Cambridge (CIE) IGCSE Physics

Your notes

Electromagnetic Effects

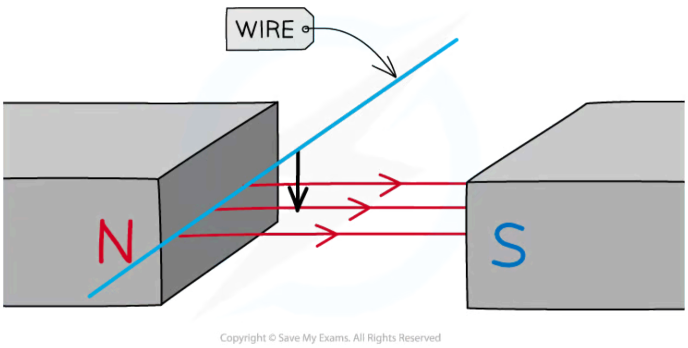
Contents

Induced e.m.f.

- An electromotive force (e.m.f.) is induced in a conductor whenever there is **relative movement** between the conductor and a magnetic field
- This could be when
  - the conductor moves in a stationary magnetic field
  - the conductor is stationary in a changing magnetic field

Induced e.m.f. due to a moving conductor

- For an electrical conductor moving in a fixed magnetic field:
  - the conductor (e.g. a wire) **cuts** the field lines
  - an e.m.f. is **induced** in the wire

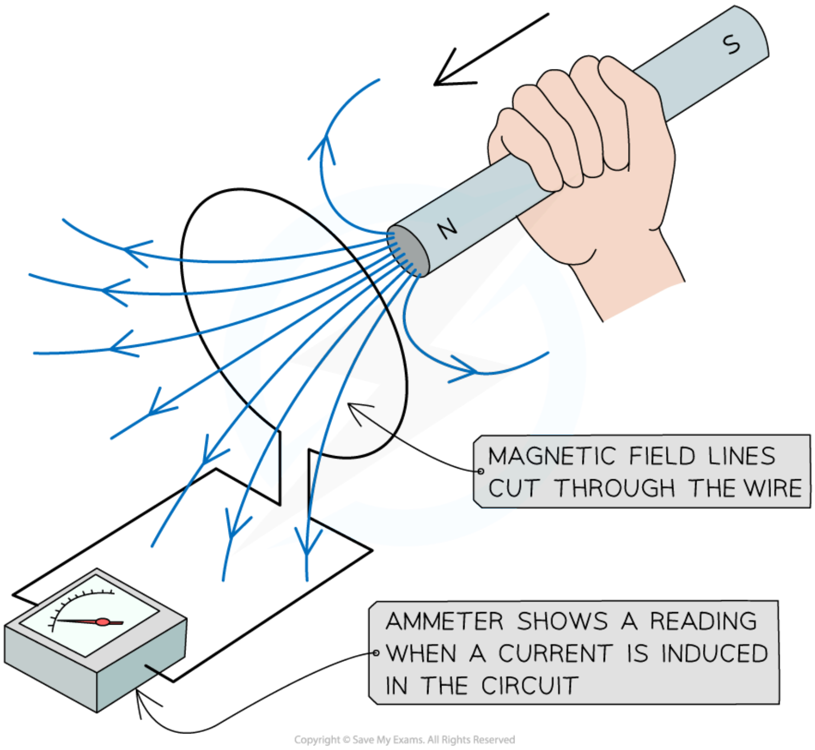


When an electrical conductor moves in a magnetic field an e.m.f. is induced

Induced e.m.f. due to a moving field

- For a fixed conductor in a changing magnetic field:
  - as the magnet moves through the conductor (e.g. a coil), the field lines **cut** through the turns on the conductor (each individual wire)
  - an e.m.f. is **induced** in the coil

Your notes



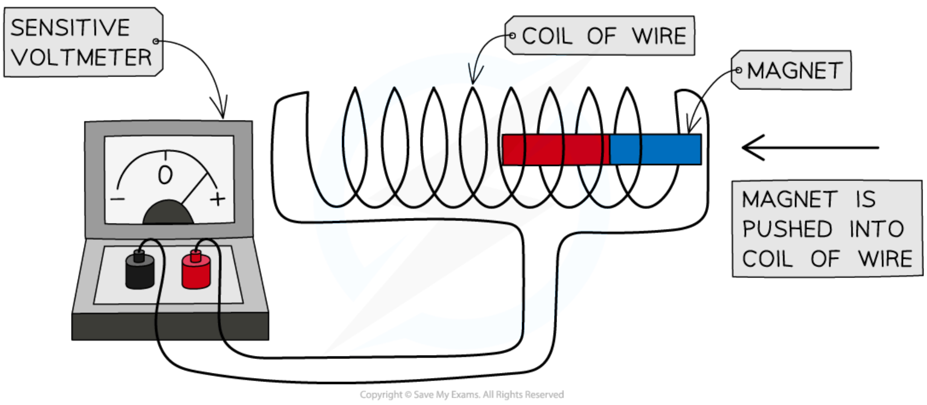
When a magnet is moved towards a wire, the changing magnetic field induces a current in the coil of wire

- A **sensitive voltmeter** can be used to measure the size of the induced e.m.f.
- If the conductor is part of a **complete circuit** then a **current** is induced in the conductor
  - This can be detected by an ammeter

Worked Example

A coil of wire is connected to a sensitive voltmeter.

When a magnet is pushed into the coil the needle on the voltmeter will deflect to the right as shown in the diagram below.



What will happen to the pointer on the voltmeter when the magnet is stationary in the centre of the coil?

A The needle will deflect to the left

B The needle will deflect to the right

C There will be no deflection of the needle

D The needle will deflect to the left and then to the right

ANSWER: C

- There is no relative movement between the coil and the magnetic field when both the magnet and coil are stationary
- Since no magnetic field lines are being cut, no e.m.f. will be induced
  - Therefore, the needle will **not** deflect
- **A**, **B** & **D** are incorrect because a deflection on the voltmeter would indicate that an e.m.f. has been induced
- This would only happen if there was relative movement between the coil and the magnetic field

Lenz's law

Extended tier only

- Lenz law states:

The direction of an induced emf always opposes the change causing it

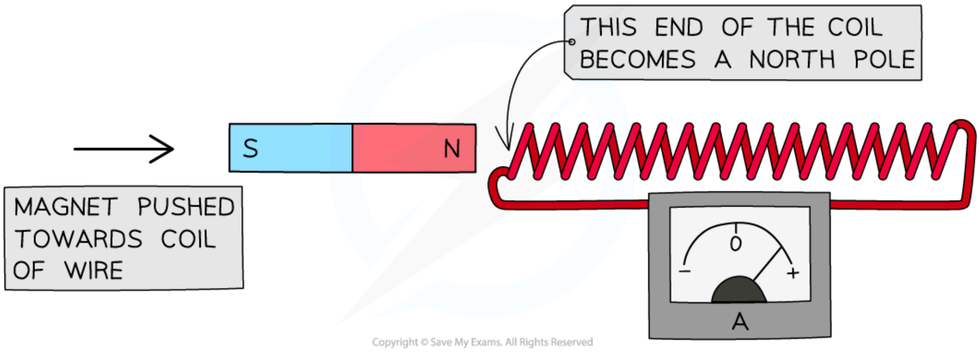
- This means that any magnetic field created by an induced emf will act so that it tries to stop the wire or magnet from moving

Demonstrating Lenz's law

- Lenz's law can be demonstrated when a magnet is pushed into, or out of, a coil of wire
- If the magnet is pushed north end first into the coil, the end of the coil closest to the magnet will become a **north pole**

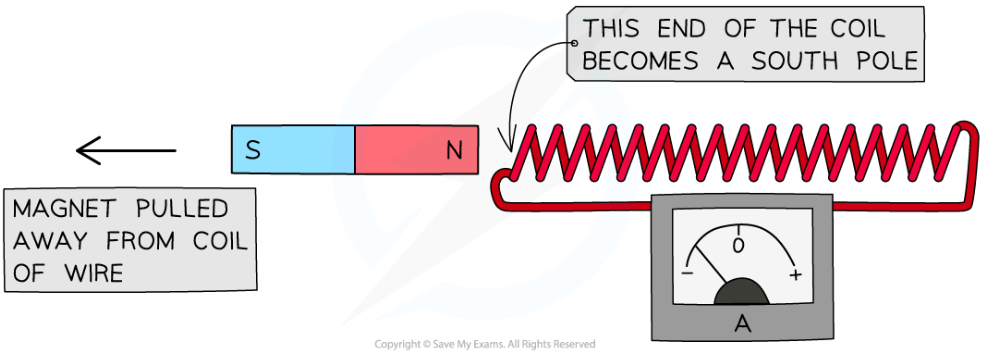
Your notes

- This happens because:
  - the changing magnetic field induces an **emf** in the coil
  - the induced emf causes a current to flow and generates a magnetic field in the coil
  - the magnetic field due to the current **opposes** the magnet being pushed into the coil
  - therefore, the end of the coil closest to the magnet acts as a **north pole**
  - this means it **repels** the north pole of the magnet



When a magnet is pushed into a coil of wire, the end of the coil closest to the magnet will become a north pole and oppose its motion

- If a magnet is now pulled away from the coil of wire, the end of the coil closest to the magnet will become a **south pole**
- This happens because:
  - the changing magnetic field induces an **emf** in the coil
  - the induced emf causes a current to flow and generates a magnetic field in the coil
  - the magnetic field due to the current **opposes** the magnet being pulled away from the coil
  - therefore, the end of the coil closest to the magnet becomes a **south pole**
  - this means it **attracts** the north pole of the magnet



Your notes

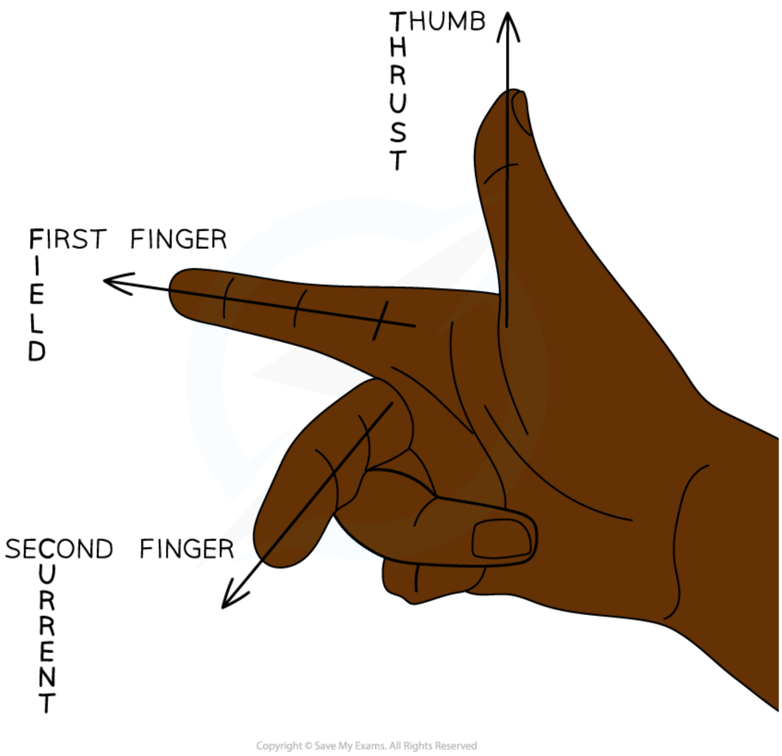
When a magnet is pulled away from a coil of wire, the end of the coil closest to the magnet will become a south pole and oppose its motion

Your notes

Right-hand dynamo rule

Extended tier only

- When moving a wire through a magnetic field, the direction of the induced emf can be determined using the **right-hand dynamo** rule
- **F**irst **F**inger = **F**ield:
  - Start by pointing the **f**irst **f**inger (on the right hand) in the direction of the **f**ield
- Thu**M**b = **M**otion:
  - Next, point the thu**m**b in the direction that the wire is **m**oving in
- Se**C**ond = **C**urrent:
  - The Se**c**ond finger will now be pointing in the direction of the **c**urrent (or, strictly speaking, the emf)



The right-hand dynamo rule can be used to deduce the direction of the induced emf

Examiner Tips and Tricks

Remember that current is always in the direction of positive charge carriers. Therefore, current flows from the positive to the negative terminal of the battery.

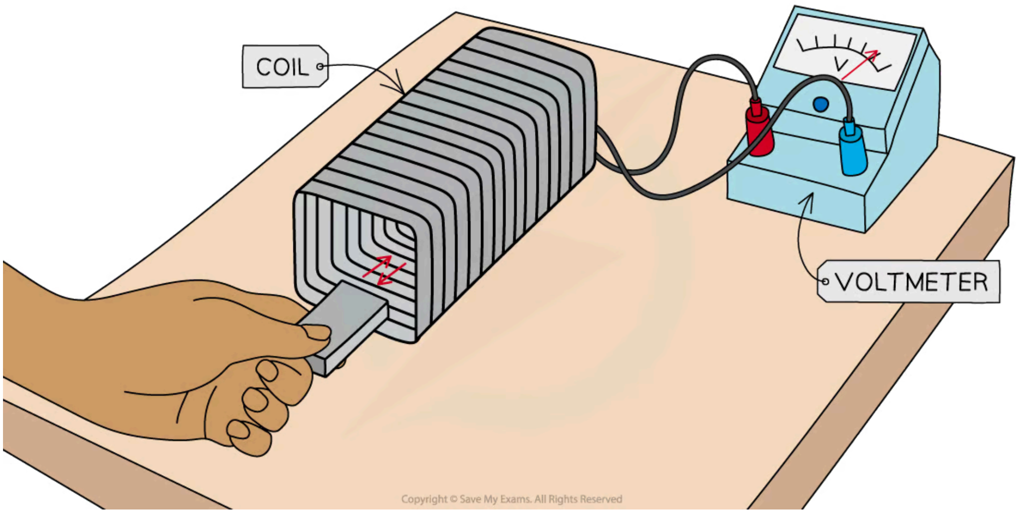
Your notes

Demonstrating induction

- Electromagnetic induction is used in:
  - electrical generators which convert mechanical energy to electrical energy
  - transformers which are used in electrical power transmission
- The phenomenon of electromagnetic induction can be demonstrated using
  - a magnet and a coil
  - a wire and a U-shaped magnet

Experiment 1: moving a magnet through a coil

- When a coil is connected to a sensitive voltmeter, a bar magnet can be moved in and out of the coil to induce an e.m.f.



An e.m.f. is induced in a coil when a bar magnet is moved through it. This can be seen by connecting the coil to a voltmeter

- The expected results are...

1. When the bar magnet is stationary, the voltmeter shows a zero reading

- When the bar magnet is held still inside, or outside, the coil, there is no cutting of magnetic field lines
- As a result, **no e.m.f. is induced** in the coil

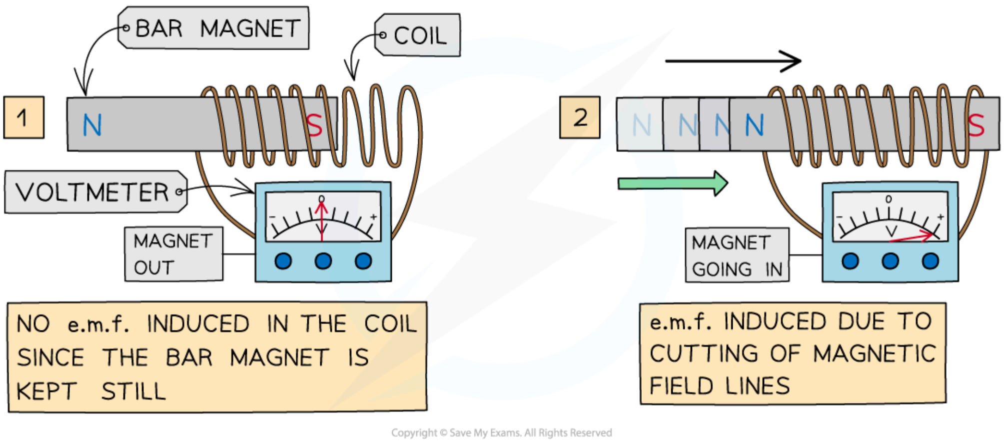
2. When the bar magnet is moved inside the coil, there is a reading on the voltmeter

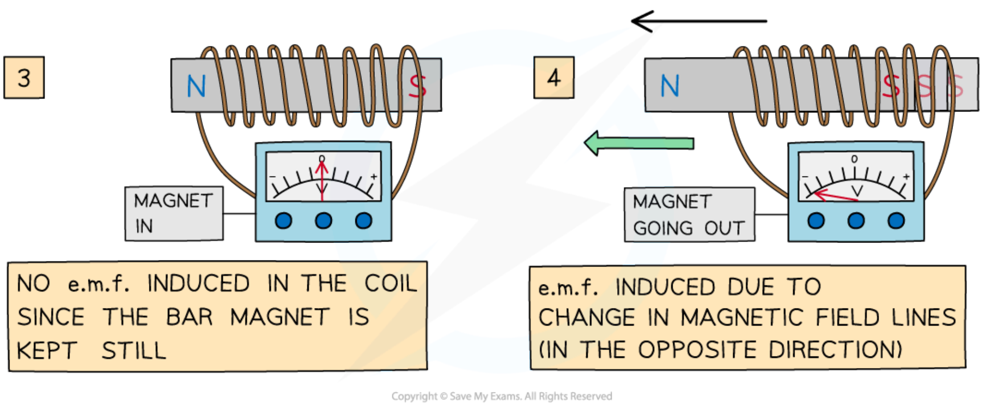
- As the bar magnet moves, its magnetic field lines are cut by the coil

- This induces an **e.m.f.** within the coil, shown momentarily by the reading on the voltmeter

3. When the bar magnet is moved back out of the coil, there is a reading on the voltmeter with the opposite sign

- As the magnet changes direction, the direction of the current changes
- An e.m.f. is induced in the **opposite direction**, shown momentarily by the reading on the voltmeter with the opposite sign





An e.m.f. is induced only when the bar magnet is moving through the coil

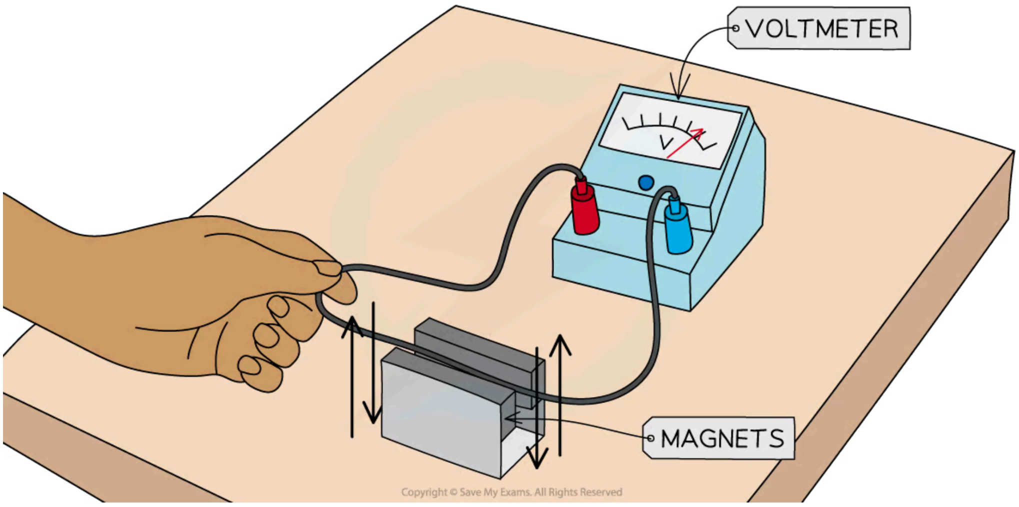
- Factors that will increase the induced e.m.f. are:
  - moving the magnet **faster** through the coil
  - adding **more turns** to the coil
  - increasing the **strength** of the bar magnet

Experiment 2: moving a wire through a magnet

- When a long wire is connected to a voltmeter and moved between two magnets, an e.m.f. is induced

Your notes

- The pattern of a magnetic field in a wire can be investigated using this setup
  - **Note:** there is no current flowing through the wire to start with



An e.m.f. is induced in a wire when it is moved between magnetic poles. This can be seen by connecting the wire to a voltmeter

- The expected results are...

1. When the wire is stationary, the voltmeter shows a zero reading

- When there is no relative motion between the wire and the magnetic field, no field lines are cut
- As a result, **no e.m.f. is induced** in the wire

2. As the wire is moved between the magnetic poles, there is a reading on the voltmeter

- As the wire moves, it cuts the magnetic field lines of the magnet
- This induces an **e.m.f.** in the wire, shown momentarily by the reading on the voltmeter

3. When the wire is moved back out of the magnet, there is a reading on the voltmeter with the opposite sign

- As the wire changes direction, the direction of the current changes
- An e.m.f. is induced in the **opposite direction**, shown momentarily by the reading on the voltmeter with the opposite sign
- Factors that will increase the induced e.m.f. are:
  - increasing the **length** of the wire
  - moving the wire between the magnets **faster**
  - increasing the **strength** of the magnets

Your notes

Factors affecting electromagnetic induction

Your notes

Factors affecting the magnitude of the induced e.m.f.

1. The speed at which the wire, coil or magnet is moved:

- Increasing the speed will increase the rate at which the magnetic field lines are cut
- This will increase the size of the induced e.m.f.

2. The number of turns on the coils in the wire:

- Increasing the number of turns on the coils in the same length of wire will increase the size of the induced emf
- Reducing the length of the wire but maintaining the same number of coils will also increase the size of the induced emf
- This is because each turn (loop) of wire in the coil cuts the magnetic field lines
- Therefore, the total induced e.m.f. increases with each additional turn (loop)

3. The size of the coils:

- Increasing the area of the coils will increase the size of the induced e.m.f.
- This is because there will be more wire to cut through the magnetic field lines

4. The strength of the magnetic field:

- Increasing the strength of the magnetic field will increase the size of the induced e.m.f.
- This is because there will be more magnetic field lines in a given area

Factors affecting the direction of the induced e.m.f.

1. The orientation of the poles of the magnet:

- Switching the poles of the magnet induces an e.m.f. in the opposite direction

2. The direction in which the wire, coil or magnet is moved:

- Reversing the direction in which the wire, coil or magnet is moved induces an e.m.f. in the opposite direction

Examiner Tips and Tricks

When discussing factors affecting the size of an induced e.m.f., make sure to use the correct terminology:

- say "add more **turns** to the coil" instead of “add more coils”. This is because these statements do not mean the same thing
- say "a **stronger** magnet" instead of "a bigger magnet". This is because larger magnets are not necessarily stronger

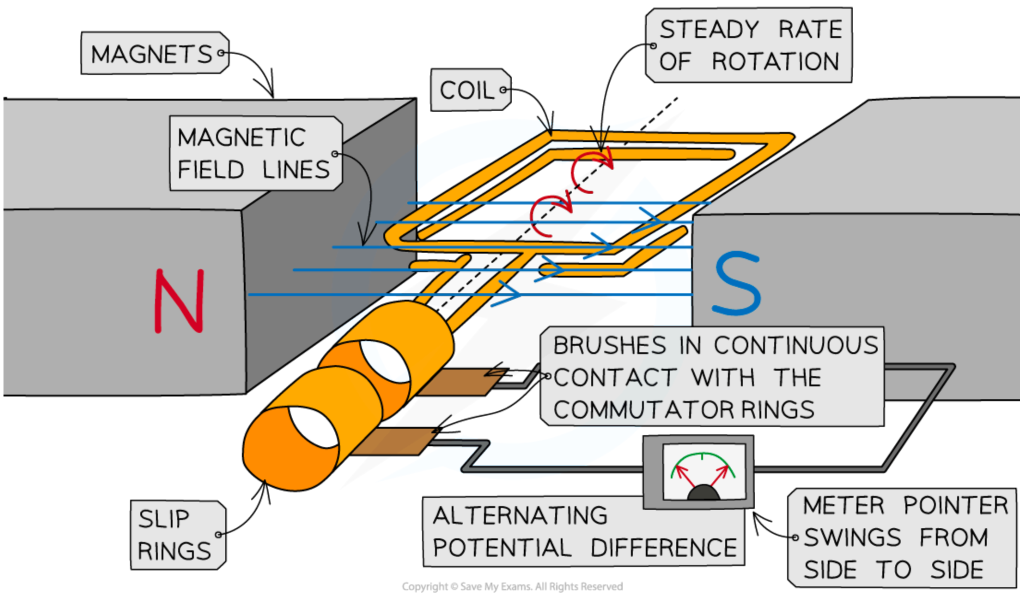
Your notes

Simple a.c. generators

Extended tier only

- An a.c. generator is a device which converts energy from **motion** into an **electrical** output
- An alternating e.m.f. is generated which causes an **alternating current** to flow
- A simple a.c. generator consists of
  - a rotating coil of wire between the poles of a permanent magnet
  - slip rings and brushes connected to an external circuit

Structure of a simple a.c. generator



A simple a.c. generator consists of a rotating coil in a magnetic field connected to an external circuit via slip rings and carbon brushes

- The functions of each component are shown in the table:

Table of components of a simple a.c. generator

Component	Function
permanent magnet	to provide a uniform magnetic field

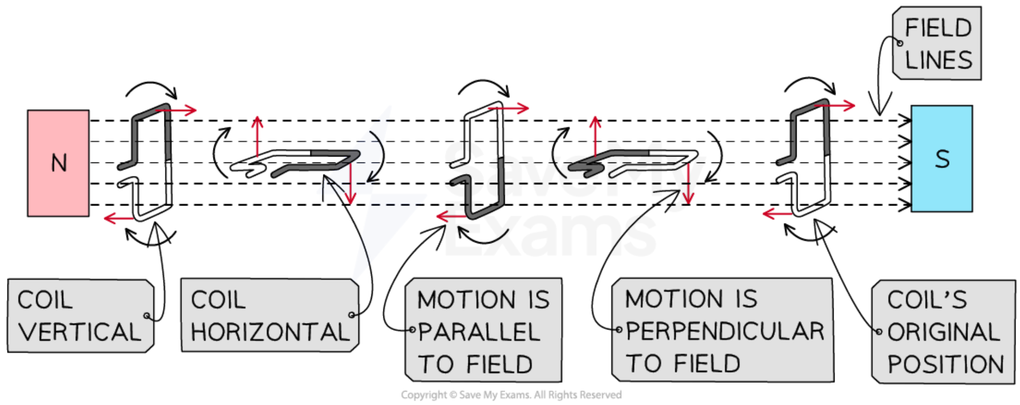
rotating coil	to cut the magnetic field as it rotates and allow an induced current to flow
slip rings	to allow the alternating current to flow between the coil and the external circuit
carbon brushes	to provide a good electrical connection between the coil and the external circuit

Your notes

Operation of an a.c. generator

- A rectangular coil rotates in a **uniform magnetic field**
- The coil is connected to an external circuit via **slip rings and brushes**
  - The induced emf in the coil can be measured by adding a galvanometer (centre-zero meter) to the external circuit
- An e.m.f. is **induced** in the coil as it **cuts** the magnetic field
  - The pointer defects first one way, then the opposite way, and then back again
  - This indicates the size and direction of the emf is constantly changing
- As a result of the alternating e.m.f., an alternating **current** is also produced as the coil rotates
  - This continues as long as the coil keeps turning in the **same** direction

Motion of an a.c. generator



The size and direction of the induced e.m.f. (and current) depend on the orientation of the coil with the field

- A maximum e.m.f. is induced when
  - the **position** of the coil is **horizontal**

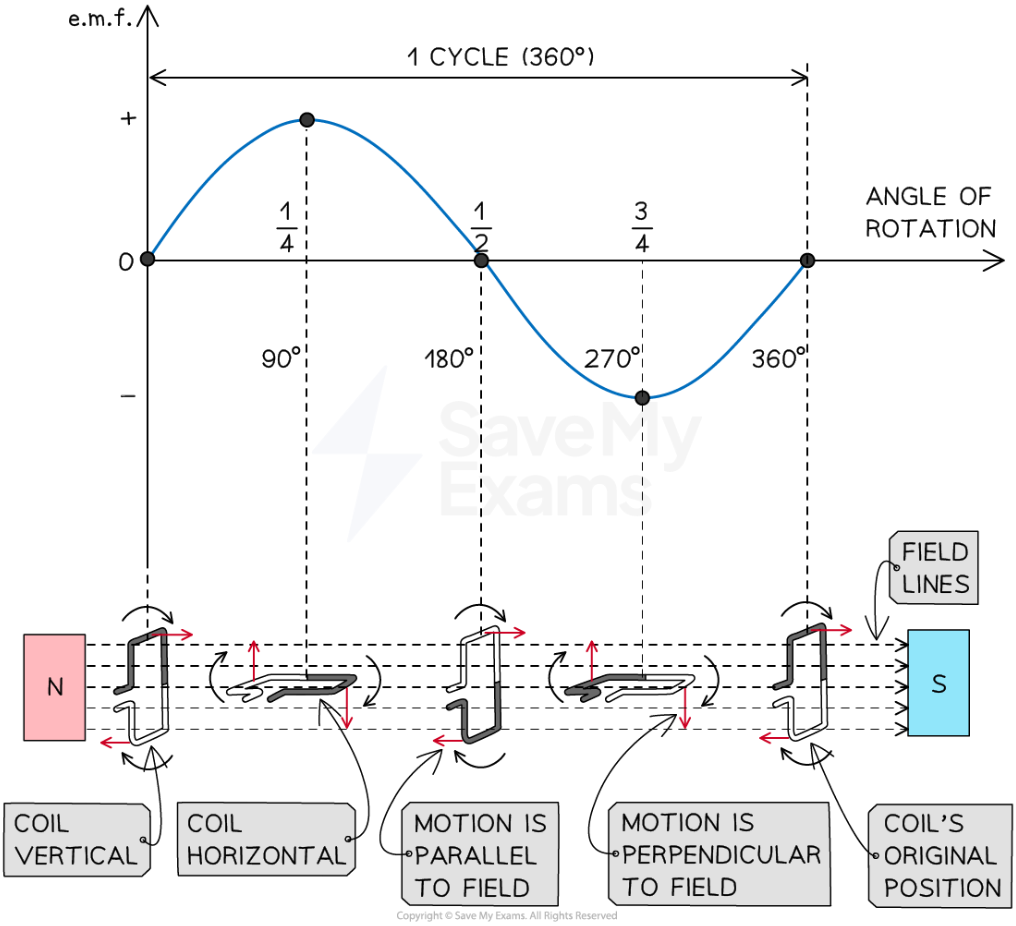
    - the **motion** of the coil is **perpendicular** to the field
- This is because the greatest number of lines are cut when the coil is moving perpendicular to the field
- No e.m.f. is induced when
    - the **position** of the coil is **vertical**
    - the **motion** of the coil is **parallel** to the field
- This is because no lines are cut when the coil is moving parallel to the field

Graphs for a.c. generators

Extended tier only

- The output of an a.c. generator can be seen on a graph of e.m.f. against time, or angle of rotation
- The shape of the graph is a sine or cosine curve, depending on the starting position of the coil
    - When it starts from a **horizontal** position (e.m.f. is at a maximum), the graph is a **cosine** curve
    - When it starts from a **vertical** position (e.m.f. is zero), the graph is a **sine** curve

Graph of induced e.m.f. with angle for an a.c. generator



Alternating e.m.f. with corresponding positions of the coil relative to the field

- When the coil is vertical at 0°
  - it is moving **parallel** to the direction of the magnetic field
  - the size of the induced e.m.f. is **zero**
- When the coil has rotated by 90°
  - it is now **horizontal** and moving **perpendicular** to the direction of the magnetic field
  - the size of the induced e.m.f. is at a **maximum**
- When the coil has rotated by 180°
  - it is **vertical** again and moving **parallel** to the direction of the magnetic field
  - the size of the induced e.m.f. is **zero**
- When the coil has rotated by 270°
  - it is **horizontal** again and moving **perpendicular** to the direction of the magnetic field

- the size of the induced e.m.f. is at a **maximum** and in the **opposite** direction to its position at 90°
- When the coil has completed a full 360° rotation
  - it is back at its starting point where it is moving **parallel** to the direction of the magnetic field
  - the size of the induced e.m.f. is **zero**

Your notes

Factor affecting a.c. generators

- The magnitude of the induced e.m.f. can be increased by:
  - increasing the **frequency** of rotation of the coil
  - increasing the number of **turns** on the coil
  - increasing the **strength** of the magnet
  - inserting a **soft iron core** into the coil

Examiner Tips and Tricks

For your exam, you need to be aware that an alternating current can be produced by:

- a **coil rotating** in a magnetic field
- a **magnet rotating** within a coil

Both will induce an e.m.f. in the coil as they both ensure the coil will experience a **changing** magnetic field.

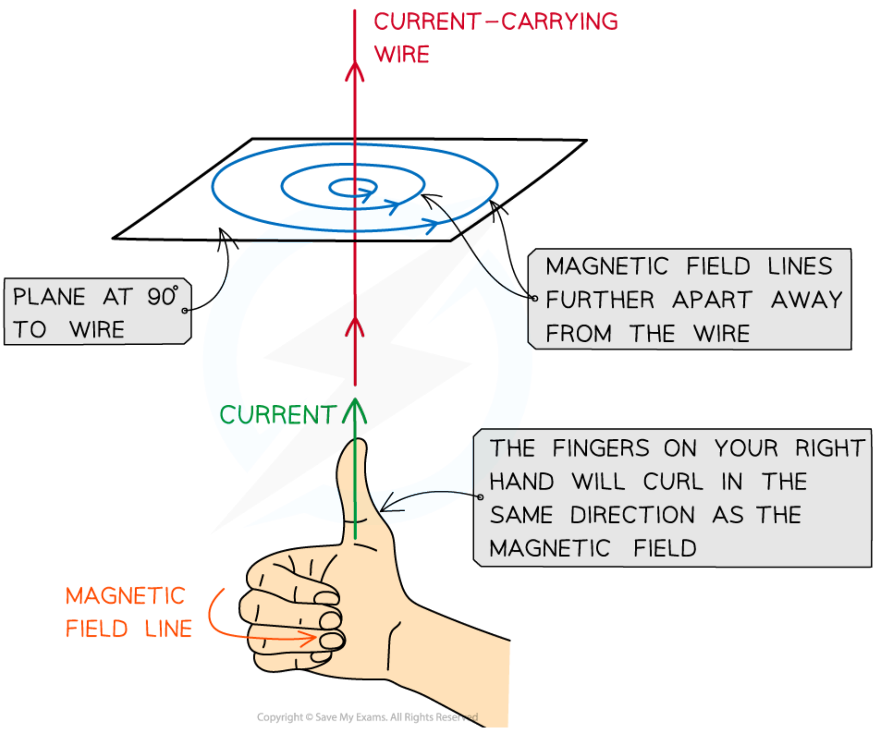
Take a look at these notes on trigonometric graphs if you need to brush up on your knowledge of sine and cosine graphs.

Magnetic fields around wires & solenoids

- **Magnetic fields** are formed wherever a current flows, such as in:
  - straight wires
  - solenoids
  - circular coils

Magnetic field due to a straight wire

- The magnetic field lines around a straight wire are
  - made up of **concentric circles**
  - centred on the wire
- A circular field pattern indicates that the magnetic field around a current-carrying wire has **no poles**
- The **right-hand grip rule** can be used to work out the **direction** of the magnetic field

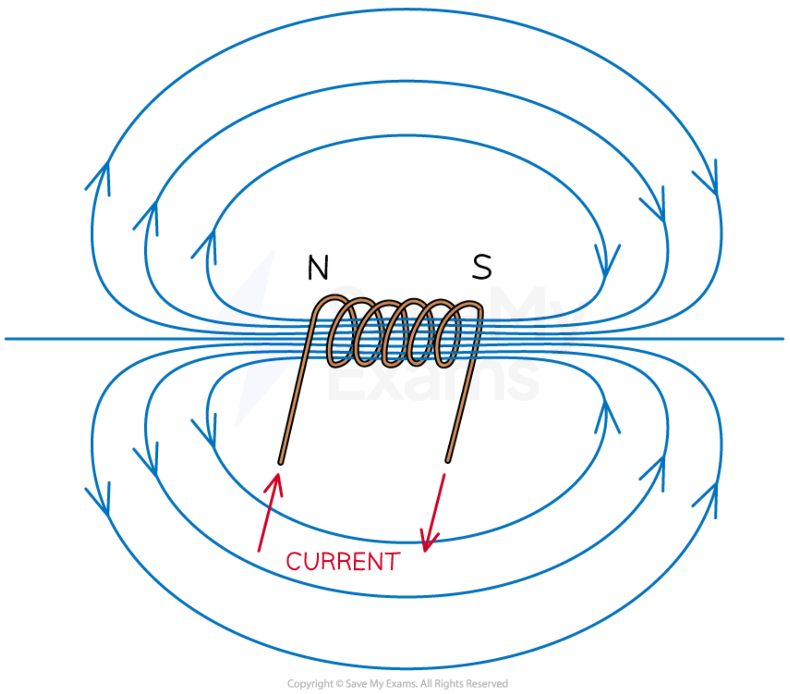


The direction of the field around a current-carrying wire can be determined using the right-hand grip rule

- The field lines are clockwise or anticlockwise around the wire, depending on the direction of the current
  - Reversing the current reverses the direction of the field
- The direction of the magnetic field can be determined using the **right-hand grip rule**
  - This is determined by pointing the **right-hand** thumb in the direction of the current in the wire and curling the fingers onto the palm
  - The direction of the curled fingers represents the direction of the magnetic field lines around the wire
  - For example, if the current is travelling vertically upwards, the magnetic field lines will be directed anticlockwise, as seen from directly above the wire
- **Note:** the direction of the current is taken to be the conventional current i.e. from **positive** to **negative**, **not** the direction of electron flow

Magnetic field due to a solenoid

- As seen from a current-carrying wire, an electric current produces a magnetic field
- An electromagnet utilises this by using a coil of wire called a **solenoid**
  - This increases the strength of the magnetic field by adding more **turns** of wire into a smaller region of space
- One end of the solenoid becomes a north pole, and the other becomes the south pole



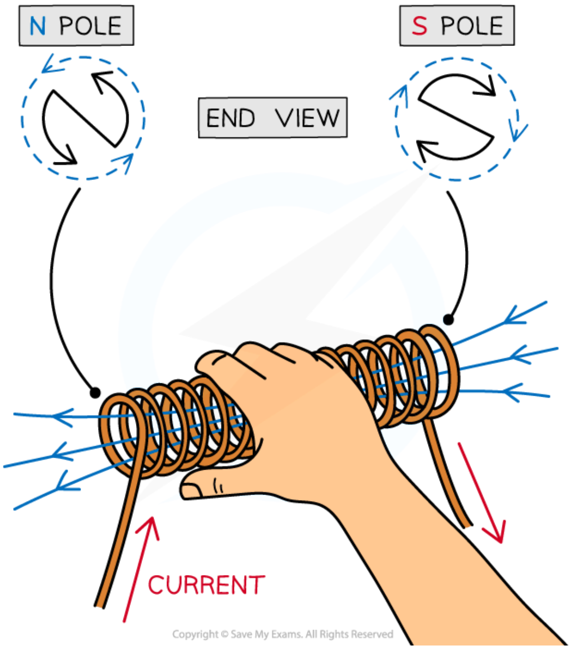
The magnetic field lines around a solenoid are similar to a bar magnet

- As a result, the field lines around a solenoid are similar to those around a bar magnet

Your notes

- The field lines **emerge** from the **north** pole
- The field lines **return** to the **south** pole

- The poles of the solenoid can be determined using the **right-hand grip rule**
  - The curled fingers represent the direction of the current flow around the coil
  - The thumb points in the direction of the field inside the coil, towards the **north pole**

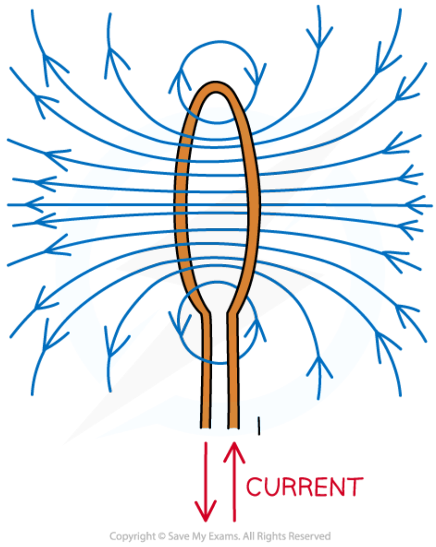


In a solenoid, the north pole forms at the end where the current flows anti-clockwise, and the south pole at the end where the current flows clockwise

Magnetic field due to a circular coil

- A circular coil is equivalent to one of the coils of a solenoid
- The field lines emerge through one side of the circle (north pole) and enter through the other (south pole)
- As with a solenoid, the direction of the magnetic field lines depends on the direction of the current
  - This can also be determined using the **right-hand grip rule**

Your notes

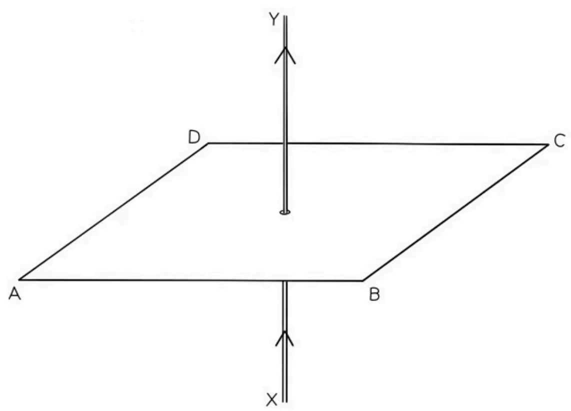


Magnetic field lines of many individual circular coils can be combined to make a solenoid

Your notes

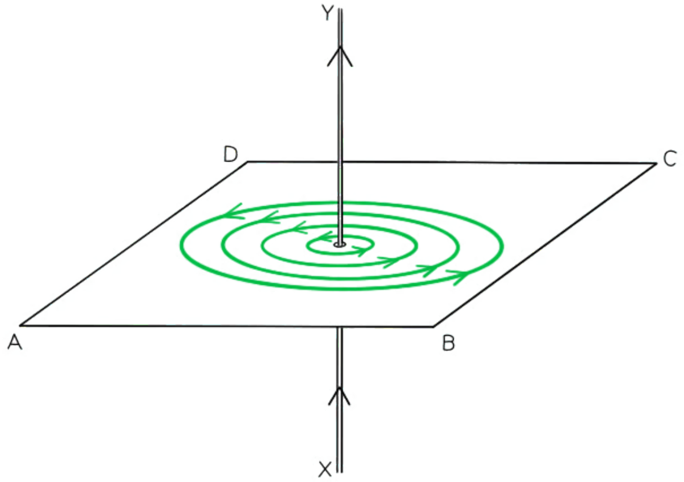
Worked Example

The current in a long, straight vertical wire is in the direction XY, as shown in the diagram.



Sketch the magnetic field lines in the horizontal plane ABCD due to the current-carrying wire. Draw at least four field lines.

Answer:



- Concentric circles
- Increasing separation between each circle
- Arrows drawn in an anticlockwise direction

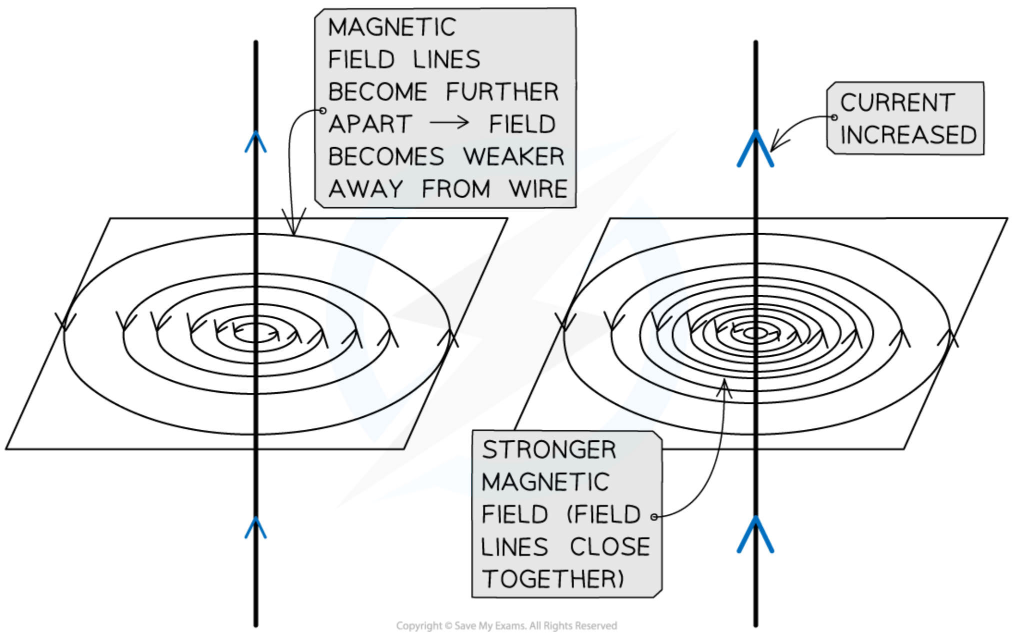
Magnetic effects of changing current

Extended tier only

Magnetic field strength around a straight wire

- The strength of the magnetic field around a wire depends on:
  - the size of the **current**
  - the **distance** from the wire
- The strength of a magnetic field **increases** as the amount of **current** flowing through the wire increases
  - This means the field lines will become **closer together**
- The strength of a magnetic field **decreases** with **distance** from the wire
  - The magnetic field is strongest near the wire and becomes weaker further away from the wire
  - This is shown by the magnetic field lines becoming **further apart**
- When the **direction** of the current changes, the magnetic field acts in the **opposite** direction

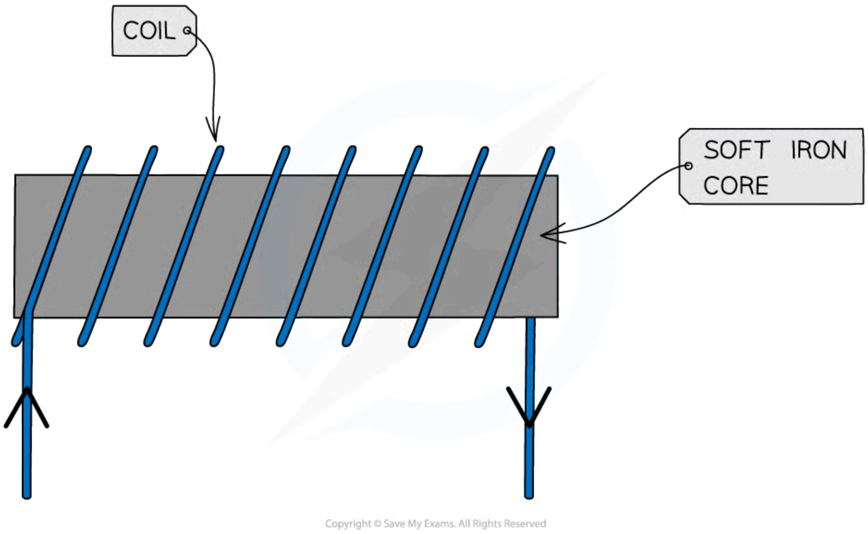
Your notes



The greater the current, the stronger the magnetic field. This is shown by more concentrated field lines

Magnetic field strength around a solenoid

- The strength of the magnetic field produced around a **solenoid** can be increased by:
  - increasing the amount of **current** flowing through the coil
  - increasing the **number of turns** on the coil
  - inserting an **iron core** into the coil
- When a soft **iron core** is inserted into a solenoid, it can be used as an electromagnet
- The iron core becomes an **induced magnet** when a current flows through the coils
- The magnetic field produced by the solenoid and the iron core will create a much **stronger** magnet overall



An electromagnet consists of a solenoid wrapped around a soft iron core

- Changing the direction of the current also changes the direction of the magnetic field produced by the iron core

Applications of the magnetic effect of a current

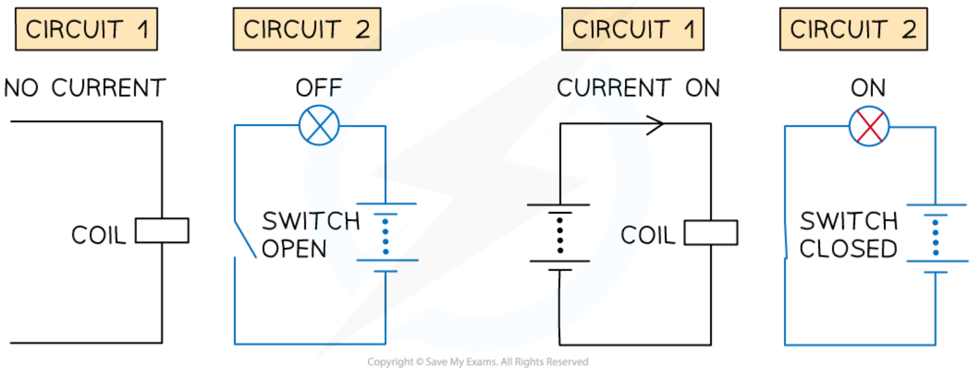
- Electromagnets are used in a wide variety of applications, including:
  - relay circuits (utilised in electric bells, electronic locks, scrapyard cranes etc)
  - loudspeakers

Relay circuits

- Electromagnets are commonly used in **relay circuits**
- Relays are switches that open and close via the action of an electromagnet
- A relay circuit consists of:
  - an electrical circuit containing an electromagnet
  - a second circuit with a switch which is near to the electromagnet in the first circuit

Operation of a relay circuit

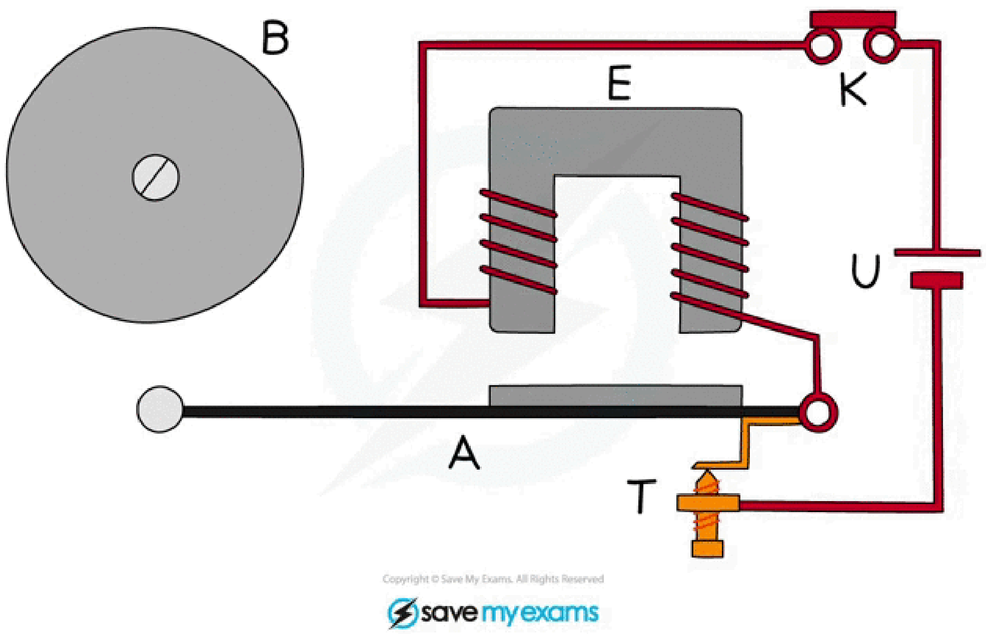
Your notes



When a current passes through the coil in Circuit 1, it attracts the switch in Circuit 2, and closing it enables a current to flow in Circuit 2

- When a current flows through **Circuit 1**:
  - a magnetic field is induced around the coil
  - the magnetic field attracts the switch, causing it to pivot and close the contacts in **Circuit 2**
  - this allows a current to flow in **Circuit 2**
- When no current flows through **Circuit 1**:
  - the magnetic force stops
  - the electromagnet stops attracting the switch
  - the current in **Circuit 2** stops flowing
- Scrapyard cranes utilise relay circuits to function:
  - When the electromagnet is switched on, it will **attract** magnetic materials
  - When the electromagnet is switched off, it will **drop** the magnetic materials
- Electric bells also utilise relay circuits to function:

Your notes



Animation: Electric bells utilise relay circuits. As the current alternates, the metal arm strikes the bell and drops repeatedly to produce the ringing effect

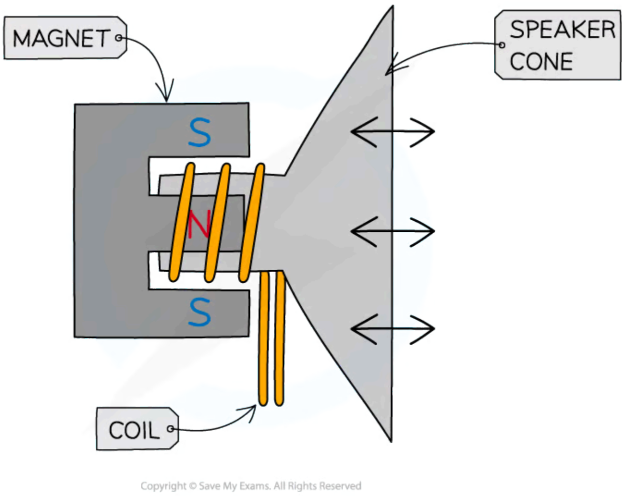
- When the button **K** is pressed:
  - a current passes through the electromagnet **E** creating a magnetic field
  - this attracted the iron armature **A**, causing the hammer to strike the bell **B**
  - the movement of the armature breaks the circuit at **T**
  - this stops the current, destroying the magnetic field and so the armature returns to its previous position
  - this re-establishes the circuit, and the whole process starts again

Loudspeakers

- Loudspeakers convert electrical signals into sound waves
  - They work due to the **motor effect**
- A loudspeaker consists of a coil of wire which is wrapped around one pole of a **permanent magnet**

Structure of a loudspeaker

Your notes



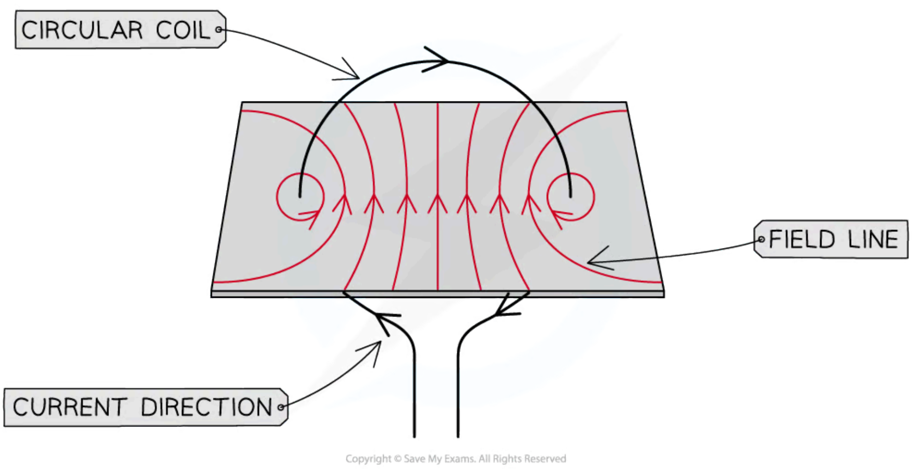
A loudspeaker converts the a.c. of an electrical signal into sound waves

- An **alternating current** passes through the coil of the loudspeaker
  - This creates a **changing magnetic field** around the coil
- As the current is constantly changing direction, the direction of the magnetic field will be **constantly changing**
- The magnetic field produced around the coil **interacts** with the field from the permanent magnet
- The interacting magnetic fields will exert a **force** on the coil
- As the magnetic field is constantly changing direction, the force exerted on the coil will **constantly change direction**
  - This makes the coil **oscillate**
- The oscillating coil causes the speaker cone to oscillate
  - This makes the air oscillate, creating **sound waves**

Your notes

Investigating the magnetic field around a wire

- The magnetic field patterns due to currents in straight wires and in solenoids can be investigated using:
  - a thick wire
  - a solenoid (a wire wrapped into a coil) - for example, a metal slinky
  - cell, ammeter, variable resistor and connecting wires
  - cardboard with holes (the holes must be large enough for the wire to fit through)
  - clamp stand
  - iron filings or a compass
- Spread the iron filings uniformly on the cardboard and place the magnetic needle on the board
- Tap the cardboard slightly and observe the orientation of iron filings
- When the current direction is reversed, the compasses point in the opposite direction showing that the direction of the field reverses when the current reverses



Experiment 1: plotting the magnetic field around a wire

1. Attach the thick wire through a hole in the middle of the cardboard and secure it to the clamp stand
   - Secure the wire vertically so it sits perpendicularly to the cardboard

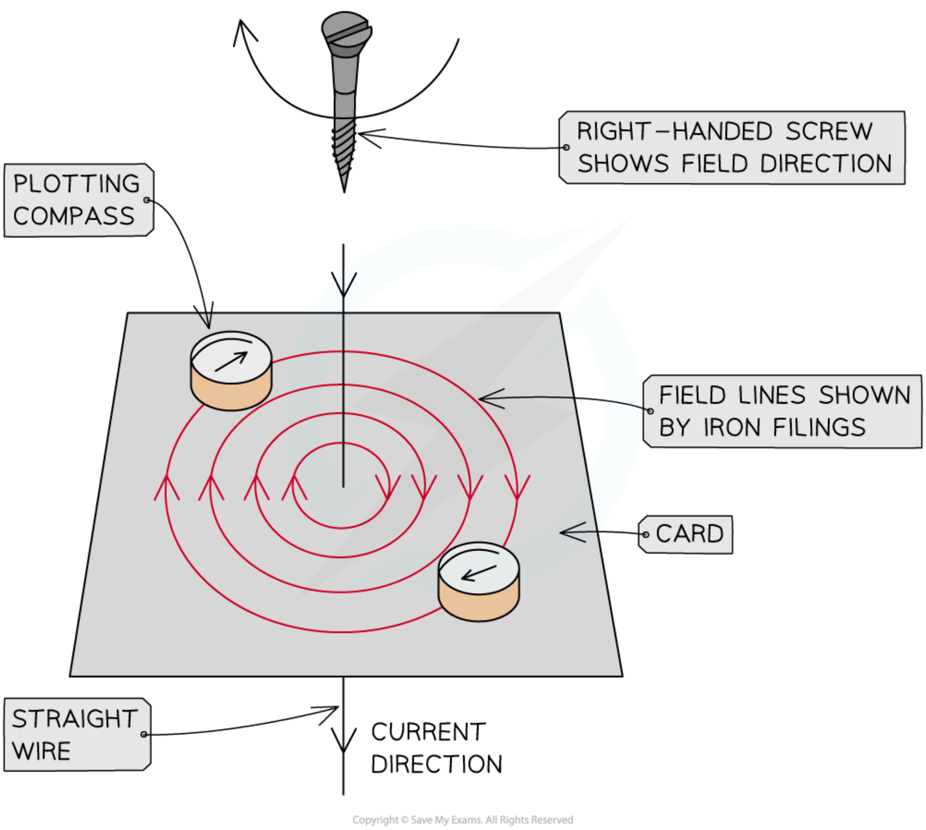
2. Attach the ends of the wire to a series circuit containing the variable resistor and ammeter on either side of the cell

Using plotting compasses:

1. Place plotting compasses on the card and draw dots at each end of the needle once it settles
    - Make sure to draw an arrow to show the direction of the field at different points
2. Move the compass so that it points away from the new dot, and repeat the process above
3. Keep repeating the previous process until there is a chain of dots on the card
4. Then remove the compass, or compasses, and link the dots using a smooth curve – this will be the magnetic field line
5. Repeat the whole process several times to create several other magnetic field lines

Using iron filings:

1. If using iron filings, simply pour the filings onto the cards and gently shake the card until the filings settle in the pattern of the magnetic field around the wire



Experiment 2: plotting the magnetic field around a solenoid

Your notes

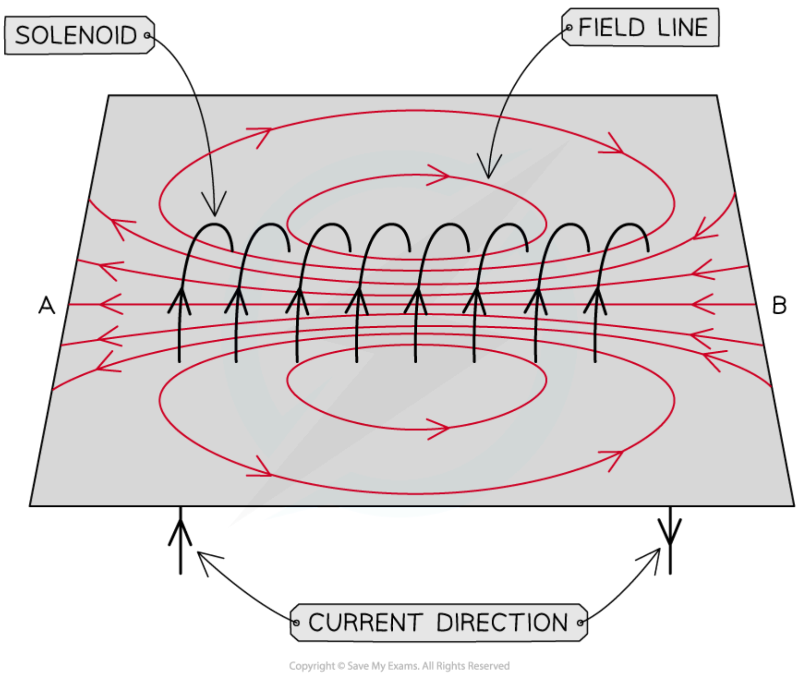
1. Attach the thick wire through a hole on one side of the cardboard and loop it through a hole on the other side of the cardboard and secure it to the clamp stand
   - Secure the wire so it forms a circular loop around the cardboard
2. Attach the ends of the wire to a series circuit containing the variable resistor and ammeter on either side of the cell

Using plotting compasses:

1. Follow the procedure outlined in Experiment 1
   - Note: this can be carried out using a solenoid, but since a solenoid is essentially many circular loops, the pattern around a circular loop can be extended to give the pattern around a solenoid

Using iron filings:

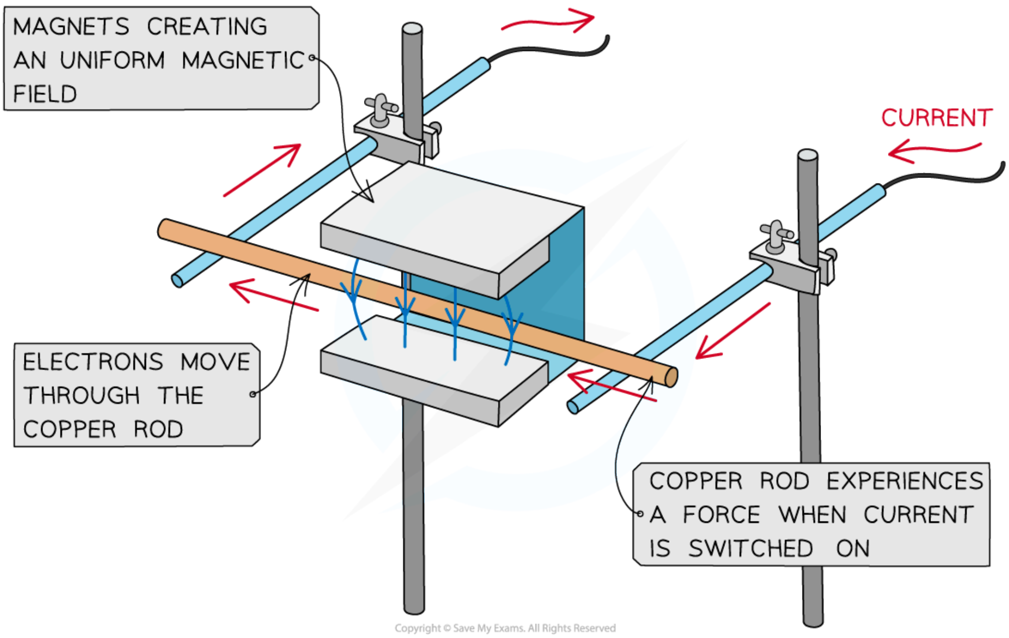
1. Take a solenoid (a metal slinky works well for this) and thread it through pre-made holes in a piece of card
2. Pour the filings onto the card and gently shake the card until the filings settle in the pattern of the magnetic field around the solenoid



Your notes

Force on a current-carrying conductor

- A current-carrying conductor produces its own **magnetic field**
  - When interacting with an external magnetic field, it therefore will experience a **force**
- A current-carrying conductor will only experience a force if the current through it is **perpendicular** to the direction of the magnetic field lines
  - A simple situation would be a copper rod placed within a uniform magnetic field
  - When current is passed through the copper rod, it experiences a force which makes it move



A copper rod moves within a magnetic field when current is passed through it

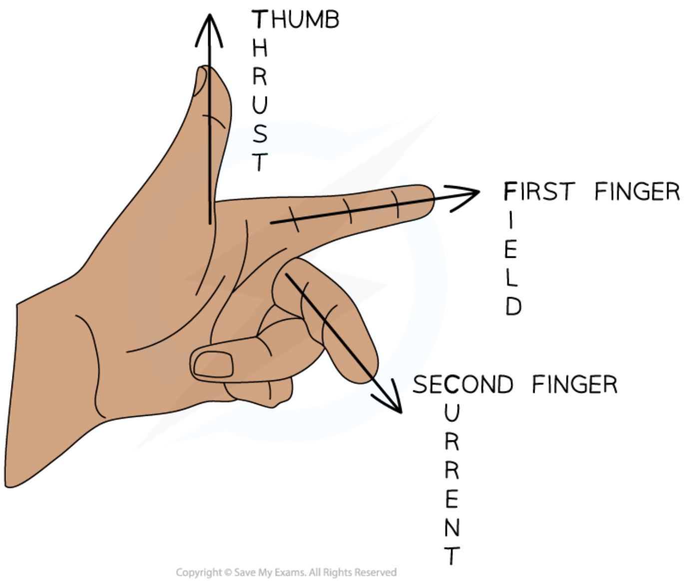
- Two ways to reverse the direction of the force (and therefore, the copper rod) are by:
  - reversing the direction of the **current**
  - reversing the direction of the **magnetic field**

Examiner Tips and Tricks

This phenomenon is sometimes referred to as 'the motor effect'. The direction of the force is determined by Fleming's left-hand rule.

Flemings left-hand rule

- The **direction** of the **force** (aka the **thrust**) on a current-carrying wire depends on the direction of
  - the current
  - the magnetic field
- The direction of the force (or thrust) can be worked out by using **Fleming's left-hand rule**:
  - the **thumb** points in the direction of the force, or thrust, on the conductor
  - the **first** finger points in the direction of the magnetic field
  - the **second** finger points in the direction of current flow (from positive to negative)



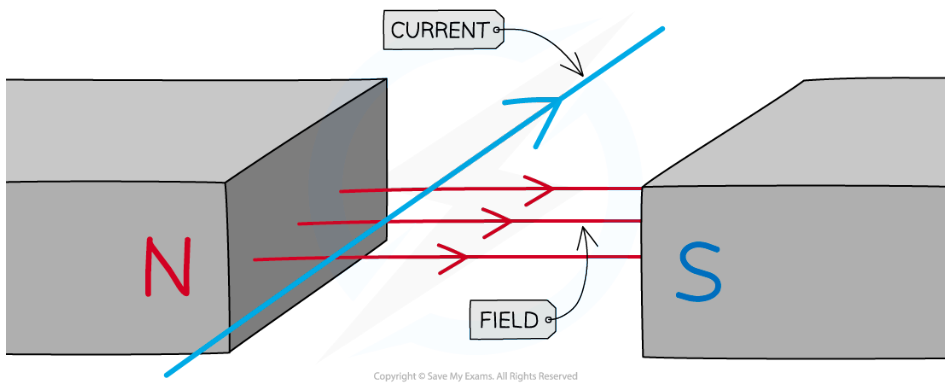
Fleming's left-hand rule can be used to determine the directions of the force, magnetic field and current

- All three will be **perpendicular** to each other in Fleming's left-hand rule questions
  - This means that sometimes the force could be into and out of the page (in 3D)

Worked Example

A current-carrying wire is placed into the magnetic field between the poles of the magnet, as shown in the diagram.

Your notes



Use Fleming's left-hand rule to show that there will be a downward force acting on the wire.

Answer:

Step 1: Determine the direction of the magnetic field

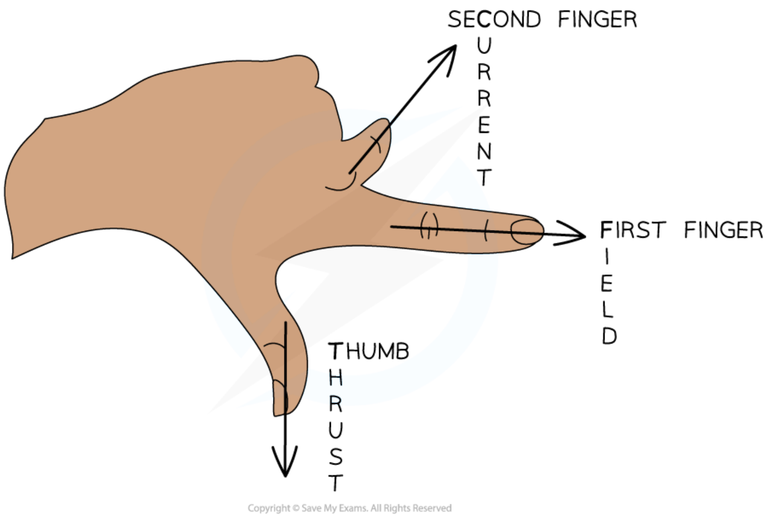
- Start by pointing your **F**irst **F**inger in the direction of the (magnetic) **F**ield

Step 2: Determine the direction of the current

- Now rotate your hand around the first finger so that the se**C**ond finger points in the direction of the **C**urrent

Step 3: Determine the direction of the force

- The **TH**umb will now be pointing in the direction of the **TH**rust (the force)
- Therefore, this will be the direction in which the wire will move



Examiner Tips and Tricks

Remember that the magnetic field is always in the direction from **North** to **South** and current is always in the direction of a **positive** terminal to a **negative** terminal.

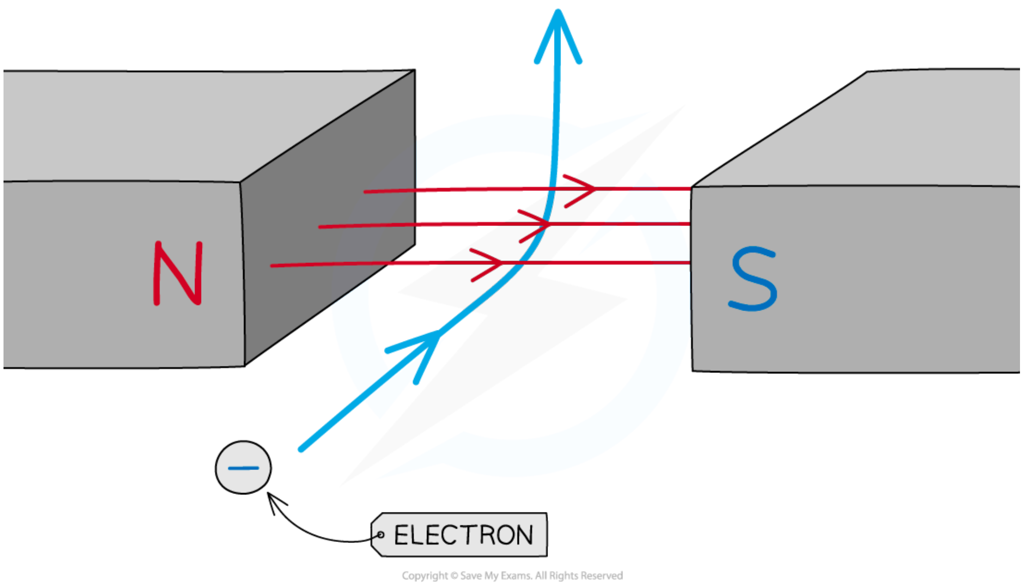
Your notes

Feel free to use Fleming's left hand rule in your exam, just don't make it too distracting for other students!

Charged particles in a magnetic field

Extended tier only

- When a current-carrying wire is placed in a magnetic field, it will experience a force if the wire is perpendicular
  - This is because the magnetic field exerts a force on each individual electron flowing through the wire
- Therefore, when a charged particle passes through a magnetic field, the field can exert a **force** on the particle, causing it to **deflect**
  - The force is always at **90 degrees** to both the direction of travel and the magnetic field lines
  - The direction can be worked out by using **Fleming's left-hand rule**
- In the case of an electron in a magnetic field
  - the second finger (current) points in the opposite direction to the direction of motion
  - this is because conventional current flows in the opposite direction to electron flow



When a charged particle (such as an electron) enters a magnetic field, it is deflected by the field

- If the particle is travelling **perpendicular** to the field lines:
  - it will experience the **maximum** force

Your notes

- If the particle is travelling **parallel** to the field lines:
  - it will experience **no** force
- If the particle is travelling at an **angle** to the field lines:
  - it will experience a **small** force

Examiner Tips and Tricks

Remember that the direction of **current** is the direction of **positive** charged. Therefore, if a particle has a negative charge (such as an electron), then the second finger (current) must point in the **opposite** direction to its direction of travel.

The left-hand rule can be applied to any charged particles, but in the IGCSE exam questions are likely to stick to electrons.

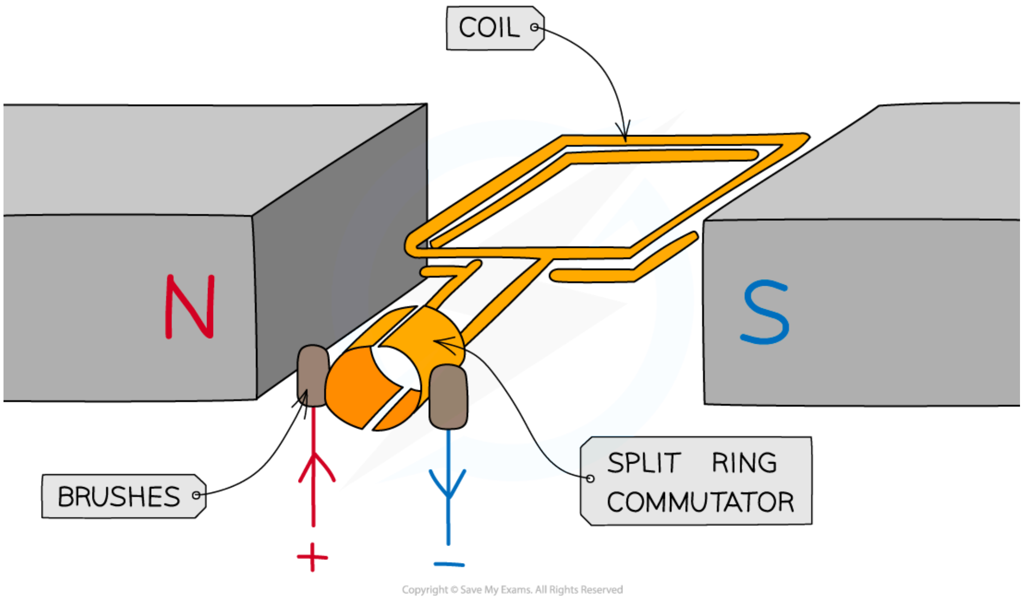
Your notes

Your notes

The d.c. motor

- The **motor effect** can be used to create a simple d.c. electric motor
  - The force on a current-carrying coil causes it to **rotate** in a single direction
- A simple d.c. motor consists of
  - a coil of wire (which is free to rotate) between the poles of a permanent magnet
  - a split-ring commutator and brushes connected to a source of **d.c.**
- The brushes and commutator are designed to reverse current every half turn:
  - the brushes ensure current is maintained without tangling wires
  - the coil rotates continuously in the same direction

Structure of a simple d.c. motor



In a simple d.c. motor, a coil placed in a magnetic field may experience a turning effect

- As current flows through the coil, it produces a magnetic field which interacts with the external magnetic field
- Forces act in opposite directions on each side of the coil, causing a **turning effect**
  - The **greater** the force on the coil, the greater the turning effect and the **faster** it will turn
- The turning effect is increased by increasing:

- the **number of turns** on the coil
- the **current** in the coil
- the **strength** of the magnetic field

Examiner Tips and Tricks

Motors and generators look very similar, but they do very different things.

When tackling a question on either of them, make sure you are writing about the right one! A **mo**tor takes in electricity and turns it into **mo**tion. A **generator** takes in motion and **generates** electricity.

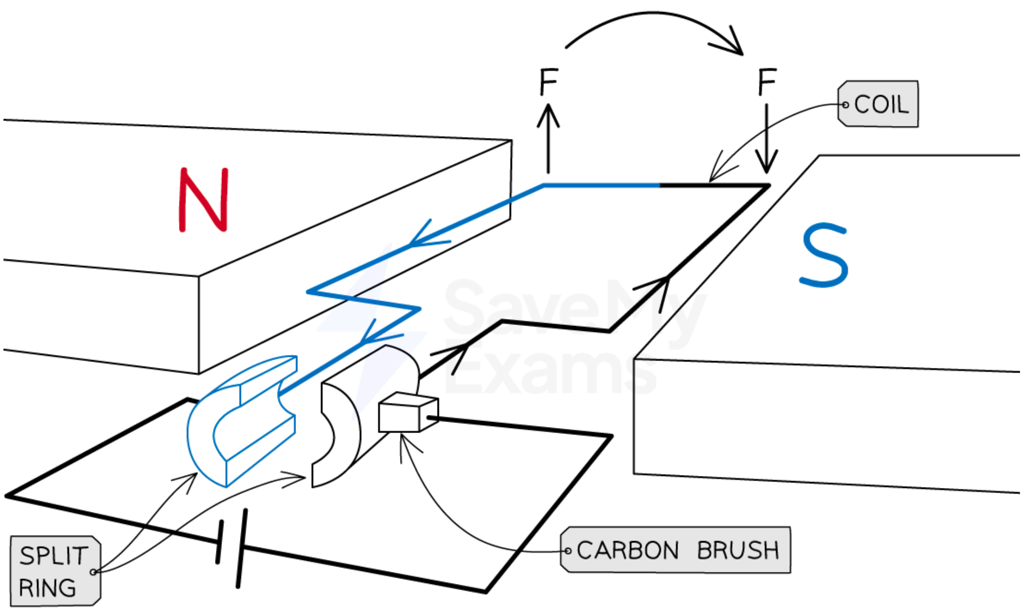
You might be expected to give explanations of how these two things happen - make sure that you understand their subtle differences!

Operation of a d.c. motor

Extended tier only

- In a d.c. motor, when the coil of wire is horizontal, it forms a complete circuit with a cell
  - The coil is attached to a **split ring** (a circular tube of metal split in two)
  - This split ring is connected in a circuit with the cell via contact with conducting **carbon brushes**

Forces on the horizontal coil in a d.c. motor

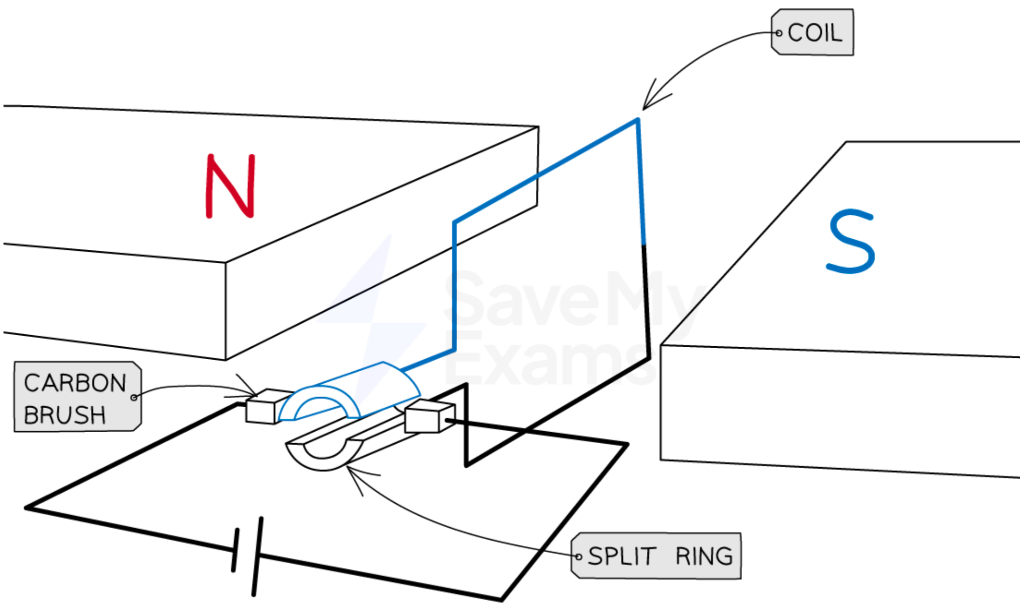


Your notes

Forces acting in opposite directions on each side of the coil, causing it to rotate. The split ring connects the coil to the flow of current

- Current flowing through the coil produces a magnetic field
  - This magnetic field interacts with the uniform external field, so a **force** is exerted on the wire
- Forces act in opposite directions on each side of the coil, causing it to rotate:
  - On the blue side of the coil, current travels towards the cell so the force acts upwards (using **Fleming's left-hand rule**)
  - On the black side, current flows away from the cell so the force acts downwards
- Once the coil has rotated 90°, the split ring is **no longer in contact** with the brushes
  - No current flows through the coil so no forces act

Coil in the vertical position in a d.c. motor



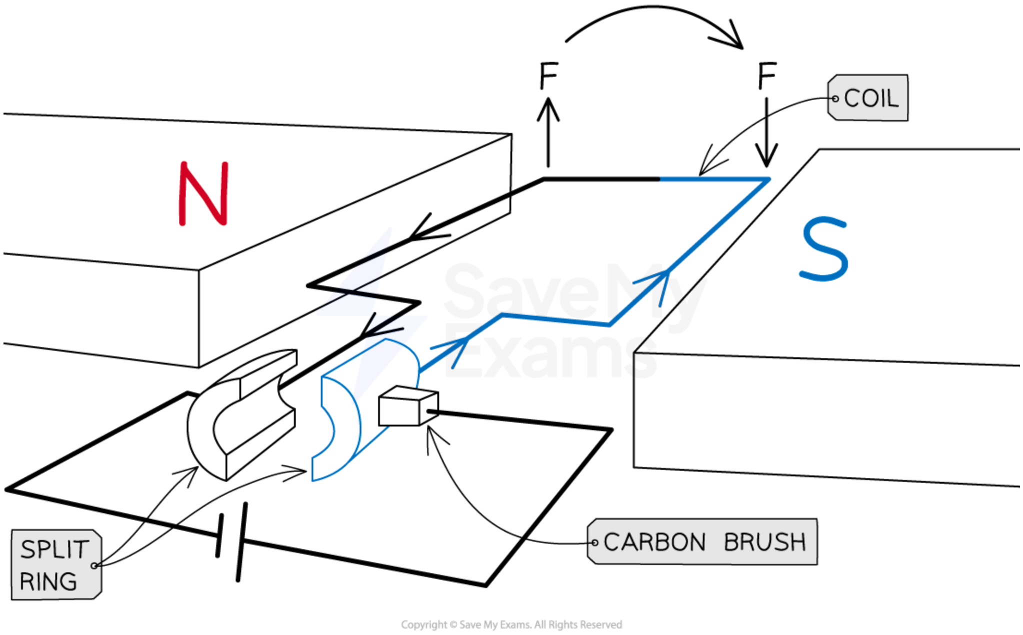
No force acts on the coil when vertical, as the split ring is not in contact with the brushes

- Even though no force acts, the momentum of the coil causes the coil to continue to rotate slightly
- The split ring reconnects with the carbon brushes and current flows through the coil again
  - Now the blue side is on the right and the black side is on the left
- Current still flows toward the cell on the left and away from the cell on the right, even though the coil has flipped

Your notes

- The black side of the coil experiences an upward force on the left and the blue side experiences a downward force on the right
- The coil continues to rotate in the same direction, forming a continuously spinning motor

Forces on the coil when rotated 180°



Even though the coil has flipped, the current still flows anticlockwise and the forces still cause rotation in the same direction

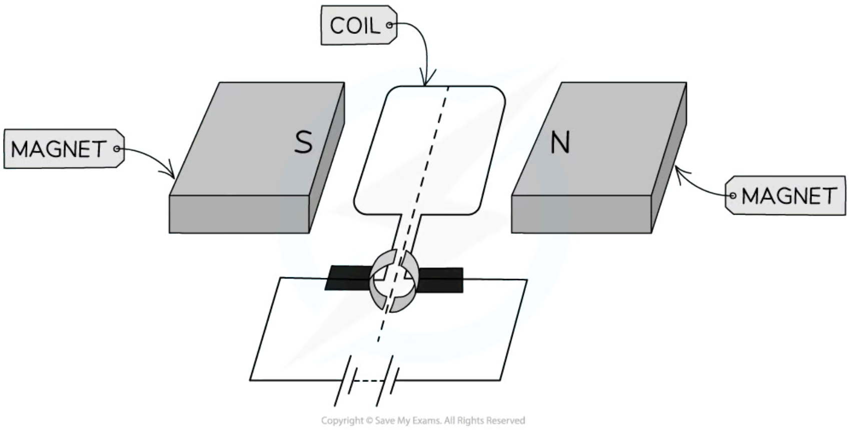
Factors affecting the d.c. motor

- The **speed** at which the coil rotates can be increased by:
  - increasing the **current**
  - using a **stronger magnet**
- The **direction of rotation** of the coil in the d.c. motor can be changed by:
  - reversing the direction of the **current supply**
  - reversing the direction of the magnetic field by reversing the **poles** of the magnet
- The **force** supplied by the motor can be increased by:
  - increasing the **current** in the coil
  - increasing the strength of the **magnetic field**
  - adding **more turns** to the coil

Your notes

Worked Example

A d.c. motor is set up as shown below.

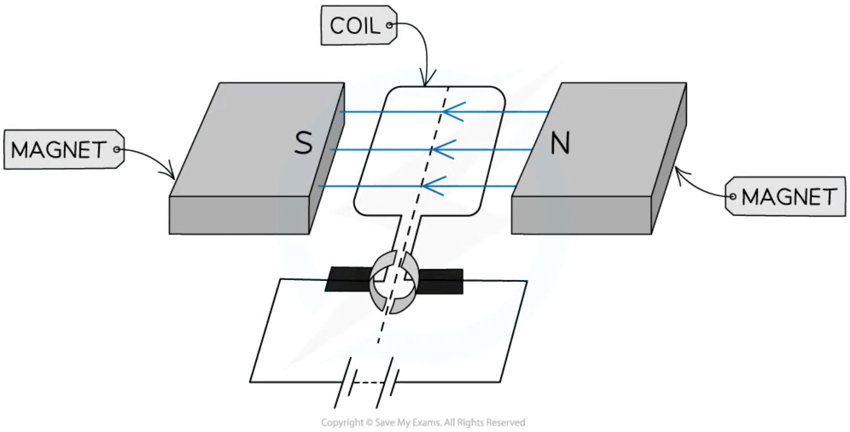


Determine whether the coil will be rotating clockwise or anticlockwise.

Answer:

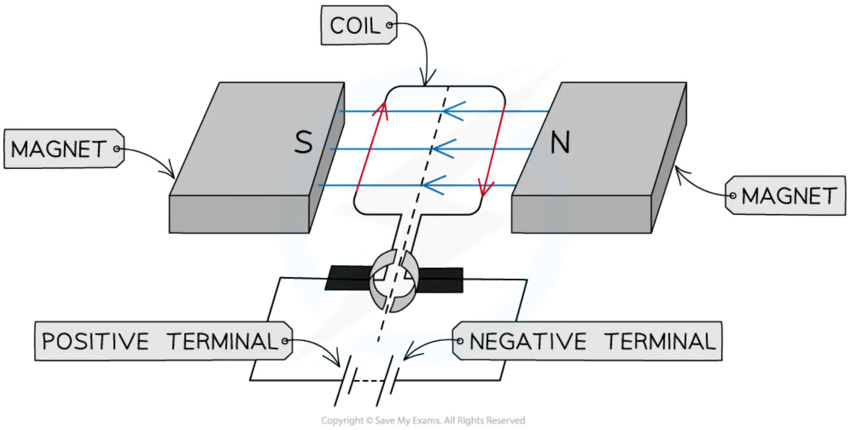
Step 1: Draw arrows to show the direction of the magnetic field lines

- These will go from the north pole of the magnet to the south pole of the magnet



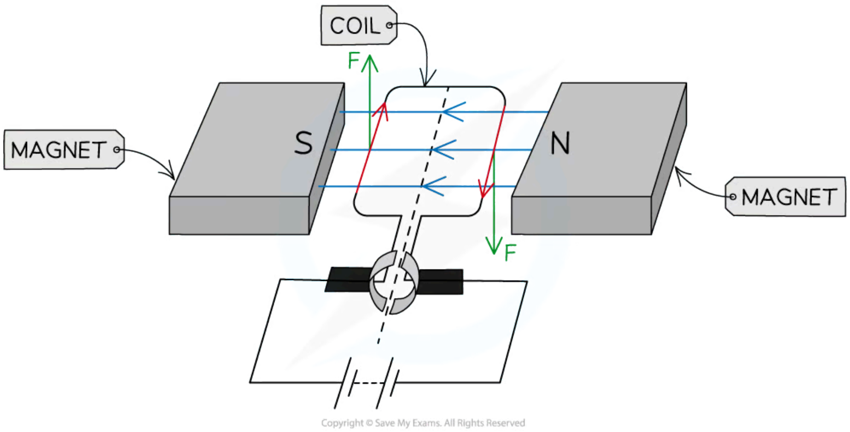
Step 2: Draw arrows to show the direction the current is flowing in the coils

- Current will flow from the positive terminal of the battery to the negative terminal



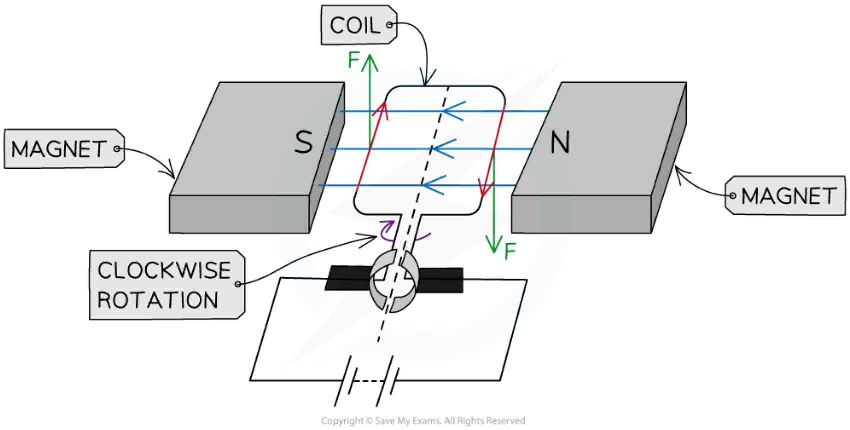
Step 3: Use Fleming's left hand rule to determine the direction of the force on each side of the coil

- Start by pointing your **F**irst **F**inger in the direction of the (magnetic) **F**ield
- Now rotate your hand around the first finger so that the se**C**ond finger points in the direction of the **C**urrent
- The **TH**umb will now be pointing in the direction of the **TH**rust (the force)



Step 4: Use the force arrows to determine the direction of rotation

- The coil will be turning **clockwise**



Your notes

Examiner Tips and Tricks

It is important to remember all the steps that cause the rotation of the coil in a d.c. motor. Use Fleming's Left Hand rule to convince yourself of the direction of the force on each side of the coil, these should be in opposite directions because the directions of the current through each side are opposite.

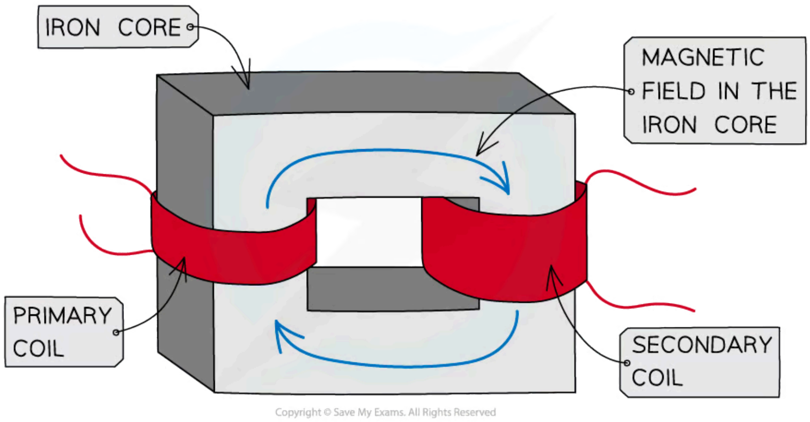
Additionally, don't be confused if you see the phrase 'split-ring **commutator**'. This is another way of referring to the split ring in the circuit and they mean the same thing.

Your notes

Structure of a transformer

- A **transformer** is a device used to **change** the size of an **alternating voltage** or **current**
  - This is achieved using the **generator effect**
- A basic transformer consists of:
  - a **primary coil**
  - a **secondary coil**
  - a **soft iron core**
- Iron is used because it is easily **magnetised**

Construction of a simple transformer



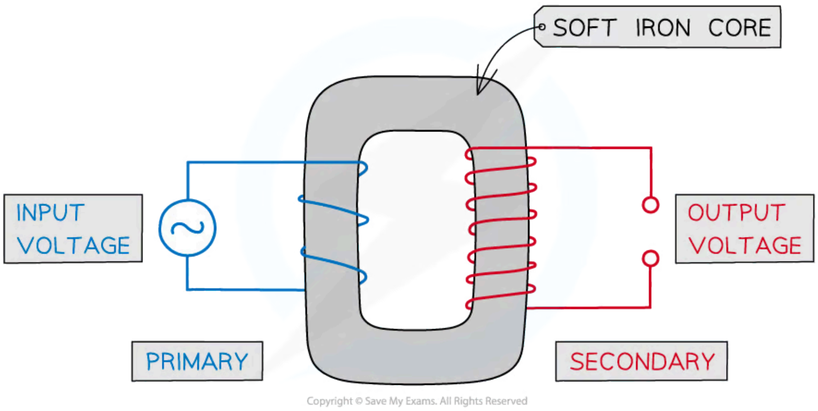
A simple transformer is made up of a primary coil and a secondary coil wound on a soft iron core

Step-up & step-down transformers

- A transformer consists of a **primary** and **secondary** coil
  - The primary coil is the **first** coil
  - The secondary coil is the **second** coil

Step-up transformer

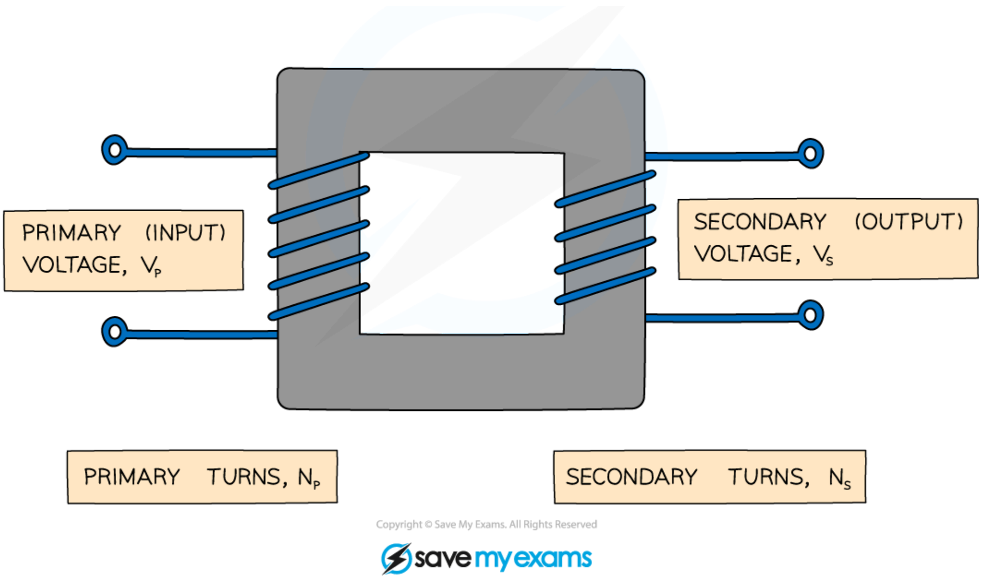
- A **step-up** transformer:
  - increases the **voltage** of a power source $\left(V_s > V_p\right)$
  - has **more turns** on the secondary coil than on the primary coil $\left(N_s > N_p\right)$



A step-up transformer has more turns on the secondary coil, which increases the size of the voltage

Step-down transformer

- A **step-down** transformer:
  - decreases the **voltage** of a power source $\left(V_s < V_p\right)$
  - has **fewer turns** on the secondary coil than on the primary coil $\left(N_s < N_p\right)$



A step-down transformer has fewer turns on the secondary coil, which decreases the size of the voltage

Operation of a transformer

Extended tier only

Your notes

- An **alternating current** is supplied to the **primary coil**
- The **current** is continually **changing direction**
  - This means it will produce a **changing magnetic field** around the primary coil
- The iron core is **easily magnetised**, so the changing magnetic field passes through it
- As a result, there is now a **changing magnetic field** inside the **secondary coil**
  - This changing field **cuts** through the secondary coil and **induces** an **emf** (voltage)
- As the magnetic field is continually changing, the induced emf will be **alternating**
  - The alternating emf will have the **same frequency** as the alternating current supplied to the primary coil
- If the secondary coil is part of a **complete circuit** it will cause an **alternating current** to flow

Your notes

Transformer calculations

- The voltages across the primary and secondary coils of a transformer can be calculated using the **transformer equation**, which states

The ratio of the voltages across the primary and secondary coils of a transformer is equal to the ratio of the number of turns on each coil

- It can be expressed by the equation:

$$\frac{\text{primary voltage}}{\text{secondary voltage}} = \frac{\text{number of turns on primary}}{\text{number of turns on secondary}}$$

- It can be expressed in symbols as follows:

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

- Where
  - V_p = voltage across the primary coil, in volts (V)
  - V_s = voltage across the secondary coil, in volts (V)
  - N_p = number of turns on the primary coil
  - N_s = number of turns on the secondary coil
- The transformer equation can be flipped upside down to give:

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

- Rearranging for the secondary voltage:

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

- This equation shows that the output (**secondary**) voltage of a transformer depends on:
  - the **number of turns** on the primary and secondary coils
  - the input (**primary**) voltage
- In a step-up transformer, $V_s > V_p$ and $N_s > N_p$

- In a step-down transformer, $V_s < V_p$ and $N_s < N_p$

Your notes

Worked Example

A transformer has 20 turns on the primary coil and 800 turns on the secondary coil.
The voltage across the primary coil is 500 V.

a) Calculate the output voltage of the secondary coil.

b) State whether this is a step-up or step-down transformer.

Answer

Part (a)

Step 1: List the known quantities

- Number of turns on the primary coil, $N_p = 20$
- Number of turns on the secondary coil, $N_s = 800$
- Voltage across the primary coil, $V_P = 500$ V

Step 2: Write down the transformer equation

- There will be less rearranging to do if V_S is on the top of the fraction

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

Step 3: Rearrange the equation to make V_S the subject

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

Step 4: Substitute the known values into the equation

$$V_S = 500 \times \frac{800}{20} = 20\,000 \text{ V}$$

Part (b)

- The secondary voltage is larger than the primary, $V_s > V_p$
- There are more turns on the secondary coil than on the primary, $N_s > N_p$
- Therefore, this is a **step-up transformer**

Your notes

Examiner Tips and Tricks

When carrying out transformer calculations, make sure you have used the **same letter** (p or s) in the **numerators** (top line) of the fraction and the **same letter** (p or s) in the **denominators** (bottom line) of the fraction.

There will be less rearranging to do in a calculation if the variable which you are trying to find is on the numerator (top line) of the fraction.

The individual loops of wire going around each side of the transformer should be referred to as **turns** and **not** coils.

Ideal transformer equation

Extended tier only

- A transformer which is **100% efficient** is called an **ideal transformer**
- Although transformers can increase the voltage of a power source, due to the **law of conservation of energy**, they cannot increase the power output
- If a transformer is 100% efficient, then the input power in the primary coil is equal to the output power of the secondary coil:

$$\text{power in primary} = \text{power in secondary}$$

- The equation to calculate electrical power is:

$$P = V \times I$$

- Where:
  - P = power, in watts (W)
  - V = voltage, in volts (V)
  - I = current, in amps (A)
- Therefore, the equation for an ideal transformer is:

$$I_p V_p = I_s V_s$$

- Where:
  - I_p = primary current, in amps (A)
  - V_p = primary voltage, in volts (V)
  - I_s = secondary current, in amps (A)
  - V_s = secondary voltage, in volts (V)
- The equation above could also be written as a ratio:

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

Your notes

Worked Example

A transformer in a travel adapter steps up a 115 V a.c. mains electricity supply to the 230 V needed for a hair dryer. A current of 5 A flows through the hairdryer.

Assuming that the transformer is 100% efficient, calculate the current drawn from the mains supply.

Answer:

Step 1: List the known quantities

- Voltage in primary coil, V_p = 115 V
- Voltage in secondary coil, V_s = 230 V
- Current in secondary coil, I_s = 5 A

Step 2: Write down the equation for an ideal transformer

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

Step 3: Substitute in the known values

$$115 \times I_p = 230 \times 5$$

Step 4: Rearrange the equation to find the primary current

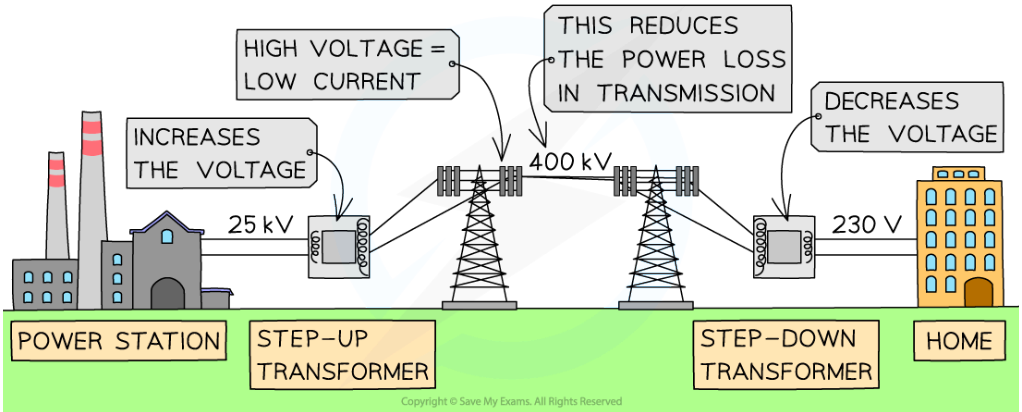
$$I_p = \frac{230 \times 5}{115}$$

$$I_p = 10 \text{ A}$$

High-voltage transmission

- Electricity is transmitted through power cables at a low current to prevent dissipation of energy
  - When current flows in a wire, there is heating in the wire due to resistance
  - Therefore, energy is dissipated to the surroundings, this energy is wasted
  - The lower the current, the more efficient the energy transfer
- Electrical power is equal to voltage × current, or $P = VI$
- This means that a low current can be achieved by increasing the voltage, so electricity must be transmitted at a **high voltage**

- A **smaller current** flowing through the power lines results in **less heat** being produced in the wire
  - This **reduces** the **energy loss** in the power lines
- The key **advantages** of high-voltage transmission of electricity are:
  - the reduced power loss in transmission cables increases the efficiency of energy transfer
  - lower currents in cables mean thinner, and therefore, cheaper cables can be used



Electricity is transmitted at high voltage, reducing the current and hence power loss in the cables using transformers

Calculating power losses

Extended tier only

- The power dissipated in the wire due to resistance is given by:

$$P = I^2 R$$

- Where:
  - P = power, in watts (W)
  - I = current, in amps (A)
  - R = resistance, in ohms (Ω)
- A **step-up** transformer is used to increase the voltage and decrease the current of electricity **before** transmission
  - A high-voltage transmission ensures the same power transfer with a smaller current
  - A smaller current means less thermal energy will be lost due to the resistance in the wire
- A **step-down** transformer is used to decrease the voltage and increase the current of electricity **after** transmission

Your notes

- High-voltage electricity is dangerous for use in homes, so it must be lowered before the current reaches consumers

Your notes

Examiner Tips and Tricks

If you forget the equation $P = I^2R$ just remember 'Twinkle twinkle little star, power equals I squared R''.