Edexcel GCSE Physics

Your notes

Electromagnetic Induction

Contents

Your notes

Generating Electricity

The Generator Effect

Higher Tier Only

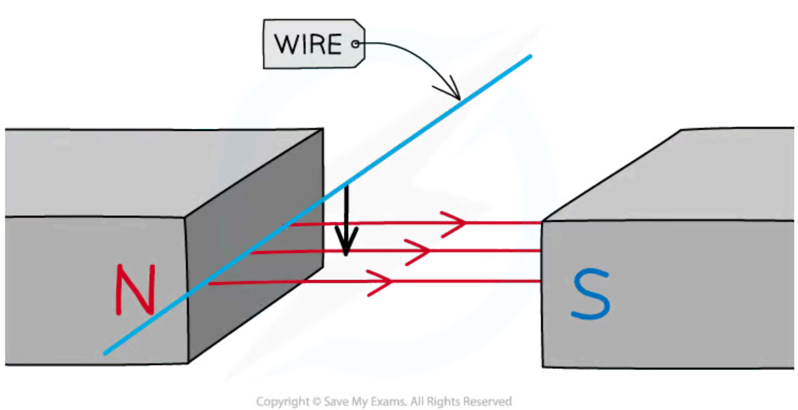
- Electromagnetic (EM) induction is used to generate electricity
- EM induction is when:

  A voltage is induced in a conductor or a coil when it moves through a magnetic field or when a magnetic field changes through it

- This is done by the conductor or coil **cutting through** the magnetic field lines of the magnetic field
- This is often referred to as the **generator effect** and is the opposite to the motor effect
  - In the motor effect, there is already a current in the conductor which experiences a force
  - In the generator effect, there is **no initial current** in the conductor but one is induced (created) when it moves through a magnetic field

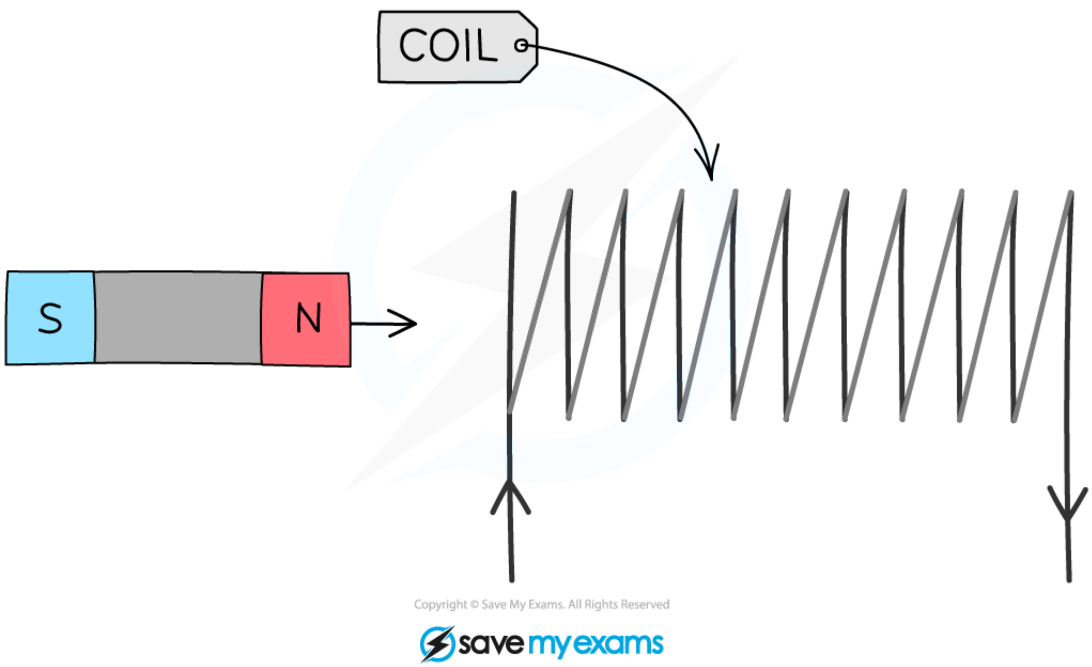
Generator Effect in the Laboratory

- A potential difference will be induced in the conductor if there is **relative movement** between the conductor and the magnetic field
- Moving the electrical conductor in a fixed magnetic field
  - When a conductor (such as a wire) is moved through a magnetic field, the wire **cuts** through the fields lines
  - This **induces a potential difference** in the wire



Moving an electrical conductor in a magnetic field to induce a potential difference

- Moving the magnetic field relative to a fixed conductor
  - As the magnet moved through the coil, the field lines **cut** through the turns on the coil
  - This **induces a potential difference** in the coil



When the magnet enters the coil, the field lines cut through the turns, inducing a potential difference

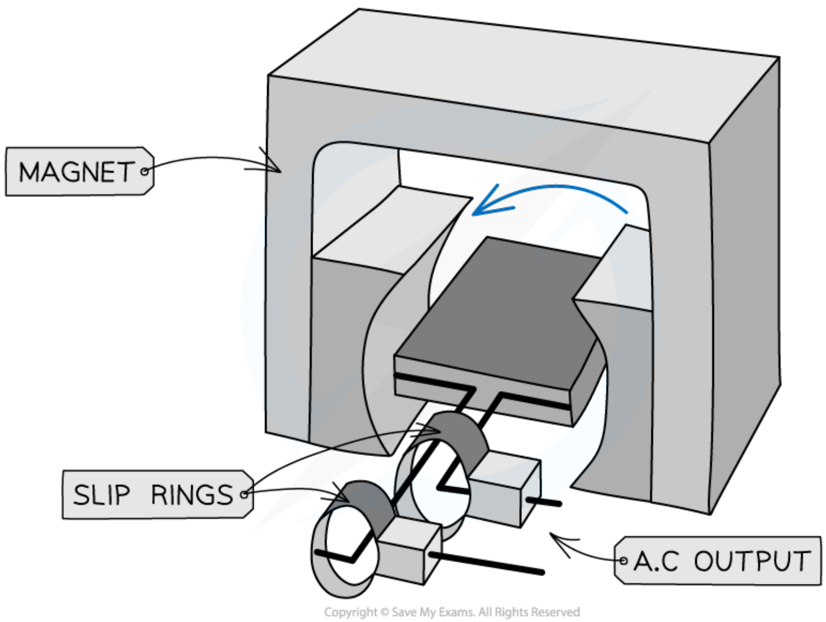
- A **sensitive voltmeter** can be used to measure the size of the induced potential difference
- If the conductor is part of a **complete circuit** then a **current** is induced in the conductor
  - This can be detected by an ammeter

Generator Effect in the Large-Scale Generation of Electrical Energy

- EM Induction can be used to generate electricity on a large scale by replacing the moving wire with a **spinning coil**
- An a.c (alternating current) generator looks very similar to a motor, but instead of connecting it to a power supply, a coil is spun to produce electricity

Your notes

- As the coil rotates, it **cuts through** the field lines
- This induces a potential difference between the end of the coil, which also then creates a current
- The electricity produce is in the form of a.c which can be found in the mains supply of a building
- This is also called an **alternator**



A.C Generator

Your notes

Factors Affecting EM Induction

Higher Tier Only

- The **size** of the induced potential difference is determined by:
  - The **speed** at which the wire, coil or magnet is moved
  - The **number of turns** on the coils of wire
  - The **size** of the coils
  - The **strength** of the magnetic field
- The **direction** of the induced potential difference is determined by:
  - The **orientation** of the poles of the magnet

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 induced potential difference**

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

- **Increasing the number of turns on the coils** in the wire will **increase the potential difference** induced
- This is because each coil will cut through the magnetic field lines and the total potential difference induced will be the result of all of the coils cutting the magnetic field lines

3. The **size** of the coils:

- **Increasing the area** of the coils will **increase the potential difference** induced
- 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 **potential difference induced**

5. The **orientation** of the poles of the magnet:

- Reversing the direction in which the wire, coil or magnet is moved

The Magnetic Field Produced

- The direction of an induced potential difference always **opposes** the change that produces it

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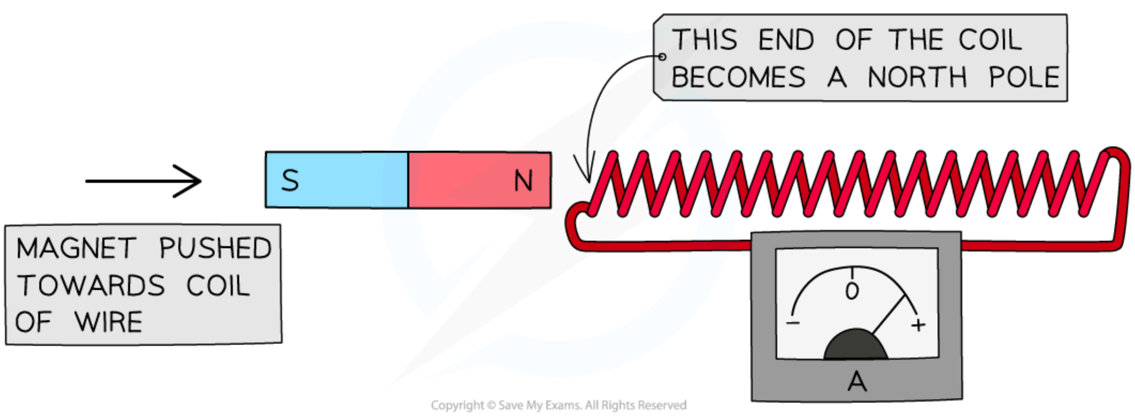
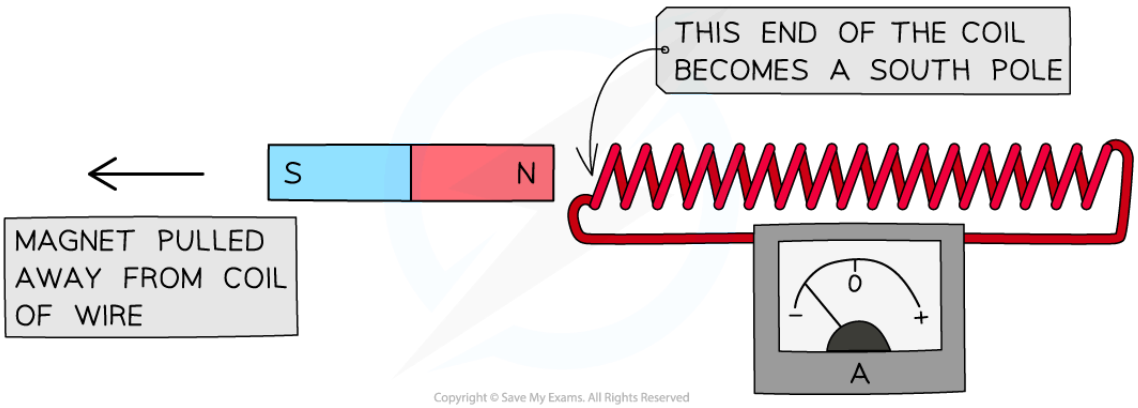
- This means that the **magnetic field** produced from EM induction also **opposes** the original change
  - The field will act so that it tries to **stop** the wire or magnet from moving
- If a magnet is pushed north end first into a coil of wire then the end of the coil closest to the magnet will become a **north pole**
- Explanation:
  - Due to the generator effect, a **potential difference** will be induced in the coil
  - The induced potential difference always **opposes** the change that produces it
  - The coil will apply a **force** to oppose the magnet being pushed into the coil
  - Therefore, the end of the coil closest to the magnet will become a **north pole**
  - This means it will **repel** the north pole of the magnet



Magnet being pushed into a coil of wire

- If a magnet is now pulled away from the coil of wire then the end of the coil closest to the magnet will become a **south pole**
- Explanation:
  - Due to the generator effect, a **potential difference** will be induced in the coil
  - The induced potential difference always **opposes** the change that produces it
  - The coil will apply a **force** to oppose the magnet being pulled away from the coil
  - Therefore, the end of the coil closest to the magnet will become a **south pole**
  - This means it will **attract** the north pole of the magnet

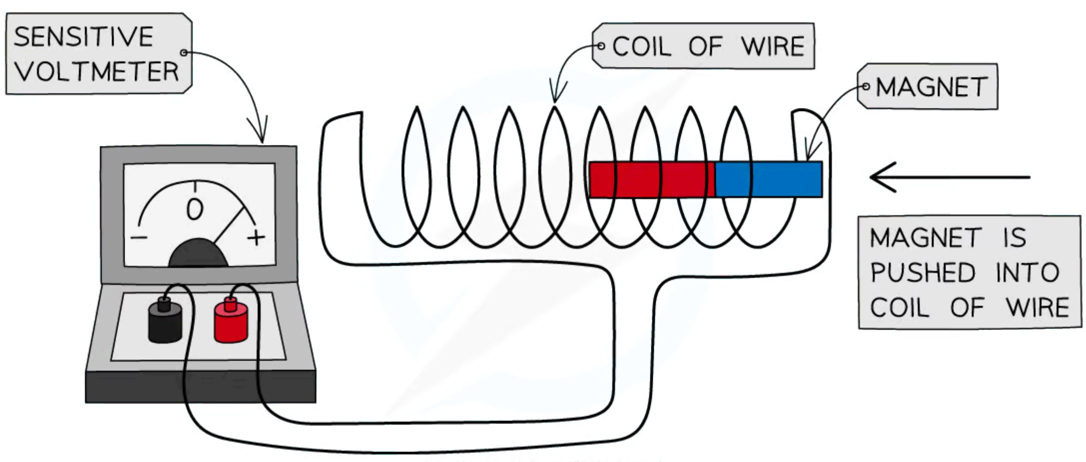


Magnet being pulled away from a coil of wire

Your notes

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:

a) Stationary in the centre of the coil?

b) Pulled back out of the centre of the coil?

Your notes

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

Part (a)

- **C** is correct because there the magnet is stationary
- This means there is no relative movement between the coil and the magnetic field, therefore there are no magnetic field lines being cut
- If the magnetic field lines are not being cut then there will not be a potential difference induced
- **A**, **B** & **D** are incorrect because a deflection on the voltmeter would indicate that a potential difference has been induced
- This could only happen if there was relative movement between the coil and the magnetic field

Answer: A

Part (b)

- **A** is correct because the magnet is moving relative to the coil
- This means that the needle on the voltmeter will deflect
- The needle on the voltmeter will deflect to the left because it is moving in the opposite direction to the diagram
- When the direction of the magnetic field lines are reversed, the direction of the induced current will be reversed
- **B** is incorrect because the magnet is moving in the opposite direction to the diagram
- This means it will deflect in the opposite direction (to the left)
- **C** is incorrect because the magnet is moving
- This means that a potential difference will be induced in the coil and the needle on the voltmeter will deflect
- **D** is incorrect because the magnet only moves in one direction
- This means the voltmeter should only deflect in one direction only

Examiner Tips and Tricks

When discussing factors affecting the induced potential difference:

- Make sure you state:
  - "Add more **turns** to the coil" instead of "Add more coils"
  - This is because these statements do not mean the same thing

- Likewise, when referring to the magnet, use the phrase:
  - "**A stronger magnet** instead of "A bigger magnet"
  - This is because larger magnets are not necessarily stronger

Your notes

Applications of the Generator Effect

Your notes

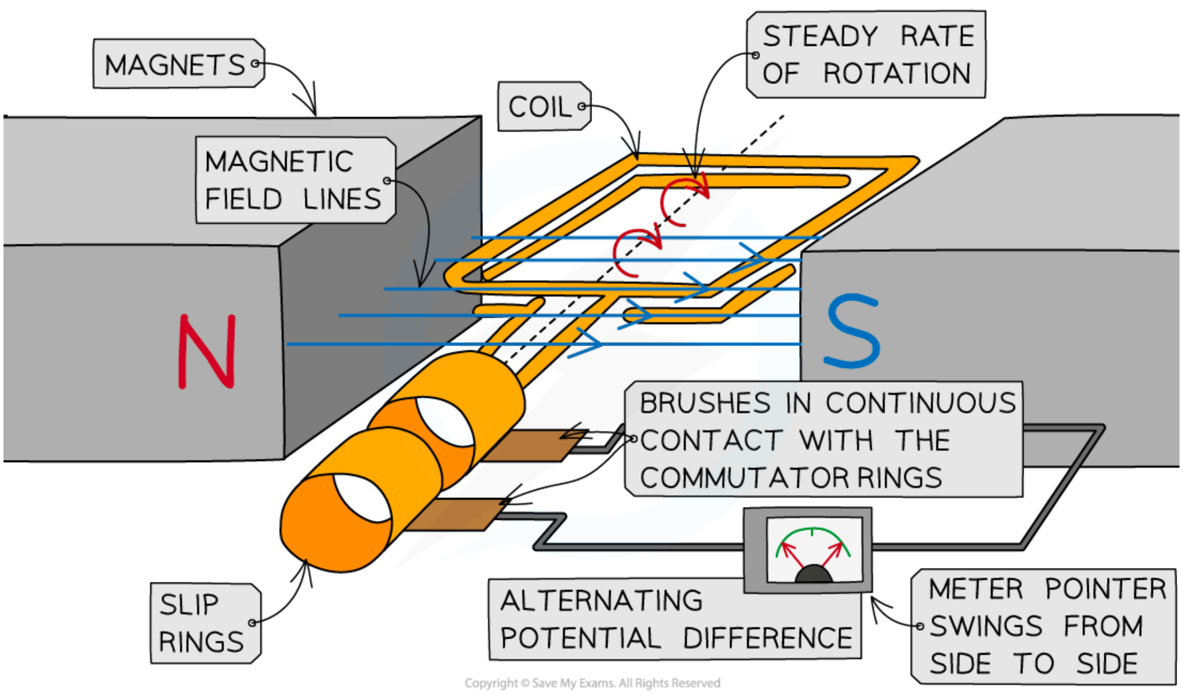
Applications of the Generator Effect

Higher Tier Only

- The **generator effect** can be used to:
  - Generate **a.c** in an **alternator**
  - Generate **d.c** in a **dynamo**

Alternator

- A simple alternator is a type of generator that converts mechanical energy to electrical energy in the form of alternating current

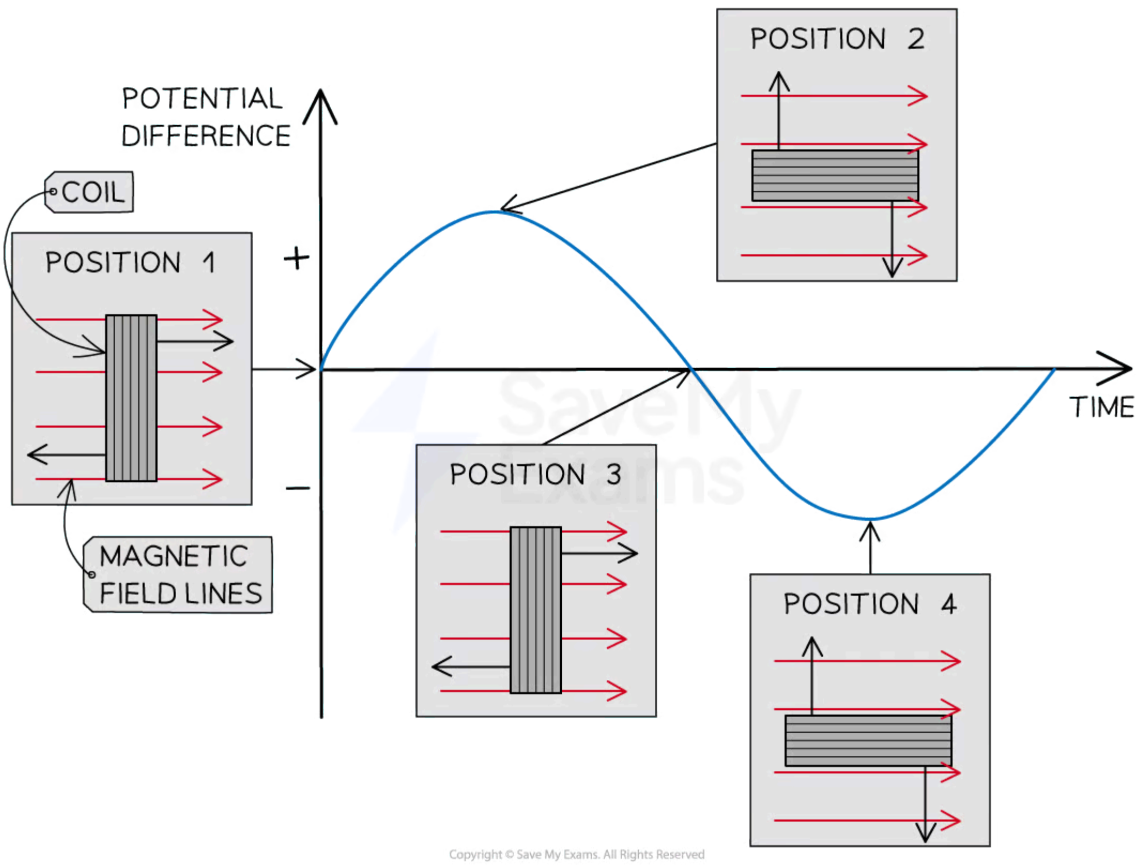


An alternator is a rotating coil in a magnetic field with commutator rings

- A rectangular coil that is forced to spin in a **uniform magnetic field**
- The coil is connected to a centre-reading meter by **metal brushes** that press on two metal **slip rings** (or commutator rings)

Your notes

  - The slip rings and brushes provide a continuous connection between the coil and the meter
- When the coil turns in one direction:
  - The pointer deflects first one way, then the opposite way, and then back again
  - This is because the coil **cuts through** the magnetic field lines and a **potential difference,** and therefore current, is **induced** in the coil
- The pointer deflects in both directions because the current in the circuit repeatedly **changes direction** as the coil spins
  - This is because the induced potential difference in the coil repeatedly changes its direction
  - This continues on as long as the coil keeps turning in the **same** direction
- The induced potential difference and the current **alternate** because they repeatedly **change direction**

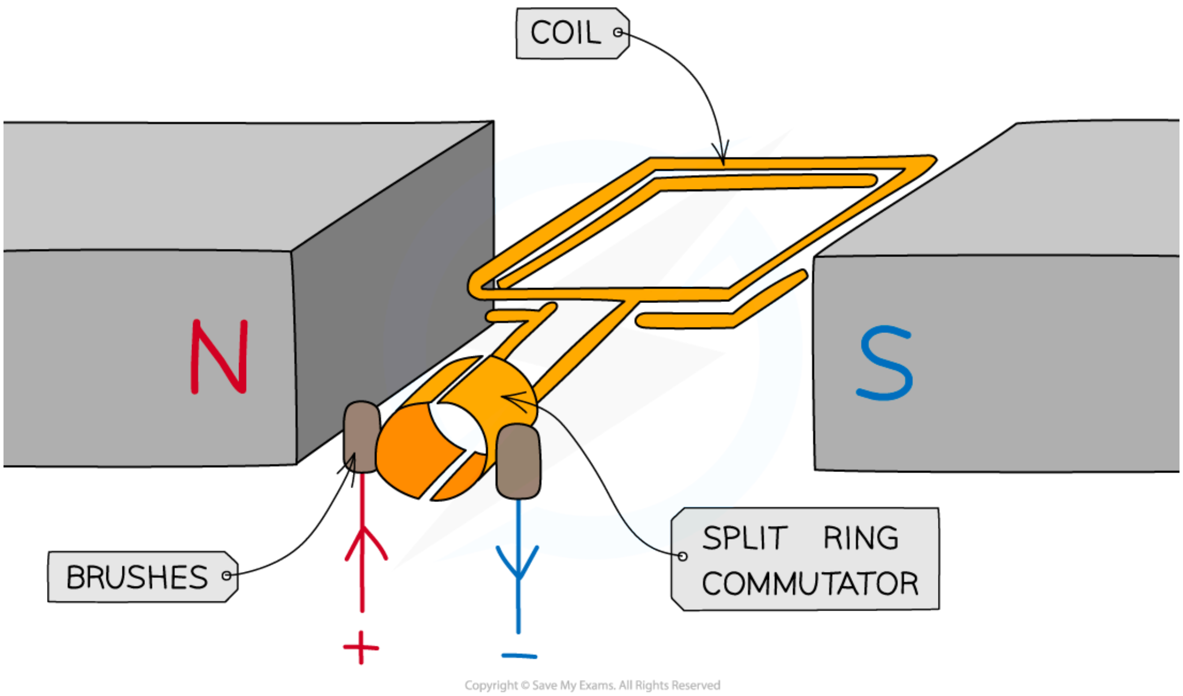


A.C output from an alternator - the current is both in the positive and negative region of the graph

Dynamos

Your notes

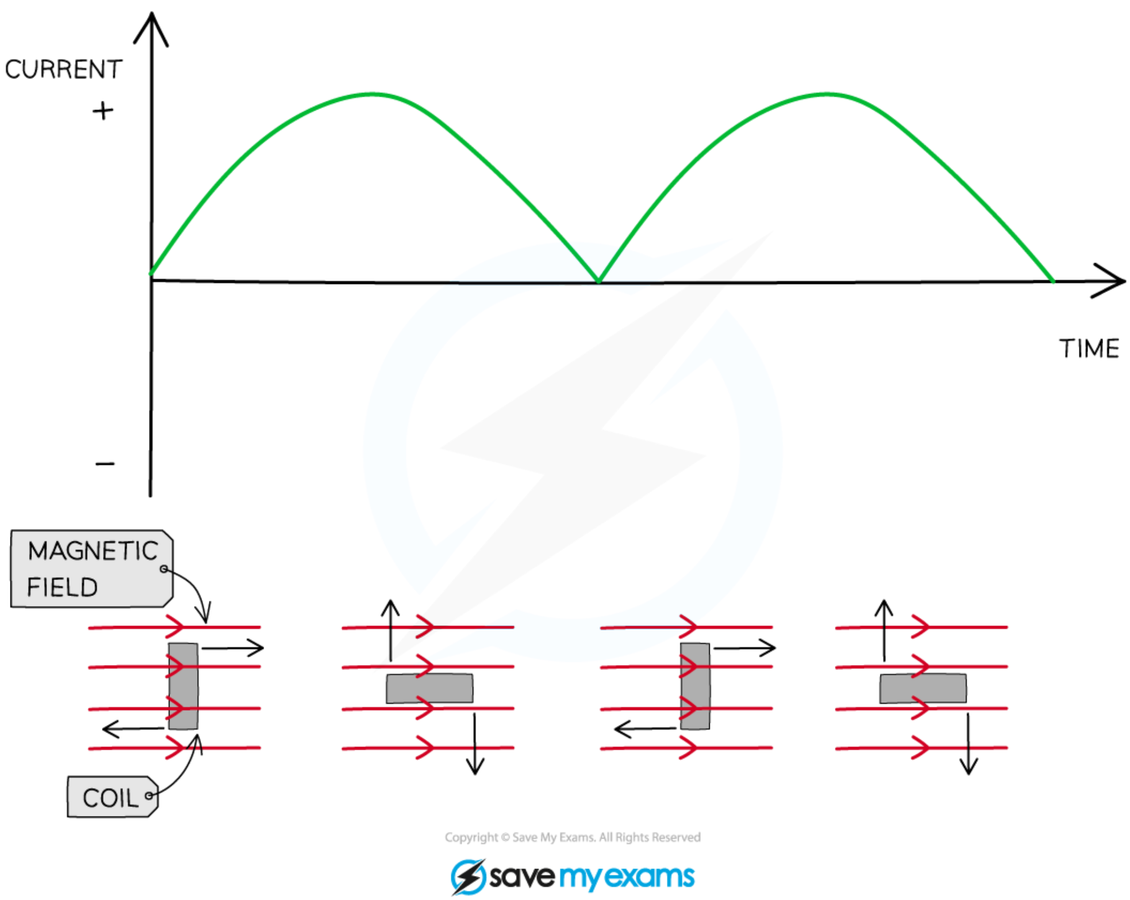
- A dynamo is a direct-current generator
- A simple dynamo is the **same** as an **alternator** except that the dynamo has a **split-ring commutator** instead of two separate slip rings



A dynamo is a rotating coil in a magnetic field connected to a split ring commutator

- As the coil rotates, it **cuts** through the field lines
  - This **induces a potential difference** between the end of the coil
- The split ring commutator changes the connections between the coil and the brushes every half turn in order to keep the current leaving the dynamo in the **same direction**
  - This happens each time the coil is perpendicular to the magnetic field lines
- Therefore, the induced potential difference **does not reverse** its direction as it does in the alternator
- Instead, it varies from zero to a maximum value twice each cycle of rotation, and never changes polarity (positive to negative)
  - This means the current is always **positive** (or always **negative**)

Your notes

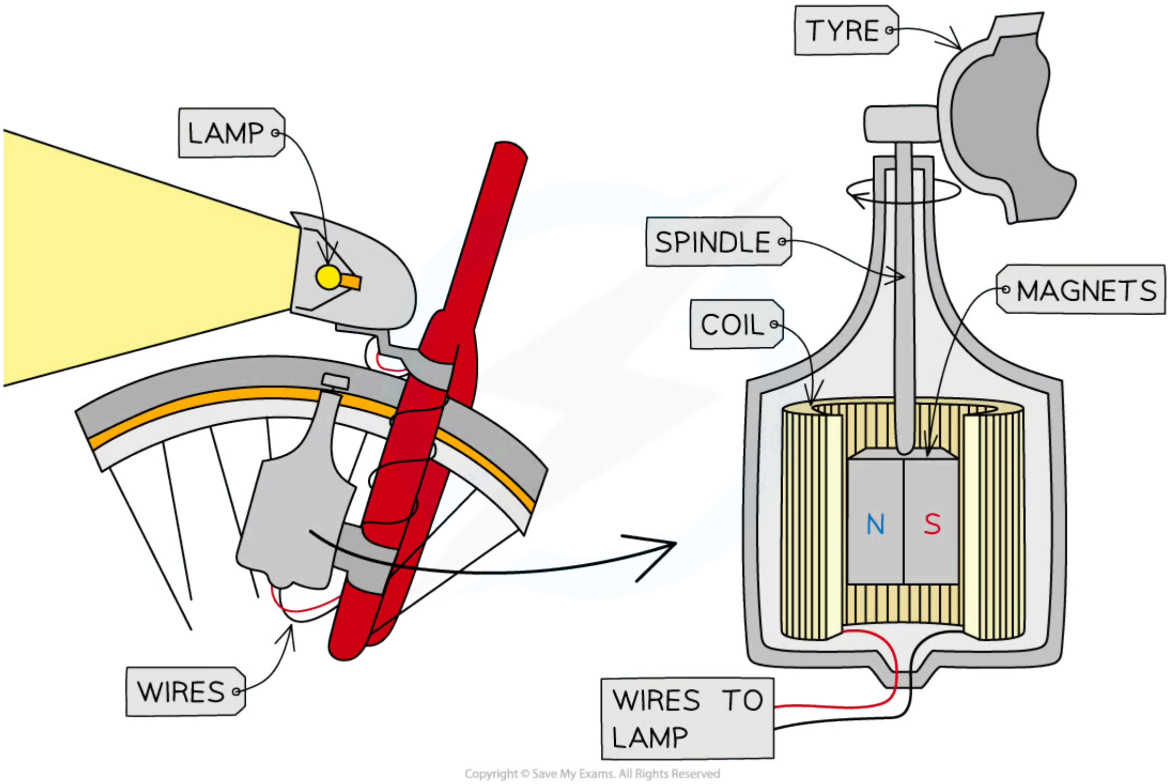


D.C output from a dynamo – the current is only in the positive region of the graph

Bicycle Dynamo

- A bicycle dynamo is used to supply electricity to bicycle lights whilst in motion
- It consists of a **rotating magnet** placed inside (or next to) a coil
- The magnet is rotated by its connection to the bicycle inside the coil
  - This is sometimes called the friction wheel and the axle / spindle
- The magnetic field lines **cut** through the sides of the coil
  - This induces a **potential difference** in the coil
- Since the magnetic field is constantly **changing direction** as it rotates, so does the output potential difference

- This means the output current is also changing direction
- Therefore, a bicycle dynamo, unlike a normal dynamo, produces **alternating** current (a.c)



A bicycle dynamo consists of a magnet rotating in a coil due to the motion of the wheels

Examiner Tips and Tricks

Motors and generators look very similar (as do microphones and loudspeakers), but they do very different things. When tackling a question on either of them, make sure you are writing about the right one! You might be expected to give the above explanations - make sure that you understand their subtle differences!

Your notes

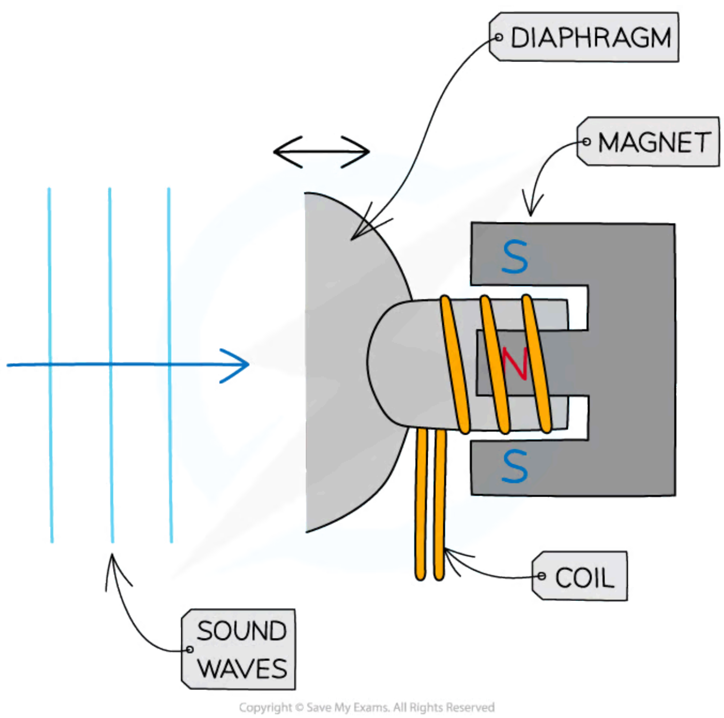
Your notes

Loudspeakers & Headphones

Higher Tier Only

Microphone

- A moving coil microphone also work using the principles of electromagnetic induction
- The convert the pressure variations in sound waves into variations in **current** in electrical circuits



A moving coil microphone

- When sound waves reach the microphone, the **pressure variations** cause the diaphragm to vibrate
  - This in turn causes the coil to move back and forth, through the magnetic field
- As it does so, the coil cuts through the field lines, inducing an **alternating** potential difference in the coil and therefore an **alternating current**

Loudspeakers & Headphones

Your notes

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

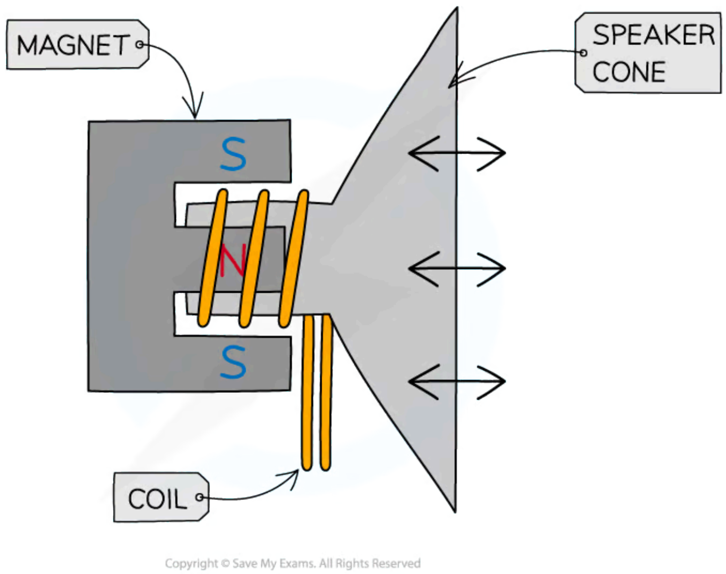


Diagram showing a cross-section of a loudspeaker

- 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
  - The direction of the force at any instant can be determined using **Fleming's left-hand rule**
- 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**

Examiner Tips and Tricks

Microphones and loudspeakers 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!

The explanation of the loudspeaker is very similar to the explanation of a motor, however **direct current** is used in a d.c motor and **alternating current** is used in a loudspeaker or headphone. You need to learn how both work.

When explaining how a loudspeaker works remember to refer to the **alternating current** and the **changing magnetic field** that it creates.

Your notes

Your notes

Transformers

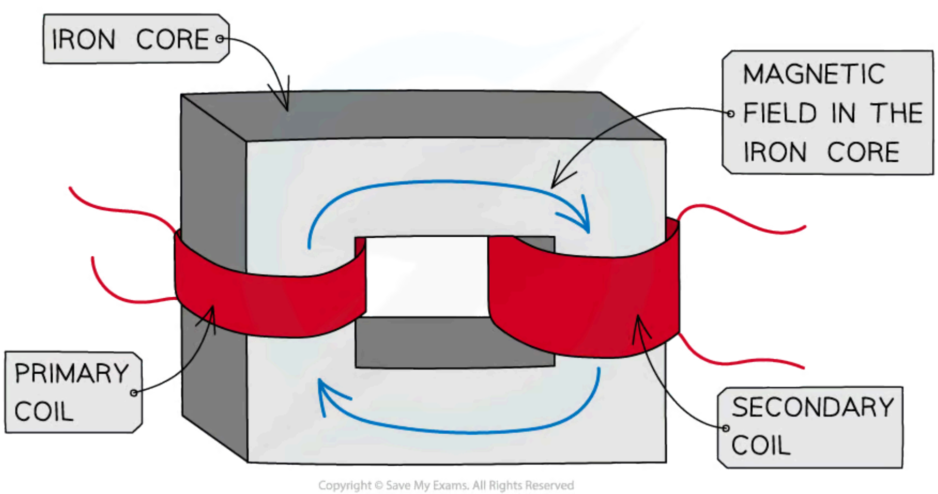
Operation of a Transformer

Higher Tier Only

- A **transformer** is a device used to **change** the value of an **alternating potential difference** or current
- This is achieved using the generator effect

Structure of a Transformer

- A basic transformer consists of:
  - A **primary coil**
  - A **secondary coil**
  - An **iron core**
- Iron is used because it is easily **magnetised**



Structure of a transformer

How a Transformer Works

- An **alternating current** is supplied to the **primary coil**
- The **current** is continually **changing direction**

Your notes

  - 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 a potential difference**
- As the magnetic field is continually changing the potential difference induced will be **alternating**
  - The alternating potential difference 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

The Role of Transformers

Higher Tier Only

- A transformer can change the **size** of an alternating voltage
- They also have a number of other roles, such as:
  - To increase the potential difference of electricity before it is transmitted across the national grid
  - To lower the high voltage electricity used in power lines to the lower voltages used in houses
  - Used in adapters to lower mains voltage to the lower voltages used by many electronic devices
- A **step-up** transformer **increases the potential difference** of a power source.
  - A step-up transformer has **more** turns on the secondary coil than on the primary coil
- A **step-down** transformer **decreases the potential difference** of a power source
  - A step-down transformer has **fewer** turns on the secondary coil than on the primary coil

Your notes

The Transformer Equation

The Transformer Equation

Higher Tier Only

- The **output potential difference** (voltage) of a transformer depends on:
  - The **number of turns** on the primary and secondary coils
  - The **input potential difference** (voltage)
- It can be calculated using the equation:

$$\frac{\text{POTENTIAL DIFFERENCE ACROSS PRIMARY COIL}}{\text{POTENTIAL DIFFERENCE ACROSS SECONDARY COIL}} = \frac{\text{NUMBER OF TURNS ON PRIMARY COIL}}{\text{NUMBER OF TURNS ON SECONDARY COIL}}$$

- This equation can be written using symbols as follows:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

- Where:
  - V_p = potential difference (voltage) across the primary coil in volts (V)
  - V_s = potential difference (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 equation above can be flipped upside down to give:

$$\frac{V_s}{V_p} = \frac{n_s}{n_p}$$

- The equations above show that:

- The **ratio** of the potential differences across the primary and secondary coils of a transformer is **equal** to the ratio of the number of turns on each coil

Your notes

Worked Example

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

a) Calculate the output potential difference

b) State what type of transformer this is

Answer:

Your notes

Part (a)

Step 1: List the known quantities

- Number of turns in primary coil, N_p = 20
- Number of turns in secondary coil, N_s = 800
- Voltage in primary coil, V_p = 500 V

Step 2: Write the equation linking the output potential difference (Vs) to the known quantities

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

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

Step 3: Rearrange the equation for V_s

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

Step 4: Substitute values into the equation

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

Part (b)

- The transformer is a **step-up** transformer
- This is because the **secondary coil** has:
    - More turns
    - A bigger output potential difference (voltage)

Examiner Tips and Tricks

When you are using the transformer equation 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.

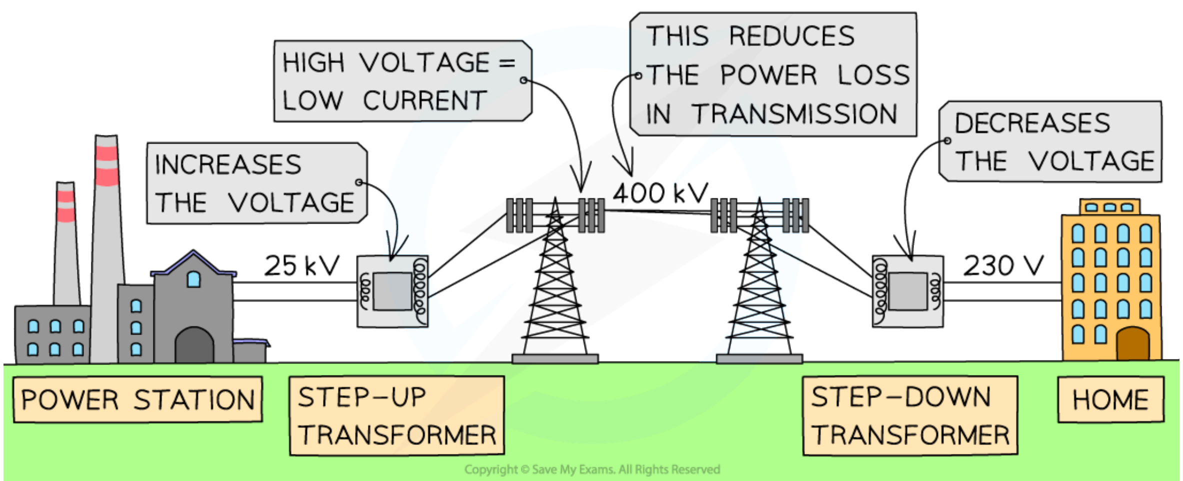
Your notes

Your notes

The National Grid

High Voltage Transmission

- When electricity is transmitted over large distances, the **current** in the wires **heats** them, resulting in **energy loss**
  - The electrical energy is transferred at **high voltages** from power stations
  - It is then transferred at **lower voltages** in each locality for domestic uses
- To transmit the same amount of **power** as the input power the **potential difference** at which the electricity is transmitted should be **increased**
  - This will result in a **smaller current being transmitted** through the power lines
  - This is because $P = IV$, so if V increases, I must decrease to transmit the same power
- A **smaller current** flowing through the power lines results in **less heat** being produced in the wire
  - This will **reduce the energy loss** in the power lines and improves the **efficiency** of the energy transfer



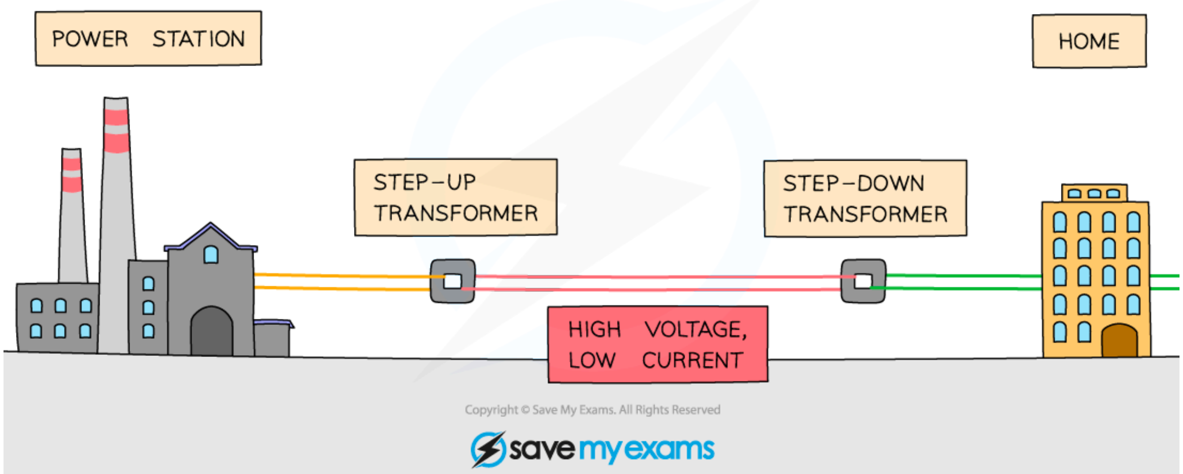
Electricity is transmitted at high voltage, reducing the current and hence power loss in the cables

Stepping Up & Down

- Transformers have a number of roles:

- They are used to increase the potential difference of electricity before it is transmitted across the national grid
- They are used to lower the high voltage electricity used in power lines to the lower voltages used in houses
- They are used in adapters to lower mains voltage to the lower voltages used by many electronic devices

- For the transmission of electricity in the national grid to be at high voltages, the voltage must be stepped up by a **step-up** transformer
  - These are placed **after the power station**
- For the domestic use of electricity, the voltage must be much lower
- This is done by stepping down by the voltage using a **step-down** transformer
  - These are placed **before buildings**



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

The Ideal Transformer Equation

Your notes

The Ideal Transformer Equation

- An **ideal** transformer would be **100% efficient**
- 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:

Input power = Output power

- The equation to calculate electrical power is:

$$P = VI$$

- Where:
  - P = power in Watts (W)
  - V = potential difference in volts (V)
  - I = current in amps (A)
- Therefore, if a transformer is 100% efficient then:

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

- Where:
  - V_p = potential difference across primary coil in volts (V)
  - I_p = current through primary coil in Amps (A)
  - V_s = potential difference across secondary coil in volts (V)
  - I_s = current through secondary coil in Amps (A)
- The equation above could also be written as:

$$P_s = V_p \times I_p$$

- Where:
  - P_s = output power (power produced in secondary coil) in Watts (W)

Your notes

Worked Example

A transformer in a travel adapter steps up a 115 V ac 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 the equation linking the known values to the current drawn from the supply, I_p

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

Step 3: Substitute in the known values

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

Step 4: Rearrange the equation to find I_p

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

Step 5: Calculate a value for I_p and include the correct unit

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

Examiner Tips and Tricks

Make sure to always check whether the current or potential difference you are substitute is for the correct coil (primary or secondary). If it helps, label these on the question on the exam paper

High Voltage Transmission

Your notes

High Voltage Transmission Equations

Higher Tier Only

- When a current passes through a wire, the current creates a heating effect which means the wires warm up
- This means they lose electrical energy as heat which reduced the **efficiency** of the transformer
    - This is due to electrical resistance which is present in all wires
- The power (energy per second) lost in the wire is given by the following equation

$$P = I^2R$$

- Where:
    - P = power in watts (W)
    - I = current in amps (A)
    - R = resistance in ohms (Ω)
- Since the power is the energy lost per second, the total energy lost in a time t will be:

$$E = P \times t$$

- Where:
    - E = energy in joules (J)
    - t = time in seconds (s)
- A step-up transformer may be used to **increase** the voltage of a power supply from the power station to the transmission wires
- The number of turns and voltage for the transformer is related by the following equation:

$$\frac{V_s}{V_p} = \frac{n_s}{n_p}$$

- Where:
    - V_p = potential difference (voltage) across the primary coil in volts (V)

Your notes

- V_s = potential difference (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

- A step-up transformer has more turns on the secondary coil, N_s, than on the primary coil, N_p
- Since a transformer cannot output more power than is put into it, **increasing** the **voltage** must result in the **current** being **lowered**

$$I_pV_p = I_sV_s$$

- Where:
  - I_p = current in the primary coil in amps (A)
  - I_s = current in the secondary coil in amps (A)
- Lower current results in **less** power and energy loss in the cables
  - This makes the transfer of electrical energy through the wires more **efficient**

Examiner Tips and Tricks

You will be expected to remember what each variable means for the equations above and their appropriate units.