

Electricity and magnetism

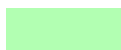
Specification J250 · Cambridge OCR

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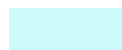
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Current

- the rate of flow of charge, in amperes (A). **Conventional current** — positive to negative terminal; electrons drift the other way.

Define Resistance

- a component's opposition to the current through it, in ohms (Ω).

Define Series circuit

- one closed loop. **Parallel circuit** — separate branches, each across the supply.

Define Diode

- current one way only. **NTC thermistor** — R falls as temperature rises. **LDR** — R falls as light rises.

Define Magnetic field

- the region round a magnet or current-carrying conductor where a magnetic material or another magnet feels a force.

Define Solenoid

- a coil whose current gives a bar-magnet-shaped field. **Electromagnet** — a solenoid with an iron core.

Define Charge

- a property of all matter, positive or negative, in coulombs (C). **Static electricity** — charge built up on an insulator, unable to flow away.

Define Potential difference

- energy transferred per unit charge between two points, in volts (V); $1 \text{ V} = 1 \text{ J/C}$.

Define Linear component

- R constant, so $I \propto V$. **Non-linear** — R changes with current, temperature or light.

Define Ammeter

- current, in **series**. **Voltmeter** — p.d., in **parallel**.

Define Power

- the rate of energy transfer, in watts (W); $1 \text{ W} = 1 \text{ J/s}$.

Define Equivalent resistance

- the single resistance with the same effect as a combination.

Define Permanent magnet

- produces its own field always. **Induced magnet** — magnetic only inside another's field.

HIGHER TIER

Define HT ONLY Magnetic flux density, B

- field strength, in teslas (T). **HT ONLY Fleming's left-hand rule** — First finger Field, seCond finger Current, thuMb Motion, at right angles.

P3.1 Static and charge

Interactions between matter and electrostatic fields, following on from P1. Charge is a fundamental property of matter, of two kinds; their effects are not normally seen because objects contain equal amounts of each.

Producing static electricity and sparking (P3.1b)

- **Rubbing two insulating surfaces together** transfers charge and produces **static electricity**.
- **Evidence that charged objects exert forces of attraction or repulsion on one another when not in contact:** rubbed polythene rods on threads swing apart; a rubbed rod deflects a stream of water or picks up paper; a charged balloon sticks to a wall. Like charges **repel**, unlike **attract**.
- **Sparking:** charge builds until the p.d. across the air gap makes the air conduct — electrons jump, with a flash and a crack. Fuel tankers are earthed to prevent it.

WATCH OUT

Learners commonly have difficulty **classifying materials as insulators or conductors**. Sort by whether they contain **free electrons**: metals and graphite conduct; plastic, glass, rubber and dry air do not, so they hold a static charge.

Learners also find it difficult to remember that **positive charge does not move to make a material positive — rather, it is the movement of electrons**. Never write "protons moved onto the rod": a positive object has **lost electrons**.

ANALOGY

Potential difference and current — the water circuit. Current is the **rate of flow of water** past a point in a pipe; potential difference is the **pressure difference** made by the pump. The pump (cell) gives every litre energy and the waterwheel (lamp) takes it back, so the same water returns — **current is the same all round a single loop**, nothing is used up — and the pressure added equals the pressure dropped, so the **p.d. across the cell equals the total p.d. across the components**.

Charge is a property of all matter (P3.1a)

- **Charge is a property of all matter**, and there are **positive and negative** charges: protons +, electrons –, neutrons neutral. Measured in **coulombs (C)**.
- In **most bodies there is an equal number of positive and negative charges**, so the body has zero net charge.

Electron transfer explains static electricity (P3.1c)

- Only **electrons** move: the material **gaining electrons becomes negative**, the one **losing electrons becomes positive**. Equal and opposite charges, so charge is conserved.
- **Static charge only builds up on insulators**; on a conductor it flows to earth at once unless the conductor is isolated.
- **Attraction of an uncharged object** (paper, a wall): the rod's field pushes electrons in it away or draws them nearer, so the near surface gains the opposite charge, which attracts more strongly than the further like charge repels.

Current and the conditions for charge to flow (P3.1d, P3.1e, P3.1f)

- **Current is a rate of flow of charge (electrons)**, and the conditions needed for charge to flow (P3.1d) are a **source of potential difference** in a **closed circuit**.
- **Current has the same value at any point in a single closed loop (P3.1e)**: charge is not used up, so an ammeter reads the same anywhere in the loop.
- **Conventional current** runs + to –; electrons in a metal drift – to +.

P3.2 Simple circuits

Current, potential difference and resistance, the relationships between them, and how they are investigated with conventional circuits.

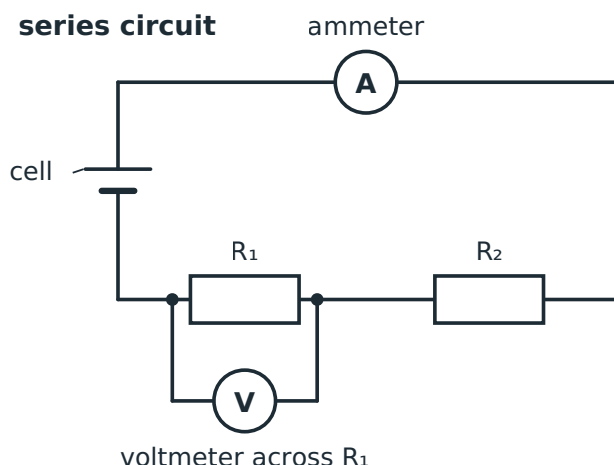
Series and parallel circuits (P3.2a)

Describe the differences between series and parallel circuits, including the **behaviour of energy, current and potential difference** and the **positioning of measuring instruments**.

	Series	Parallel
Path	One loop only	A separate branch per component
Current	Same everywhere	Splits : branch currents add to the supply current
Potential difference	Shares out : p.d.s add to the supply p.d.	Same across every branch
Adding a component	Resistance increases , current falls, lamps dim	Resistance decreases , supply current rises, lamps stay bright
If one breaks	Everything stops	Only that branch stops
Energy	Each charge passes through every component in turn	Each charge passes through one branch, giving up all its energy there
Meters	Ammeter in series in the loop	Ammeter in series in the branch; voltmeter always in parallel

Current and potential difference in series and in parallel circuits.

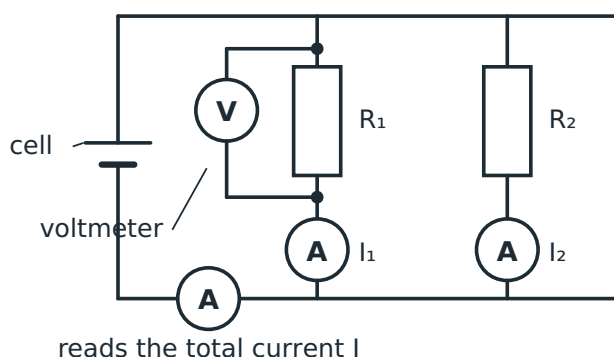
series circuit



In series

- the current is the same through every component: $I_1 = I_2 = I_3$
- the potential differences add up to the p.d. of the supply: $V = V_1 + V_2$
- the resistances add up: $R_{\text{total}} = R_1 + R_2$
- adding a resistor in series increases the total resistance, so the current gets smaller

parallel circuit



In parallel

- the potential difference across each branch is the same as the supply p.d.: $V = V_1 = V_2$
- the branch currents add up to the total current: $I = I_1 + I_2$
- the total resistance of two resistors is less than the resistance of the smallest resistor
- adding a resistor in parallel gives the current more paths, so the total resistance falls and the total current gets bigger

Representing d.c. circuits (P3.2b)

Represent d.c. circuits with the conventions of positive and negative terminals, and the symbols that represent common circuit elements. Draw with straight lines and right-angled corners; **conventional current** leaves the **positive** terminal. J250's list:

Component	Symbol	What it does
Cell / battery / d.c. supply	Long thin (+) and short thick (–) line; cells in a row	Provides the p.d.
Switch	Break in the line with a hinged lever	Opens or closes the circuit
Fixed / variable resistor	Plain rectangle; rectangle with a diagonal arrow	Fixed or adjustable opposition
Filament lamp	Circle with a cross	Energy by light and heating
Diode	Triangle pointing at a bar	Current one way only
LDR / NTC thermistor	Circle round a rectangle, two inward arrows; rectangle with an angled line	R falls as light, or temperature, rises
Ammeter / voltmeter	Circle with A; circle with V	Current, in series ; p.d., in parallel

Circuit symbols: those named by P3.2b, plus the battery, LED and fuse, which J250 does not name.



cell

supplies a potential difference



battery

two or more cells joined in series



switch (open)

no current can flow



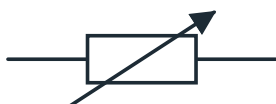
switch (closed)

current can flow



fixed resistor

resistance stays constant



variable resistor

resistance can be changed



filament lamp

resistance rises as it gets hotter



ammeter

measures current, A connect in series



voltmeter

measures p.d., V connect in parallel



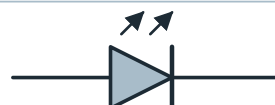
fuse

melts if the current is too high



diode

current flows one way only



LED

light-emitting diode emits light when on



thermistor

resistance falls as temperature rises



LDR

light-dependent resistor

Current, resistance and potential difference (P3.2c, P3.2d)

- Recall that current (I) depends on both resistance (R) and potential difference (V), and the units in which these are measured (P3.2c) — amperes (A), ohms (Ω), volts (V) — including the definition of potential difference: energy transferred per unit charge, $1 \text{ V} = 1 \text{ J/C}$.
- At fixed p.d., more resistance means less current; at fixed resistance, more p.d. means more current.

ANALOGY

Resistance — the crowded corridor. A wide, empty corridor lets people through easily: low resistance. A long, narrow one full of furniture slows them, and they bump into things and warm the place up: high resistance, energy going to the thermal store. Push harder (raise the p.d.) and more get through per second. Heating a filament shakes the furniture about, so a lamp's resistance rises as it glows.

Linear and non-linear components (P3.2e, P3.2f, P3.2g, P3.2h)

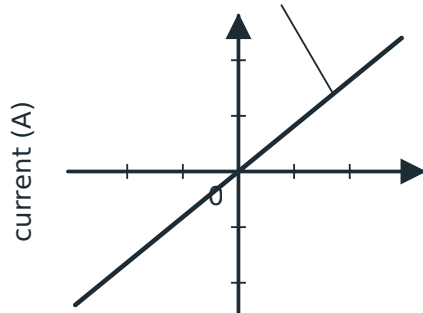
- Explain that for some resistors the value of R remains constant, but that in others it can change as the current changes (P3.2e).
- Explain the design and use of circuits to explore such effects (P3.2f), with wire of varying resistance, filament lamps, diodes, NTC thermistors and LDRs: the component in series with an ammeter and variable resistor, and a voltmeter in parallel across it.
- Use graphs to explore whether circuit elements are linear or non-linear (P3.2g) and relate the curves produced to the function and properties of circuit elements (P3.2h). *Linear: a straight line through the origin, R constant. Non-linear: a curve, so R differs at every point and must come from $R = V \div I$ at that point, not from the gradient. Steeper means smaller resistance.*

Component	I-V graph	R	Why
Fixed resistor at constant temperature	Straight line through the origin, both ways	Constant	Temperature constant, so the ions vibrate no more than before
Filament lamp	S-shaped curve, flattening at high V	Increases with current	The filament heats; ions vibrate more, so electrons collide more often
Diode	Almost none until about 0.6 V forward, then steep; none in reverse	Very low forward, very high reverse	It conducts one way only

Current–potential difference graphs for an ohmic conductor, a filament lamp and a diode.

ohmic conductor

straight line through 0

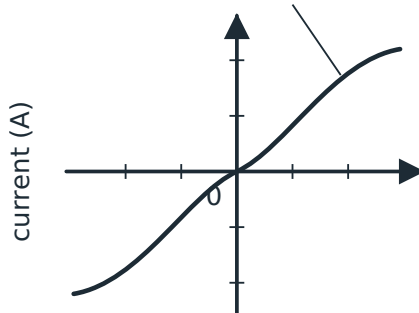


potential difference (V)

- at a constant temperature
- current is directly proportional to p.d.
- resistance stays constant
- e.g. a fixed resistor

filament lamp

curve gets shallower

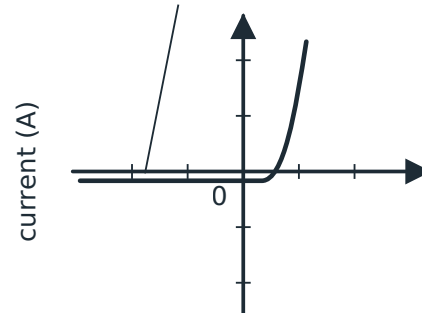


potential difference (V)

- as the current rises the filament gets hotter
- its resistance increases, so the graph is not linear
- same shape both ways

diode

no current in reverse



potential difference (V)

- current flows in one direction only
- in reverse the resistance is very high, so almost no current flows

- **NTC thermistor** — resistance **falls** as **temperature rises**; thermostats, fire alarms.
- **LDR** — resistance **falls** as **light intensity rises**; street-light switching.

d.c. circuits for measurement and testing (P3.2k)

- **Measuring** an unknown resistance: ammeter in **series**, voltmeter in **parallel**, $R = V \div I$, repeated and meaned.
Testing a component: vary the p.d. with a **variable resistor** and look for the expected I – V shape.
- **Sensing circuits**: a **thermistors** or **LDR** in series with a fixed resistor. As the sensor's resistance falls it takes a smaller share of the supply p.d., so the p.d. across the fixed resistor rises and can switch a heater or alarm.

Resistors in series and in parallel (P3.2i, P3.2j)

Explain why, if two resistors are in series the net resistance is increased, whereas with two in parallel the net resistance is decreased — **qualitative explanation only (P3.2i)**, and calculate the currents, potential differences and resistances in d.c. series and parallel circuits (P3.2j).

- **Series**: charge passes through both, meeting more total opposition, so the equivalent resistance exceeds either alone.
- **Parallel**: charge has **more than one path**, so more flows per second for the same p.d. — like opening a second checkout — and the equivalent resistance is **smaller than the smaller** of the two.

Power and energy in circuits (P3.2l, P3.2m)

Explain how the power transfer in any circuit device is related to the potential difference across it and the current, and to the energy changes over a given time (P3.2l): *each coulomb gives up V joules and I coulombs pass each second, so $V \times I$ joules are transferred per second.* P3.2m: apply the equations relating potential difference, current, quantity of charge, resistance, power, energy and time, and solve problems for circuits which include resistors in series, using the concept of equivalent resistance.

WATCH OUT

Learners find **potential difference very difficult to grasp**, and find it difficult to understand **the behaviour of charge in circuits and through components, and how this relates to energy or work done within a circuit**:

- **Current is not used up.** The charge leaving the cell returns to it; a lamp uses **energy**, not charge, which is why the ammeter reads the same before and after it.
- **P.d. is a difference between two points**, so it is measured **across** a component with a voltmeter in parallel. "The p.d. at a point" is meaningless.
- **Energy per coulomb is the link.** The cell gives each coulomb V joules and each component takes a share, the shares adding to what the cell supplied — hence p.d.s adding in series.

P3.3 Magnets and magnetic fields

With the flow of charge understood, we turn to the link between moving charge and magnetism — magnets, and the fields around magnets and current-carrying wires.

Poles, permanent and induced magnets (P3.3a, P3.3b)

Describe the attraction and repulsion between unlike and like poles for permanent magnets (P3.3a), with diagrams of magnetic field patterns around bar magnets:

- **Like poles repel; unlike poles attract** — non-contact forces, acting through space and through non-magnetic materials.
- **N–S** field lines run from one magnet into the other and the magnets are pulled together; **N–N** or **S–S** lines curve away, with a **neutral point** between them where the fields cancel.
- Magnets attract **magnetic materials** (iron, steel, cobalt, nickel) but never repel them — repulsion is the only sure test for a permanent magnet.

Describe the difference between permanent and induced magnets (P3.3b):

	Permanent	Induced
Field	Produces its own all the time	Only magnetic inside another magnet's field
Material	"Hard", e.g. steel	"Soft", e.g. iron
Removed from a field	Keeps its magnetism	Loses most or all of it quickly
Behaviour	Can attract or repel	Always attracted , never repelled

Induction explains why a magnet picks up a paper clip that picks up another: each becomes an induced magnet, the nearest pole always the **opposite** one.

Characteristics of a magnetic field (P3.3c)

Describe the characteristics of the magnetic field of a magnet, showing how strength and direction change from one point to another, and ways of investigating this:

- **Direction:** lines run **from north to south outside** the magnet; the direction at a point is the direction of the force on a test **north** pole.
- **Strength: the closer the lines, the stronger the field.** Lines are closest at the **poles**, so the field is strongest there and weakens with distance; lines never cross.
- **Investigating:** iron filings on paper over the magnet, tapped gently; or a **plotting compass** moved round it, marking the needle's direction and joining the dots.

The magnetic effect of a current, and solenoids (P3.3e, P3.3f, P3.3g)

Describe how to show that a current can create a magnetic effect, and describe the directions of the magnetic field around a conducting wire (P3.3e).

- A **plotting compass** near a straight current-carrying wire deflects, returns to north when the current is switched off, and deflects the other way if the current is reversed.
- The field is **concentric circles** in a plane at right angles to the wire. Direction from the **right-hand grip rule**: right thumb along the **conventional current**, curled fingers giving the field.
- Recall that the strength of the field depends on the **current and the distance from the conductor (P3.3f)**: larger current, stronger field; further away, weaker, shown by circles drawn further apart.

Explain how solenoid arrangements can enhance the magnetic effect (P3.3g). In a **solenoid** the circular fields of the turns **add together**, giving a **strong, uniform field inside** and an outside field shaped like a **bar magnet's**; the grip rule on the coil gives the north end. The effect is enhanced by more **current**, more **turns** per unit length, and an **iron core**, which becomes an induced magnet and greatly strengthens the field — an **electromagnet**, switchable and adjustable. Uses: scrapyards, cranes, electric bells, relays, circuit breakers.

WATCH OUT

Learners hold the misconception that **larger magnets will always be stronger magnets**. Size is not strength: a small neodymium magnet easily out-pulls a large, weak ceramic one.

They also have difficulty with **field line density being an indicator of field strength**. The lines are a convention, not real objects — **crowded lines mean a strong field**, so the field weakens as they spread out.

Learners often do not know that **the geographic and magnetic poles are not located in the same place**. They are hundreds of kilometres apart, which is why a compass needle points a few degrees off true north.

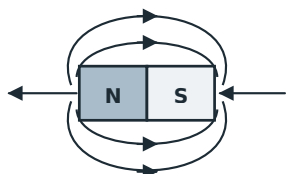
Compasses and the Earth's magnetic core (P3.3d)

Explain how the behaviour of a magnetic (dipping) compass is related to evidence that the core of the Earth must be magnetic.

- A compass holds a tiny bar magnet free to rotate, so with no other magnet near it lines up with the **Earth's field** — evidence the field comes from **inside the planet**, generated in its **liquid iron and nickel core**.
- A **dipping compass**, free to rotate vertically, tips steeply near the poles and lies flat at the equator, showing a **vertical component** — the pattern of a bar magnet buried in the core.

Magnetic field patterns around a bar magnet, a current-carrying wire and a solenoid.

Field around a bar magnet



Field lines run from the north pole to the south pole, and are closest together at the poles where the field is strongest.

Two magnets: attract and repel



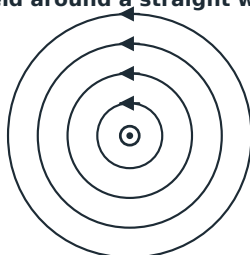
unlike poles attract — they pull together



like poles repel — they push apart

The arrows show the forces on the magnets. These are non-contact forces.

Field around a straight wire carrying a current

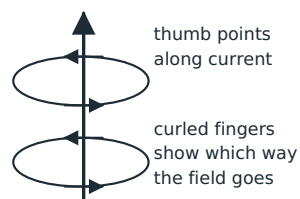


The field lines are circles around the wire.

They are closer together near the wire, where the field is strongest.

The dot means the current comes out of the page.

Right-hand grip rule

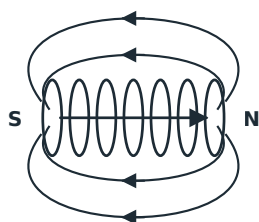


thumb points along current

curled fingers show which way the field goes

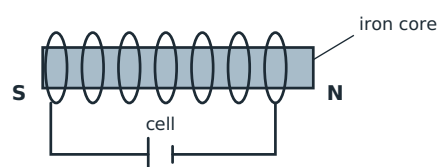
Solenoid and electromagnet

Solenoid



Outside, the field has the same shape as a bar magnet's. Inside the coil the field is strong and uniform (evenly spaced parallel lines).

Electromagnet



An electromagnet is a solenoid with an iron core. Iron is easily magnetised, so the core makes the magnetic field much stronger.

HT ONLY The motor effect and Fleming's left-hand rule (P3.3h, P3.3i)

HT ONLY Describe how a magnet and a current-carrying conductor exert a force on one another (P3.3h).

- The wire's own circular field and the magnet's field **interact**: on one side they reinforce, on the other they cancel, so the wire is pushed from the strong side to the weak side. By Newton's third law the wire pushes back **equally and oppositely** on the magnet.
- The **jumping wire** shows it: a loose wire between the poles of a horseshoe magnet flicks out of the gap the instant the current is switched on, and the other way if current or magnet is reversed.
- The force is **greatest when the conductor is at right angles to the field** and **zero when parallel to it**.

HT ONLY Show that Fleming's left-hand rule represents the relative orientations of the force, the current and the magnetic field (P3.3i). Hold the **left** hand with thumb and first two fingers **mutually at right angles**: **First finger** — **Field** (north to south); **seCond finger** — **Current** (conventional); **thuMb** —

Motion, the force. Reversing **either** current **or** field reverses the force; reversing **both** leaves it unchanged.

Fleming's left-hand rule

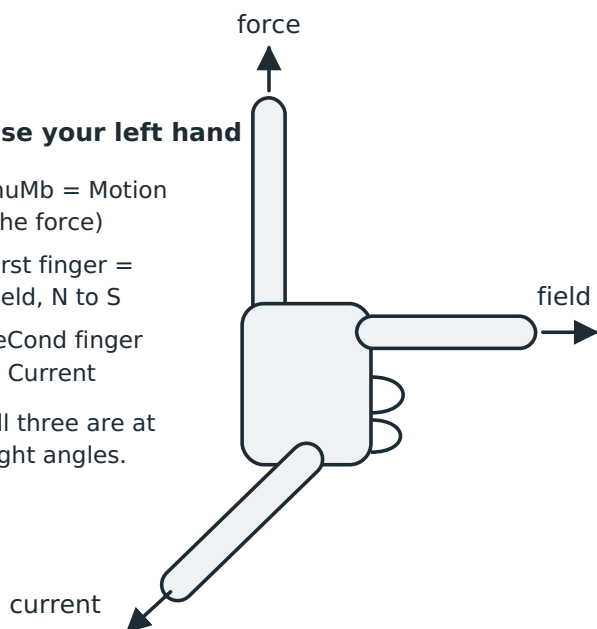
Use your left hand

thuMb = Motion
(the force)

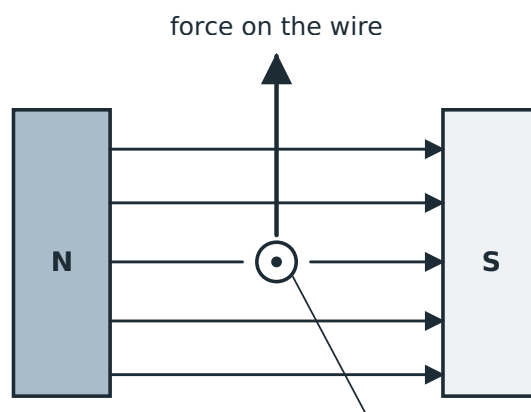
First finger =
Field, N to S

seCond finger
= Current

All three are at
right angles.



The motor effect



The dot shows current coming out of the page.
The field runs from the north pole to the south.

First finger along the field, seCond finger along
the current: the thuMb then gives the force.

Size of the force

force = magnetic flux density $\times$ current $\times$ length

$$F = B I l$$

force, F , in newtons, N

magnetic flux density, B , in tesla, T

current, I , in amperes, A

length, l , in metres, m

The conductor must be at right angles to
the magnetic field for this equation to apply.

HT ONLY Calculating the force, and the electric motor (P3.3j, P3.3k)

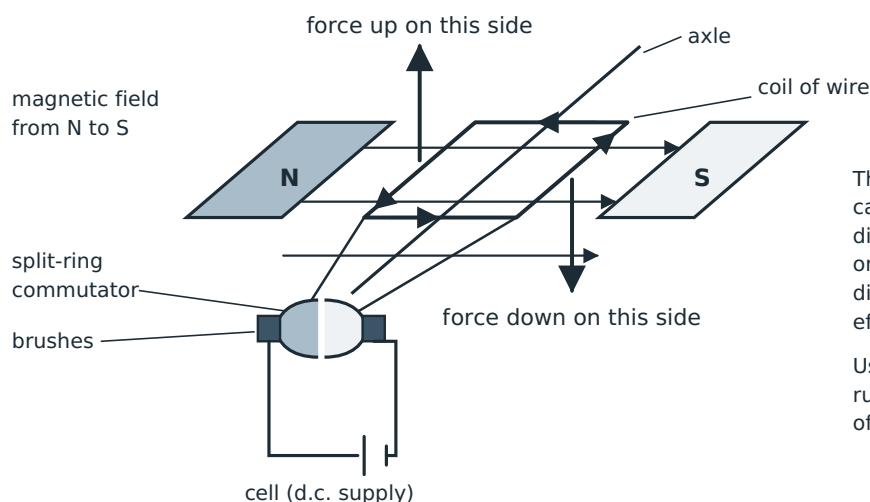
HT ONLY Explain how the force exerted from a magnet and a current-carrying conductor is used to cause rotation in electric motors (P3.3k) — an understanding of how motors work, but knowledge of the structure of a motor is not expected.

- A rectangular coil sits between a magnet's poles, current flowing **one way** along one side and **the other way** along the opposite side, so Fleming's left-hand rule gives a **force up on one side and down on the other**, turning the coil.
- Half a turn later those sides have swapped and the forces would turn it back; the **split-ring commutator** prevents this by **reversing the current every half turn**, keeping rotation continuous.
- The motor turns **faster** with a larger current, a stronger field or more turns, and the **other way** if current or magnet is reversed.

A simple d.c. motor, and why it needs a split-ring commutator.

Higher tier only

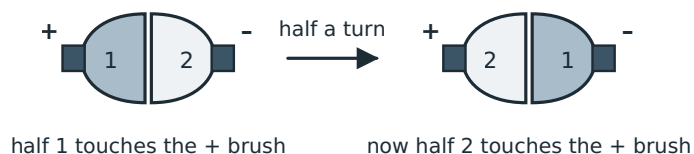
A simple d.c. electric motor



The two sides of the coil carry current in opposite directions, so the forces on them are in opposite directions. This turning effect rotates the coil.

Use Fleming's left-hand rule to find the direction of each force.

Why the split-ring commutator is needed



Every half turn the halves swap brushes, so the current in the coil reverses.

Each side of the coil moves from the north side of the magnet to the south side every half turn.

Reversing the current at the same moment keeps the force on each side turning the coil the same way.

Without the commutator the coil would stop after half a turn.

HIGHER TIER

NOTE

Practical suggestions — magnets and the motor effect (no PAG). Suspended magnets showing attraction and repulsion; plotting fields with iron filings and a plotting compass; the dipping compass; the field around a current-carrying wire and around a solenoid; factors affecting the magnetic effect, such as number of turns and length; **HT ONLY** the jumping wire demonstration and simple motors. A solenoid's field is uniform inside and bar-magnet-shaped outside, and the clips it lifts rise with current, with turns, and sharply with an iron core. Work away from ironwork, which distorts compass plots, and switch off between readings, since a warming coil raises its resistance. Keep strong magnets away from phones, cards and pacemakers.

NOTE

Not required by J250. Combined Science P3 has **no** electric field diagrams, **no** electromagnetic induction and **no** alternators, dynamos, transformers, microphones or loudspeakers. Mains electricity, a.c. and d.c. and the National Grid come in **P6**, on Paper 6 / Paper 12.