ELECTRICITY AND MAGNETISM

KS3 Physics | Year 8

STUDENT EDITION

Contents

Name: ______________________ Teacher: ______________________

Key Terms Glossary

Alternating current (AC)	Electric current that repeatedly changes direction.
Ammeter	An instrument used to measure electric current, connected in series.
Charge	A property of matter measured in Coulombs (C); can be positive or negative.
Conductor	A material that allows the flow of electric charge (current) through it.
Coulomb (C)	The unit of electric charge. 1 C = approximately 6.2×10^{1} electrons.
Current (I)	The rate of flow of electric charge past a point; measured in Amperes (A).
Direct current (DC)	Electric current that flows in one direction only at a constant rate.
Domain	A tiny group of atoms in a magnetic material that acts like a mini-magnet.
Earthing	Connecting a conductor to the ground; used as a safety measure in electrical appliances.
Electric field	A region where a charged object experiences a force.
Electromagnet	A magnet created by passing an electric current through a coil of wire.
Electromagnetic induction	The production of a voltage (and current) in a conductor when the magnetic field through it changes.
Fuse	A safety device containing a thin wire that melts if too much current flows, breaking the circuit.
Insulator	A material that does not allow the flow of electric charge through it.
Ion	A charged atom — formed when an atom gains or loses electrons.
Magnetic field	A region where a magnet or magnetic material experiences a force.
Motor effect	The force on a current-carrying conductor placed in a magnetic field.
National Grid	The network of cables and transformers that distributes electricity across the UK.
Parallel circuit	A circuit in which components are connected alongside one another in separate branches.
Permanent magnet	A magnet that retains its magnetism without needing a current; e.g. steel.
Potential difference (V)	The energy transferred per coulomb of charge between two points; measured in Volts (V).
Power (P)	The rate of energy transfer; measured in Watts (W). $P = E/t$ or $P = IV$.
Resistance (R)	The opposition to the flow of electric current; measured in Ohms (). $R = V/I$.
Series circuit	A circuit in which components are connected one after another in a single loop.
Solenoid	A cylindrical coil of wire that produces a magnetic field similar to a bar magnet.
Static charge	A build-up of electric charge on the surface of an insulating material.
Step-down transformer	A transformer that decreases voltage (fewer secondary turns than primary turns).
Step-up transformer	A transformer that increases voltage (more secondary turns than primary turns).

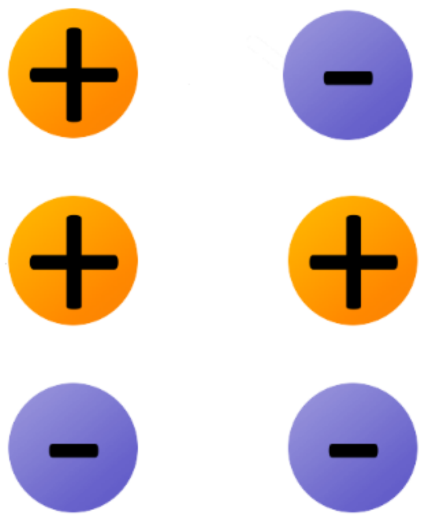
Temporary magnet	A magnet that loses its magnetism easily; e.g. iron.
Tesla (T)	The unit of magnetic field strength.
Transformer	A device that changes the voltage of an alternating current using two coils on an iron core.
Voltmeter	An instrument used to measure potential difference, connected in parallel.

Lesson 1
What is everything made of?

Part 1 — Atoms and Charge

Information

All matter consists of atoms.	1
Atoms contain three types of smaller particles: protons, neutrons and electrons.	2
Protons are positively charged. Electrons are negatively charged. Neutrons have no charge.	3
Objects that are charged can affect other charged objects using the non-contact force of electrostatic charge.	4
When two objects have the same charge (both positive or both negative), they will **repel** one another.	5
If the objects are of opposite charge, they will **attract** each other.	6
Generally, the atom has a neutral charge as it has an equal number of protons and electrons.	7
If an atom loses an electron it becomes positively charged. If it gains an electron it becomes negatively charged.	8
Charged atoms are called **ions**.	9



Electrostatic forces: opposite charges attract, like charges repel

Questions

Q1. Which particles inside the atom are charged?

Q2. What is the overall charge of an atom? What does it become if it gains or loses electrons?

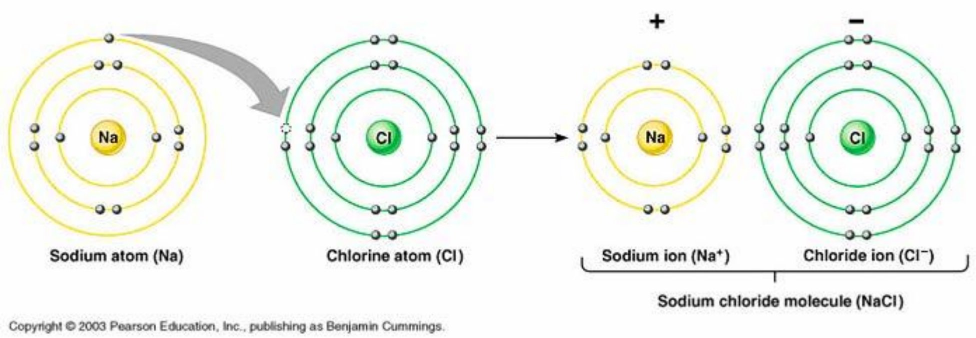
Q3. State the rule about electrostatic forces between two objects that have the same charge.

Q4. State the rule about electrostatic forces between two objects that have opposite charges.

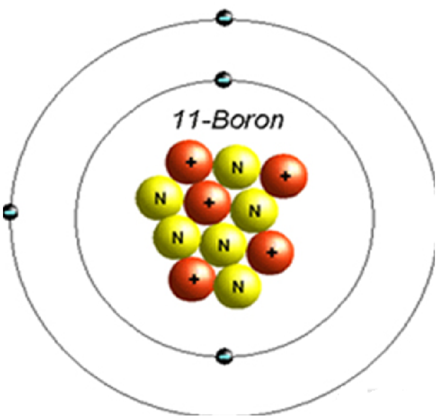
Part 2 — Electrons, Ionisation and Materials

Information

Protons and electrons are usually found gathered together in atoms, which in turn make up objects and materials.	1
Protons and neutrons are held at the centre of the atom in the **nucleus** — it is not easy to change their number.	2
Electrons are on the outside of atoms in electron shells, making it possible for a small number to be removed or added.	3
When two materials are rubbed together, friction causes one material to lose electrons and the other to gain electrons.	4
If a material loses electrons, it becomes **positively** charged overall.	5
If a material gains electrons, it becomes **negatively** charged overall.	6
This process of gaining or losing electrons is called **ionisation**.	7
Write down the overall charge of an object with 5 protons, 5 neutrons and 4 electrons, and explain your reasoning.	8



Ionisation: sodium and chlorine atoms gaining and losing electrons



Atomic structure: protons, neutrons and electrons (Boron atom)

Questions

Q1. Where are protons and electrons usually found instead of being on their own?

Q2. Which parts of the atom are harder to remove, and which are easier to remove? Why?

Q3. What happens to the charge of an atom when electrons are removed? When electrons are added?

Q4. An object has 5 protons, 5 neutrons and 4 electrons. What is its overall charge? Explain your answer.

Part 3 — Measuring Charge and Induced Charge

Information

When we describe how positive or negative an object is overall, we say we want to know its **charge**.	1
We could measure charge by counting electrons, but the charge on each electron is extremely small.	2
Instead, we measure charge in **Coulombs (C)**. One Coulomb equals approximately 6.2 billion billion electrons.	3
Typical charges: a charged rod 7×10^{-9} C; a simple circuit carries 1 C per second; a phone battery holds about 7,200 C.	4
Sometimes an object can appear charged even when no electrons have been added or removed — this is **induced charge**.	5
A positively charged object attracts electrons to the nearby surface of an uncharged object.	6
A negatively charged object repels electrons away from the nearby surface of an uncharged object.	7
When electrons have been attracted to or repelled from a surface, we say the uncharged object has an induced charge.	8

Questions

Q1. What do we mean by the term "charge"?

Q2. Why do we not measure charge by counting the number of electrons?

Q3. What is the unit of charge that we use?

Q4. What is meant by the term "induced charge"?

Exam-Style Questions

Exam Q1. State the overall charge of an atom. Explain why. [2 marks]

Exam Q2. An atom gains two electrons. What charge does it now have? Explain your answer. [2 marks]

Exam Q3. Describe what is meant by "induced charge" and explain how it occurs. [3 marks]

Exam Q4. Why are charged atoms called ions? [1 mark]

Lesson 2
What makes a material an insulator or a conductor?

Part 1 — Electric Fields

Information

All charged objects have an **electric field** around them, which shows how they will interact with other charged particles. 1

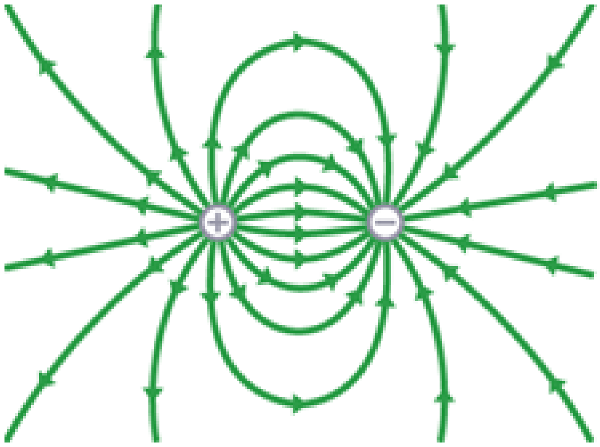
An electric field is a region where charges experience a force. 2

Electric fields are shown as diagrams with arrows — the direction of the arrow shows the direction in which a positive charge would move. 3

The closer together the arrows are, the stronger the field and the greater the force experienced by charges in that field. 4

This means the field is stronger closer to the charged object. 5

An electric field exists between an electron and a proton, with the arrows pointing from positive to negative. 6



Electric field between a proton (+) and an electron (–)

Questions

Q1. What is an electric field?

Q2. What does the direction of the arrow in an electric field diagram show?

Q3. How would you show a stronger field in a field diagram?

Part 2 — Conductors, Insulators and Semiconductors

Information

An **electrical conductor** is a material that allows the flow of charge (electrical current) to move through it. 1

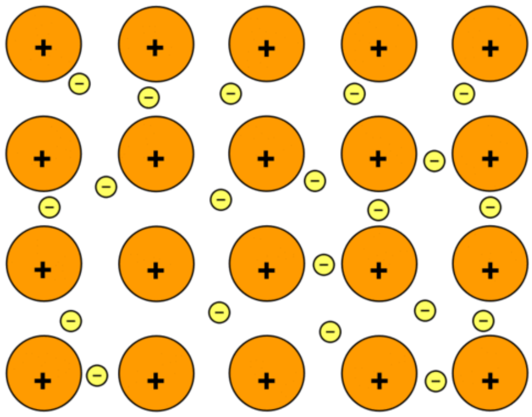
An **electrical insulator** is a material that does not allow the flow of charge (electrical current) to move through it. 2

A **semiconductor** is a material that conducts current only partly — its ability to allow charge flow is between that of an insulator and a conductor. 3

Metals are a special case — metals have delocalised electrons (electrons that are spread throughout the metal and can move freely), which is why metals can all conduct electricity. 4

The more a material is an insulator, the higher its resistance to the flow of electrical current. 5

Examples of conductors: copper, iron, graphite, salt water. Examples of insulators: rubber, plastic, wood, glass. 6



Metal structure: positive ions surrounded by delocalised electrons

Questions

Q1. What is an electrical conductor? Give two examples.

Q2. What is an electrical insulator? Give two examples.

Q3. What is a semiconductor? How is it different from a conductor?

Q4. Why can metals conduct electricity? What is special about their electrons?

Part 3 — Testing Materials for Conductivity

Information

We can test whether a material is a conductor or an insulator by placing it in a simple circuit with a bulb. 1

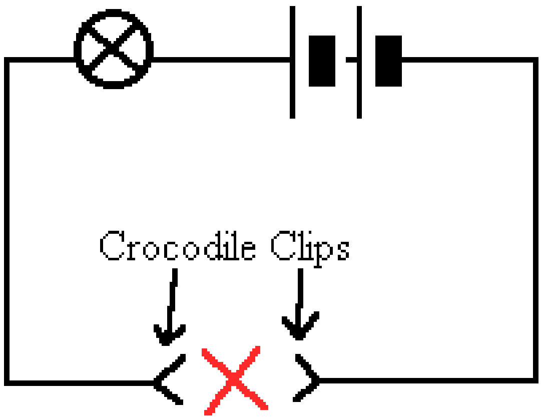
If the bulb lights brightly, the material is a good conductor. If it does not light at all, the material is an insulator. 2

The order from most conductive to most insulating depends on how brightly the bulb glows. 3

The resistance of a material describes how much it opposes the flow of electrical current. 4

High resistance = insulator; low resistance = conductor. 5

We can rank materials in order of conductivity based on the brightness of a bulb in a test circuit. 6



Testing circuit: material placed between crocodile clips

Questions

Q1. Describe how you would test whether a material is a conductor or insulator using a simple circuit.

Q2. What observation tells you a material is a good conductor in this test?

Q3. What observation tells you a material is an insulator?

Q4. Why should you not touch a light switch with wet hands?

Exam-Style Questions

Exam Q1. What is the difference between an electrical conductor and an electrical insulator? [2 marks]

Exam Q2. Explain why metals are good conductors of electricity in terms of their electrons. [3 marks]

Exam Q3. What is a semiconductor? Give one example. [2 marks]

Exam Q4. Describe the electric field around a positively charged sphere. What would the field diagram look like? [2 marks]

Lesson 3
What causes an object to gain static charge?

Part 1 — Building Up Static Charge

Information

When two **insulating** materials are rubbed together, **friction** causes electrons to be transferred from one material to the other.	1
The material that **loses** electrons becomes **positively** charged overall.	2
The material that **gains** electrons becomes **negatively** charged overall.	3
This build-up of charge on an object that cannot easily conduct is called **static charge**.	4
Static charge cannot easily flow away because insulators do not allow electrons to move freely.	5
Examples include rubbing a plastic rod with a cloth, or shuffling across a carpet in socks.	6

Questions

Q1. What causes static charge to build up when two insulating materials are rubbed together?

Q2. Which material becomes positively charged — the one that gains or the one that loses electrons?

Q3. Why does static charge build up in insulators rather than conductors?

Part 2 — Discharge and Earthing

Information

If a charged insulating material is brought close to a **conducting** material (such as a metal), **earthing** (discharge) can take place.	1
For a positively charged material: electrons jump **from** the conducting material **to** the positively charged insulator.	2
For a negatively charged material: electrons jump **from** the negatively charged insulator **to** the conducting material.	3
As a result, the material that was charged becomes neutral — it has no overall charge.	4
This is called **earthing** or **discharge**.	5
A static electric shock occurs when charge suddenly moves from a charged object to a person (or from a person to an object) through the air or by contact.	6

Questions

Q1. What happens when a charged insulating material is brought near a conducting material?

Q2. Describe what happens to a negatively charged rod when it is brought near a conductor and earthing takes place.

Q3. What is "earthing"?

Part 3 — The Coulomb and Effects of Static Charge

Information

Charge is measured in **Coulombs (C)**.	1
When a rod is rubbed with a cloth, approximately 6.2 billion electrons are transferred — this is about 7×10^{-9} C.	2
In a simple circuit with a lightbulb, about 6.2 billion billion electrons move around each second — this is 1 C.	3
A charged rod can attract small, uncharged pieces of paper because of **induced charge**.	4
A charged balloon can stick to a wall for the same reason.	5
Charged objects can also deflect a thin stream of water — the water molecules are attracted towards the charged rod.	6

Questions

Q1. What is the unit of charge?

Q2. How can a charged rod attract small pieces of paper even though the paper has no charge?

Q3. Describe two observations you might make when a charged rod is held near a stream of water.

Exam-Style Questions

Exam Q1. Describe how static charge builds up when a plastic rod is rubbed with a cloth. [3 marks]

Exam Q2. A negatively charged rod is touched onto a piece of aluminium foil. Explain what happens to the charge on the rod. [3 marks]

Exam Q3. Explain why rubbing a balloon and placing it against a wall makes the balloon stick. [3 marks]

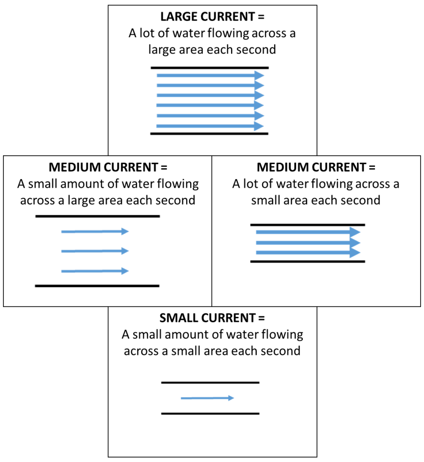
Exam Q4. State two differences between static charge and the charge in an electrical circuit. [2 marks]

Lesson 4
What is electric current?

Part 1 — Understanding Current

Information

Electric current is the amount of charge (from charged particles) flowing past a given point each second.	1
We can compare current in a wire to current in a river — in a river, current is the amount of water flowing past a point each second.	2
In a wire, current is the amount of **charge** flowing past a point each second.	3
The size of the current depends on the **amount of charge** and the **time** it takes to flow.	4
A large amount of charge flowing each second = a large current. A small amount = a small current.	5
Current is measured in **Amperes** (shortened to **A**).	6
We measure current using an **ammeter**, which must be placed **in series** (in the main loop of the circuit).	7



Current analogy: large/medium/small current compared to water flow

Questions

Q1. What is electric current?

Q2. How is current in a river similar to current in an electrical circuit?

Q3. What two factors affect how large the current is?

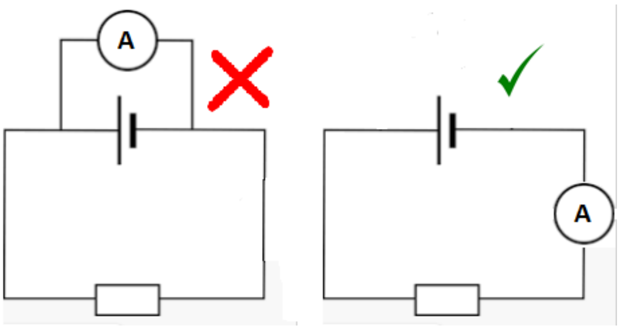
Q4. What instrument is used to measure current? How must it be connected?

Part 2 — Calculating Current

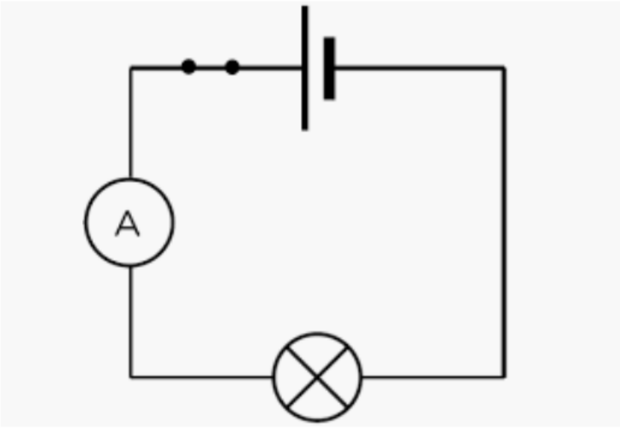
Information

Current can be calculated using the equation:	1
Current (A) = Charge (C) ÷ Time (s)	2
In symbols: $\mathbf{I = Q / t}$ where I = current (A), Q = charge (C), t = time (s)	3
Rearranging: $Q = I \times t$ and $t = Q / I$	4

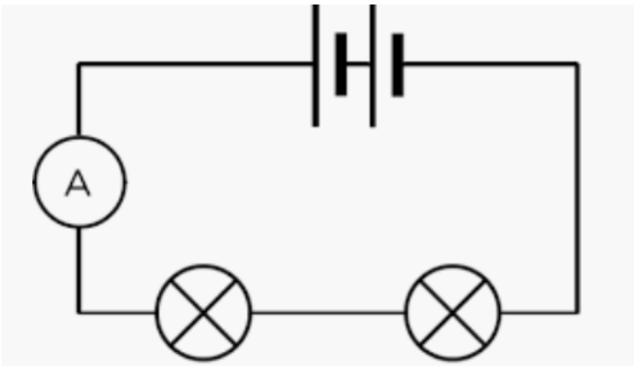
Example: If 100 C of charge flows past a point in 50 s, the current = 100/50 = **2 A**.	5
Example: Lightning — 4,000 C in 0.2 s gives a current of 4000/0.2 = **20,000 A**.	6
As more components are added to a series circuit, the current **decreases** because there is more resistance.	7



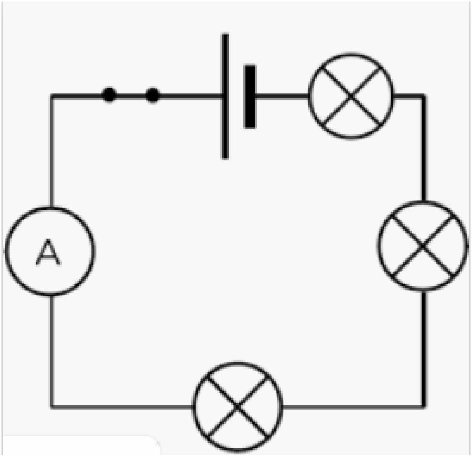
Ammeter: correct (series) vs incorrect (parallel)



Series circuit with cell, ammeter and bulb



Two-bulb series circuit



Three-bulb series circuit

Questions

Q1. Write the equation used to calculate current, including units.

Q2. What is the current when 100 C of charge flows past a point in 50 seconds?

Q3. What is the current if 1500 C flows down a wire in 30 s?

Q4. Calculate the current of a toaster when 12,000 C of charge flows through it in 2 minutes (120 s).

Q5. Calculate the current of a hairdryer when 6,000 C flows through it in 30 seconds.

Part 3 — More Current Calculations and Circuit Observations

Information

As you add more bulbs to a series circuit, the ammeter reading goes **down** — more components means more resistance.	1
When more cells are added to a series circuit, the ammeter reading goes **up**.	2
Practice using the equation I = Q/t for a range of situations:	3

Calculate current of a fridge: in 5 minutes (300 s), 150,000 C flows through it.	4
In 30 seconds, 24 C flows through a battery.	5
Remember to convert minutes to seconds when needed: 1 minute = 60 seconds.	6
Always check units: Charge in Coulombs (C), Time in seconds (s), Current in Amperes (A).	7

Questions

Q1. Calculate the current of a fridge when 150,000 C of charge flows through it in 5 minutes (300 s).

Q2. In 30 seconds, 24 C of charge flows through a battery. Calculate the current in the battery.

Q3. Calculate the current of a very powerful lightning bolt if 20,000 C of charge flows to the ground in 0.01 s.

Q4. As you add more bulbs to a series circuit, what happens to the current? Suggest why.

Exam-Style Questions

Exam Q1. Define electric current. [1 mark]

Exam Q2. Write the equation for current and state the units of each quantity. [2 marks]

Exam Q3. A student collects data showing 60 C of charge flows past a point in 30 seconds. Calculate the current. Show your working. [2 marks]

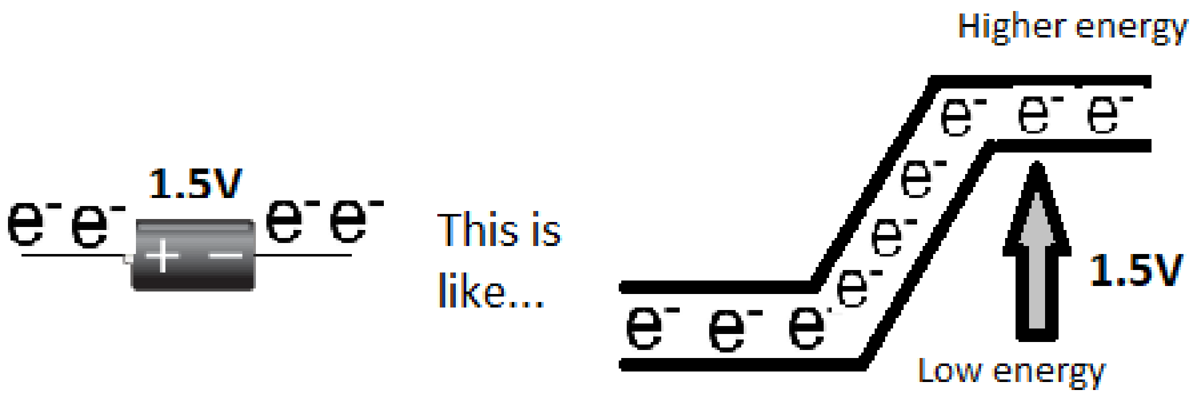
Exam Q4. Explain why an ammeter must be connected in series in a circuit. [2 marks]

Lesson 5
What is potential difference and how do we build circuits?

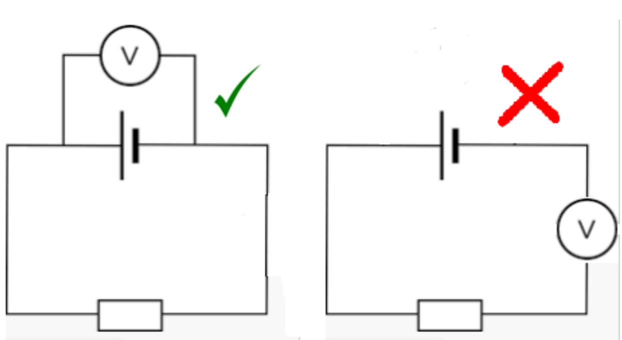
Part 1 — Energy in Circuits and Potential Difference

Information

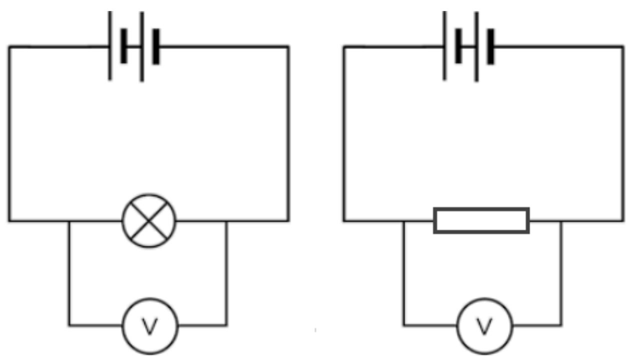
Energy is something that can be stored and used to make changes happen. In circuits, chemical energy in a cell gives electrons kinetic energy.	1
Potential Difference (PD), also known as **voltage**, is the difference in energy *per coulomb of charge* between two points.	2
Potential difference is measured in **Volts (V)**.	3
A cell **increases** the energy of charges flowing through it — we say it provides a positive potential difference.	4
A bulb or resistor **decreases** the energy of charges — the potential difference across it is negative (energy is transferred out).	5
Potential difference = Energy transferred / Charge: **V = E / Q**	6
We measure PD using a **voltmeter** connected **in parallel** — across the component.	7



Cell as energy source: electrons gain energy moving from – to +



Voltmeter: correct (parallel) vs incorrect (series)



Voltmeter across a bulb and across a resistor

Questions

Q1. What is potential difference (voltage)?

Q2. What are the units of potential difference?

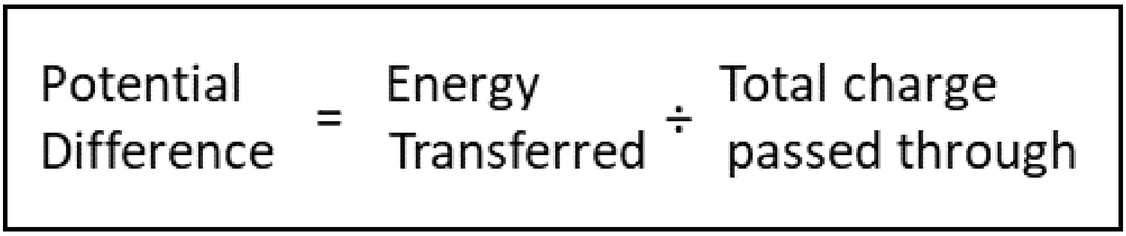
Q3. How should a voltmeter be connected? What is this connection type called?

Q4. What is another name for potential difference?

Part 2 — Calculating Potential Difference

Information

Potential difference can be calculated using: **V = E / Q**	1
where V = potential difference (V), E = energy transferred (J), Q = charge (C)	2
Rearranging: E = V × Q and Q = E / V	3
Example: AA battery — 12 J transferred to 4 C of charge V = 12/4 = **3 V**.	4
Example: Car battery — 6000 J transferred to 500 C V = 6000/500 = **12 V**.	5
Example: Mains electricity — 230 V across a plug socket.	6
The higher the potential difference, the more energy each coulomb of charge receives.	7



Potential Difference = Energy Transferred ÷ Total charge passed through

Questions

Q1. Write the equation for potential difference. State the units for each quantity.

Q2. Calculate the potential difference when 10 J of energy are transferred to 2 C of charge.

Q3. Calculate the potential difference if 100 C of charge passes through a cell that provides 50 J of energy.

Q4. Calculate the potential difference if 12 J of energy is transferred from a battery when 600 C of charge passes through.

Q5. Extension: There is a PD of 3.6 V across a battery. Calculate the energy transferred when 60 C flows through it. Use: E = Q × V

Part 3 — Building Circuits

Information

Circuit diagrams use standard symbols to represent components — always use these symbols when drawing circuits.	1
To build a circuit: (1) place components from the main loop first; (2) connect wires correctly; (3) add any additional loops (e.g. voltmeter in parallel).	2
A circuit must form a complete, closed loop for current to flow.	3
Components include: cell, battery (multiple cells), bulb, resistor, variable resistor, ammeter, voltmeter, buzzer, switch.	4
An ammeter is placed **in series**; a voltmeter is placed **in parallel**.	5

As more cells are added to a series circuit, the potential difference increases and so does the current.	6

Questions

Q1. What is the first step when building a series circuit?

Q2. How is an ammeter connected in a circuit? How is a voltmeter connected?

Q3. Draw the circuit symbols for: a cell, a bulb, a resistor, a voltmeter, and an ammeter.

Q4. As more cells are added to a series circuit, what happens to the potential difference? What effect does this have on the current?

Exam-Style Questions

Exam Q1. Define potential difference. [1 mark]

Exam Q2. State the equation for potential difference and the units of each quantity. [2 marks]

Exam Q3. A battery transfers 165 J of energy to 0.5 C of charge. Calculate the potential difference of the battery. [2 marks]

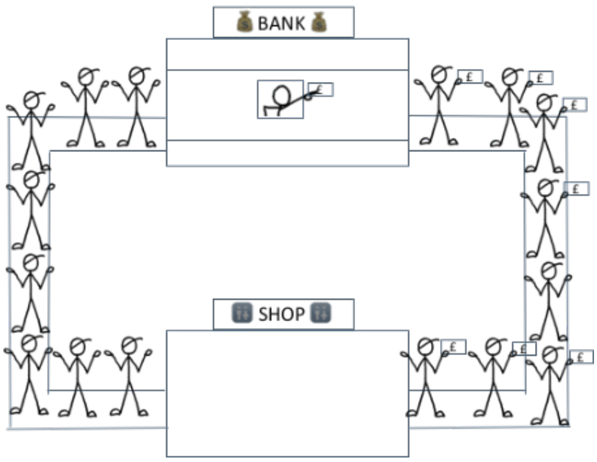
Exam Q4. Explain why a voltmeter is connected in parallel rather than in series. [2 marks]

Lesson 6
How can models help us understand circuits?

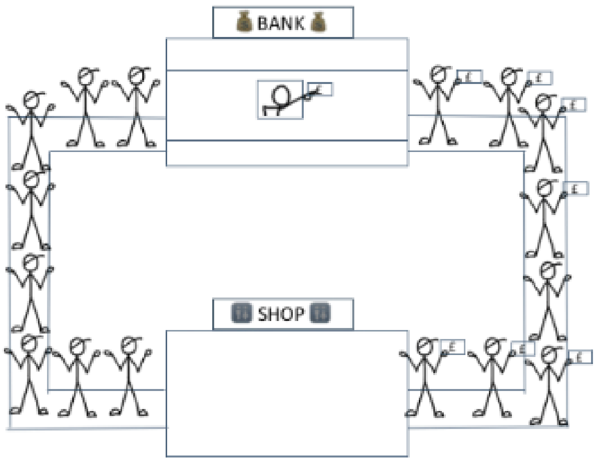
Part 1 — The Rope Model

Information

Scientists use **models** to explain things that are difficult to observe directly.	1
In the **rope model**, a loop of rope is used to represent an electrical circuit.	2
The rope represents the electrons flowing around the circuit.	3
The person pulling the rope represents the cell (energy source).	4
The person gripping the rope (acting as a bulb) represents a component that transfers energy.	5
Pulling the rope harder (more force) represents a higher voltage — the rope moves faster and the hands of the "bulb" person get warmer.	6
Pulling with less force represents a lower voltage — the rope moves more slowly and less heat is produced.	7
A weakness of the model: rope is continuous, while electrons are discrete particles. The rope model also cannot show branching (parallel circuits).	8



Rope model: 1 cell + 1 bulb (series)



Shopaholic model: 1 bank + 1 shop (series)

Questions

Q1. In the rope model, what does the rope represent? What does the person pulling represent?

Q2. What happens to the speed of the rope when the pulling force increases? What does this represent in a circuit?

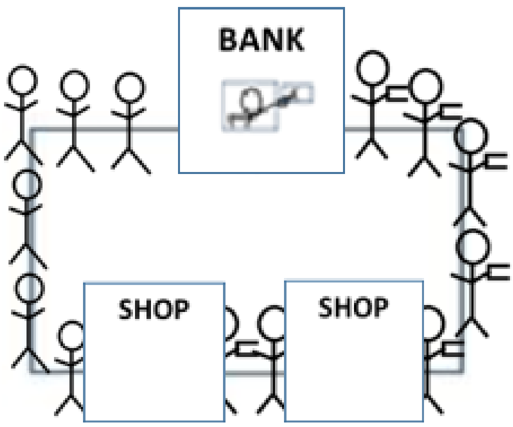
Q3. Write down one strength and one weakness of the rope model.

Part 2 — The Shopaholic Model

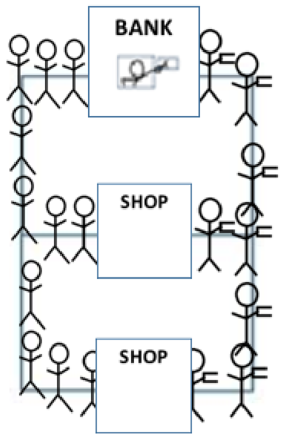
Information

In the **shopaholic model**, shoppers walking around shops represent electrons moving around a circuit.	1
The bank represents the cell — it gives out money (energy) to the shoppers (electrons).	2
The shops represent components (bulbs/resistors) — they receive money (energy) from the shoppers.	3

When the bank gives out more money: shoppers move faster (higher current), and shops receive more money each second (more power transferred).	4
When a shop has more items to sell (more resistance): shoppers slow down (lower current), and less money is received per second.	5
One bank, two shops in series = one cell, two bulbs in series.	6
One bank, two shops on separate paths = one cell, two bulbs in parallel.	7



Shopaholic: 1 bank + 2 shops in series



Shopaholic: 1 bank + 2 shops in parallel

Questions

Q1. In the shopaholic model, what does the bank represent? What do the shoppers represent?

Q2. What happens to the current (speed of shoppers) when the bank gives out more money?

Q3. What happens to the current when a shop has more items to sell (more resistance)?

Q4. Draw circuit diagrams for: (a) 1 bank cashier + 1 shop, (b) 1 bank cashier + 2 shops in series, (c) 1 bank cashier + 2 shops in parallel.

Part 3 — Evaluating Models

Information

No model is perfect — all models have strengths (things they explain well) and limitations (things they get wrong).	1
Both the rope and shopaholic models show that energy is transferred from source to component.	2
Both models show that more resistance leads to less current.	3
The shopaholic model works better for parallel circuits — shoppers can take different paths (different shops in separate branches).	4
Neither model shows that electrons carry charge or that the charge is what transfers energy.	5
Real electrons carry negative charge; in circuit diagrams, conventional current flows from + to –, which is *opposite* to electron flow.	6

Questions

Q1. Give two things that the shopaholic model shows correctly about electrical circuits.

Q2. Give two things about electricity that the shopaholic model does NOT correctly represent.

Q3. Why is the shopaholic model better than the rope model for representing parallel circuits?

Exam-Style Questions

Exam Q1. Describe the shopaholic model of a circuit. What does each part represent? [3 marks]

Exam Q2. Suggest one limitation of the rope model of an electric circuit. [1 mark]

Exam Q3. In the shopaholic model, what happens to the "shoppers" when a second shop is added in series? What does this tell us about the circuit? [2 marks]

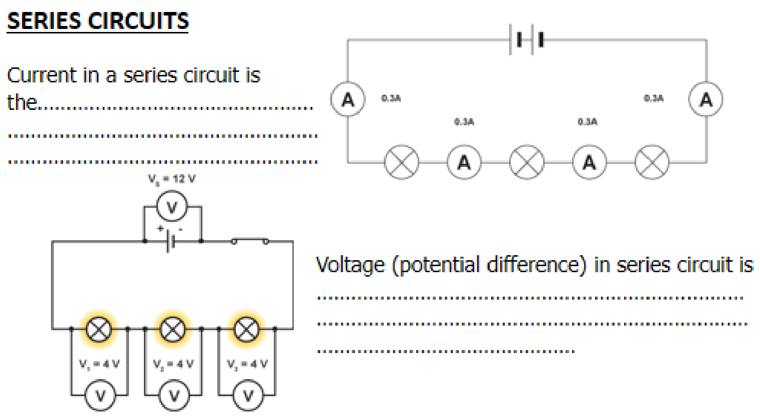
Lesson 7

The Four Circuit Rules

Part 1 — Series Circuits — Current and Voltage

Information

In a **series circuit**, electrical components are connected one after another in a single loop.	1
An electron passes through **every** component on its way round the circuit.	2
If one component fails (e.g. a bulb goes out), the circuit is broken and current cannot flow anywhere.	3
Rule 1 — Current in series: The current is the **same** everywhere in a series circuit. An ammeter reads the same value wherever it is placed.	4
Rule 2 — Voltage in series: The potential differences across the components **add up** to the total PD supplied by the cell(s).	5
This is because energy must be conserved — all the energy given by the cell is shared among the components.	6



Series circuits: fill in the current and voltage values

Questions

Q1. In a series circuit, what happens to the current if one bulb breaks?

Q2. State the rule for current in a series circuit.

Q3. State the rule for potential difference in a series circuit.

Q4. A series circuit has a 6 V cell and three equal bulbs. What is the potential difference across each bulb?

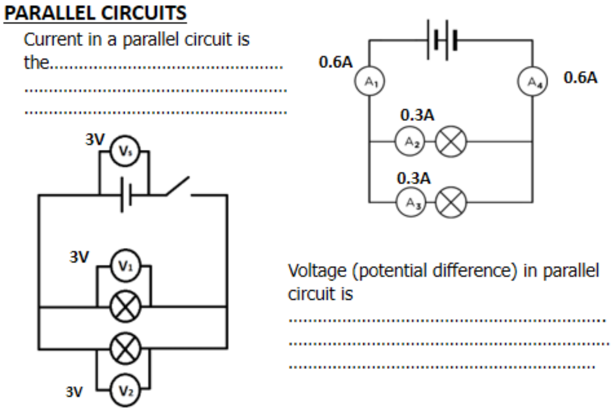
Part 2 — Parallel Circuits — Current and Voltage

Information

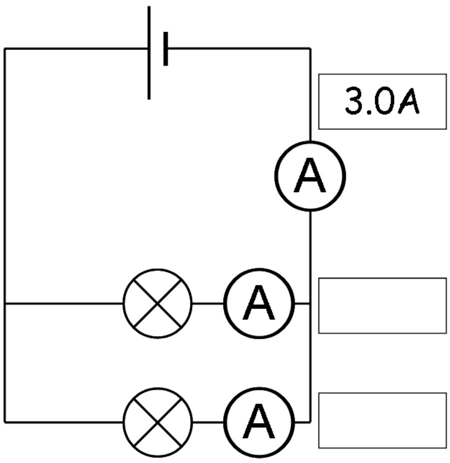
In a **parallel circuit**, electrical components are connected alongside one another, forming extra loops.	1
An electron passes through **only one** of the parallel components on its way round the circuit.	2
If one branch fails, current can still flow through the other branches — other components remain on.	3
Rule 3 — Current in parallel: The current from the cell **splits** between the parallel branches. The total current from the cell = sum of currents in each branch.	4

Rule 4 — Voltage in parallel: The potential difference is the **same** across each parallel branch, and equal to the PD of the cell. 5

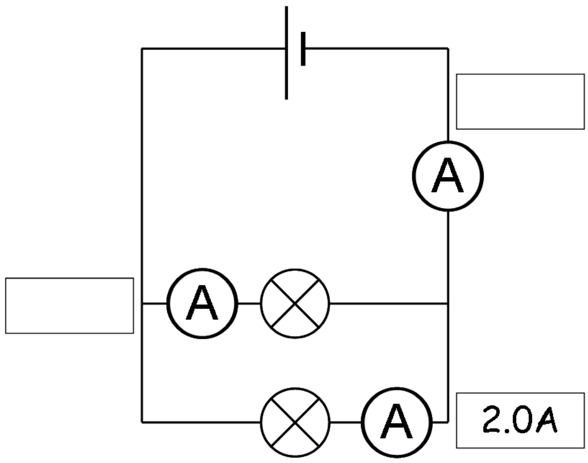
This is because the energy per coulomb along each parallel path is the same. 6



Parallel circuits: fill in the current and voltage values



Parallel circuit: 3.0 A splits between branches



Parallel circuit: 2.0 A total current

Questions

Q1. In a parallel circuit, what happens if one bulb breaks?

Q2. State the rule for current in a parallel circuit.

Q3. State the rule for potential difference in a parallel circuit.

Q4. Why does the total current from the cell increase when more bulbs are added in parallel?

Part 3 — Applying the Four Rules

Information

The four rules are: (1) current same in series; (2) voltage splits in series; (3) current splits in parallel; (4) voltage same in parallel. 1

In a series circuit: total voltage $= V_1 + V_2 + V_3$; current I is the same everywhere. 2

In a parallel circuit: voltage V is the same across each branch; total current $I = I_1 + I_2$. 3

Adding more bulbs in series: current decreases (more resistance), each bulb gets less voltage. 4

Adding more bulbs in parallel: current increases (more paths), each bulb still gets full voltage. 5

A voltmeter reads zero if connected across a wire (no resistance, no energy transferred).	6

Questions

Q1. A series circuit has a 12 V cell with two bulbs. Bulb A has 4 V across it. What is the voltage across bulb B?

Q2. A parallel circuit has a 6 V cell with two branches. Branch 1 carries 0.5 A and branch 2 carries 0.3 A. What is the total current from the cell?

Q3. Explain why a voltmeter reads zero when connected across a piece of wire.

Q4. Explain why Christmas tree lights connected in series all go out when one bulb breaks, but lights connected in parallel do not.

Exam-Style Questions

Exam Q1. State the rule for current in a series circuit. **[1 mark]**

Exam Q2. State the rule for potential difference in a parallel circuit. **[1 mark]**

Exam Q3. A series circuit contains a 9 V cell and three components with potential differences of 2 V, 3 V and x V. Calculate x. **[2 marks]**

Exam Q4. Explain why, when more bulbs are added in parallel, the total current from the cell increases but the voltage across each bulb stays the same. **[4 marks]**

Lesson 8

How do current and potential difference change in circuits?

Part 1 — Investigating Series Circuits

Information

In a series circuit, the ammeter reads the same wherever it is placed — this confirms that the current is the same throughout.	1
The voltmeter reads the same across the cell and across a single component (if there is only one) — all the PD is used by the component.	2
The voltmeter reads **zero** across a plain wire — no energy is transferred there.	3
Adding more **cells** in series increases the total PD, which increases the current.	4
Adding more **bulbs** in series decreases the current (more resistance), and each bulb gets a smaller share of the total voltage.	5
These relationships confirm Rules 1 and 2 of circuits.	6

Questions

Q1. What conclusion can you draw from the fact that the ammeter reads the same wherever it is placed in a series circuit?

Q2. As more cells are added to a series circuit, what happens to (a) the ammeter reading and (b) the voltmeter reading across a single cell?

Q3. As more bulbs are added to a series circuit, what happens to the voltmeter reading across a single bulb? Explain why.

Part 2 — Investigating Parallel Circuits

Information

As more bulbs are added **in parallel**, the **ammeter** reading in the main circuit goes **up** — each new branch draws extra current.	1
The voltmeter reading across a single bulb in parallel **stays the same** — each branch receives the full cell PD.	2
This confirms Rules 3 and 4 of circuits.	3
The total current from the cell = sum of the individual branch currents.	4
Adding bulbs in parallel does **not** share the voltage, but it does share (add up) the current.	5
This is why parallel wiring is used in homes — each appliance receives the full mains voltage.	6

Questions

Q1. As more bulbs are added in parallel, what happens to the ammeter reading in the main circuit? Why?

Q2. As more bulbs are added in parallel, what happens to the voltmeter reading across a single cell? Why?

Q3. Why is parallel wiring used for household circuits?

Part 3 — Explaining Circuit Observations

Information

Conclusion 1: Ammeter reads the same everywhere in a series circuit current is the same throughout a series circuit.	1
Conclusion 2: Voltmeter reads zero across a wire wire has no resistance, so no energy is transferred.	2
Conclusion 3: More cells in series more PD more current.	3
Conclusion 4: More cells higher voltmeter reading across each cell.	4
Conclusion 5: More bulbs in series more resistance less current.	5
Conclusion 6: More bulbs in series PD is split more ways each bulb gets a smaller share.	6
Conclusion 7: More bulbs in parallel more current from cell.	7
Conclusion 8: More bulbs in parallel voltmeter across cell unchanged.	8

Questions

Q1. Explain conclusion 5: "As you add more bulbs to a series circuit, the ammeter reading goes down."

Q2. Explain conclusion 7: "As you add more bulbs in parallel, the ammeter reading goes up."

Q3. Explain conclusion 8: "As you add more bulbs in parallel, the voltmeter reading across the cell stays the same."

Exam-Style Questions

Exam Q1. Explain why, as more bulbs are added in series, the ammeter reading decreases but the voltmeter reading across each individual bulb also decreases. [4 marks]

Exam Q2. A student adds a second identical bulb in parallel to a circuit. Explain what happens to (a) the total current and (b) the voltage across each bulb. [4 marks]

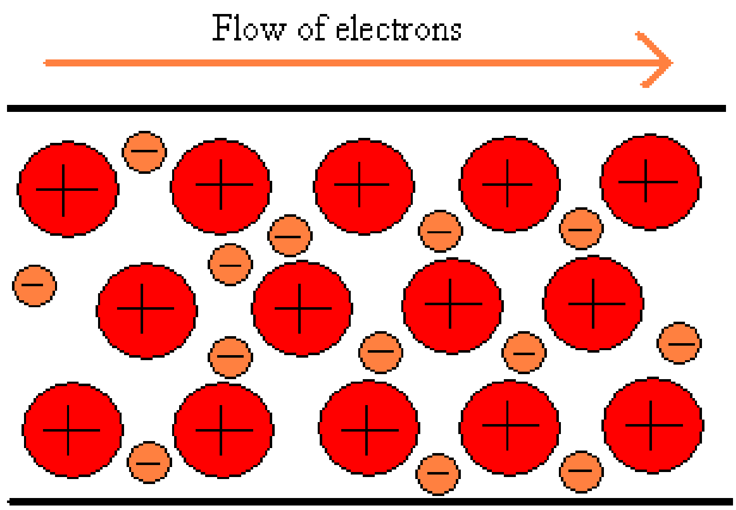
Exam Q3. Why does a voltmeter read zero when placed across a connecting wire? [2 marks]

Lesson 9
How do we calculate the resistance of something in a circuit?

Part 1 — What is Resistance?

Information

Resistance is the degree to which a component opposes the flow of electric current.	1
Resistance is caused by electrons colliding with ions in a conductor as they move through it.	2
The more collisions, the harder it is for current to flow, and the greater the resistance.	3
The resistance of a wire **increases** as its **length increases** (more ions to collide with).	4
The resistance of a wire **increases** as its **thickness (cross-sectional area) decreases** (fewer paths for electrons).	5
If PD is **high** and current is **low**, resistance must be **high**.	6
If PD is **low** and current is **high**, resistance must be **low**.	7
Resistance is measured in **Ohms ()**.	8



Electrons flowing through a conductor: collisions cause resistance

Questions

Q1. What is resistance?

Q2. What causes resistance in a wire?

Q3. How does the length of a wire affect its resistance?

Q4. How does the thickness of a wire affect its resistance?

Part 2 — Calculating Resistance

Information

Resistance can be calculated using Ohm's Law:	1
Resistance () = Potential Difference (V) ÷ Current (A)	2

In symbols: **R = V / I** where R = resistance (), V = potential difference (V), I = current (A)	3
Rearranging: V = I × R and I = V / R	4
Example: Lightbulb with 2 V across it and 0.2 A through it R = 2/0.2 = **10** .	5
Example: Metal ruler with 0.012 V and 1000 A R = 0.012/1000 = **0.000012** (very low — it is a conductor).	6
Example: Wet pencil wood with 10 V and 0.002 A R = 10/0.002 = **5000** (high — it is an insulator).	7

Questions

Q1. Write the equation for resistance. State the units of each quantity.

Q2. What is the resistance of a lightbulb if it is provided with 12 V and the current through it is 1.2 A?

Q3. What is the resistance of a resistor if there is a PD of 3.0 V across it and a current of 0.02 A through it?

Q4. What is the resistance of a resistor with 25 V across it and 0.25 A through it?

Part 3 — Resistance in Context

Information

Components with high resistance (like bulbs and resistors) reduce the current in a circuit.	1
Components with very low resistance (like wires) allow current to flow freely.	2
We can find resistance by measuring the PD across a component and the current through it, then using R = V/I.	3
Adding a resistor in series with a circuit reduces the current for a given PD.	4
Changing resistance changes the brightness of a bulb — higher resistance means less current and a dimmer bulb.	5
A **variable resistor** allows the resistance to be adjusted, which in turn controls the current.	6

Questions

Q1. A lead pencil has a PD of 3 V across it and a current of 0.1 A. Calculate its resistance.

Q2. If a piece of wet wood has a resistance of 5000 and a PD of 10 V across it, what current flows through it?

Q3. Explain how a variable resistor can be used to control the brightness of a bulb.

Exam-Style Questions

Exam Q1. State the equation for resistance and the units of each quantity. [2 marks]

Exam Q2. A resistor has a potential difference of 12 V across it and a current of 0.3 A through it. Calculate the resistance. [2 marks]

Exam Q3. Explain in terms of electrons and ions why the resistance of a long wire is greater than the resistance of a short wire of the same material. [3 marks]

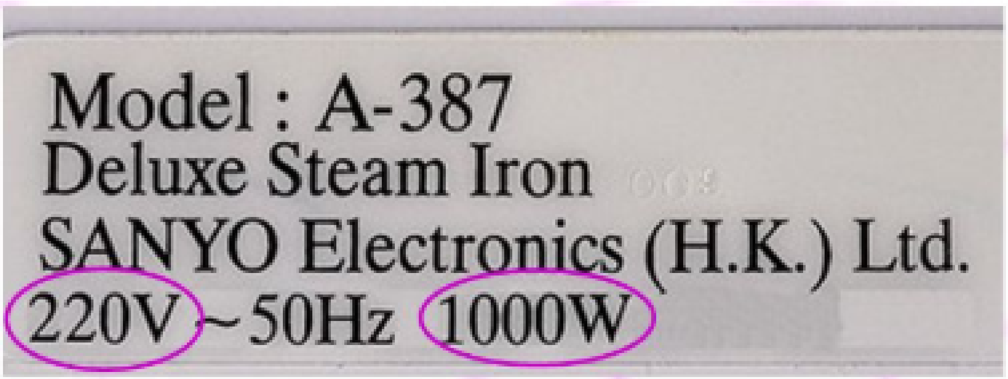
Exam Q4. Explain how you would use an ammeter and voltmeter to determine the resistance of a component. [3 marks]

Lesson 10
How much energy is transferred each second in a circuit?

Part 1 — What is Power?

Information

Power is the amount of energy transferred **per second**.	1
Power is measured in **Watts (W)**. 1 W = 1 J of energy transferred per second.	2
We can find out how quickly a device uses energy from its **power rating** (shown on the label).	3
A 1000 W iron uses 1000 J of energy every second.	4
Power can be calculated from energy and time: **P = E / t**	5
where P = power (W), E = energy transferred (J), t = time (s).	6
Examples: Fridge (200 W), Large Bulb (36 W), Microwave (800 W), Tumble-dryer (3000 W).	7



Power rating label: 1000 W iron uses 1000 J every second

10 W vs 60 W bulb: higher power rating uses more energy per second

Questions

Q1. What is power?

Q2. What are the units of power?

Q3. Write the equation for power in terms of energy and time.

Q4. Which appliance has the highest power rating: fridge (200 W), microwave (800 W), or tumble-dryer (3000 W)?

Part 2 — Calculating Power

Information

Two equations for power in electrical circuits:	1
P = E / t (energy divided by time)	2
P = I × V (current multiplied by potential difference)	3
Both give power in Watts (W).	4
P = I × V is useful when you know the current and voltage of a component but not the energy directly.	5
Example: Fridge — 1 A at 200 V P = 1 × 200 = 200 W.	6
Example: Kettle — 10 A at 230 V P = 10 × 230 = 2300 W.	7
Choose the equation based on which quantities you have been given.	8

Questions

Q1. Write both equations for electrical power.

Q2. If Sophie uses a hairdryer for 20 s and it uses 2000 J of energy, what is its power?

Q3. A kettle draws 10 A of current and is connected to a 230 V supply. What is its power?

Q4. A hairdryer uses a 100 V source and 10 A flows through it. How much power is it using?

Q5. Helen has a kettle that uses 4 J of energy and takes 5 minutes (300 s) to boil. What is the power?

Part 3 — More Power Calculations

Information

Power = Energy / Time and Power = Current × Potential Difference.	1
To decide which equation to use, look at which quantities you are given.	2
If you know energy (J) and time (s), use P = E/t.	3
If you know current (A) and potential difference (V), use P = I × V.	4
Remember to convert minutes to seconds: 1 minute = 60 seconds.	5
A higher power rating means more energy is used per second — more expensive to run.	6
The most expensive appliance to run is the one with the highest power rating.	7

Questions

Q1. A microwave uses 4,800 J of energy in 60 s. Calculate its power rating.

Q2. Ed charges his phone using a 40 V source with 4 A flowing through it. What is the power?

Q3. A large bulb uses 72 J in 2 s. Calculate its power rating.

Q4. Which is more expensive to run: a 800 W microwave or a 3000 W tumble-dryer? Explain.

Exam-Style Questions

Exam Q1. State two equations for electrical power, giving the units of each quantity. [4 marks]

Exam Q2. A tumble-dryer uses 27,000,000 J of energy in 9000 s. Calculate its power rating. [2 marks]

Exam Q3. A fridge draws 1 A of current and is connected to a 200 V supply. Calculate its power. [2 marks]

Exam Q4. Explain what power rating means and how it is useful for choosing electrical appliances. [3 marks]

Lesson 11
What are the features of electricity in the home that help keep us safe?

Part 1 — Electrical Hazards and Safety in the Home

Information

UK mains electricity is at **230 V** and alternates with a frequency of **50 Hz** (50 times per second).	1
Electricity is dangerous because current passing through the body can cause burns and stop the heart.	2
A person is electrocuted when they form a link between the high-voltage supply and the **ground (earth)**.	3
This is why birds on power lines are safe — they do not connect the high voltage to the ground.	4
Water greatly increases the risk because it lowers the resistance of the body, allowing more current to flow.	5
Common household hazards: damaged cables, overloaded sockets, using electrical appliances near water, bare wires.	6

Identify at least 4 electrical hazards in this image

Electrocution: current flows through a person to earth

Questions

Q1. What is the voltage and frequency of UK mains electricity?

Q2. What causes a person to be electrocuted? What is meant by "earthing" in this context?

Q3. Why are birds safe when sitting on a power line?

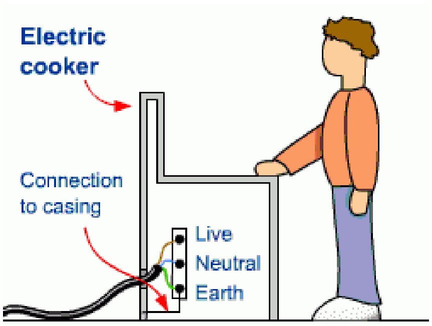
Q4. Why is water particularly dangerous around electricity?

Part 2 — Safety Features: Plugs and Wiring

Information

UK plugs are made of **plastic** (insulator) to prevent the user from touching the live wires inside.	1
Plug sockets have extra plastic to prevent fingers from touching live contacts.	2
Bathrooms do not have standard plug sockets because of the increased risk from water and damp hands.	3
Metal-cased appliances have an **earth wire** — a direct connection between the metal case and the ground.	4
If the metal case accidentally becomes live, current flows safely through the earth wire instead of through a person.	5
UK plugs contain three wires: **live (brown)** — carries current in; **neutral (blue)** — carries current out; **earth (green/yellow)** — safety.	6

UK plug socket with safety shutter



Earth wire connected to the metal casing of an electric cooker

Questions

Q1. Why are plugs made of plastic?

Q2. What is the purpose of an earth wire in a metal-cased appliance?

Q3. Name the three wires in a UK plug and give the colour of each.

Q4. Why are there no standard plug sockets in bathrooms?

Part 3 — Fuses and Circuit Breakers

Information

A **fuse** is a thin wire that **melts** if the current exceeds its rated value, breaking the circuit.	1
Fuses protect wiring and appliances from damage due to too much current.	2

The fuse should be rated **slightly higher** than the normal operating current of the device.	3
Standard fuse ratings: **3 A, 5 A, 13 A**.	4
If a device normally uses 3 A, use a 5 A fuse. If it uses 10 A, use a 13 A fuse.	5
A **circuit breaker** (RCD) performs the same function as a fuse but can be reset after tripping.	6
Modern homes use circuit breakers in the fuse box (consumer unit) instead of fuses.	7

Questions

Q1. What is a fuse made from? How does it work?

Q2. Which fuse should you use for a kettle that requires 10 A during normal operation?

Q3. Which fuse should you use for a toaster that uses 4 A normally?

Q4. Which fuse should you use for a large bulb that normally requires 3 A?

Exam-Style Questions

Exam Q1. Explain how a fuse protects an electrical appliance. [3 marks]

Exam Q2. A hairdryer normally draws 9 A. Which fuse should be used — 3 A, 5 A or 13 A? Explain your choice. [2 marks]

Exam Q3. Explain why metal-cased appliances have an earth wire. [3 marks]

Exam Q4. Why are there no plug sockets in bathrooms? [2 marks]

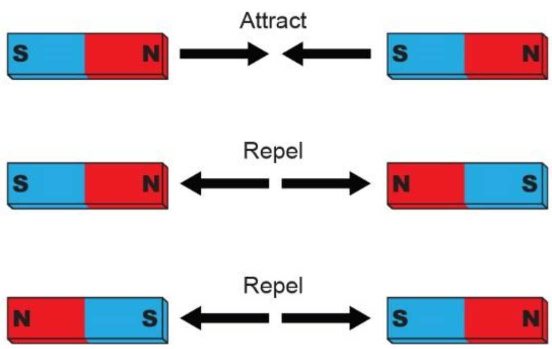
Lesson 12

What are magnets and how do they behave?

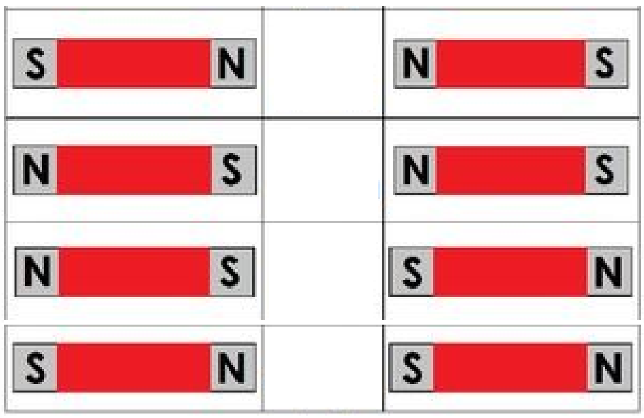
Part 1 — Properties of Magnets

Information

A **magnet** is an object that attracts or is attracted by other magnetic materials.	1
The elements that are magnetic are **iron, cobalt and nickel**. Their alloys (mixtures) are also magnetic.	2
Every magnet has a **north pole** and a **south pole**.	3
The north pole of a magnet points towards geographic north when free to move.	4
Like poles repel: north–north or south–south.	5
Unlike poles attract: north–south.	6
Magnets were first discovered as "lodestones" — the oldest known reference is from 600 BC by the Greek philosopher Thales.	7



Bar magnets: unlike poles attract, like poles repel



Label each pair of magnets: attract or repel?

Questions

Q1. What is a magnet?

Q2. Which three elements are magnetic?

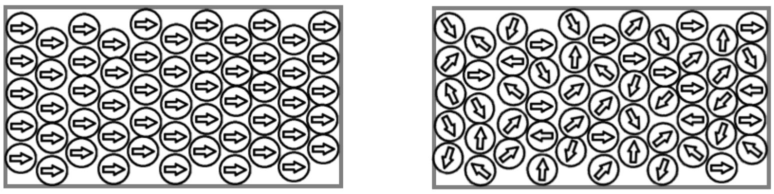
Q3. What is the rule for the force between two north poles placed close together?

Q4. What is the rule for the force between a north pole and a south pole?

Part 2 — Magnetic Domains and Temporary vs Permanent Magnets

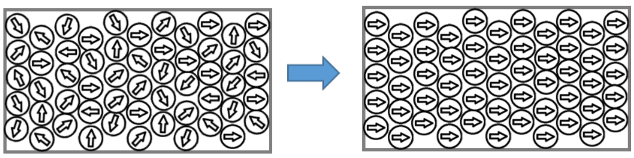
Information

Magnetic materials are made up of tiny groups of atoms called **domains**, which act like mini-magnets.	1
When all domains line up in the same direction, the object is **magnetised**.	2
When domains face random directions, the material is not magnetised overall.	3
Even unmagnetised magnetic materials are still **attracted** to magnets — but they do not attract each other.	4
Stroking a magnetic material with a permanent magnet can align the domains, magnetising it.	5
Temporary magnets (e.g. iron): easily magnetised and demagnetised; heating causes domains to return to random orientation.	6
Permanent magnets (e.g. steel): harder to magnetise but stay magnetised for longer because the domains resist moving back.	7

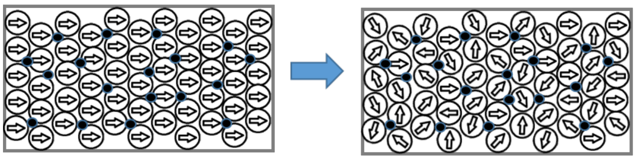


Magnetised **Not Magnetised**

Magnetic domains: all aligned (magnetised) vs random (not magnetised)



Domains aligned — material magnetised



Domains random — material not magnetised

Questions

Q1. What is a magnetic domain?

Q2. What is a temporary magnet? Give an example of a material used to make one.

Q3. What is a permanent magnet? Give an example of a material used to make one.

Q4. Why does heating a temporary magnet cause it to lose its magnetism?

Part 3 — Magnetic Interactions

Information

A **permanent magnet** near another permanent magnet: can attract (opposite poles) or repel (like poles).	1
A permanent magnet near an **unmagnetised magnetic material**: will attract — cannot repel.	2
Two unmagnetised magnetic materials near each other: nothing happens.	3
A magnet near a **non-magnetic material** (e.g. wood, plastic, aluminium): nothing happens.	4
Use this table to predict what will happen for any combination of magnetic objects.	5

Iron is used for temporary magnets in electromagnets; steel is used for permanent magnets in compasses.	6

Questions

Q1. What would happen if you brought a permanent magnet near an unmagnetised iron nail?

Q2. What would happen if you brought two unmagnetised iron nails near each other?

Q3. What would happen if you brought a permanent magnet near a plastic ruler?

Q4. Why is iron better suited for temporary magnets while steel is better for permanent magnets?

Exam-Style Questions

Exam Q1. State which elements are magnetic. [1 mark]

Exam Q2. Explain, in terms of domains, why stroking an iron nail with a permanent magnet magnetises the nail. [3 marks]

Exam Q3. Explain why iron is used for temporary magnets and steel is used for permanent magnets. [3 marks]

Exam Q4. A student brings two objects together: one is a permanent magnet and the other is an unmagnetised iron nail. Describe and explain what happens. [2 marks]

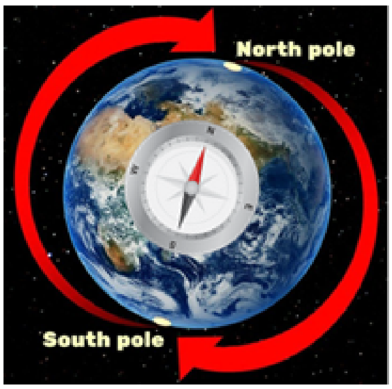
Lesson 13
What is a magnetic field and how can we draw it?

Part 1 — Compasses and Navigation

Information

A **compass** is a magnetised piece of steel on a pivot — it can spin freely to align with a magnetic field.	1
The Earth has a weak magnetic field — a freely spinning compass needle aligns with it, pointing north.	2
Compasses were first used in ancient China, originally as lodestones on a string, pointing south.	3
A compass can be used to navigate because it always shows which direction is north.	4
If a stronger magnet is placed near a compass, the needle aligns with the stronger field instead of Earth's field.	5
This is why compasses should be kept away from magnets and electronic devices.	6

Compass: label the parts



Earth's magnetic field: compass needle aligns with it

Questions

Q1. What is a compass made from?

Q2. Why does a compass point north?

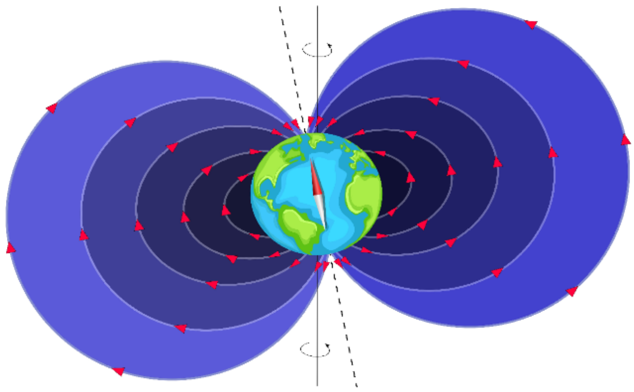
Q3. When might a compass give you the wrong direction?

Q4. What is the purpose of a compass in navigation?

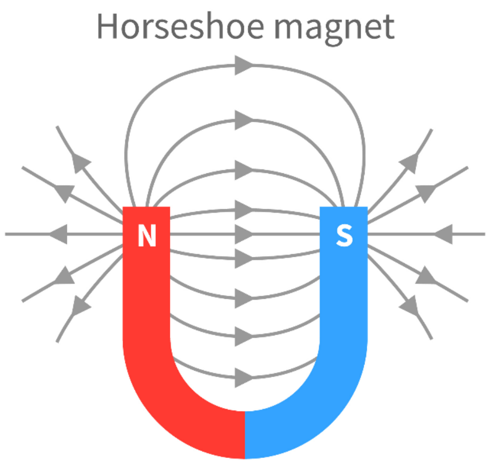
Part 2 — Drawing Magnetic Field Lines

Information

All magnetised objects have a **magnetic field** around them — a region where other magnets experience a force.	1
Magnetic field lines always point from **north to south** outside the magnet.	2
The direction of the arrow shows the direction of the force on a north pole placed at that point.	3
The **closer** the field lines are together, the **stronger** the field.	4
Two ways to find field lines: (1) place a compass at multiple points around a magnet and mark the direction it points; (2) spread iron filings around the magnet and observe the pattern.	5
The field is strongest at the poles — where the lines are most concentrated.	6



Magnetic field around a bar magnet: compass method



Magnetic field around a horseshoe magnet: field lines shown

Questions

Q1. What is a magnetic field?

Q2. What do the arrows on field lines represent?

Q3. How would you show a stronger field in a field diagram?

Q4. Describe two methods used to find the shape of the magnetic field around a bar magnet.

Part 3 — Comparing Electric and Magnetic Fields

Information

Both electric and magnetic fields are regions where forces act on objects placed within them.	1
Electric fields act on **charged objects**; magnetic fields act on **magnets and magnetic materials**.	2
Both types of field are shown with arrows — the direction of the arrow indicates the direction of the force on a "test" object.	3
In both cases, closer field lines indicate a stronger field.	4
Both fields can cause attraction or repulsion.	5
Unlike electric fields (which exist around charged objects), magnetic fields exist around all magnetised materials.	6

Questions

Q1. State two similarities between electric fields and magnetic fields.

Q2. State one difference between electric fields and magnetic fields.

Q3. In a field diagram for a bar magnet, where are the field lines closest together? What does this tell you?

Exam-Style Questions

Exam Q1. Describe what a magnetic field is and explain how to represent it using a diagram. [3 marks]

Exam Q2. Explain why a compass placed near a bar magnet does not point north. [2 marks]

Exam Q3. Describe two ways to map the magnetic field around a bar magnet. [2 marks]

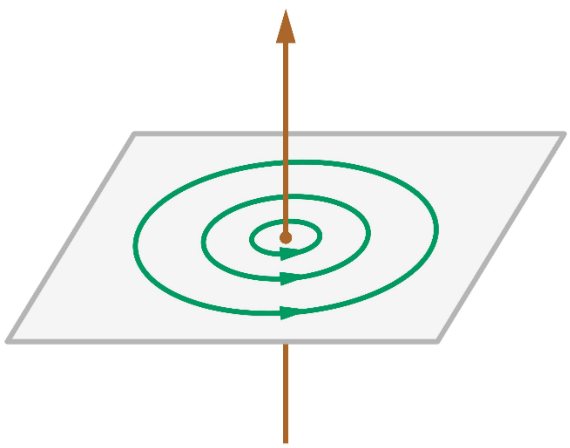
Exam Q4. Where is the magnetic field of a bar magnet strongest? How can you tell from the field diagram? [2 marks]

Lesson 14
What kind of magnetic field is generated around a current-carrying conductor?

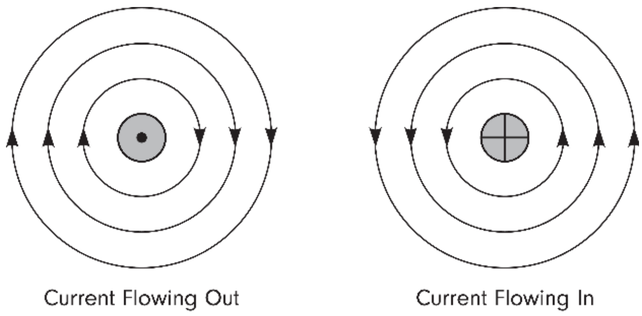
Part 1 — Magnetic Fields from Currents

Information

Magnetic fields are not only produced by permanent magnets — any **moving charged particle** generates a magnetic field.	1
Therefore, any conductor carrying a current also has a magnetic field around it.	2
The magnetic field around a current-carrying wire is **circular** — the field lines form concentric circles around the wire.	3
Unlike a bar magnet, the field around a straight wire has no distinct north or south pole.	4
The strength of the magnetic field increases as the current through the wire increases.	5
This discovery links electricity and magnetism, showing they are related phenomena.	6



Circular magnetic field around a current-carrying wire (3D view)



Cross-section view: field circles around the wire

Questions

Q1. How can a magnetic field be created without a permanent magnet?

Q2. What is the shape of the magnetic field around a current-carrying straight wire?

Q3. How is the magnetic field around a wire different from the field around a bar magnet?

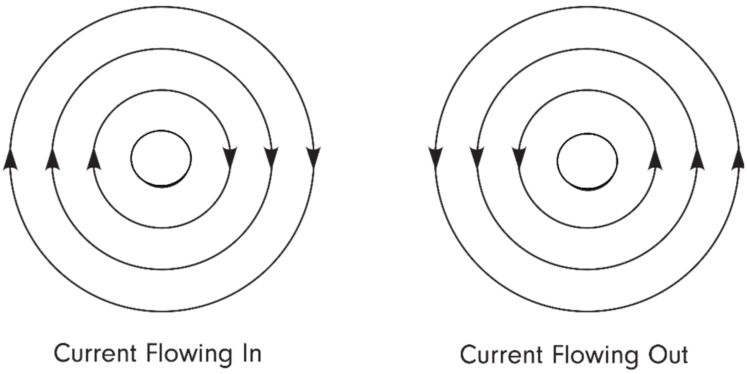
Q4. What happens to the strength of the magnetic field if the current through the wire increases?

Part 2 — Representing Current Direction in Diagrams

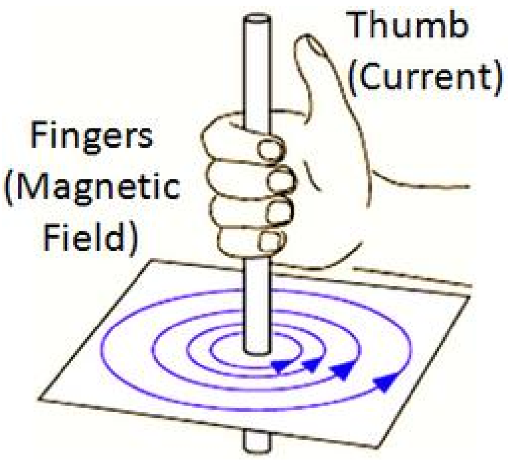
Information

It is difficult to draw a 3D circular field in 2D, so we use a cross-section view of the wire.	1
A **dot** (•) in the wire represents current coming **out of the page towards you**.	2
A **cross** (×) in the wire represents current going **into the page away from you**.	3
This is based on imagining an arrow: a dot = the point of the arrow coming toward you; a cross = the feathers of the arrow going away from you.	4

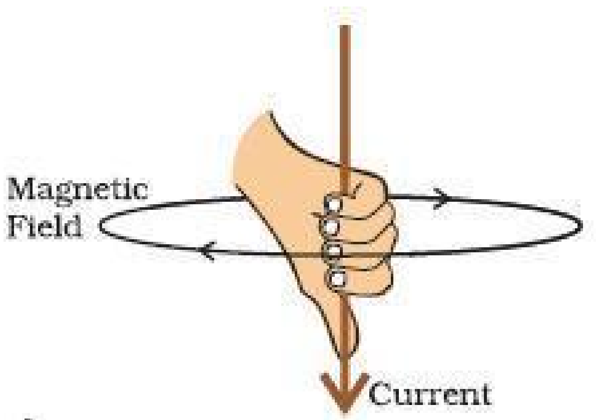
The magnetic field goes in a **anticlockwise** direction around the wire when current is coming out of the page.	5
The magnetic field goes in a **clockwise** direction around the wire when current is going into the page.	6



Dot (current out of page) and cross (current into page) notation



Right-hand grip rule demonstration



Right-hand grip rule: thumb = current, fingers = field

Questions

Q1. What does a dot symbol in a cross-section of a wire represent?

Q2. What does a cross symbol in a cross-section of a wire represent?

Q3. In what direction do the field lines run when current is coming out of the page?

Part 3 — The Right-Hand Grip Rule

Information

The **Right-Hand Grip Rule** tells you the direction of the magnetic field around a wire.	1
Grip the wire with your right hand, with your thumb pointing in the direction of the (conventional) current flow.	2
Your fingers curl in the direction of the magnetic field.	3
A stronger field is shown by drawing the field lines closer together.	4
Increasing current stronger field field lines closer together.	5
Decreasing current weaker field field lines further apart.	6
This relationship between current and magnetic field is the basis for building electromagnets.	7

Questions

Q1. Describe how to use the right-hand grip rule.

Q2. What effect does increasing the current through a wire have on its magnetic field?

Q3. How do you show the difference between a strong magnetic field and a weak one in a diagram?

Exam-Style Questions

Exam Q1. Explain why a wire carrying a current has a magnetic field around it. [2 marks]

Exam Q2. Describe the shape of the magnetic field around a current-carrying straight wire. How does this differ from the field around a bar magnet? [3 marks]

Exam Q3. A wire is shown in cross-section with a dot symbol (•). State the direction of the current and the direction of the magnetic field. [2 marks]

Exam Q4. Describe how to use the right-hand grip rule to find the direction of a magnetic field around a wire. [2 marks]

Lesson 15
How are electromagnets made and how can they be strengthened?

Part 1 — What is an Electromagnet?

Information

An **electromagnet** is a magnet made from a coil of wire carrying a current — it can be switched on and off. 1

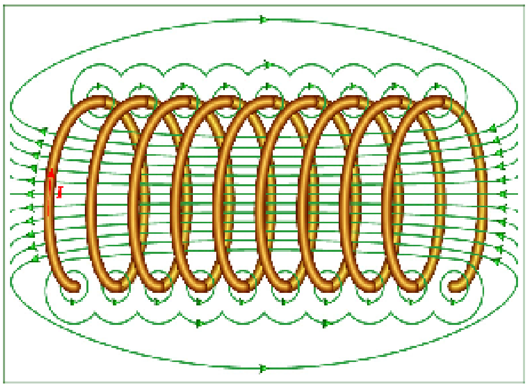
When current flows through the wire, a magnetic field is produced. When current is switched off, the field disappears. 2

Winding the wire into a loop concentrates the field inside the loop, making it stronger. 3

Adding more loops (a **solenoid**) significantly increases the strength of the magnetic field. 4

A solenoid is a cylindrical coil of wire — it produces a magnetic field similar to a bar magnet, with north and south poles. 5

The advantages of an electromagnet over a permanent magnet: the magnetism can be switched on/off and its strength can be varied. 6



Electromagnet: insulated wire coiled around an iron nail

Questions

Q1. What is an electromagnet?

Q2. What do you need to do to wire to make it into an electromagnet?

Q3. What is a solenoid?

Q4. State two advantages of an electromagnet over a permanent magnet.

Part 2 — Strengthening an Electromagnet

Information

Three ways to make an electromagnet stronger: (1) **increase the current**; (2) **add more coils** of wire; (3) **add an iron core**. 1

An iron core inside the solenoid significantly increases the field strength because iron "channels" the magnetic field. 2

Iron is used (not steel) because iron is a **temporary magnet** — it loses its magnetism when the current is switched off. 3

Steel would remain magnetised after switching off, meaning the electromagnet could not be fully turned off.	4
Increasing the current more moving electrons stronger magnetic field electromagnet picks up more.	5
The relationship between current and number of paper clips held is approximately proportional.	6

Questions

Q1. State three ways to increase the strength of an electromagnet.

Q2. Why is iron used for the core of an electromagnet rather than steel?

Q3. Predict what would happen to the number of paper clips held by the electromagnet if the current is doubled.

Part 3 — Uses of Electromagnets

Information

Electromagnets are used in many everyday applications.	1
Scrapyard cranes: powerful electromagnets lift and move heavy metal objects; switching off drops the load.	2
Electric bells: the electromagnet repeatedly attracts and releases a striker to ring the bell.	3
Door entry systems: an electromagnet holds a door shut; switching it off allows the door to open.	4
Loudspeakers and headphones: a varying current produces a varying magnetic field that moves a cone to produce sound.	5
Electric motors: electromagnets create forces on current-carrying coils to produce rotation.	6
The ability to turn the magnetism on and off is key to all these applications.	7

Questions

Q1. Give three uses of electromagnets.

Q2. Explain why the ability to switch an electromagnet off is important for a scrapyard crane.

Q3. In the electromagnet investigation, why must the paperclips all be the same size?

Exam-Style Questions

Exam Q1. Describe how an electromagnet is made. [2 marks]

Exam Q2. Explain why iron is used as the core of an electromagnet rather than steel. [3 marks]

Exam Q3. A student investigates the strength of an electromagnet by counting the paperclips it holds. State three variables the student should control to make the test fair. [3 marks]

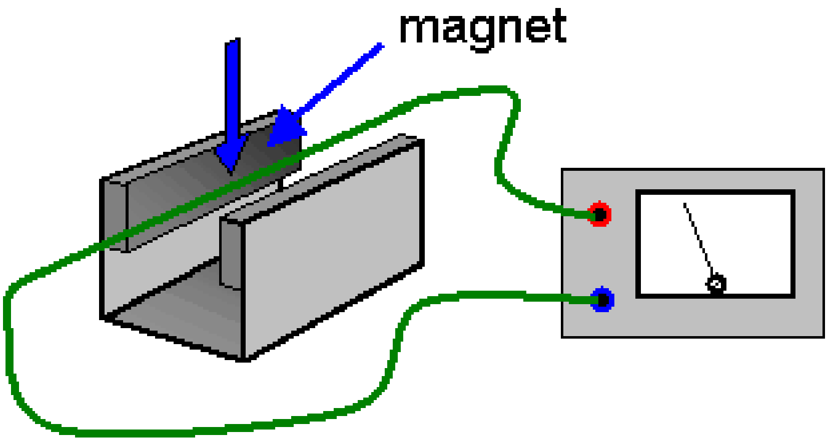
Exam Q4. Give two advantages of an electromagnet over a permanent magnet for use in a scrapyard crane. [2 marks]

Lesson 16
How big is the force on a wire in a magnetic field?

Part 1 — The Motor Effect

Information

When a current-carrying wire is placed inside a magnetic field, the wire experiences a **force**.	1
This is called **the motor effect**.	2
If there is no current through the wire, the wire experiences no force.	3
Reversing the direction of the current reverses the direction of the force.	4
Reversing the direction of the magnetic field also reverses the direction of the force.	5
The strength of the magnetic field is measured in **Tesla (T)**.	6
Some examples: Earth's field 0.00005 T; fridge magnet 0.005 T; hospital MRI scanner 8 T.	7



Motor effect: current-carrying wire between magnet poles experiences a force

Questions

Q1. What happens when a wire carrying a current is placed in a magnetic field?

Q2. What is the motor effect?

Q3. What two things could you change to reverse the direction of the force on the wire?

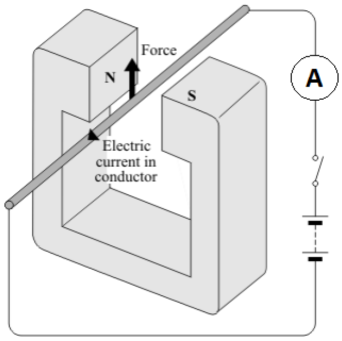
Q4. What are the units of magnetic field strength?

Part 2 — Investigating the Motor Effect

Information

The size of the force on the wire depends on: (1) the **current** (I); (2) the **magnetic field strength** (B); (3) the **length** of wire in the field (L).	1
To investigate: place a wire on a top pan balance inside a magnetic field; pass different currents and record the apparent mass change.	2
Force (N) = measured mass (kg) × 9.8 (gravitational field strength, N/kg).	3
The graph of force against current shows a **proportional** (straight line through origin) relationship.	4

This means: doubling the current doubles the force.	5
An anomaly is a data point that does not fit the general pattern — identified on a graph as a point far from the line of best fit.	6



Measuring force on a wire: top-pan balance registers the force

Questions

Q1. State three factors that affect the size of the force on a current-carrying wire in a magnetic field.

Q2. Describe how to find the force on a wire from a measured mass.

Q3. What pattern would you expect to see on a graph of force against current?

Q4. How can you identify an anomaly in your data from a graph?

Part 3 — The Force Equation

Information

The force on a current-carrying wire can be calculated using: **F = B × I × L**	1
where F = force (N), B = magnetic field strength (T), I = current (A), L = length of wire in the field (m).	2
Example: 0.1 m wire in Earth's field (0.00005 T) with 2 A: F = 0.00005 × 2 × 0.1 = 0.00001 N.	3
Example: 0.1 m wire in scrapyard electromagnet (1 T) with 2 A: F = 1 × 2 × 0.1 = 0.2 N.	4
The larger the field, the current, or the length — the greater the force.	5
Remember: length must be in **metres** (convert cm to m by dividing by 100).	6

Questions

Q1. Write the equation for the force on a current-carrying wire in a magnetic field.

Q2. Calculate the force on 1 m of wire in a magnetic field of 0.01 T with a current of 0.35 A.

Q3. A scrapyard electromagnet (1 T) is placed across 50 cm of wire carrying 7.2 A. Calculate the force on the wire.

Q4. Calculate the force on 10 cm of wire in a 0.5 T field with a current of 19 A.

Q5. What is the force on 2 m of hairdryer wire in a 0.2 T field with 3 A flowing through it?

Exam-Style Questions

Exam Q1. State the equation for the force on a current-carrying conductor in a magnetic field. Include units. [3 marks]

Exam Q2. A wire of length 0.5 m carries a current of 4 A in a magnetic field of strength 0.3 T. Calculate the force on the wire. [2 marks]

Exam Q3. Explain why a wire with no current flowing through it does not experience a force when placed in a magnetic field. [2 marks]

Exam Q4. A fridge has 50 C of charge flowing across it every 5 s. Calculate the current. [2 marks]

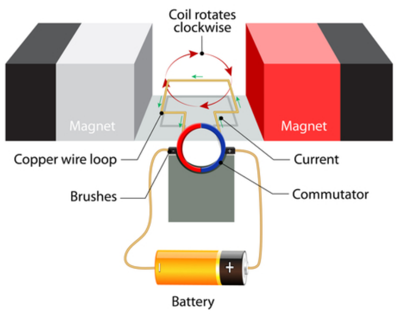
Lesson 17
How does a simple electric motor work?

Part 1 — The Motor Effect and Rotation

Information

An **electric motor** uses the motor effect to convert electrical energy into kinetic (rotational) energy.	1
A coil of wire is placed inside a magnetic field. When current flows through the coil, each side of the coil experiences a force.	2
The force on the left side is in the **opposite** direction to the force on the right side.	3
This is because the current in the two sides of the coil travels in **opposite directions**.	4
The two opposite forces create a **turning effect** (torque) — the coil rotates.	5
All electric motors need: (1) a coil of wire; (2) a magnetic field; (3) a current flowing through the coil.	6

A simple electric motor



Simple electric motor: coil of wire in a magnetic field

Questions

Q1. What energy transfer takes place in an electric motor?

Q2. Why do the two sides of the coil in an electric motor move in opposite directions?

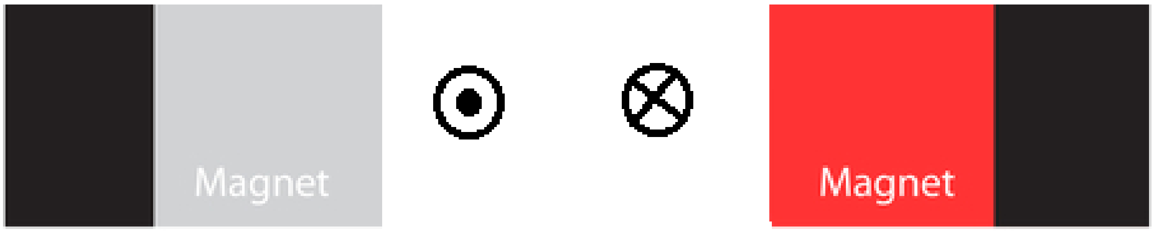
Q3. State the three things needed to make an electric motor.

Part 2 — Applications of Electric Motors

Information

Electric motors are used in any situation requiring circular or rotational motion.	1
Common applications: electric cars, electric fans, drills, washing machines.	2
Less obvious applications: hairdryers (spin the fan inside), lifts (wind cable up/down), roller shutters.	3
Increasing the current increases the speed/force of the motor.	4
Adding a resistor decreases the current and therefore reduces the motor's speed.	5
Changing the direction of the current reverses the direction of rotation.	6

Removing the magnet means there is no magnetic field — the motor effect cannot occur and the motor stops. 7



Motor coil cross-section: dot/cross shows force direction on each side

Questions

Q1. Give three examples of devices that use electric motors.

Q2. What happens to the speed of a motor if a resistor is added to the circuit? Explain why.

Q3. What would happen if the magnet were removed from an electric motor? Explain.

Q4. How could you reverse the direction of spin of an electric motor?

Part 3 — How the Coil Continues to Spin

Information

For the coil to continue spinning, the current direction must be reversed every half turn. 1

This is achieved using a **split-ring commutator** — a ring split into two halves that swaps the connections each half rotation. 2

Without the commutator, the coil would oscillate back and forth rather than rotating continuously. 3

Brushes maintain electrical contact between the stationary power supply and the rotating commutator. 4

Increasing the number of coils in an electric motor increases the force and produces smoother rotation. 5

Increasing the number of coils or the current or using stronger magnets all increase the motor's power. 6

Questions

Q1. What is a split-ring commutator and what does it do?

Q2. Why does the coil need the current direction to be reversed every half turn?

Q3. State two ways to increase the power of an electric motor.

Exam-Style Questions

Exam Q1. Describe how a simple electric motor works. Include what energy is transferred and what components are needed. [4 marks]

Exam Q2. Explain why the two sides of a coil in an electric motor move in opposite directions. [3 marks]

Exam Q3. A student adds a variable resistor to the circuit of an electric motor. Explain how this can be used to control the speed of the motor. [3 marks]

Exam Q4. What is the purpose of the split-ring commutator in an electric motor? [2 marks]

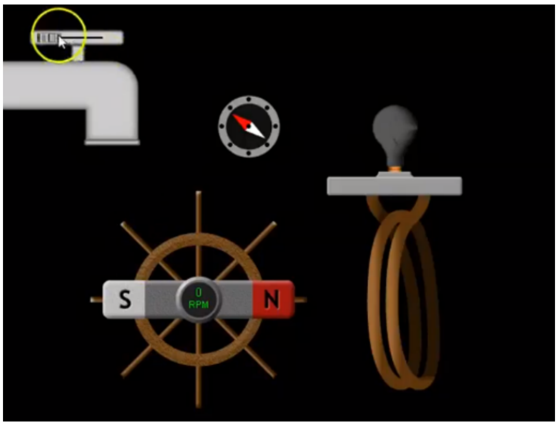
Lesson 18

How can electricity be generated using a magnet?

Part 1 — Electromagnetic Induction

Information

When a magnet is moved into or out of a coil of wire, a **potential difference (voltage) is induced** and a current flows — this is called **electromagnetic induction**.	1
A current is induced whenever the **magnetic field through the coil changes**.	2
Moving the magnet faster induces a **larger** potential difference and brighter current.	3
Moving the south pole into the coil produces a potential difference in the **opposite direction** to the north pole entering.	4
Moving the magnet in from the opposite end also reverses the potential difference.	5
This principle is used in **generators** to produce electrical energy from kinetic energy.	6



Electromagnetic induction: moving a magnet through a coil induces a voltage

Questions

Q1. What is electromagnetic induction?

Q2. What causes a potential difference to be induced in a coil?

Q3. What happens to the induced voltage when the magnet is moved faster?

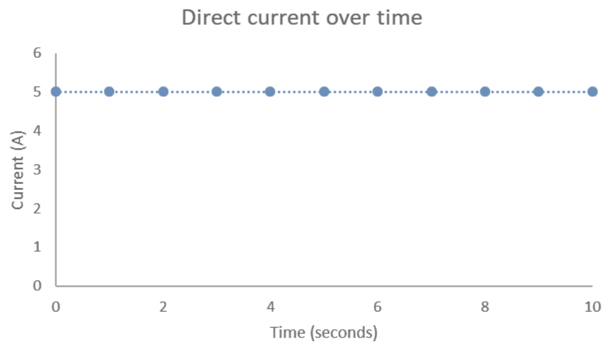
Q4. What happens to the direction of the induced current when the south pole enters instead of the north pole?

Part 2 — Generators: AC and DC

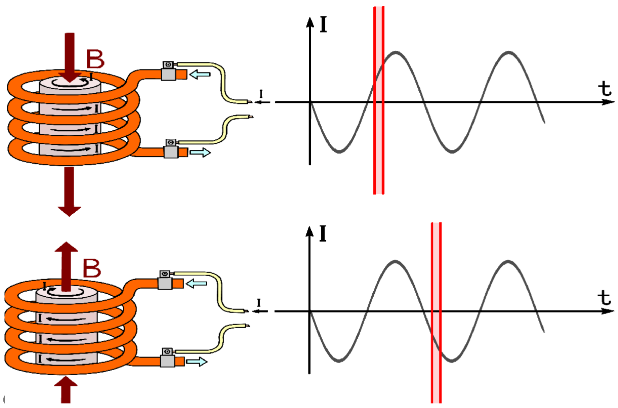
Information

A **generator** uses coils of wire and magnets to produce electricity (induce a current in a circuit).	1
In a generator, a coil of wire rotates inside a magnetic field — the changing magnetic field induces a current.	2
A cell produces **direct current (DC)** — current always flows in the same direction at a constant rate.	3
A generator produces **alternating current (AC)** — the current repeatedly changes direction as the coil rotates.	4

UK mains electricity is AC at 50 Hz (changes direction 50 times per second).	5
We do not notice the lights flickering from AC because human eyes can only detect changes up to 25–30 times per second.	6



Generator output: AC voltage produced as coil rotates



AC vs DC: alternating current from generator; direct current from cell

Questions

Q1. What is a generator?

Q2. What is the difference between direct current (DC) and alternating current (AC)?

Q3. Why do we not notice that the lights in a room are powered by alternating current?

Q4. What is the frequency of UK mains AC?

Part 3 — Increasing Generator Output and Comparing Motors and Generators

Information

The output of a generator can be increased by: (1) spinning the coil faster; (2) using more coils; (3) using stronger magnets.	1
Larger loops of wire also increase the output because more field lines pass through a larger area.	2
A generator is essentially an **electric motor in reverse**: an input of kinetic energy produces an electrical output.	3
An electric motor inputs electrical energy and outputs kinetic energy.	4
Both generators and motors use coils of wire and magnets.	5
Increasing the number of coils affects the output of both motors and generators.	6

Questions

Q1. State three ways to increase the output voltage of a generator.

Q2. How is a generator similar to an electric motor?

Q3. Which device: (a) converts kinetic energy to electrical energy; (b) converts electrical energy to kinetic energy?

Q4. Decide if each statement refers to a motor, a generator, or both: (a) made from coils and magnets; (b) used in power stations; (c) used in electric drills.

Exam-Style Questions

Exam Q1. Explain how a generator produces electricity. [3 marks]

Exam Q2. State three ways to increase the output of a generator. [3 marks]

Exam Q3. Explain the difference between alternating current (AC) and direct current (DC). [2 marks]

Exam Q4. Explain why we do not notice that the lights in a room are powered by alternating current. [2 marks]

Lesson 19

What is the national grid and how does a transformer work?

Part 1 — The National Grid

Information

The **national grid** is the network of power lines and transformers that carries electricity from power stations to homes and businesses. 1

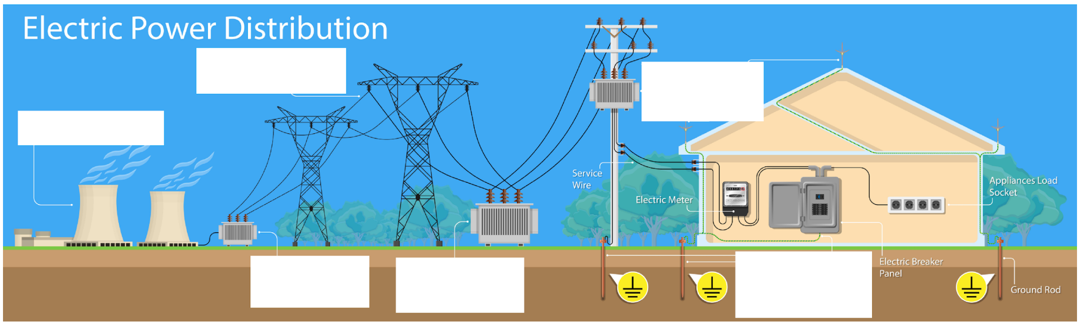
Electricity is generated in power stations at around 25,000 V using turbines and generators. 2

It is transmitted across the country through high-voltage cables at up to **400,000 V**. 3

Before entering homes, the voltage is reduced to **230 V** for safe use. 4

High-voltage transmission is used because: at higher voltage, the current is lower, which means less energy is wasted as heat in the cables. 5

Power = Current × Voltage. For the same power, higher voltage means lower current — and less heating (wasted energy). 6



The national grid: power station step-up transformer cables step-down homes

Questions

Q1. What is the national grid?

Q2. Why is electricity transmitted at high voltage across the country?

Q3. What voltage is electricity reduced to before entering homes?

Part 2 — Transformers

Information

A **transformer** is a device that changes the voltage of an alternating current. 1

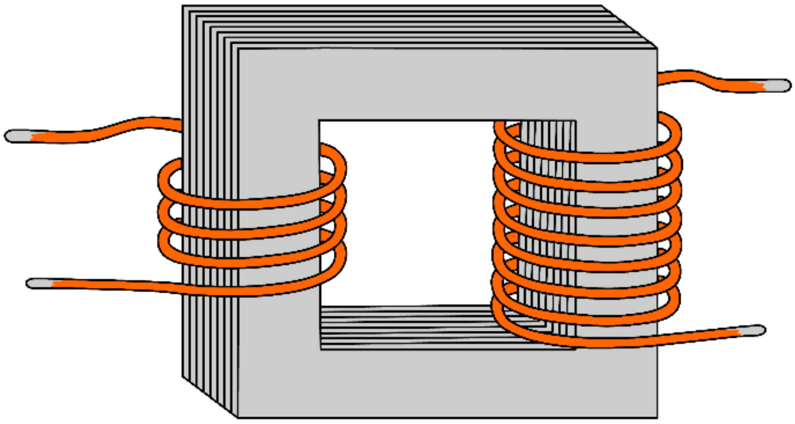
It consists of two coils of wire (the **primary coil** and the **secondary coil**) wound around an iron core. 2

A **step-up transformer** increases the voltage (secondary coil has more turns than the primary). 3

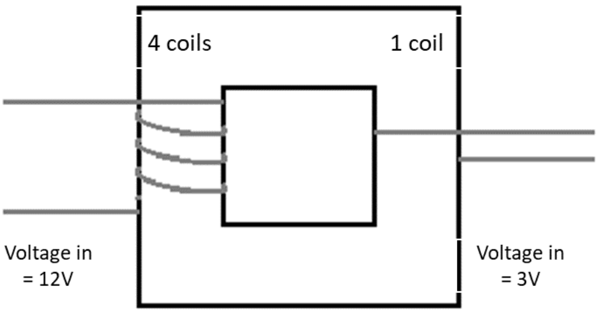
A **step-down transformer** decreases the voltage (secondary coil has fewer turns than the primary). 4

Transformers only work with **alternating current (AC)** — not with DC. 5

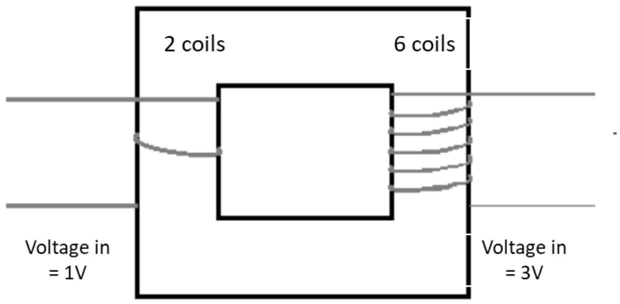
The ratio of voltages equals the ratio of turns: $V_p / V_s = N_p / N_s$. 6



Transformer: primary and secondary coils wound on an iron core



Step-down: 4 primary 1 secondary coil (V decreases)



Step-up: 2 primary 6 secondary coils (V increases)

Questions

Q1. What is a transformer?

Q2. What is the difference between a step-up and a step-down transformer?

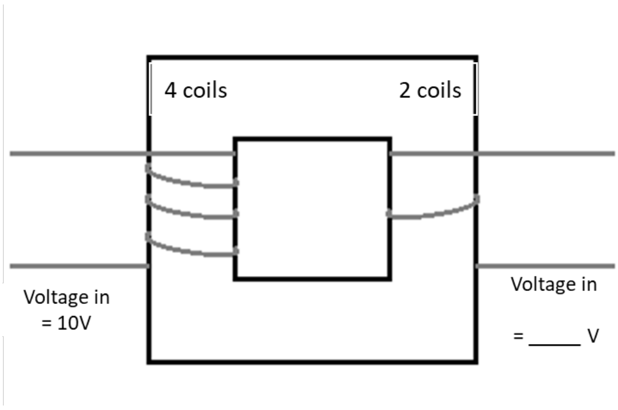
Q3. Why do transformers only work with alternating current?

Q4. A transformer has 100 turns on the primary and 500 turns on the secondary. If the primary voltage is 25,000 V, what is the secondary voltage?

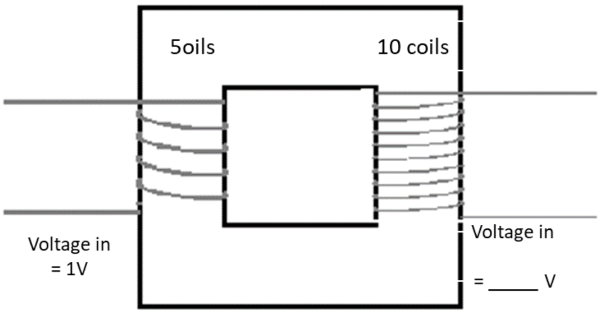
Part 3 — The National Grid: Step-up and Step-down Transformers

Information

At the power station, a **step-up transformer** raises the voltage from ~25,000 V to ~400,000 V for transmission.	1
This high voltage reduces the current in the cables, minimising energy wasted as heat.	2
Near homes, a **step-down transformer** reduces the voltage from 400,000 V back to 230 V for safe use.	3
Without step-up transformers: the current would be very high, wasting enormous amounts of energy in the cables.	4
Without step-down transformers: the full 400,000 V would reach homes — immediately and fatally dangerous.	5
Using both types of transformer makes electricity supply both efficient and safe.	6



Calculate the missing voltage (4 2 coils)



Calculate the missing voltage (5 10 coils)

Questions

Q1. Where in the national grid is a step-up transformer used? What does it do?

Q2. Where is a step-down transformer used? What does it do?

Q3. What would happen if electricity were transmitted at low voltage without a step-up transformer? Explain in terms of current and energy loss.

Q4. Why is it essential to use a step-down transformer before the electricity enters homes?

Exam-Style Questions

Exam Q1. Explain why electricity is transmitted at high voltage through the national grid. [3 marks]

Exam Q2. A step-up transformer has 200 turns on the primary coil and 4000 turns on the secondary. If the primary voltage is 25,000 V, calculate the secondary voltage. [2 marks]

Exam Q3. Explain why transformers only work with alternating current. [2 marks]

Exam Q4. Describe the journey of electricity from a power station to a home, including the role of each type of transformer. [4 marks]