

Magnetism and electromagnetism

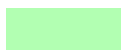
Specification 8463 · AQA

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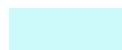
Revision notes for one topic, free to download.

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 Magnetic pole

- the place on a magnet where the magnetic forces are strongest.

Define Magnetic material

- a material a magnet attracts: iron, steel, cobalt and nickel.

Define Magnetic field

- the region around a magnet where a force acts on another magnet or on a magnetic material.

Define Non-contact force

- a force between objects that are not touching, e.g. magnetic attraction.

Define Solenoid

- a wire shaped into a coil, giving a strong, uniform field inside it.

Define Magnetic flux density (B)

- a measure of the strength of a magnetic field, in tesla (T).

Define Fleming's left-hand rule

- the rule giving the relative orientation of force, current and field in the motor effect.

Define Alternator

- a generator with slip rings, producing ac; a **dynamo** has a split-ring commutator and produces dc.

Define Step-up transformer

- $V_s > V_p$; **step-down transformer** — $V_s < V_p$.

Define Permanent magnet

- a magnet that produces its own magnetic field.

Define Induced magnet

- a material that becomes a magnet in a magnetic field and loses most/all of its magnetism quickly when removed.

Define Magnetic field line

- a line showing field direction, drawn from the north (seeking) pole to the south (seeking) pole.

Define Magnetic compass

- a small bar magnet whose needle points along the field it is in.

Define Electromagnet

- a solenoid with an iron core.

Define Motor effect

- the force a magnet and a current-carrying conductor in its field exert on each other.

Define Generator effect

- inducing a potential difference when a conductor moves relative to a magnetic field, or the field around it changes.

Define Transformer

- a primary coil and a secondary coil wound on an iron core, used to change an alternating potential difference.

Define National Grid

- the system of transformers and cables transferring electrical power from power stations to consumers.

7.1 Permanent and induced magnetism, magnetic forces and fields

7.1.1 Poles of a magnet

- The **poles** of a magnet are the places where the magnetic forces are strongest. Every magnet has a **north (seeking)** and a **south (seeking)** pole.
- Two **like** poles **repel**; two **unlike** poles **attract**. These are examples of a **non-contact force**.
- A **permanent magnet** produces its own magnetic field.
- An **induced magnet** is a material that becomes a magnet when placed in a magnetic field. Induced magnetism **always causes a force of attraction**, and an induced magnet loses most/all of its magnetism quickly when removed from the field.

	Permanent magnet	Induced magnet
Field	Produces its own, always	Magnetic only while in another magnet's field
Poles	Fixed N and S poles	Poles induced so the nearer pole is always opposite to the one causing it
Force	Can attract or repel	Always attraction
Removed from the field	Unchanged	Loses most/all magnetism quickly
Example	Bar magnet, compass needle	Iron paperclip hanging from a magnet

WATCH OUT

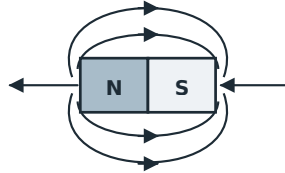
"A magnet picks up a paperclip, so the paperclip is a magnet." It is an **induced** magnet — poles are induced in it the right way round to attract. That is why a magnet can never repel a plain iron paperclip, and why a hanging chain of clips collapses the moment the magnet is removed.

7.1.2 Magnetic fields

- The **magnetic field** is the region around a magnet where a force acts on another magnet or on a **magnetic material** (iron, steel, cobalt, nickel).
- The force between a magnet and a magnetic material is **always one of attraction**.
- The **strength** of the field depends on the **distance from the magnet**, and is **greatest at the poles**.
- The **direction** of the field at a point is the direction of the force that would act on **another north pole** placed there. Field lines run **from north to south**.
- Drawing a bar magnet's field: lines are **closest together at the poles** (strongest field) and **spread out** further away (weaker field); each line has an **arrow** from N to S; lines never cross.

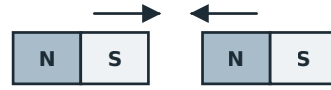
The field around a bar magnet, and the fields between attracting and repelling poles

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



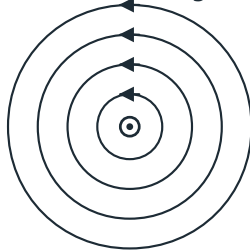
unlike poles attract — they pull together



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

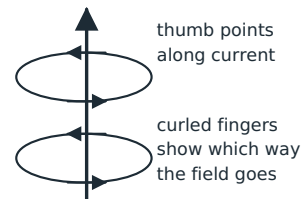


The field lines are circles around the wire.

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

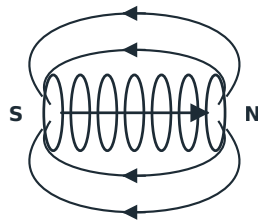


thumb points along current

curled fingers show which way the field goes

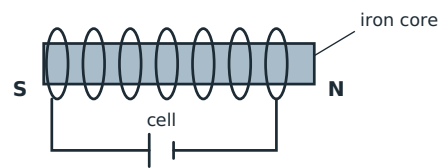
Solenoid and electromagnet

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.

ANALOGY

Field lines work like **contour lines on a map**: the lines are not real objects, but where they bunch tightly the ground is steep — and where field lines bunch tightly the field is strong.

Plotting the field pattern with a compass:

1. Place the bar magnet on paper and draw round it.
2. Put a **plotting compass** near one pole; mark a dot at each end of the needle.
3. Move the compass so the needle's tail sits on the dot just marked; mark the new head position. Repeat to the other pole.
4. Join the dots into a smooth line, arrowed in the direction the compass north pointed, then start again elsewhere to build up the pattern.

The Earth's magnetic field. A magnetic compass contains a **small bar magnet**, and its needle points in the direction of the **Earth's magnetic field**. Since only a magnetic field can turn a compass, and it turns with no other magnet nearby, the field must come from the Earth itself — evidence that the Earth's core must be magnetic.

7.2 The motor effect

7.2.1 Electromagnetism

- When a current flows through a conducting wire, a **magnetic field** is produced around the wire. Its strength depends on the **current** and the **distance from the wire**.
- **Straight wire:** the field is a set of **concentric circles** centred on the wire, spaced further apart further out. Direction comes from the **right-hand grip rule** — point the thumb of your right hand along the current and your curled fingers give the field direction.
- Demonstrating the magnetic effect of a current: pass a vertical wire through a horizontal card, put plotting compasses on the card, switch on the current — the compasses swing into circles, and all reverse if the current reverses.
- Shaping a wire to form a **solenoid** increases the strength of the magnetic field. The field inside a solenoid is strong and uniform (straight, parallel, evenly spaced lines).
- The field **around** a solenoid is similar in shape to that of a bar magnet, with a north pole at one end. The right-hand grip rule works here too: curl your fingers the way the current flows round the coils and your thumb points to the **north** end.
- Adding an iron core increases the strength of a solenoid's field. An electromagnet is a solenoid with an iron core.
- To increase the magnetic effect: more current, more turns, add an iron core. An electromagnet can be **switched on and off** — used in scrapyard cranes, electric bells, relays and circuit breakers.
- **PHYSICS ONLY** You should be able to interpret diagrams of electromagnetic devices to explain how they work: find the coil (where the field is made), the core, and the moving part.

HIGHER TIER

7.2.2 Fleming's left-hand rule **HT ONLY**

- **HT ONLY** When a conductor carrying a current is placed in a magnetic field, the magnet producing the field and the conductor exert a force on each other. This is the **motor effect**, caused by the magnet's field interacting with the field made by the current.
- **HT ONLY** The force is greatest when the conductor is at right angles to the field and **zero when it is parallel** to it.
- **HT ONLY** Factors affecting the **size** of the force: **magnetic flux density** B , current I , and **length** of conductor in the field l .
- **HT ONLY** Reversing **either** the current **or** the field reverses the force; reversing **both** leaves it unchanged. **HT ONLY Fleming's left-hand rule** gives the relative orientation of force, current and field. Hold the **left hand** with thumb and first two fingers at right angles: **First finger = Field** (N to S), **seCond finger = Current** (conventional, + to -), **thuMb = Motion** (the force).

Fleming's left-hand rule

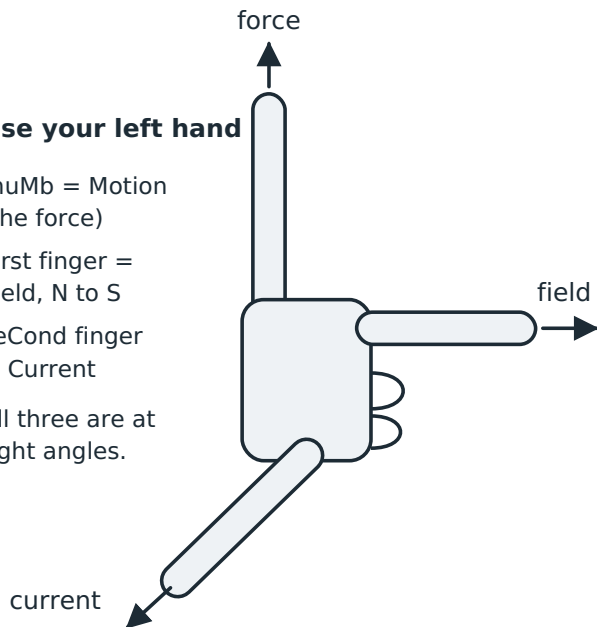
Use your left hand

thuMb = Motion
(the force)

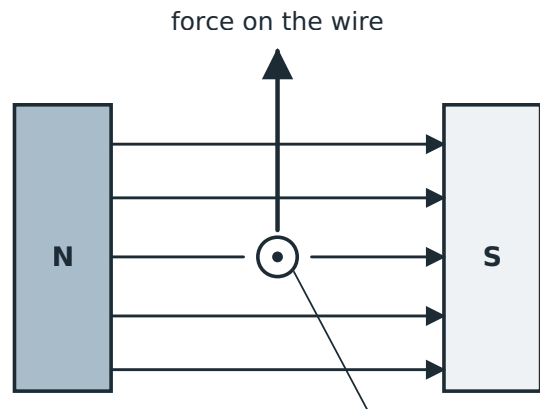
First finger =
Field, N to S

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 × current × 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.

ANALOGY

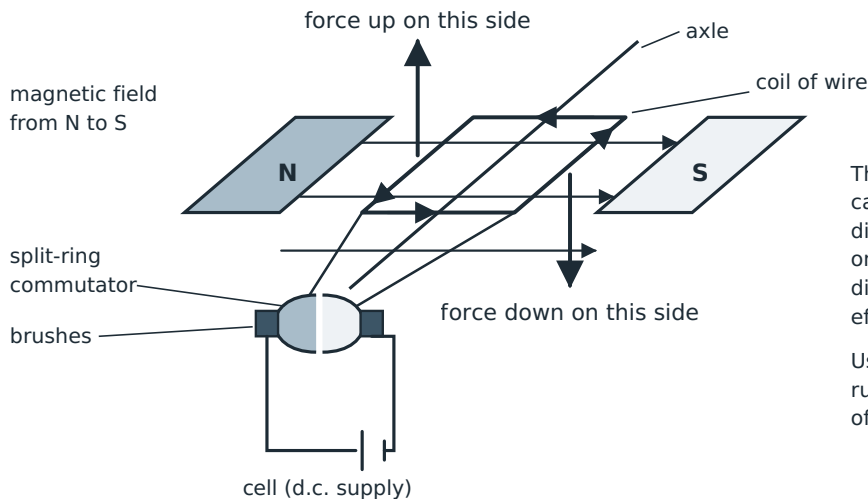
The memory device is hidden in the finger names: First finger = Field, seCond finger = Current, thuMb = Motion. Use the **left** hand for the motor effect — "L for Left, L for the Load being pushed". The **right** hand belongs to the grip rule for the field around a wire.

HIGHER TIER

7.2.3 Electric motors HT ONLY

- **HT ONLY** A coil of wire carrying a current in a magnetic field tends to rotate. This is the basis of an **electric motor**.
- **HT ONLY** Explaining the rotation: 1. The coil sits between the poles of a permanent magnet and carries a current. 2. Its two sides carry current in **opposite** directions, so by Fleming's left-hand rule one side is pushed **up** and the other **down**. 3. This pair of forces gives a **turning effect**, so the coil rotates. 4. A **split-ring commutator** reverses the current in each side every half turn, so the coil keeps turning the same way.
- **HT ONLY** Larger current, stronger field or more turns makes it turn faster. Reversing the current **or** the field reverses the rotation.

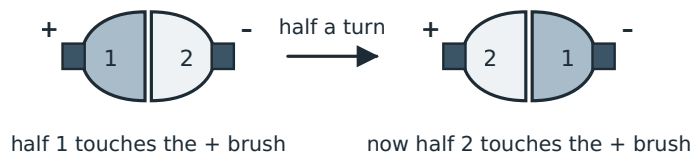
A simple d.c. electric motor



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

7.2.4 Loudspeakers **PHYSICS ONLY**

HT ONLY

- **PHYSICS ONLY HT ONLY** Loudspeakers and headphones use the motor effect to convert **variations in current** in electrical circuits into the **pressure variations in sound waves**.
- **PHYSICS ONLY HT ONLY** A **moving-coil loudspeaker**: 1. An **alternating current** passes through a coil wrapped round one pole of a permanent magnet. 2. The current in the field produces a **force on the coil** (motor effect). 3. As the current alternates, the force **reverses** each half cycle, so the coil vibrates in and out. 4. The coil is attached to a **cone**, which vibrates with it, creating **pressure variations** in the air — a sound wave. 5. The sound's frequency matches the frequency of the ac; a larger current gives a larger amplitude and a louder sound.
- **PHYSICS ONLY HT ONLY** Headphones work the same way with a smaller coil and diaphragm.

7.3 Induced potential, transformers and the National Grid PHYSICS ONLY

HIGHER TIER

HT ONLY

HIGHER TIER

7.3.1 Induced potential PHYSICS ONLY

HT ONLY

- **PHYSICS ONLY HT ONLY** If a conductor **moves relative to a magnetic field**, or the **magnetic field around a conductor changes**, a **potential difference is induced** across the ends of the conductor. If it is part of a **complete circuit**, a **current is induced**. This is the **generator effect**.
- **PHYSICS ONLY HT ONLY** An induced current generates a magnetic field that opposes the original change — the movement of the conductor or the change in field. This is why a generator gets harder to turn as more current is drawn from it.
- **PHYSICS ONLY HT ONLY** Factors affecting the **size** of the induced p.d./current: the **speed** of movement, the **strength of the magnetic field**, the **number of turns** on the coil, and the **area** of the coil.
- **PHYSICS ONLY HT ONLY** Factors affecting the **direction**: the **direction of movement** of the conductor or magnet, and the **polarity (orientation) of the magnetic field** — reverse either and the induced p.d. reverses.
- **PHYSICS ONLY HT ONLY** With nothing moving and no change in the field, **no potential difference is induced**.

HIGHER TIER

NOTE

PHYSICS ONLY HT ONLY The **whole of section 7.3** is physics only and Higher Tier only.

ANALOGY

Induced potential is like pushing a swing door that pushes back. Move the magnet into the coil and the coil "objects", making its own field that opposes your movement, so you must keep doing work. Stop moving and the induced p.d. falls to zero; push faster and both the push-back and the induced potential difference are bigger.

WATCH OUT

Motor effect and generator effect are easy to swap. Check what is **supplied**: current supplied and something moves = **motor** effect; movement supplied and a potential difference appears = **generator** effect.

	Motor effect	Generator effect PHYSICS ONLY HT ONLY
Input	Current in a wire in a magnetic field	Movement of a conductor relative to a field, or a changing field
Output	Force / movement	Induced potential difference (and current if the circuit is complete)
Energy transfer	Electrical → kinetic	Kinetic → electrical
Key rule	Fleming's left-hand rule	Induced current opposes the change that caused it
Devices	Electric motor, loudspeaker, headphones	Alternator, dynamo, microphone, transformer

7.3.2 Uses of the generator effect **PHYSICS ONLY****HT ONLY**

- **PHYSICS ONLY HT ONLY** The generator effect is used in an **alternator to generate ac** and in a **dynamo to generate dc**. **PHYSICS ONLY HT ONLY Alternator:** a coil rotates in a magnetic field, connected by **slip rings and brushes** so each end of the coil always stays connected to the same side of the circuit. The induced p.d. **reverses every half turn**, giving **ac**. **PHYSICS ONLY HT ONLY Dynamo:** the same, but a **split-ring commutator** swaps the connections every half turn so the output never reverses, giving **dc**. **PHYSICS ONLY HT ONLY Potential difference–time graphs:** the alternator gives a sine curve equally above and below zero (p.d. is at a **peak** when the coil is parallel to the field, because the sides are then moving at right angles to the field lines and cutting them fastest, and **zero** when the coil is at right angles to the field, because the sides are then moving along the field lines and cutting none); the dynamo gives the same shape with every negative half flipped above the axis. Spinning **faster** makes the peaks **higher** and **closer together** on both.

7.3.3 Microphones **PHYSICS ONLY****HT ONLY**

PHYSICS ONLY HT ONLY Microphones use the generator effect to convert the pressure variations in sound waves into variations in current in electrical circuits.

- **PHYSICS ONLY HT ONLY** A **moving-coil microphone** (essentially a loudspeaker working in reverse): 1.

Pressure variations in the sound wave make a **diaphragm** vibrate. 2. The diaphragm is attached to a **coil** in the field of a permanent magnet, so the coil moves in the field. 3. The movement **induces a potential difference** across the coil, so a current flows. 4. The current varies in step with the sound wave — frequency matching the sound's frequency, size depending on its amplitude.

7.3.4 Transformers **PHYSICS ONLY****HT ONLY**

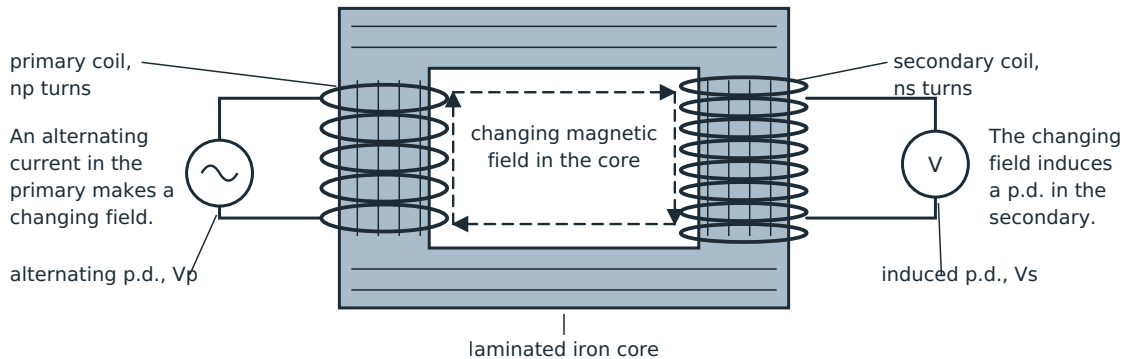
- **PHYSICS ONLY HT ONLY** A basic **transformer** consists of a primary coil and a secondary coil wound on an iron core. Iron is used as it is easily magnetised.
- **PHYSICS ONLY HT ONLY** How it works: 1. An **alternating** p.d. across the primary coil drives an alternating current in it. 2. This produces a **continually changing magnetic field** in the iron core. 3. The core carries that changing field to the secondary coil, where it **induces an alternating potential difference**.
- **PHYSICS ONLY HT ONLY** A transformer **only works with ac**: with dc the field would be steady, nothing would change, and no p.d. would be induced.
- **PHYSICS ONLY HT ONLY** Knowledge of laminations and eddy currents is not required. In a **step-up** transformer $V_s > V_p$; in a **step-down** transformer $V_s < V_p$.

HT ONLY A basic transformer: primary coil, iron core and secondary coil

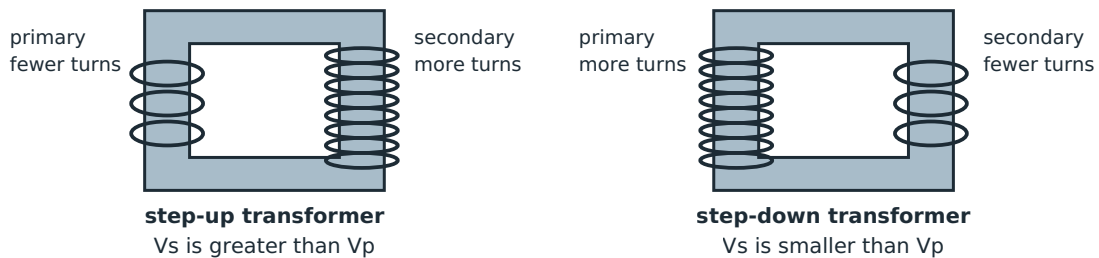
Physics only

Higher tier only

A basic transformer



Step-up and step-down transformers



The transformer equations

$$V_p / V_s = n_p / n_s$$

V_p and V_s are the potential differences across the coils, in volts, V.
 n_p and n_s are the numbers of turns.
 Iron is used because it is easily magnetised.

$$V_s \times I_s = V_p \times I_p$$

power output (secondary) = power input (primary), if the transformer is 100% efficient.
 power, in watts, W; current, I, in amperes, A
 A transformer only works with a.c., not d.c.

HIGHER TIER

The National Grid.

PHYSICS ONLY HT ONLY Power stations generate at about 25 000 V. Step-up

transformers raise this to 400 000 V for transmission; step-down transformers reduce it in stages to 230 V for homes. For a given power, a higher potential difference means a smaller current, and since power wasted heating the cables is $P = I^2 R$, a smaller current wastes far less energy.

WATCH OUT

Transformers do not create energy. Stepping the p.d. **up** steps the current **down** by the same factor, so the power is unchanged for an ideal transformer. The National Grid's saving comes entirely from the **smaller current in the cables**.