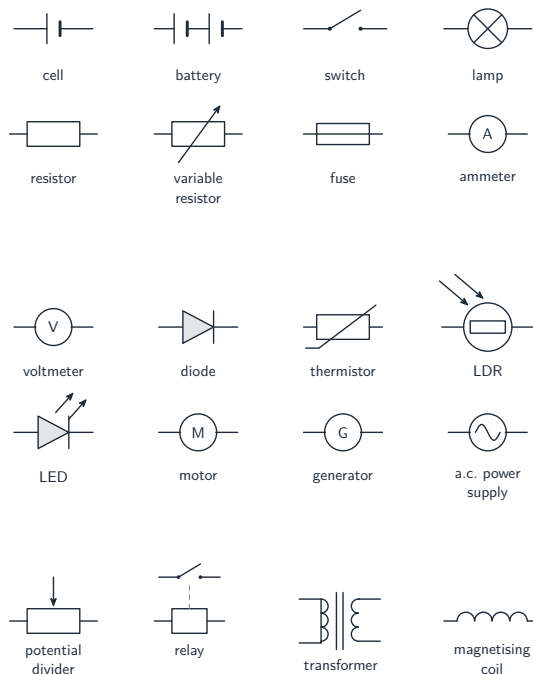
*A household electricity meter counts the energy used, in kilowatt-hours (kWh) –
billing uses the change in its reading, together with the tariff*

Circuits

■ Circuit components

You should know these components and how they behave:

Component	What it does
cell / battery	drives current round the circuit (a battery is two or more cells)
power supply	a source of d.c. or a.c.
switch	breaks or completes the circuit
resistor (fixed)	gives a fixed resistance
variable resistor	a resistance you can change, to control the current
fuse	melts and breaks the circuit if the current is too big
lamp / heater	turns electrical energy into light / into heat
thermistor	the NTC type studied here falls in resistance when hotter
light-dependent resistor (LDR)	its resistance falls as the light gets brighter
diode / light-emitting diode (LED)	lets current one way only; an LED also gives out light
relay	a switch worked by an electromagnet (small current controls a big one)
motor	turns electrical energy into movement
bell	makes a sound
transformer	changes the size of an a.c. voltage



The standard symbols used to draw circuit diagrams



Real resistors: the coloured bands give each one's resistance in ohms

■ Series and parallel

In a **series** circuit the parts form one single loop:

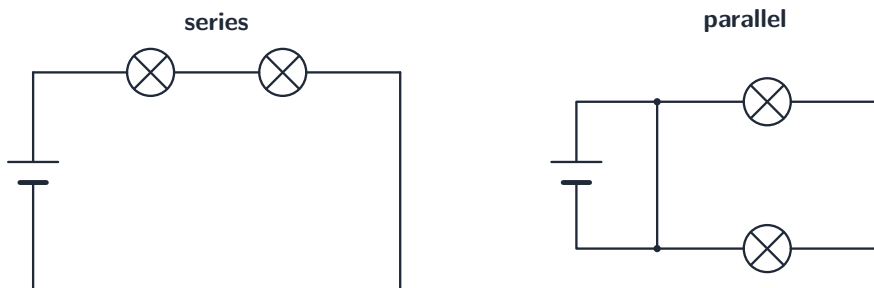
- the current is the same at every point;
- the supply p.d. is shared between the components;
- cells in series add their e.m.f.s (when they point the same way);

- resistors in series add up: $R_{\text{total}} = R_1 + R_2 + \dots$

In a **parallel** circuit the parts are on separate branches:

- each branch gets the full supply p.d.;
- the current splits, so the current from the source is bigger than the current in any one branch;
- the **total resistance** is less than the smallest single resistance.

Lamps in a home are wired in parallel: each gets the full voltage, and if one fails the others stay on.



In a series circuit the components share one loop; in a parallel circuit each lamp has its own branch

For calculations (with the rules above):

- at a **junction**, the total current flowing in equals the total current flowing out;
- in series, the supply p.d. equals the sum of the p.d.s across the components;
- in parallel, the p.d. across each branch is the same;
- two resistors in parallel combine as

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Worked example. A $6\ \Omega$ resistor and a $3\ \Omega$ resistor are connected in parallel. Find their combined resistance.

Use the parallel-resistance relation because both resistors have the same p.d.:

$$\begin{aligned}\frac{1}{R_{\text{total}}} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{R_{\text{total}}} &= \frac{1}{6\ \Omega} + \frac{1}{3\ \Omega} = \frac{1}{2\ \Omega}\end{aligned}$$

$$R_{\text{total}} = 2\ \Omega$$

Notice the combined resistance ($2\ \Omega$) is smaller than the smaller of the two resistors.

■ Potential dividers

Two resistors in series share the supply voltage. This is a **potential divider**

. For the same current, a bigger resistance has a bigger p.d. across it, so the bigger resistor takes the bigger share:

$$\frac{R_1}{R_2} = \frac{V_1}{V_2}$$

A *variable potential divider* uses a movable contact to change the output voltage smoothly, for example from 0 V up to the full supply. If you use a thermistor or an LDR as one of the resistors, the output voltage changes with temperature or light – handy for switching a heater or a lamp on and off automatically.

Electrical safety

A home is fed by the mains. The mains is dangerous if it is used wrongly.

■ Hazards

These are **hazards** (dangers) with mains electricity:

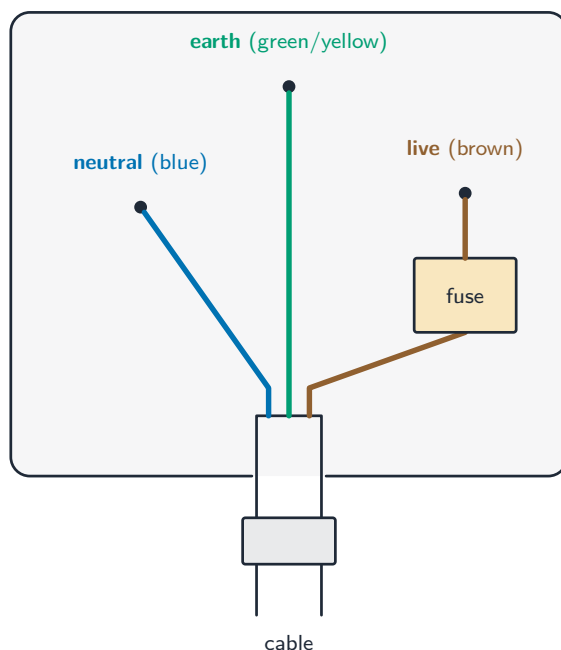
- damaged **insulation** – bare wires can give a shock or start a fire;
- **overheating** cables – too much current makes a cable hot, which can start a fire;
- **damp** conditions – water lets current pass into a person, raising the risk of a shock;
- **overloading** – plugging too many appliances into one **socket** draws too much current.

■ Live, neutral and earth

A mains cable has three wires:

- the **live wire** carries the high voltage;
- the **neutral wire** completes the circuit at about zero voltage;
- the **earth wire** is a safety wire joined to the ground.

A switch (and a fuse) must be fitted in the *live* wire. Opening that switch disconnects the appliance from the live supply in the circuit model. A switch being off is not proof that real equipment is safe to open or work on.



*In a three-pin plug the **live** (brown) and **neutral** (blue) carry the current, the **earth** (green/yellow) is the safety wire, and the **fuse** always sits in the live wire.*

■ Fuses, trip switches and earthing

A fuse is a thin wire that melts if the current gets too big, breaking the circuit before the cable overheats. For a simplified exam choice, select a **fuse rating** above normal working current and appropriate for the stated cable and appliance limits. For real equipment, use the specified protection.

An overcurrent **trip switch** (circuit breaker) opens the circuit when excessive current is detected and can be reset after the fault is corrected. Operating time depends on the device and fault; it is not always faster than every fuse.

The metal **casing** of an appliance must be made safe in one of two ways:

- **earthed** : the casing is joined to the earth wire. If a live wire touches the casing, a large current flows to earth and blows the fuse.
- **double-insulated** : double or reinforced insulation separates the user from live parts; a non-conducting outer casing is a common example. A plastic-looking case alone does not establish double insulation. Such an appliance needs no protective earth connection; its fuse still protects circuit cabling.



A home consumer unit contains different protection devices. An MCB responds to overcurrent; an RCD responds to an imbalance between live and neutral currents. The printed ratings describe different properties, not a single trip current.

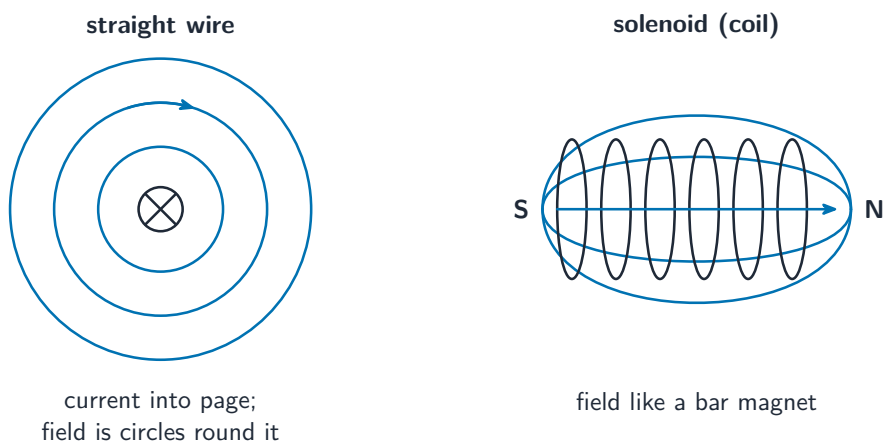
Electromagnetic effects

■ The magnetic effect of a current

A current in a wire makes a magnetic field around it.

- Around a straight wire the field lines are circles around the wire; the field is stronger close to the wire. Reverse the current and the field reverses.
- A **solenoid** (a long **coil** of wire) makes a field just like a bar magnet, with a N pole at one end and a S pole at the other. The field inside is strong and even.

You can show both patterns with iron filings or a plotting compass. For a solenoid of fixed length, increasing current or turns, or adding a soft-iron core, strengthens the field. Around a straight wire, the field strengthens with current and weakens with distance.



A current makes circular field lines around a straight wire, and a bar-magnet-like field for a solenoid

The magnetic effect is used in a relay and in a loudspeaker. In a relay, a small current in a coil magnetises a soft-iron core, which pulls a switch closed in a second circuit. The second circuit can carry a large current, so a small switch or a sensor can safely control a motor or a heater (for example, the ignition switch of a car starts its motor through a relay). In a **loudspeaker** a changing current in a coil makes the coil push and pull a paper cone, which moves the air and makes sound.

■ Electromagnetic induction

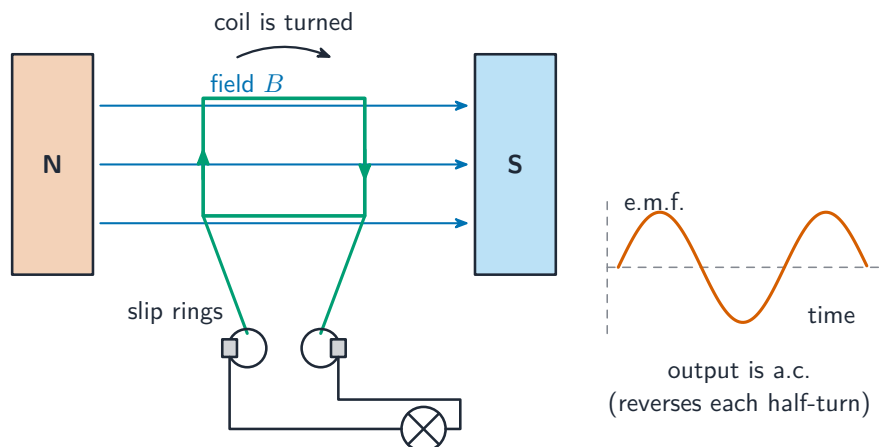
When a wire moves across a magnetic field, or the field through a coil changes, an e.m.f. is **induced** in the wire. If the wire is part of a complete circuit, this e.m.f. drives a current. This is **electromagnetic induction**.

To show it: move a magnet in and out of a coil joined to a sensitive meter, and watch the needle flick. The induced e.m.f. is bigger when you use a stronger magnet, move faster, or use more turns on the coil. The induced e.m.f. always acts to *oppose* the change that causes it. For a wire moving upward across a rightward field in a closed circuit, the right-hand rule gives induced conventional current into the page. Its motor-effect force is downward, opposing the motion. The direction of the induced current is given by **Fleming's right-hand rule**: hold the thumb, first finger and second finger of the right hand at right angles to one another; the thumb points along the motion of the wire, the first finger along the field (N to S), and the second finger then gives the induced current.

■ The a.c. generator

An **a.c. generator** turns movement into electricity. A coil is spun in a magnetic field (or a magnet is spun near a coil). As it turns, the field through the coil keeps changing, so an alternating e.m.f. is induced.

- **Slip rings** and carbon **brushes** carry the current out to the circuit while the coil keeps turning.
- For a coil rotating at constant speed, the e.m.f. magnitude is greatest when the coil's plane is parallel to the magnetic field, and zero when its plane is perpendicular to the field. "Flat" and "upright" depend on how a diagram is drawn, so use the field direction as the reference. So the e.m.f.-time graph is a wave: peak, zero, opposite peak, zero, for each turn.



Turning the coil induces an alternating e.m.f.; the slip rings carry the a.c. out to the circuit

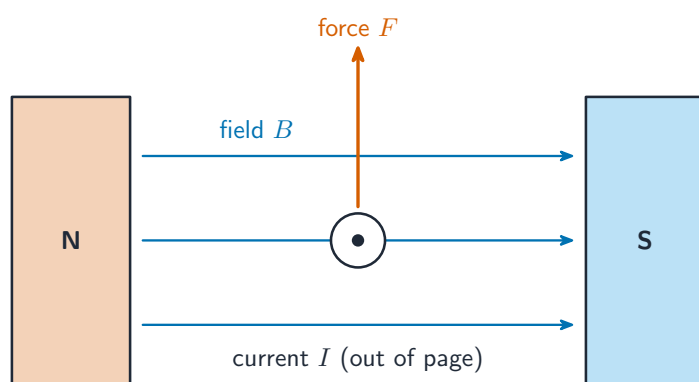
■ Force on a current-carrying conductor

When a current-carrying wire lies in a magnetic field, the field of the wire and the field of the magnet push on each other, so the wire feels a force. This is the **motor effect**.

- Reverse the current, *or* reverse the field, and the force reverses.
- Make the current bigger or the field stronger, and the force is bigger.

For a conductor perpendicular to the field, the force is perpendicular to both field and current. A conductor parallel to the field has no motor-effect force. You can find the force direction with **Fleming's left-hand rule** : thumb = force (motion), first finger = field (N to S), second finger = current.

Showing the force. Lay a stiff copper wire (or a strip of aluminium foil) between the poles of a U-shaped magnet and connect it to a cell through a switch. When the current flows, the wire jumps up or down. Reverse the cell and the wire jumps the other way; turn the magnet over and it reverses again. A bigger current or a stronger magnet gives a bigger jump.



F , B and I are all at 90° (Fleming's left-hand rule)

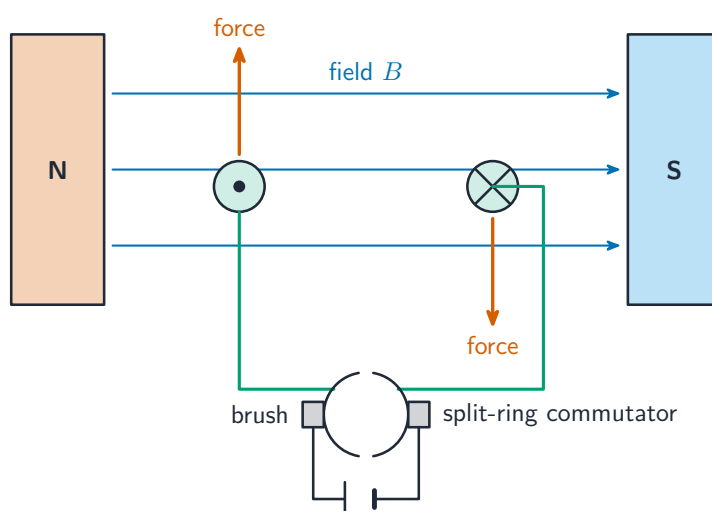
A current-carrying wire in a magnetic field feels a force at right angles to both the field and the current

A moving stream of charged particles acts as a current, so motion across a magnetic field can produce a sideways force – it **deflects** the beam. (Remember electrons flow opposite to the conventional current.)

■ The d.c. motor

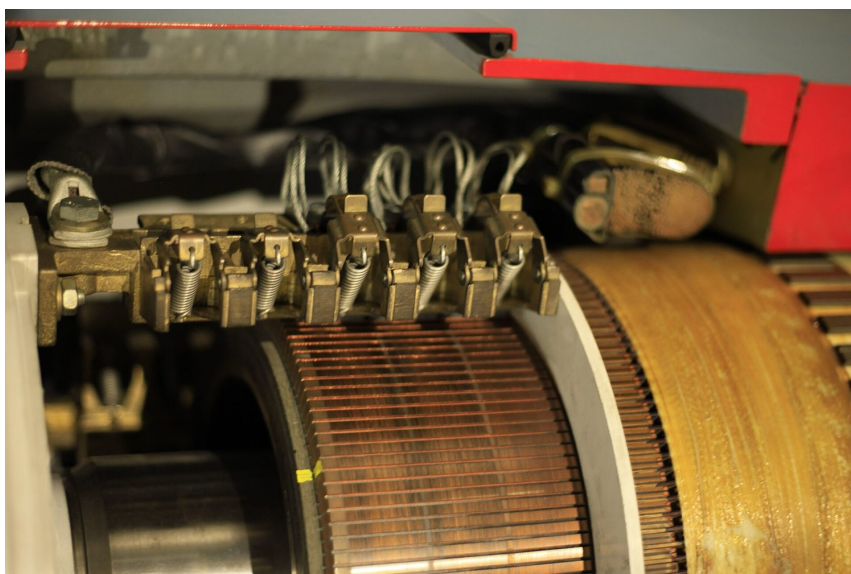
A coil carrying a current in a magnetic field feels a **turning effect**, because the forces on its two sides act in opposite directions. This is a **d.c. motor**. The turning effect is bigger with more turns on the coil, a bigger current, or a stronger field.

A **split-ring commutator** swaps the current direction in the coil every half-turn. This keeps the coil turning the same way instead of stopping after half a turn.



the two forces form a couple that turns the coil

The forces on the two sides of the coil form a couple; the split-ring commutator keeps it turning one way



In a real d.c. machine, carbon brushes press on the copper commutator bars to feed current to the spinning coil

■ The transformer

A **transformer** changes the size of an a.c. voltage. It has two coils wound on a **soft-iron core** :

- the **primary coil** takes in the a.c. voltage;
- the **secondary coil** gives out the changed voltage.

The a.c. in the primary makes a changing magnetic field in the core. The core carries this field to the secondary, where it induces an a.c. e.m.f. The voltages and the numbers of turns are linked by:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

Worked example. A transformer has 1200 turns on the primary coil and 100 turns on the secondary coil. The primary is connected to a 240 V a.c. supply. Find the secondary voltage.

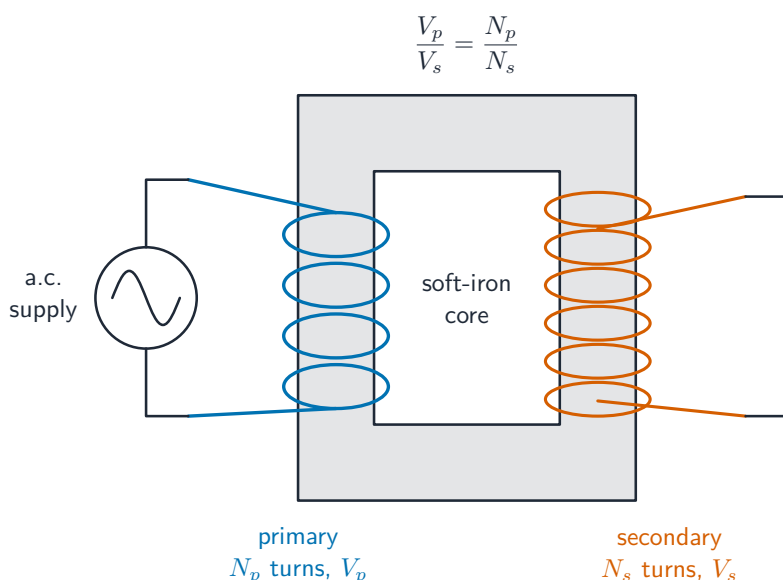
Use the voltage-to-turns ratio, then rearrange for the secondary voltage:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = V_p \frac{N_s}{N_p}$$

$$V_s = (240 \text{ V}) \frac{100}{1200} = 20 \text{ V}$$

Fewer turns on the secondary, so this is a step-down transformer.



The changing field in the core links the two coils; the voltage ratio equals the turns ratio



A real transformer on a power pole steps the high voltage in the cables down to domestic supply voltage; this is still hazardous

If the secondary has more turns it is a **step-up** transformer (voltage rises); fewer turns make a **step-down** transformer (voltage falls). For example, a transformer changing 240 V to 12 V is a step-down type, and the primary has 20 times as many turns as the secondary.

If a transformer is 100% efficient, the power in equals the power out:

$$I_p V_p = I_s V_s$$

So a step-up transformer raises the voltage but lowers the current.

■ Why we use high voltage to send power

Electricity is sent across the country by **high-voltage transmission**. The power lost as heat in the cables is

$$P = I^2 R$$

where R is the resistance of the cables. A step-up transformer raises the voltage and so lowers the current for the same power ($P = IV$). A smaller current means much less power wasted in the cables. A step-down transformer then lowers the voltage for domestic supply; mains voltage remains hazardous.



Pylons hold the cables that carry electricity at very high voltage, which keeps the current – and the wasted power – low

Exam tips

- **Current** is the same everywhere in a **series** circuit; in a **parallel** circuit it splits between the branches. Voltage (p.d.) is shared out in series, but is the same across every parallel branch.
- Adding resistors in **series** increases the total resistance ($R_1 + R_2$); adding them in **parallel** makes the total *less* than the smallest single resistor.
- An **ammeter** goes in *series* and has very low resistance; a **voltmeter** goes in *parallel* across a component and has very high resistance.

- In a **transformer** $\frac{V_p}{V_s} = \frac{N_p}{N_s}$: more turns on the secondary steps the voltage *up*, fewer steps it *down*. A transformer needs a changing magnetic field; steady d.c. does not give a sustained secondary output
- Power is sent across country at **high voltage** so the current – and the heat wasted in the cables, $P = I^2 R$ – is small.
- Fit the **switch and the fuse in the live wire**, and choose a fuse rating just above the appliance's normal working current.

Worked practice and source grounding

These original practice tasks support syllabus 4.1–4.5. They are not reproduced past-paper questions.

■ Compare series and parallel

Connect fixed $2\ \Omega$ and $4\ \Omega$ resistors to an ideal $6\ \text{V}$ source. Find the current and p.d. for each resistor in each arrangement.

In series, add the resistances; then use Ohm's law to find the common current:

$$R_{\text{total}} = R_1 + R_2$$

$$R_{\text{total}} = (2\ \Omega) + (4\ \Omega) = 6\ \Omega$$

$$I = \frac{V}{R_{\text{total}}}$$

$$I = \frac{6\ \text{V}}{6\ \Omega} = 1\ \text{A}$$

The p.d. across each resistor follows from this same current:

$$V_1 = IR_1$$

$$V_1 = (1\ \text{A})(2\ \Omega) = 2\ \text{V}$$

$$V_2 = IR_2$$

$$V_2 = (1\ \text{A})(4\ \Omega) = 4\ \text{V}$$

In parallel, each branch has the full supply p.d. Use Ohm's law separately for each branch, then conserve charge at the junction:

$$I_1 = \frac{V}{R_1}$$

$$I_1 = \frac{6 \text{ V}}{2 \Omega} = 3 \text{ A}$$

$$I_2 = \frac{V}{R_2}$$

$$I_2 = \frac{6 \text{ V}}{4 \Omega} = 1.5 \text{ A}$$

$$I_{\text{total}} = I_1 + I_2$$

$$I_{\text{total}} = (3 \text{ A}) + (1.5 \text{ A}) = 4.5 \text{ A}$$

Charge is conserved; it is not used up by the resistors.

■ Follow a potential-divider output

An ideal 6 V supply connects to a fixed 2 kΩ resistor and an NTC thermistor in series. Take the unloaded output across the thermistor. Find the output before and after warming reduces its resistance from 4 kΩ to 1 kΩ.

The p.d. ratio equals the resistance ratio. Before warming:

$$\frac{V_{\text{fixed}}}{V_{\text{thermistor}}} = \frac{R_{\text{fixed}}}{R_{\text{thermistor}}}$$

$$\frac{V_{\text{fixed}}}{V_{\text{thermistor}}} = \frac{2 \text{ k}\Omega}{4 \text{ k}\Omega} = \frac{1}{2}$$

$$V_{\text{fixed}} + V_{\text{thermistor}} = V_{\text{supply}}$$

$$\frac{1}{2}V_{\text{thermistor}} + V_{\text{thermistor}} = 6 \text{ V}$$

$$V_{\text{thermistor}} = \frac{6 \text{ V}}{1.5} = 4 \text{ V}$$

After warming, use the new resistance in the same ratio and sum:

$$\frac{V_{\text{fixed}}}{V_{\text{thermistor}}} = \frac{R_{\text{fixed}}}{R_{\text{thermistor}}}$$

$$\frac{V_{\text{fixed}}}{V_{\text{thermistor}}} = \frac{2 \text{ k}\Omega}{1 \text{ k}\Omega} = 2$$

$$V_{\text{fixed}} + V_{\text{thermistor}} = V_{\text{supply}}$$

$$2V_{\text{thermistor}} + V_{\text{thermistor}} = 6 \text{ V}$$

$$V_{\text{thermistor}} = \frac{6 \text{ V}}{3} = 2 \text{ V}$$

The output across the thermistor falls. The output across the other resistor rises from 2 V to 4 V; the two p.d.s still add to 6 V.

■ Time a generator waveform

A coil turns twice each second and its plane starts perpendicular to the magnetic field. It starts at zero e.m.f., reaches a peak after a quarter-turn, zero after a half-turn, the opposite peak after three quarters, and zero after one turn. One turn takes half a second, so the period is 0.50 s. The sign of the first peak depends on the chosen rotation and terminal reference.

■ Find an ideal transformer's input current

Given $V_p = 240 \text{ V}$, $V_s = 20 \text{ V}$ and $I_s = 3.0 \text{ A}$, find I_p . This model assumes 100% efficiency, so input power equals output power:

$$I_p V_p = I_s V_s$$

$$I_p = \frac{I_s V_s}{V_p}$$

$$I_p = \frac{(3.0 \text{ A})(20 \text{ V})}{240 \text{ V}} = 0.25 \text{ A}$$

■ Compare transmission losses

For the same transmitted power, raise the transmission voltage by a factor of ten. Find the change in current and cable heating, assuming the same cable resistance.

Rearrange the power relation and use equal transmitted power:

$$P = IV$$

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

$$I_{\text{new}} = \frac{P}{10V_{\text{old}}} = \frac{I_{\text{old}}}{10}$$

Cable heating depends on the square of the current:

$$P_{\text{loss}} = I^2 R$$

$$P_{\text{loss,new}} = \left(\frac{I_{\text{old}}}{10} \right)^2 R = \frac{I_{\text{old}}^2 R}{100}$$

The heating loss falls to one hundredth. High voltage does not itself make the cable resistance smaller.

■ Grounding and scope

Scope was checked against the local Cambridge IGCSE Physics 0625 syllabus extracts 4.1–4.5. Demand spot-check: June 2025 paper 41 questions 6–8 and their official schemes require magnetic materials and field spacing, graph identification, resistance and energy with minutes converted to seconds, parallel-branch current, generator timing and transmission/turns ratio. This is a spot-check, not a claim that every mapped paper has been re-audited.

Historical paper files and bank entries were read without modification. Safety clarifications: Electrical Safety First: plugs and fuses, HSE: electrical isolation, Association for Science Education: double insulation. Demonstrations use supervised low-voltage classroom equipment; these notes do not instruct students to work on mains appliances.