Chapter 1: Conservation and dissipation of energy

Knowledge organiser

Systems

A **system** is an object or group of objects.

Whenever anything changes in a system, energy is transferred between its stores or to the surroundings.

A **closed system** is one where no energy can escape to or enter from the surroundings. The total energy in a closed system never changes.

Energy stores

kinetic	energy an object has because it is moving
gravitational potential	energy an object has because of its height above the ground
elastic potential	energy an elastic object has when it is stretched or compressed
thermal (or internal)	energy an object has because of its temperature (the total kinetic and potential energy of the particles in the object)
chemical	energy that can be transferred by chemical reactions involving foods, fuels, and the chemicals in batteries
nuclear	energy stored in the nucleus of an atom
magnetic	energy a magnetic object has when it is near a magnet or in a magnetic field
electrostatic	energy a charged object has when near another charged object

Energy transfers

Energy can be transferred to and from different stores by:

Heating
Energy is transferred from one object to another object with a lower temperature.

Waves
Waves (e.g., light and sound) can transfer energy.

Electricity
An electric current transfers energy.

Forces (mechanical work)
Energy is transferred when a force moves or changes the shape of an object.

Examples of energy transfers

When you stretch a rubber band, energy from your chemical store is mechanically transferred to the rubber band's elastic potential store.

When a block is dropped from a height, energy is mechanically transferred (by the force of gravity) from the block's gravitational potential store to its kinetic store.

When this block hits the ground, energy from its kinetic energy store is transferred mechanically and by sound waves to the thermal energy store of the surroundings.

The electric current in a kettle transfers energy to the heating element's thermal energy store. Energy is then transferred by heating from the heating element's thermal energy store to the thermal energy store of the water.

When an object slows down due to friction, energy is mechanically transferred from the object's kinetic store to its thermal store, the thermal store of the object it is rubbing against, and to the surroundings.

Work done

When an object is moved by a force **work** is done on the object. The force transfers energy to the object. The amount of energy transferred is equal to the work done. You can calculate the work done (and the energy transferred) using the equation:

work done (J) = force (N) x distance moved along the line of action of the force (m)

Calculating the energy in an energy store

An object's gravitational potential energy store depends on its height above the ground, the gravitational field strength, and its mass.

gravitational potential energy (J) = mass (kg) × gravitational field strength (N/kg) × height (m)

$$E_p = m\,g\,h$$

An object's kinetic energy store depends only on its mass and speed.

kinetic energy (J) = 0.5 × mass (kg) × (speed)^2 (m/s)

$$E_k = \frac{1}{2} m\,v^2$$

The elastic potential energy store of a stretched spring can be calculated using:

elastic potential energy (J) = 0.5 × spring constant (N/m) × (extension)^2 (m)

$$E_e = \frac{1}{2} k\,e^2$$ (assuming the limit of proportionality has not been exceeded)

Power is how much work is done (or how much energy is transferred) per second. The unit of power is the watt (W).

1 watt = 1 joule of energy transferred per second

$$\text{power (W)} = \frac{\text{energy transferred (J)}}{\text{time (s)}}$$

$$P = \frac{E}{t}$$

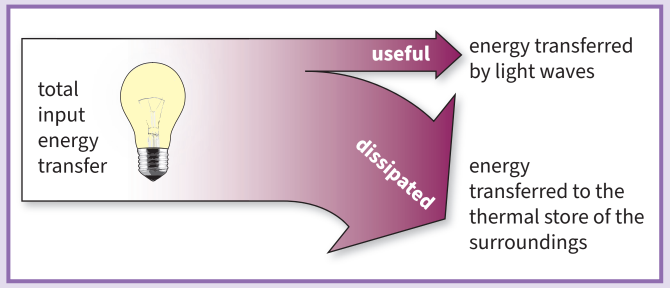
or

$$\text{power (W)} = \frac{\text{work done (J)}}{\text{time (s)}}$$

$$P = \frac{W}{t}$$

Useful and dissipated energy

Energy cannot be created or destroyed – it can only be transferred usefully, stored, or dissipated (wasted).



Energy is never entirely transferred usefully – some energy is always dissipated, meaning it is transferred to less useful stores.

All energy eventually ends up transferred to the thermal energy store of the surroundings.

In machines, work done against the force of friction usually causes energy to be wasted because energy is transferred to the thermal store of the machine and its surroundings.

Lubrication is a way of reducing unwanted energy transfer due to friction.

Streamlining is a way of reducing energy wasted due to air resistance or drag in water.

Use of thermal insulation is a way of reducing energy wasted due to heat dissipated to the surroundings.

Efficiency is a measure of how much energy is transferred usefully. You must know the equation to calculate efficiency as a *decimal*:

$$\text{efficiency} = \frac{\text{useful output energy transfer (J)}}{\text{total input energy transfer (J)}}$$

or

$$\text{efficiency} = \frac{\text{useful power output (W)}}{\text{total power input (W)}}$$

To give efficiency as a *percentage*, just multiply the result from the above calculation by 100 and add the % sign to the answer.

Key terms

Make sure you can write a definition for these key terms.

chemical, closed system, dissipated, efficiency, elastic potential, electrostatic, gravitational potential, kinetic, lubrication, magnetic, nuclear, power, streamlining, system, thermal, work done

Chapter 1: Conservation and dissipation of energy

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P1 questions		Answers
1	Name the five energy stores	Put paper here	kinetic, gravitational potential, elastic potential, thermal, chemical
2	Name the four ways in which energy can be transferred.		heating, waves, electric current, mechanically (by forces)
3	What is a system?	Put paper here	an object or group of objects
4	What is a closed system?		a system where no energy can be transferred to or from the surroundings – the total energy in the system stays the same
5	What is work done?	Put paper here	energy transferred when a force moves an object
6	What is the unit for energy?		joules (J)
7	What is one joule of work?		the work done when a force of 1 N causes an object to move 1 m in the direction of the force
8	Describe the energy transfer when a moving car slows down.	Put paper here	energy is transferred mechanically from the kinetic store of the car to the thermal store of its brakes. Some energy is dissipated to the thermal store of the surroundings
9	Describe the energy transfer when an electric kettle is used to heat water.	Put paper here	the electric current in a kettle transfers energy to the heating element's thermal store – energy is then transferred by heating from the heating element's thermal store to the thermal store of the water
10	Describe the energy transfer when a ball is fired using an elastic band.	Put paper here	energy is transferred mechanically from the elastic store of the elastic band to the kinetic store of the band – some energy is dissipated to the thermal store of the surroundings
11	Describe the energy transfer when a battery powered toy car is used.	Put paper here	energy is transferred electrically from the chemical store of the battery to the kinetic store of the toy car – some energy is dissipated to the thermal store of the surroundings
12	Describe the energy transfer when a falling apple hits the ground.		energy is transferred from the kinetic store of the apple and dissipated to the thermal store of the surroundings by sound waves
13	Name the unit that represents one joule transferred per second.	Put paper here	watt (W)
14	A motor is 30% efficient. What does that mean?		30% of the energy is usefully transferred and 70% is dissipated

Chapter 2: Energy transfer by heating

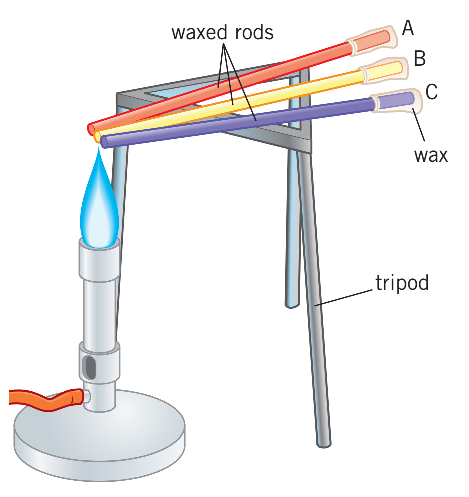
Knowledge organiser

Thermal conductivity

The **thermal conductivity** of a material tells you how quickly energy is transmitted through it by thermal conduction.

You can test the thermal conductivity of rods made of different metals using this experimental set-up. Each rod must have the same diameter and length, and the same temperature difference between its ends.

One end of each rod is covered in wax and the other ends are heated equally. The faster the wax melts, the higher the thermal conductivity of the metal.



Insulating buildings

Heating bills can be expensive so it is important to reduce the rate of heat loss from buildings.

Some factors that affect the rate of heat loss from a building include:

1. the thickness of its walls and roof
2. the thermal conductivity of its walls and roof.

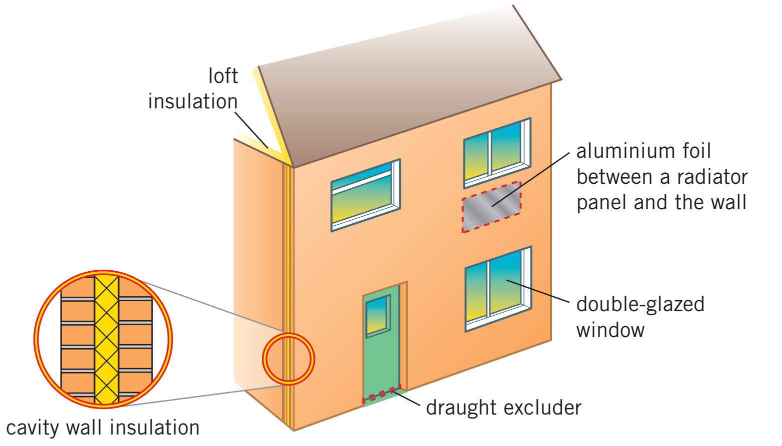
   lower thermal conductivity = lower rate of heat loss

The thermal conductivity of the walls and roof can be reduced by using **thermal insulators**.

A thermal insulator is a material which has a low thermal conductivity. The rate of energy transfer through an insulator is low.

The energy transfer per second through a material depends on:

1. the material's thermal conductivity
2. the temperature difference between the two sides of the material
3. the thickness of the material.



Specific heat capacity

When a substance is heated or cooled the temperature change depends on:

- the substance's mass
- the type of material
- how much energy is transferred to it.

Every type of material has a **specific heat capacity** – the amount of energy needed to raise the temperature of 1 kg of the substance by 1 °C.

The energy transferred to the thermal store of a substance can be calculated from the substance's mass, specific heat capacity, and temperature change:

change in thermal energy (J) = mass (kg) × specific heat capacity (J/kg°C) × temperature change (°C)

$$\Delta E = m\, c\, \Delta\theta$$

This equation will be given to you on the equation sheet, but you need to be able to select and apply it to the correct questions.

Key terms

Make sure you can write a definition for these key terms.

absorb *specific heat capacity* *thermal conductivity* *thermal insulator*

Chapter 2: Energy transfer by heating

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P2 questions	Answers
1	What does a material's thermal conductivity tell you?	how well it conducts heat
2	Which materials have low thermal conductivity?	thermal insulators
3	Give three factors that determine the rate of thermal energy transfer through a material.	thermal conductivity of material, temperature difference, thickness of material
4	What factors affect the rate of heat loss from a building?	thickness of walls and roof, thermal conductivity of walls and roof, the temperature difference between the two sides of the wall/roof
5	Define specific heat capacity.	amount of energy needed to raise the temperature of 1 kg of a material by 1 °C

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Chapter 3: Energy resources

Knowledge organiser

Energy resources

The main ways in which we use the Earth's energy resources are:

- generating electricity
- heating
- transport.

Most of our energy currently comes from **fossil fuels** – coal, oil, and natural gas.

Reliability and environmental impact

Some energy resources are more reliable than others. **Reliable** energy resources are ones that are available all the time (or at predictable times) and in sufficient quantities.

Both **renewable** and **non-renewable** energy resources have some kind of **environmental impact** when we use them.

Non-renewable energy resources

- not replaced as quickly as they are used
- will eventually run out

For example, fossil fuels and nuclear fission.

Renewable energy resources

- can be replaced at the same rate as they are used
- will not run out

For example, solar, tidal, wave, wind, geothermal, biofuel, and hydroelectric energies.

Non-renewable energy resources

Resource	Main uses	Source	Advantages	Disadvantages
coal	generating electricity	extracted from underground	• enough available to meet current energy demands • reliable – supply can be controlled to meet demand • relatively cheap to extract and use	• will eventually run out • release carbon dioxide when burned – one of the main causes of climate change • release other polluting gases, such as sulfur dioxide (from coal and oil) which causes acid rain • oil spills in the oceans kill marine life
oil	generating electricity transport heating			
natural gas	generating electricity heating			
nuclear fission	generating electricity	mining naturally occurring elements, such as uranium and plutonium	• no polluting gases or greenhouse gases produced • enough available to meet current energy demands • large amount of energy transferred from a very small mass of fuel • reliable – supply can be controlled to meet demand	produces nuclear waste, which is: • dangerous • difficult and expensive to dispose of • stored for centuries before it is safe to dispose of. nuclear power plants are expensive to: • build and run • decommission (shut down).

Renewable energy resources

Resource	Main uses	Source	Advantages	Disadvantages
solar energy	generating electricity	sunlight transfers energy to solar cells	can be used in remote places very cheap to run once installed no pollution/greenhouse gases produced	supply depends on weather expensive to buy and install cannot supply large scale demand
	heating	sunlight transfers energy to solar heating panels		
hydroelectric energy	generating electricity	water flowing downhill turns generators	low running cost no fuel costs reliable and supply can be controlled to meet demand	expensive to build hydroelectric dams flood a large area behind the dam, destroying habitats and resulting in greenhouse gas production from rotting vegetation
tidal energy	generating electricity	turbines on tidal barrages turned by water as the tide comes in and out	predictable supply as there are always tides can produce large amounts of electricity no fuel costs no pollution/greenhouse gases produced	tidal barrages: – change marine habitats and can harm animals – restrict access and can be dangerous for boats – are expensive to build and maintain cannot control supply supply varies depending on time of month
wave energy	generating electricity	floating generators powered by waves moving up and down	low running cost no fuel costs no pollution/greenhouse gases produced	floating generators: – change marine habitats and can harm animals – restrict access and can be dangerous for boats – are expensive to build, install, and maintain dependent on weather cannot supply large scale demand
wind energy	generating electricity	turbines turned by the wind	low running cost no fuel costs no pollution/greenhouse gases produced	supply depends on weather large amounts of land needed to generate enough electricity for large scale demand can produce noise pollution for nearby residents
geothermal energy	generating electricity heating	radioactive substances deep within the Earth transfer heat energy to the surface	low running cost no fuel costs no pollution/greenhouse gases produced	expensive to set up only possible in a few suitable locations around the world
biofuels	generating electricity transport	fuel produced from living or recently living organisms, for example, plants and animal waste	can be **carbon neutral** – the amount of carbon dioxide released when the fuel is burnt is equal to the amount of carbon dioxide absorbed when the fuel is grown reliable and supply can be controlled to meet demand	expensive to produce biofuels growing biofuels requires a lot of land and water that could be used for food production can lead to deforestation – forests are cleared for growing biofuel crops

Key terms

Make sure you can write a definition for these key terms.

biofuel · carbon neutral · environmental impact · fossil fuel · geothermal · hydroelectric · non-renewable · reliability · renewable

Chapter 3: Energy resources

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P3 questions	Answers
1	What is a non-renewable energy resource?	will eventually run out, is not replaced at the same rate it is being used
2	What is a renewable energy resource?	will not run out, it is being (or can be) replaced at the same rate as which it is used
3	What are the main renewable and non-renewable resources available on Earth?	renewable: solar, tidal, wave, wind, geothermal, biofuel, hydroelectric non-renewable: coal, oil, gas, nuclear
4	What are the main advantages of using coal as an energy resource?	enough available to meet current demand, reliable, can control supply to match demand, cheap to extract and use
5	What are the main disadvantages of using coal as an energy resource?	will eventually run out, releases CO_2 which contributes to climate change, releases sulfur dioxide which causes acid rain
6	What are the main advantages of using nuclear fuel as an energy resource?	lot of energy released from a small mass, reliable, can control supply to match demand, enough fuel available to meet current demand, no polluting gases
7	What are the main disadvantages of using nuclear fuel as an energy resource?	waste is dangerous and difficult and expensive to deal with, expensive initial set up, expensive to shut down and to run
8	What are the main advantages of using solar energy?	can be used in remote places, no polluting gases, no waste products, very low running cost
9	What are the main disadvantages of using solar energy?	unreliable, cannot control supply, initial set up expensive, cannot be used on a large scale
10	What are the main advantages of using tidal power?	no polluting gases, no waste products, reliable, can produce large amounts of electricity, low running cost, no fuel costs
11	What are the main disadvantages of using tidal power?	can harm marine habitats, initial set up expensive, cannot increase supply when needed, amount of energy varies on time of month, hazard for boats
12	What are the main advantages of using wave turbines?	no polluting gases produced, no waste products, low running cost, no fuel costs
13	What are the main disadvantages of using wave turbines?	unreliable, dependent on weather, cannot control supply, initial set up expensive, can harm marine habitats, hazard for boats, cannot be used on a large scale
14	What are the main disadvantages of using wind turbines?	unreliable, dependent on weather, cannot control supply, take up lot of space, can produce noise pollution
15	What are the advantages and the disadvantages of using geothermal energy?	advantages: no polluting gases, low running cost disadvantages: initial set up expensive, available in few locations
16	What are the main advantages and disadvantages of using biofuels?	advantages: can be ‘carbon neutral’, reliable disadvantages: expensive to produce, use land/water that might be needed to grow food
17	What are the main advantages and disadvantages of using hydroelectric power?	advantages: no polluting gases, no waste products, low running cost, no fuel cost, reliable, can be controlled to meet demand disadvantages: initial set up expensive, dams can harm/ destroy marine habitats

Chapter 4: Electric circuits

Knowledge organiser

Electric current

Electric current is when **charge** flows. The charge in an electric circuit is carried by electrons.

The unit of current is the ampere (amp, A).

1 ampere = 1 coulomb of charge flow per second

Charge (C) = current (A) x time (s)

In circuit diagrams, current flows from the positive terminal of a cell or battery to the negative terminal. This is known as conventional current.

In a single closed loop, the current has the same value at any point in the circuit.

Metals are good conductors of electricity because they contain delocalised electrons, which are free to flow through the structure.

Potential difference

Potential difference (p.d.) is a measure of how much energy is transferred between two points in a circuit. The unit of potential difference is the volt (V).

- The p.d. across a component is the work done on it by each coulomb of charge that passes through it.
- The p.d. across a power supply or battery is the energy transferred to each coulomb of charge that passes through it.

For electrical charge to flow through a circuit there must be a source of potential difference.

Potential difference (V) = energy transferred (J)/ charge (C)

Charge

An atom has no charge because it has equal numbers of positive protons and negative electrons.

When electrons are removed from an atom it becomes *positively* charged. When electrons are added to an atom it becomes *negatively* charged.

Resistance

When electrons move through a circuit, they collide with the ions and atoms of the wires and components in the circuit. This causes **resistance** to the flow of charge.

The unit of resistance is the ohm (Ω).

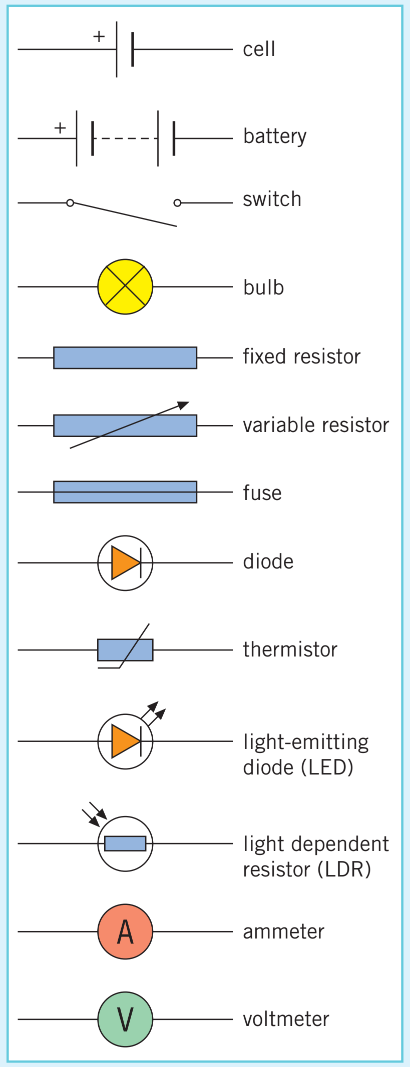
A long wire has more resistance than a short wire because electrons collide with more ions as they pass through a longer wire.

The resistance of an electrical component can be found by measuring the current and potential difference:

potential difference (V) = current (A) × resistance (Ω)

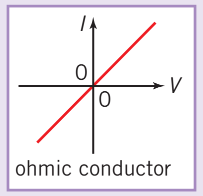
$V = IR$

Circuit components

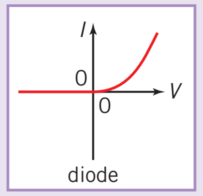


Current-potential difference graphs

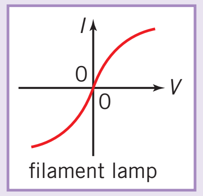
A graph of current through a component against the p.d. across it (I–V graph), is known as the component characteristic.



Current is directly proportional to the p.d. in an ohmic conductor at a constant temperature. The resistance is constant.



The current through a diode only flows in one direction – called the forward direction. There needs to be a minimum voltage before any current will flow.



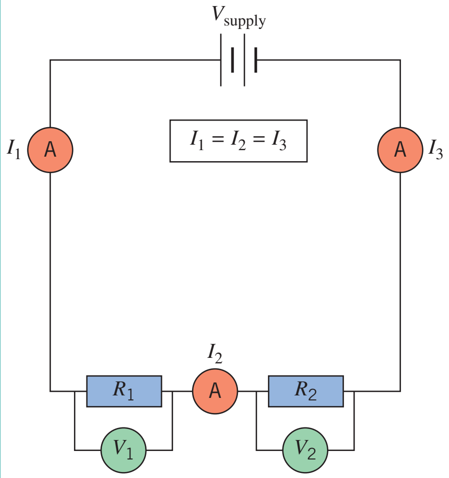
As more current flows through the filament, its temperature increases. The atoms in the wire vibrate more, and collide more often with electrons flowing through it, so resistance increases as temperature increases. The resistance of a thermistor decreases and temperature increases. The resistance of a light dependent resistor (LDR) decreases as light intensity increases.

The resistance of an ohmic conductor can be found by calculating the gradient at that point and taking the inverse:

$$\text{resistance} = \frac{1}{\text{gradient}}.$$

Series circuits

In a series circuit, the components are connected one after the other in a single loop. If one component in a series circuit stops working the whole circuit will stop working.



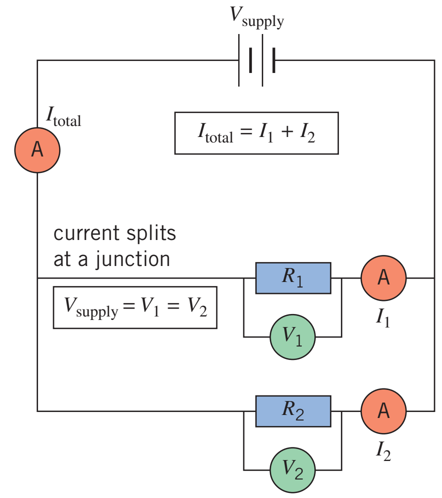
$V_1 + V_2 = V_{supply}$

$R_{total} = R_1 + R_2 + \ldots$

Components with a higher resistance will transfer a larger share of the total p.d. because $V = IR$ (and current is the same through all components).

Parallel circuits

A parallel circuit is made up of two or more loops through which current can flow. If one branch of a parallel circuit stops working, the other branches will not be affected.



The total resistance of two or more components in parallel is always less than the smallest resistance of any branch. This is because adding a loop to the circuit provides another route for the current to flow, so more current can flow in total even though the p.d. has not changed. Adding more resistors in parallel decreases the total resistance of a circuit.

Key terms

Make sure you can write a definition for these key terms.

ampere charge coulomb current electrostatic force LDR parallel potential difference resistance series thermistor

Chapter 4: Electric circuits

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P4 questions	Answers
1	What is electric current?	rate of flow of charge
2	What units are charge, current, and time measured in?	coulombs (C), amperes (A), seconds (s) respectively
3	What is the same at all points when charge flows in a closed loop?	current
4	What must there be in a closed circuit so that electrical charge can flow?	source of potential difference (p.d.)
5	Which two factors does current depend on and what are their units?	resistance in ohms (Ω), p.d. in volts (V)
6	What happens to the current if the resistance is increased but the p.d. stays the same?	current decreases
7	What is an ohmic conductor?	conductor where current is directly proportional to the voltage so resistance is constant (at constant temperature)
8	What happens to the resistance of a filament lamp as its temperature increases?	resistance increases
9	What happens to the resistance of a thermistor as its temperature increases?	resistance decreases
10	What happens to the resistance of a light-dependent resistor when light intensity increases?	resistance decreases
11	What are the main features of a series circuit?	same current through each component, total p.d. of power supply is shared between components, total resistance of all components is the sum of the resistance of each component
12	What are the main features of a parallel circuit?	p.d. across each branch is the same, total current through circuit is the sum of the currents in each branch – total resistance of all resistors is less than the resistance of the smallest individual resistor

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Chapter 5: Electricity in the home

Knowledge organiser

Mains electricity

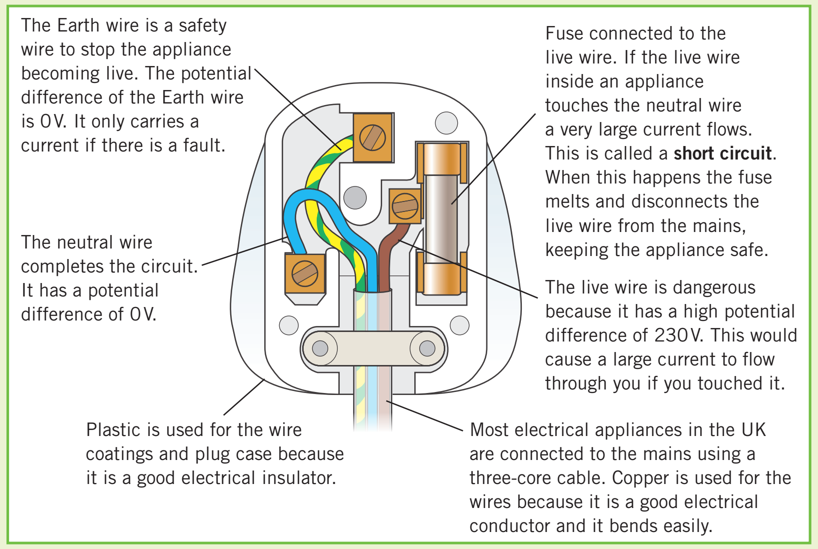
A cell or a battery provides a **direct current (dc)**. The current only flows in one direction and is produced by a **direct potential difference**.

Mains electricity provides an **alternating current (ac)**. The current repeatedly reverses direction and is produced by an **alternating potential difference**.

The positive and negative terminals of an alternating power supply swap over with a regular frequency.

The frequency of the mains electricity supply in the UK is 50 Hz and its voltage is 230 V.

Plugs



Why do transformers improve efficiency?

A high potential difference across the transmission cables means that a lower current is needed to transfer the same amount of power, since:

power (W) = current (A) × potential difference (V)

$$P = IV$$

A lower current in the cables means less electrical power is wasted due to heating of the cables, since the power lost in heating a cable is:

power (W) = current^2 (A) × resistance (Ω)

$$P = I^2R$$

This makes the National Grid an efficient way to transfer energy.

If 100% efficiency is assumed:

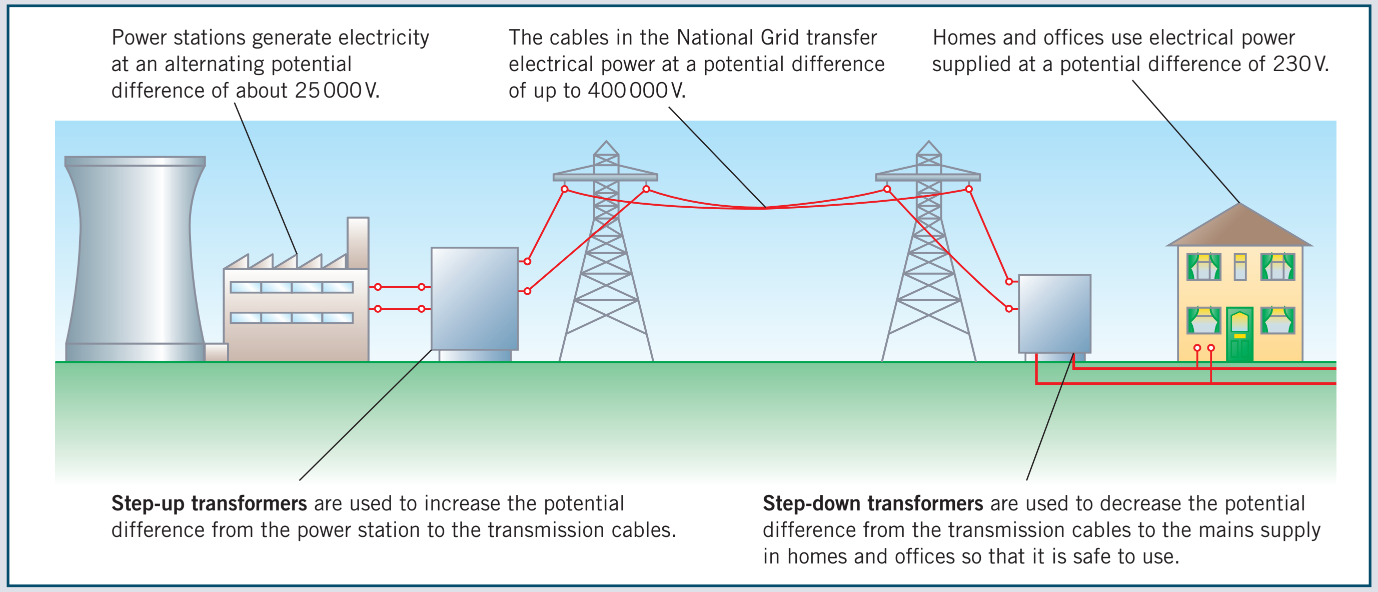
primary potential difference × primary current = secondary potential difference × secondary current

$$V_p I_p = V_s I_s$$

The National Grid

The **National Grid** is a nationwide network of cables and transformers that link power stations to homes, offices, and other consumers of mains electricity.

Transformers are devices that can change the potential difference of an alternating current.



By making the grid potential difference much higher, a smaller current is needed to transfer the same power. Therefore, the National Grid is an efficient way to transfer power due to less heating loss in the wire.

Energy transfer in electrical appliances

Electrical appliances transfer energy.

For example, an hairdryer transfers energy electrically from a chemical store (e.g., the fuel in a power station) to the kinetic energy store of the fan inside the hairdryer and to the thermal energy store of the heating filaments inside the hairdryer.

When you turn an electrical appliance on, the potential difference of the mains supply causes charge (carried by electrons) to flow through it.

You can calculate the **charge flow** using the equation:

charge flow (C) = current (A) × time (s)

$$Q = It$$

You can find the energy transferred to an electrical appliance when charge flows through it using:

energy transferred (J) = charge flow (C) × potential difference (V)

$$E = QV$$

You can find the energy transferred by an electrical appliance using the equation:

energy transferred (J) = power (W) x time (s)

Key terms

Make sure you can write a definition for these key terms.

alternating current
alternating potential difference
charge flow
coulombs
direct current
direct potential difference
fuse
National Grid
short circuit
step-down transformer
step-up transformer

Chapter 5: Electricity in the home

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P5 questions	Answers
1	Why is the current provided by a cell called a direct current (d.c.)?	only flows in one direction
2	What is an alternating current (a.c.)?	current that repeatedly reverses direction
3	What kind of current is supplied by mains electricity?	alternating current
4	What is the frequency and voltage of mains electricity?	50 Hz, 230 V
5	What colours are the live, neutral, and earth wires in a three-core cable?	live = brown, neutral = blue, earth = green and yellow stripes
6	What is the function of the live wire in a three-core cable?	carries the alternating potential difference from the supply
7	What is the function of the neutral wire in a three-core cable?	completes the circuit
8	What is the function of the earth wire in a three-core cable?	safety wire to stop the appliance becoming live
9	When is there a current in the earth wire?	when there is a fault
10	Why is the live wire dangerous?	provides a large p.d. that would cause a large current to flow through a person if they touched it
11	What is the National Grid?	nationwide network of cables and transformers that link power stations to customers
12	What are step-up transformers used for in the National Grid?	increase the p.d. from the power station to the transmission cables
13	What are step-down transformers used for in the National Grid?	decrease the p.d. from the transmission cables to the mains supply in buildings so that it is safe to use
14	How does having a large potential difference in the transmission cables help to make the National Grid an efficient way to transfer energy?	large p.d. means a small current is needed to transfer the same amount of power, small current in the transmission cables means less electrical power is wasted due to heating
15	What two things does energy transfer to an appliance depend on?	power of appliance, time it is switched on for
16	What are the units for power, current, potential difference, and resistance?	watts (W), amps (A), volts (V), ohms (Ω)

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Chapter 6: Molecules and matter

Knowledge organiser

Changes of state

Changes of state and conservation of mass

Changes of state are physical changes because no new substances are produced. The mass always stays the same because the number of particles does not change.

Particles and kinetic energy

When the temperature of a substance is increased, the kinetic energy store of its particles increases and the particles vibrate or move faster.

If the kinetic store of a substance's particles increases or decreases enough, the substance may change state.

Density

You can calculate the density of an object if you know its mass and volume:

$$\text{density (kg/m}^3\text{)} = \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$$

$$\rho = \frac{m}{V}$$

L

States of matter

State		
Gas	**Arrangement**	• particles are spread out • almost no forces of attraction between particles • large distance between particles on average
Gas	**Movement**	• particles move randomly at high speed
Gas	**Properties**	• low density • no fixed volume or shape • can be compressed and can flow • spread out to fill all available space
Liquid	**Arrangement**	• particles are in contact with each other • forces of attraction between particles are weaker than in solids
Liquid	**Movement**	• particles are free to move randomly around each other
Liquid	**Properties**	• usually lower density than solids • fixed volume • shape is not fixed so they can flow
Solid	**Arrangement**	• particles held next to each other in fixed positions by strong forces of attraction
Solid	**Movement**	• particles vibrate about fixed positions
Solid	**Properties**	• high density • fixed volume • fixed shape (unless deformed by an external force)

Internal energy

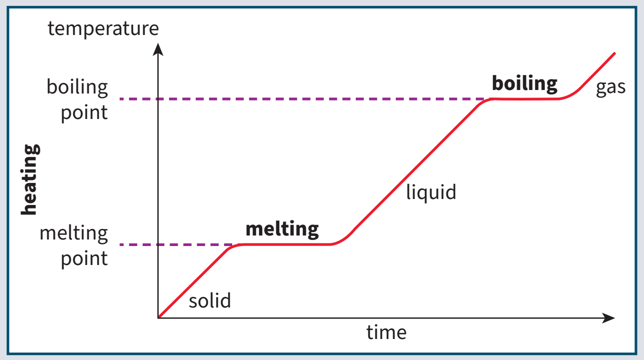
Heating a substance increases its **internal energy**.

Internal energy is the sum of the total kinetic energy the particles have due to their motion and the total potential energy the particles have due to their positions relative to each other.

Latent heat

In a graph showing the change in temperature of a substance being heated or cooled, the flat horizontal sections show when the substance is changing state.

The energy transfers taking place during a change in state do not cause a change in temperature, but do change the internal energy of the substance.



The energy transferred when a substance changes state is called the **latent heat**.

Specific latent heat – the energy required to change 1 kg of a substance with no change in temperature.

Specific latent heat of fusion – the energy required to melt 1 kg of a substance with no change in temperature.

Specific latent heat of vaporisation – the energy required to evaporate 1 kg of a substance with no change in temperature.

The energy needed to change the state of a substance can be calculated using the equation:

$$\text{thermal energy for a change in state (J)} = \text{mass (kg)} \times \text{specific latent heat (J/kg)}$$

$$E = m \times l$$

The relationship between temperature and pressure in gases

Gas temperature

The particles in a gas are constantly moving in random directions and with random speeds.

The temperature of a gas is related to the average kinetic energy of its particles.

When a gas is heated, the particles gain kinetic energy and move faster, so the temperature of the gas increases.

Gas pressure

The pressure a gas exerts on a surface, such as the walls of a container, is caused by the force of the gas particles hitting the surface.

The pressure of a gas produces a net force at right angles to the walls of a container or any surface.

If the temperature of a gas in a sealed container is increased, the pressure increases because

- the particles move faster so they hit the surfaces with more force
- the number of these impacts per second increases, exerting more force overall.

If a gas is compressed quickly, for example, in a bicycle pump, its temperature can rise. This is because

- compressing the gas requires a force to be applied to the gas – this results in work being done to the gas, since work done = force × distance
- the energy gained by the gas is not transferred quickly enough to its surroundings.

Key terms

Write a definition for these key terms.

boiling, condensation, conservation of mass, density, evaporation, freezing, fusion, internal energy, latent heat, melting, specific latent heat, sublimation, vaporisation

Chapter 6: Molecules and matter

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

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	P6 questions	Answers
1	Which two quantities do you need to measure to find the density of a solid or liquid?	mass and volume
2	What happens to the particles in a substance if its temperature is increased?	they move faster and the energy in their kinetic energy store increases
3	Why are changes of state physical changes?	no new substances are produced and the substance will have the same properties as before if the change is reversed
4	Why is the mass of a substance conserved when it changes state?	the number of particles does not change
5	What is the internal energy of a substance?	the total kinetic energy and potential energy of all the particles in the substance
6	Why does a graph showing the change in temperature as a substance cools have a flat section when the substance is changing state?	the energy transferred during a change in state causes a change in the internal energy of the substance
7	What is the name given to the energy transferred when a substance changes state?	latent heat
8	What is the specific latent heat of a substance?	the energy required to change the state of one kilogram of that substance with no change in temperature
9	What is the specific latent heat of fusion a substance?	the energy required to change one kilogram of the substance from solid to liquid at its melting point, without changing its temperature
10	What is the specific latent heat of vaporisation of a substance?	the energy required to change one kilogram of the substance from liquid to vapour at its boiling point, without changing its temperature
11	On a graph of temperature against time for a substance being heated up or cooled down, what do the flat (horizontal) sections show?	the time when the substance is changing state and the temperature is not changing
12	What property of a gas is related to the average kinetic energy of its particles?	temperature

Chapter 7: Radioactivity

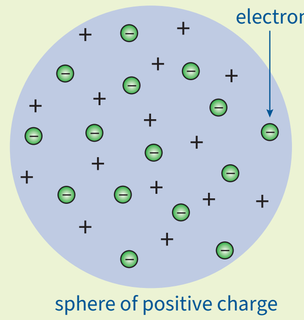
Knowledge organiser

Dalton's model

John Dalton thought the atom was a neutral solid sphere you cannot divide into smaller parts.

Plum pudding model

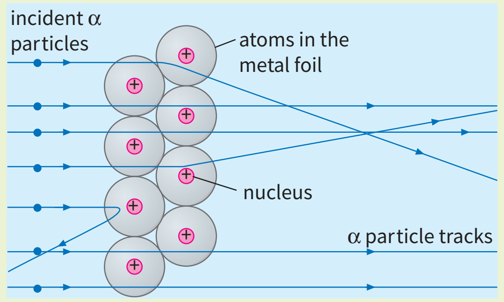
The discovery of negatively charged electrons led to the plum pudding model – a cloud of positive charge with electrons embedded in it.



Alpha scattering experiment

Positively charged alpha particles were fired at a thin sheet of gold foil.

- Most went straight through
- Some were deflected by small amounts
- 1 in 10 0000 deflected through large angles



Nuclear model

To explain the results, scientists deduced that there is a small positively charged nucleus at the centre of the atom where most of the mass is concentrated. The negative electrons orbit the nucleus.

Bohr's model

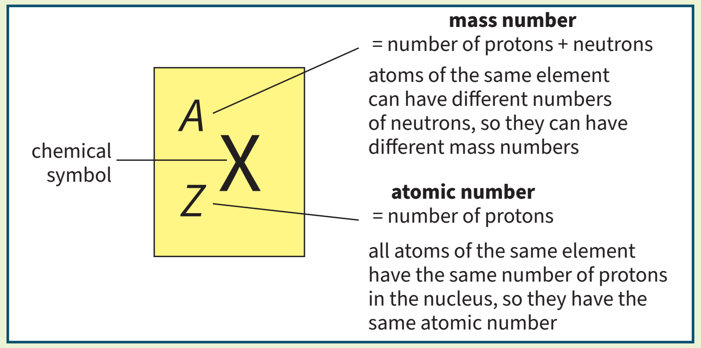
Bohr suggested the electrons orbit at specific distances called energy levels.

Basic structure of an atom

The nucleus, which is 10 000 times smaller than the radius of the atom, consists of two particles:

- positively charged protons
- neutrons which are neutral

An atom is uncharged overall and has equal numbers of protons and electrons.



Isotopes are atoms of the same element, with the same number of protons but a different numbers of neutrons.

Radioactive decay

Radioactive decay is when nuclear radiation is emitted by unstable atomic nuclei so that they become more stable. It is a *random* process. This radiation can knock electrons out of atoms in a process called **ionisation**.

Type of radiation	Change in the nucleus	Ionising power	Range in air	Stopped by	Decay equation
α alpha particle (two protons and two neutrons)	nucleus loses two protons and two neutrons	highest ionising power	travels a few centimetres in air	stopped by a sheet of paper	$^{A}_{Z}X \rightarrow {}^{(A-4)}_{(Z-2)}Y + {}^{4}_{2}\alpha$
β beta particle (fast-moving electron)	a neutron changes into a proton and an electron	high ionising power	travels ≈ 1 m in air	stopped by a few millimetres of aluminium	$^{A}_{Z}X \rightarrow {}^{A}_{(Z+1)}Y + {}^{0}_{-1}\beta$
γ gamma radiation (short-wavelength, high-frequency EM radiation)	some energy is transferred away from the nucleus	low ionising power	virtually unlimited range in air	stopped by several centimetres of thick lead or metres of concrete	$^{A}_{Z}X \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$

Half-life

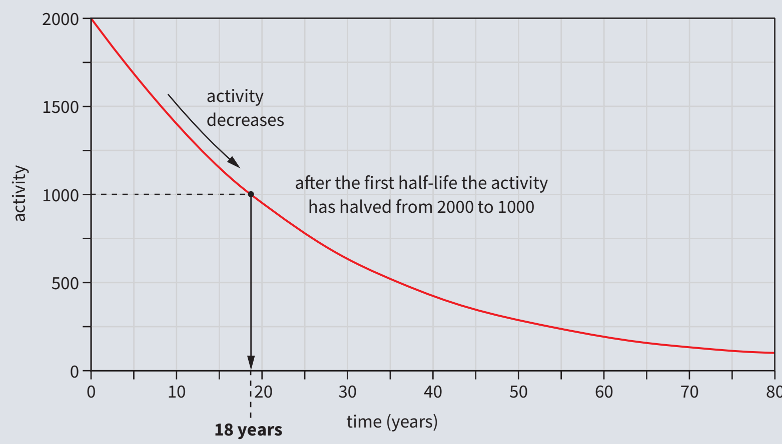
The **half-life** of a radioactive source is the time

- for half the number of unstable nuclei in a sample to decay
- for the count rate or activity of a source to halve.

The half-life of a source can be found from a graph of its count rate or activity against time.

To find the reduction in activity after a given number of half-lives:

1. calculate the activity after each half-life
2. subtract the final activity from the original activity.



The time taken for the activity to halve is 18 years. This is the half-life of this substance.

(HT only) Net decline can be given as a ratio: $\textit{net daecline} = \dfrac{\textit{reduction in activity}}{\textit{original activity}}$

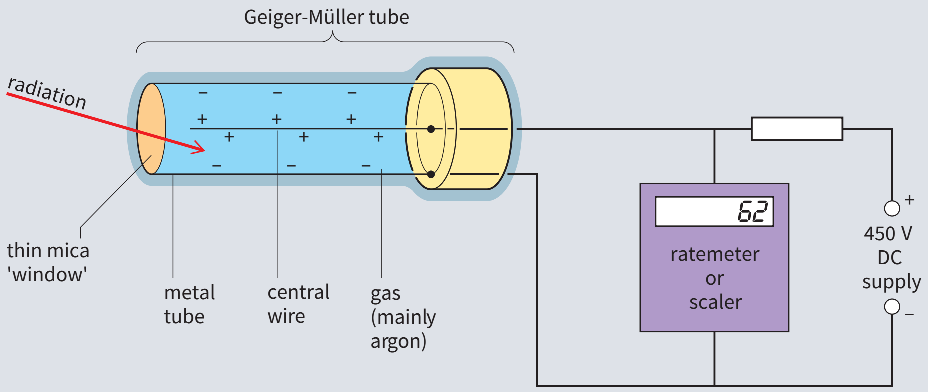
Activity and count rate

The **activity** of a radioactive source is the rate of decay of an unstable nucleus, measured in becquerel (Bq).

1 Bq = 1 decay per second

Detectors (e.g., **Geiger-Müller tubes**) record a **count rate** (number of decays detected per second).

$$\textit{count rate after } n \textit{ half-lives} = \frac{\textit{initial count rate}}{2^n}$$



Key terms

Make sure you can write a definition for these key terms.

atom alpha activity atomic number beta count rate electron gamma Geiger-Müller tube half-life ionisation irradiation isotope mass number net decline neutron plum pudding model proton radiation dose radioactive decay

Chapter 7: Radioactivity

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P7 questions	Answers
1	Describe the basic structure of an atom.	nucleus containing protons and neutrons, around which electrons orbit in fixed energy levels/shells
2	Describe the plum pudding model of the atom.	sphere of positive charge with negative electrons embedded in it
3	What charges do protons, neutrons, and electrons carry?	protons = positive, neutrons = no charge, electrons = negative
4	Why do atoms have no overall charge?	equal numbers of positive protons and negative electrons
5	What is the radius of an atom?	around 1×10^{-10} m
6	What is ionisation?	process which adds or removes electrons from an atom
7	What is the mass number of an element?	number of protons + number of neutrons
8	Which particle do atoms of the same element always have the same number of?	protons
9	What are isotopes?	atoms of the same element (same number of protons) with different numbers of neutrons
10	What were the two main conclusions from the alpha particle scattering experiment?	• most of the mass of an atom is concentrated in the nucleus • nucleus is positively charged
11	What are the three types of nuclear radiation?	alpha, beta, and gamma
12	Which type of nuclear radiation is the most ionising?	alpha
13	What is the range in air of alpha, beta, and gamma radiation?	a few cm, 1 m, and unlimited, respectively
14	What are the equation symbols for alpha and beta particles?	$^{4}_{2}\alpha$ and $^{0}_{-1}\beta$
15	What is meant by the half-life of a radioactive source?	time taken for half the unstable nuclei to decay or the time taken for the count rate to halve

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Scalars and vectors

Scalar quantities only have a magnitude (e.g., distance and speed).

Vector quantities have a magnitude *and* a direction (e.g., velocity and displacement).

Forces

A **force** can be a push or pull on an object caused by an interaction with another object. Forces are vector quantities.

Contact forces occur when two objects are touching each other.

For example, friction, air-resistance, tension, and normal contact force.

Non-contact forces act at a distance (without the two objects touching).

For example, gravitational force, electrostatic force, and magnetic force.

Newton's Third Law

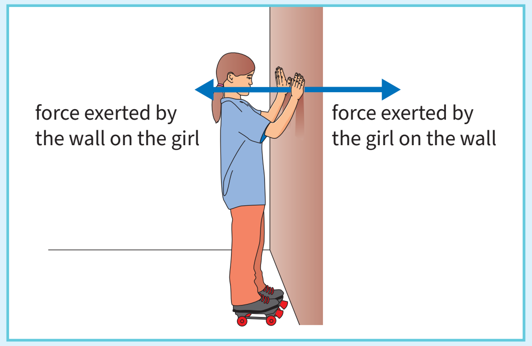
Newton's Third Law states that whenever two objects interact with each other, they exert *equal and opposite* forces on each other.

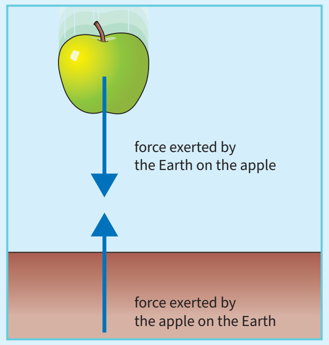
This means that forces always occur in pairs.

Each pair of forces:

- act on separate objects
- are the same size as each other
- act in opposite directions along the same line
- are of the same type, for example, two gravitational forces or two electrostatic forces.

Force pairs





Resultant forces

If two or more forces act on an object along the same line, their effect is the same as if they were replaced with a single **resultant force**. The resultant force is

- the sum of the magnitudes of the forces if they act in the same direction
- the difference between the magnitudes of the forces if they act in opposite directions.

If the resultant force on an object is zero, the forces are said to be **balanced**.

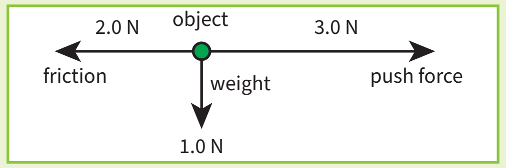
Newton's First law

Newton's First Law states that the velocity, speed, and/or direction of an object will only change if a resultant force is acting on it. This means that:

- if the resultant force on a stationary object is zero, the object will remain stationary
- if the resultant force on a moving object is zero, it will continue moving at the same velocity, in a straight line.

Drawing forces

Free body diagrams use arrows to show all of the forces acting on a single object. For example:



A dot or circle represents the object, with the forces drawn as arrows:

- the arrow length represents the magnitude of the force
- the arrow direction shows the direction of the force.

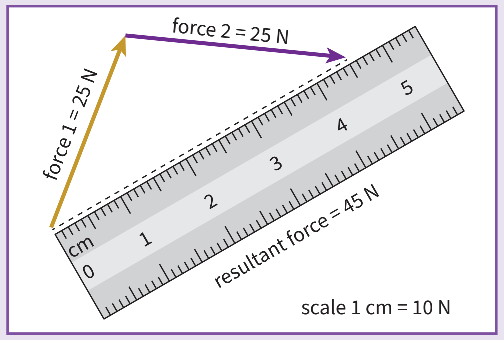
Key terms

Make sure you can write a definition for these key terms.

balanced, centre of mass, contact force, free body diagram, force pair, force, Newton's First Law, non-contact force, resultant, scalar, vector

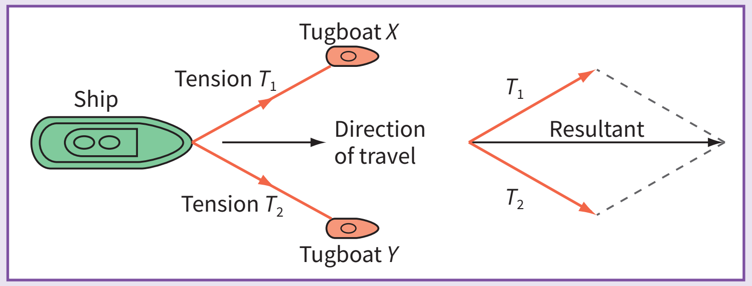
Scale drawings (HT only)

Scale drawings can be used to find the resultant of two forces which are not acting along the same line.



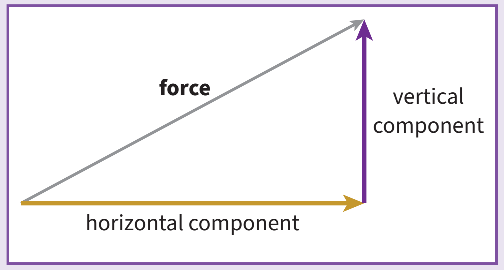
The forces are drawn end to end. The resultant can then be drawn between the two ends, forming a triangle.

You can use the parallelogram of forces where the two forces are drawn to scale as sides of a parallelogram.



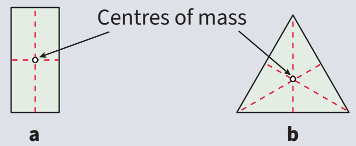
Resolving forces

A single force can always be resolved (split) into two component forces at right angles to each other:



The two component forces added together give the same effect as the single force.

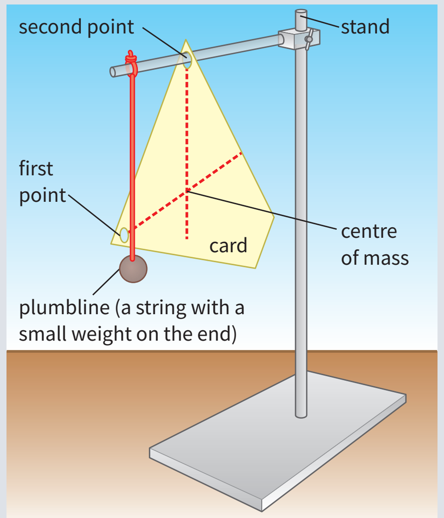
Centre of mass



For a flat symmetrical object, the centre of mass is where the axes of symmetry meet.

The point through which the weight of an object can be considered to act.

For a flat irregularly shaped object, find the centre of mass by suspending the object from different points. The centre of mass always lies beneath the point of suspension.



Chapter 8: Forces in balance

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P8 questions	Answers
1	What is a scalar quantity?	only has a size (magnitude)
2	What is a vector quantity?	has both a size and direction
3	What is a force?	a push or pull that acts on an object due to the interaction with another object
4	Is force a vector or scalar quantity?	vector
5	What is a contact force?	when objects are physically touching (e.g., friction, air-resistance, tension, normal contact force)
6	What is a non-contact force?	when objects are physically separated (e.g., gravitational, electrostatic, magnetic)
7	What is the same about the interaction pair of forces when two objects interact with each other?	the forces are the same size
8	What is different about the interaction pair of forces when two objects interact with each other?	forces are in opposite directions
9	What is the size of the resultant force on an object if the forces on it are balanced?	zero
10	What is the centre of mass?	the point through which the weight of an object can be considered to act
11	What can you say about clockwise and anticlockwise moments on a balanced object?	sum of all the clockwise moments about any point = sum of all the anticlockwise moments about that point
12	What does Newton's First Law say?	the velocity of an object will only change if a resultant force is acting on it
13	What is the resultant force on a stationary object?	zero
14	What is the resultant force on an object moving at a steady speed in a straight line?	zero
15	What does Newton's Third Law say?	when two objects interact they exert equal and opposite forces on each other

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Chapter 9: Motion

Knowledge organiser

Speed

distance travelled (m) = speed (m/s) × time (s)

$$s = v \times t$$

The symbol for distance is s, and the symbol for speed is v.

In reality, objects rarely move at a constant speed. So it can be useful to calculate average speed:

$$\text{average speed (m/s)} = \frac{\text{total distance travelled (m)}}{\text{total time taken (s)}}$$

Some typical average speeds are:

- walking ≈ 1.5 m/s
- running ≈ 3 m/s
- cycling ≈ 6 m/s

The speed of sound and the speed of the wind also change depending on the conditions. A typical value for the speed of sound is 300 m/s

Velocity

The **velocity** of an object is its speed in a given direction.

Velocity is a vector quantity because it has a magnitude and direction.

An object's velocity changes if its direction changes, even if its speed is constant.

An object moving in a circle can have a constant speed but its velocity is always changing because its direction is always changing.

Acceleration

Acceleration is the change in velocity of an object per second. It is a vector quantity.

The unit of acceleration is metres per second squared, m/s².

An object is accelerating if its speed or its direction (or both) are changing. A negative acceleration means an object is slowing down, and is called **deceleration**.

Acceleration can be calculated using:

$$\text{acceleration (m/s}^2) = \frac{\text{change in velocity (m/s)}}{\text{time taken (s)}}$$

$$a = \frac{\Delta v}{t}$$

Uniform acceleration is when the acceleration of an object is constant.

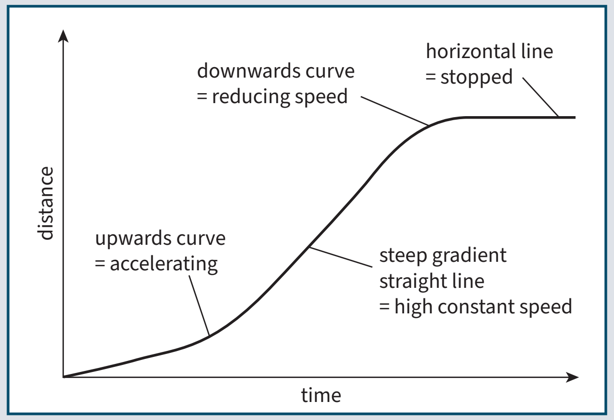
The following equation applies to objects with uniform acceleration:

(final velocity)^2 – (initial velocity)^2 = 2 × acceleration × distance

$$v^2 - u^2 = 2as$$

Distance–time graphs

A distance–time graph shows how the distance travelled by an object travelling in a straight line changes with time.

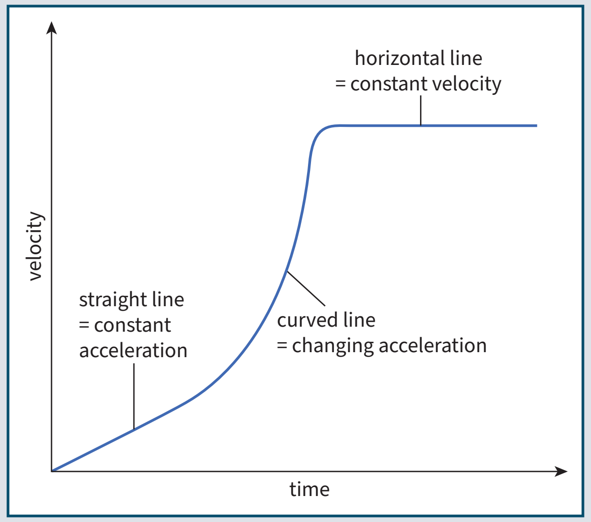


The gradient of the line in a distance–time graph is equal to the object's speed.

If the object is accelerating, the speed at any time can be found by calculating the gradient of a tangent to the curved line at that time.

Velocity–time graphs

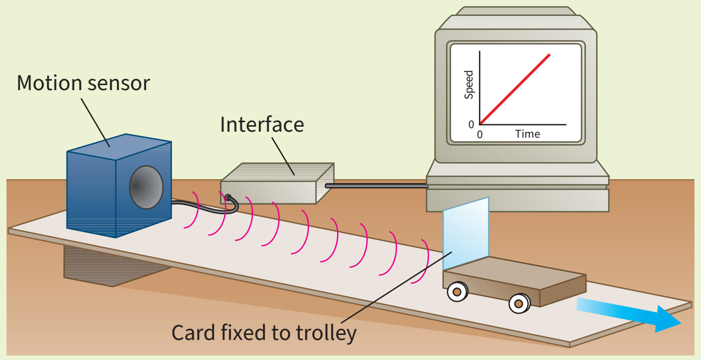
A velocity–time graph shows how the velocity of an object changes with time.



The gradient of the line in a velocity–time graph is equal to the object's acceleration.

Investigating acceleration

Motion sensors which are attached to a computer can be used to record how the velocity of an object changes.

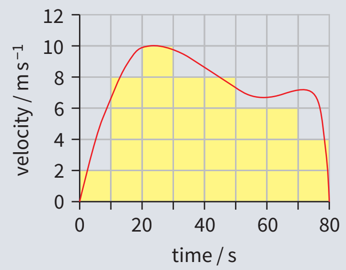


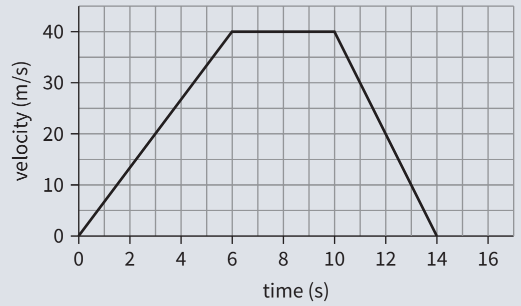
As the trolley accelerates down the runway, the velocity increases with time. Therefore, the line on the graph will go up and remain straight to suggest that the acceleration of the trolley is constant.

Alternatively, making the runway steeper will mean the trolley accelerates faster, and the line on the graph will be steeper.

Displacement (HT only)

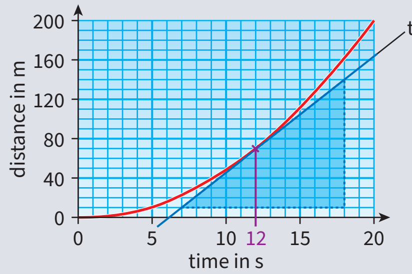
The displacement of an object, or the distanced travelled by an object, can be calculated from the area under a velocity-time graph. This can be done by measuring or counting squares.

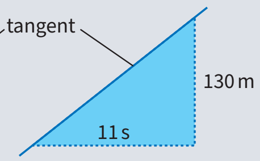




Finding the gradient of a tangent (HT only)

A **tangent** is a straight line which touches the curve at a point and is drawn in the direction of the slope at that point.





at time = 12 s,

gradient of triangle = $\frac{\text{height}}{\text{base}}$

speed = gradient of triangle = $\frac{130\text{ m}}{11\text{ s}}$ = 11.8 m/s

The speed at 12 seconds is 118 m/s

Key terms

Make sure you can write a definition for these key terms.

acceleration | deceleration | displacement | gradient | speed | tangent | uniform acceleration | velocity

Chapter 9: Motion

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P9 questions	Answers
1	How do you find the speed from a distance-time graph if the object is accelerating?	Draw a tangent to the curve and find the gradient.
2	What is the difference between speed and velocity?	speed is a scalar quantity and only has a magnitude (size), velocity is a vector quantity and has both magnitude and direction
3	What factors can affect the speed at which someone walks, runs, or cycles?	age, fitness, terrain, and distance travelled
4	What are typical speeds for a person walking, running, and cycling?	1.5 m/s, 3.0 m/s, and 6.0 m/s respectively
5	What are typical speeds of a car and a train?	13–30 m/s and 50 m/s respectively
6	What is a typical speed for sound travelling in air?	330 m/s
7	What is acceleration?	change in velocity of an object per second
8	What is the unit of acceleration?	m/s^2
9	How can an object be accelerating even if it is travelling at a steady speed?	if it is changing direction
10	What is happening to an object if it has a negative acceleration?	it is slowing down
11	What information does the gradient of the line in a distance–time graph provide?	speed
12	What information does the gradient of the line in a velocity–time graph provide?	acceleration
13	How can the distance travelled by an object be found from its velocity–time graph?	calculate the area under the graph

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Chapter 10: Force and motion 1

Knowledge organiser

Force and acceleration

If the velocity of an object changes it must be acted on by a **resultant force**. The acceleration is always in the same direction as the resultant force.

Gravity

The force of **gravity** close to the Earth is due to the planet's **gravitational field strength**.

Weight is the force acting on an object due to gravity.

The weight of an object

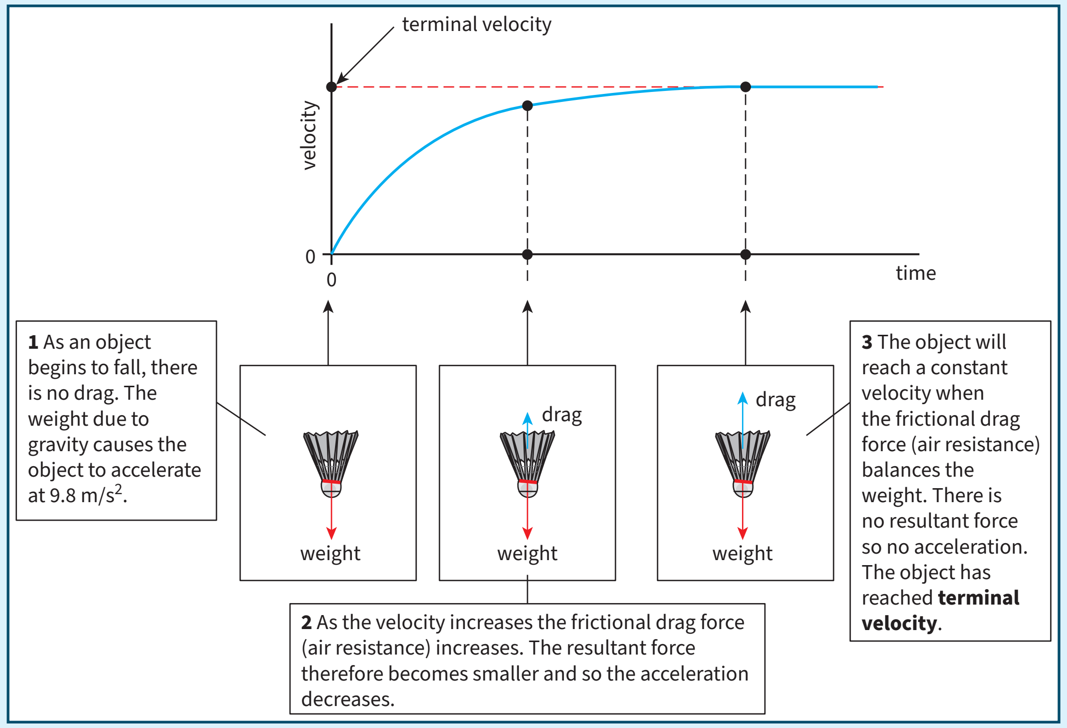
- can be considered to act at the object's **centre of mass**
- can be measured using a calibrated spring-balance (newtonmeter).

(L) weight (N) = mass (kg) × gravitational field strength (N/kg)

$$W = m\,g$$

Weight and mass are directly proportional to each other, which can be written as $W \propto m$, so as the mass of an object doubles, its weight doubles.

Graph of terminal velocity



Newton's Second Law

Newton's Second Law says that the acceleration a of an object:

- is proportional to the resultant force on the object

$$a \propto F$$

- is inversely proportional to the mass of the object

$$a \propto \frac{1}{m}$$

Resultant force, mass and acceleration are linked by the equation:

(L) resultant force (N) = mass (kg) × acceleration (m/s²)

$$F = ma$$

The **inertial mass** of an object is a measure of how difficult it is to change the velocity of an object. It can be found using:

$$\text{inertial mass (kg)} = \frac{\text{force (N)}}{\text{acceleration (m/s}^2\text{)}}$$

$$m = \frac{F}{a}$$

Terminal velocity

For an object falling through a fluid:

- there are two forces acting – its weight due to gravity and the drag force
- the weight remains constant
- the drag force is small at the beginning, but gets bigger as it speeds up
- the resultant force will get smaller as the drag force increases
- the acceleration will decrease as it falls
- if it falls for a long enough time, the object will reach a final steady speed.

Terminal velocity is the constant velocity a falling object reaches when the frictional force acting on it is equal to its weight.

If an object is only acted on by gravity the acceleration will be 9.8 m/s²

Momentum (HT only)

Momentum is a property of all moving objects. It is a vector quantity.

Momentum depends on the mass and velocity of an object and is defined by the equation:

momentum (kg m/s) = mass (kg) × velocity (m/s)

(L)

$$p = mv$$

Law of Conservation of Momentum

The **Law of Conservation of Momentum** states that:

In a closed system, the total momentum before an event (e.g., a collision or an explosion) is *equal* to the momentum after an event.

If two moving objects collide the law of conservation can be written as:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

m_1 = mass of object 1

m_2 = mass of object 2

u_1 = initial velocity of object 1

u_2 = initial velocity of object 2

v_1 = final velocity of object 1

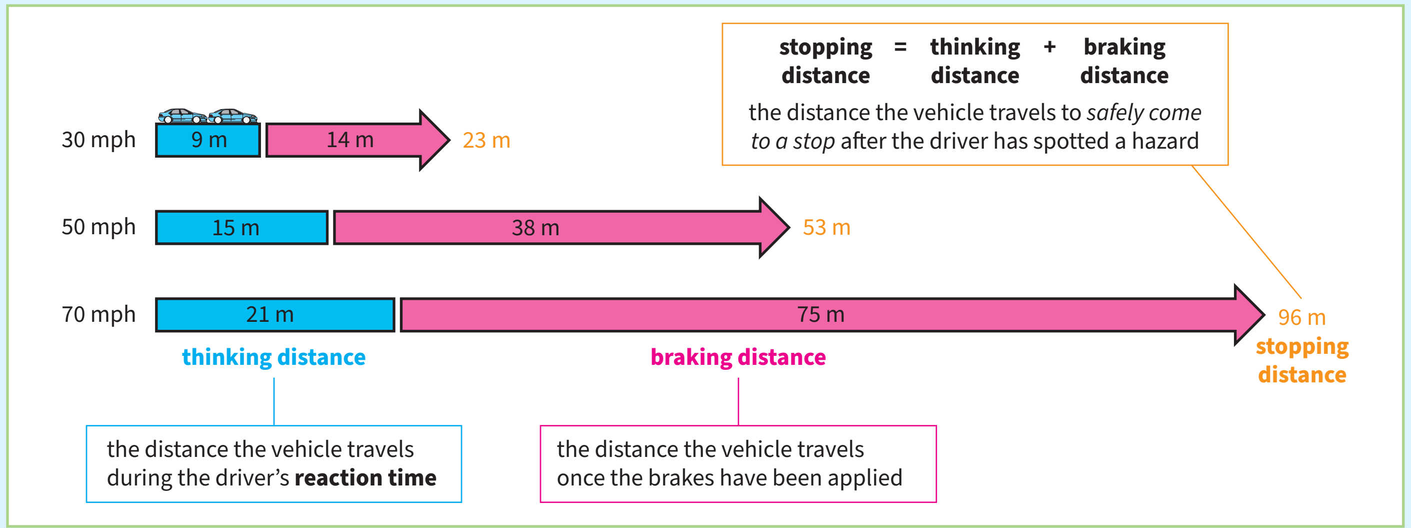
v_2 = final velocity of object 2

Key terms

Make sure you can write a definition for these key terms.

acceleration | centre of mass | gravitational field strength | inertia | inertial mass | momentum | Newton's Second Law | recoil | resultant force | terminal velocity | weight

Forces and braking



Factors affecting braking distance:

- speed of the car
- road conditions
- conditions of the brakes and the tyres

Factors affecting thinking distance:

- speed of the car
- tiredness
- drugs
- alcohol
- distractions

Deceleration (HT only)

Deceleration of a vehicle can be calculated using the equation

$v^2 = u^2 + 2as$

where s is the distance travelled, u is the initial speed, and v is the final speed.

Deformation

Deformation is a change in the shape of an object caused by stretching, squashing (compressing), bending, or twisting.

More than one force has to act on a stationary object to deform it, otherwise the force would make it move.

Elastic deformation – the object can go back to its original shape and size when the forces are removed.

Inelastic deformation – the object does not go back to its original shape or size when the forces are removed.

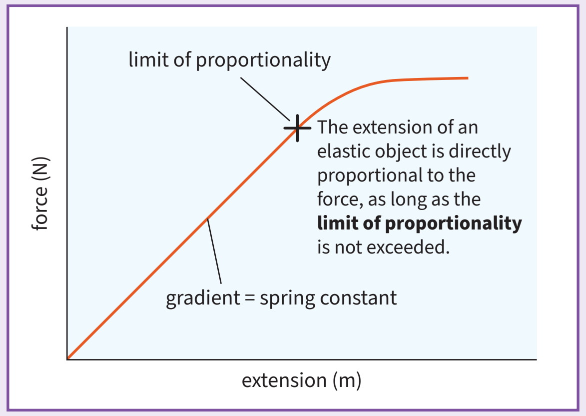
Graphs of force against extension for elastic objects

The spring constant can be calculated using the equation:

L *force applied* (N) = *spring constant* (N/m) × *extension* (m)

$$F = k\,e$$

This relationship also applies to compressing an object, where e would be compression instead of extension.



Key terms

Make sure you can write a definition for these key terms.

braking distance *deceleration* *deformation* *elastic* *inelastic* *limit of proportionality* *reaction time* *stopping distance* *thinking distance*

Chapter 10: Force and motion

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P10 questions	Answers
1	What is the name given to the distance a vehicle travels to safely come to a stop after the driver has spotted a hazard?	stopping distance
2	What is thinking distance?	the distance vehicle travels during driver's reaction time
3	What is braking distance?	the distance vehicle travels once brakes have been applied
4	What is the relationship between stopping distance, thinking distance, and braking distance?	stopping distance = thinking distance + braking distance
5	Does the speed of a vehicle have a bigger effect on braking distance or thinking distance?	braking distance
6	Which distance is proportional to the speed of the vehicle?	thinking distance
7	What are three factors that can affect the braking distance of a vehicle?	speed, road conditions, condition of tyres and brakes
8	What can happen if the braking force used to stop a vehicle is very large?	brakes may overheat / the car may skid
9	What is elastic deformation?	an object can go back to its original shape and size when deforming forces are removed
10	What is inelastic deformation?	an object does not go back to its original shape and size when deforming forces are removed
11	How do you find the spring constant from a force-extension graph of a spring?	find the gradient of the straight line section

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Chapter 11: Wave properties

Knowledge organiser

Waves in air, fluids, and solids

Waves transfer energy from one place to another without transferring matter. Waves may be **transverse** or **longitudinal**.

For waves in water and air, it is the wave and not the substance that moves.

- When a light object is dropped into still water, it produces ripples (waves) on the water which spread out, but neither the object nor the water moves with the ripples.
- When you speak, your voice box vibrates, making sound waves travel through the air. The air itself does not travel away from your throat, otherwise a vacuum would be created.

Mechanical waves require a substance (a medium) to travel through.

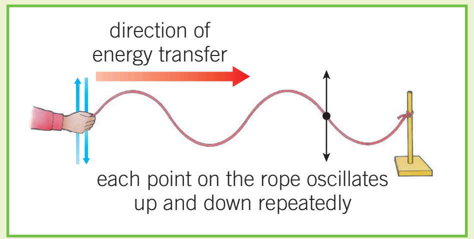
Examples of mechanical waves include sound waves, water waves, waves on springs and ropes, and seismic waves produced by earthquakes.

When waves travel through a substance, the particles in the substance **oscillate** (vibrate) and pass energy on to neighbouring particles.

Transverse waves

The oscillations of a transverse wave are *perpendicular* (at right angles) to the direction in which the waves transfer energy.

Ripples on the surface of water are an example of transverse waves.

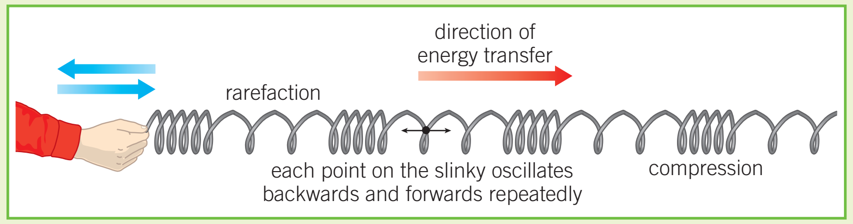


Longitudinal waves

The oscillations of a longitudinal wave are *parallel* to the direction in which the waves transfer energy.

Longitudinal waves cause particles in a substance to be squashed closer together and pulled further apart, producing areas of **compression** and **rarefaction** in the substance.

Sound waves in air are an example of longitudinal waves.



Wave motion is described by a number of properties.

Property	Description	Unit
amplitude A	maximum displacement of a point on a wave from its undisturbed position	metre (m)
frequency f	number of waves passing a fixed point per second	hertz (Hz)
period T	time taken for one complete wave to pass a fixed point	second (s)
wavelength λ	distance from one point on a wave to the equivalent point on the next wave	metre (m)
wave speed v	distance travelled by each wave per second, and the speed at which energy is transferred by the wave	metres per second (m/s)

Properties of waves

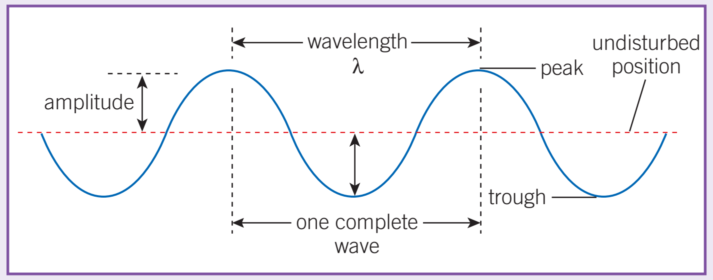
Frequency and period are related by the equation:

$$\text{period (s)} = \frac{1}{\text{frequency (Hz)}} \qquad T = \frac{1}{f}$$

All waves obey the wave equation:

$$\text{wave speed (m/s)} = \text{frequency (Hz)} \times \text{wavelength (m)}$$

$$v = f\lambda$$



When waves travel from one medium to another, their speed and wavelength may change but the frequency always stays the same.

The speed of ripples on water can be slow enough to measure using a stopwatch and ruler, and applying the equation:

$$\text{speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$

The speed of sound in air can be measured by using a stopwatch to measure the time taken for a sound to travel a known distance, and applying the same equation.

Reflection of waves

When waves arrive at the boundary between two different substances, one or more of the following things can happen:

Absorption – the energy of the waves is transferred to the energy stores of the substance they travel into (for example, when food is heated in a microwave)

Reflection – the waves bounce back

Refraction – the waves change speed and direction as they cross the boundary

Transmission – the waves carry on moving once they've crossed the boundary, but may be refracted

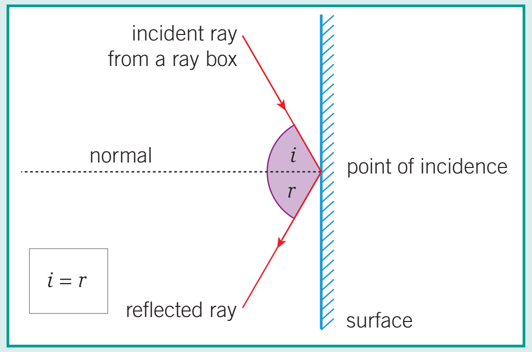
Ray diagrams can be used to show what happens when a wave is reflected at a surface.

To correctly draw a ray diagram for reflection:

1. use a ruler to draw all lines for the rays
2. draw a single arrow on the rays to show the direction the wave is travelling
3. draw a dotted line at right angles to the surface at the point of **incidence** (this line is normal to the surface)
4. label the normal, angle of incidence (i), and angle of reflection (r).

When reflection happens at a surface, the angle of incidence is always equal to the angle of reflection:

$$i = r$$



Key terms

Make sure you can write a definition for these key terms.

absorption · amplitude · compression · frequency · incidence · longitudinal · mechanical wave · oscillate · period · ray diagram · reflection · rarefaction · transmission · transverse · wavelength · wave speed

Chapter 11: Wave properties

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P11 questions	Answers
1	What is a transverse wave?	oscillations/vibrations are perpendicular (at right angles) to the direction of energy transfer
2	What is a longitudinal wave?	oscillations/vibrations are parallel to the direction of energy transfer
3	Give an example of a transverse wave.	electromagnetic waves
4	Give an example of a longitudinal wave.	sound waves
5	What is a compression?	area in longitudinal waves where the particles are squashed closer together
6	What is a rarefaction?	area in longitudinal waves where the particles are pulled further apart
7	What is the amplitude of a wave?	maximum displacement of a point on the wave from its undisturbed position
8	What is the wavelength of a wave?	distance from a point on one wave to the equivalent point on the adjacent wave
9	What is the frequency of a wave?	number of waves passing a fixed point per second
10	What unit is frequency measured in?	hertz (Hz)
11	What property of a wave always stays the same when it travels from one medium to another?	frequency
12	What rule do waves follow when they reflect off a surface?	angle of incidence = angle of reflection
13	What happens when waves are transmitted at a boundary between two substances?	they carry on moving at a different speed
14	What happens when waves are absorbed by a substance?	energy of the wave is transferred to energy stores of the substance

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Chapter 12: Electromagnetic waves

Knowledge organiser

The electromagnetic spectrum

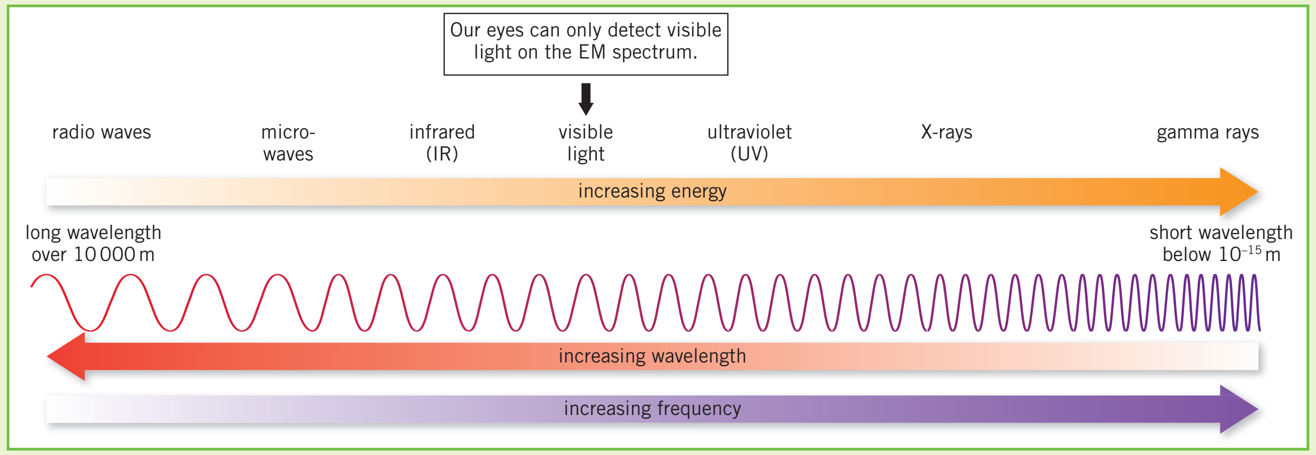
Electromagnetic (EM) waves are **transverse** waves that transfer energy from their source to an absorber. For example, infrared waves emitted from a hot object transfer thermal energy.

EM waves form a continuous **spectrum**, and are grouped by their wavelengths and frequencies.

EM waves all travel at the same velocity through air or a vacuum. They travel all at a speed of 3×10^8 m/s through a vacuum.

(HT only) Different substances may absorb, transmit, **refract**, or **reflect** EM waves in ways that vary with their wavelength.

Refraction occurs when there is a difference in the velocity of an EM wave in different substances.

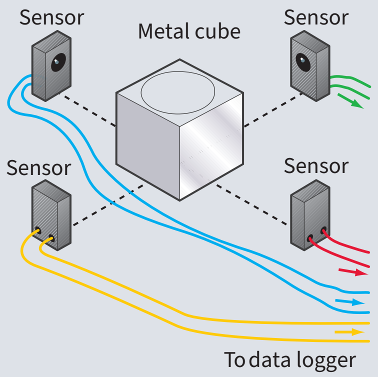


Infrared radiation (required practical)

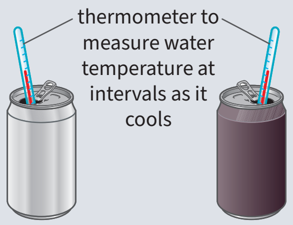
This practical investigates the rates of absorption and radiation of infrared radiation from different surfaces.

You should be able to plan a method to determine the rate of cooling due to emission of infrared radiation and evaluate your method.

Using infrared detectors to measure the radiation emitted by different surfaces



Monitoring the rate of cooling in cans with different surfaces



To be accurate and precise in your investigation you need to:

- use an infrared detector with a suitable meter, where possible
- ensure that you always put the detector the same distance from the surface
- repeat measurements and calculate an average.

Properties of EM waves

EM waves of a wide range of frequencies can be absorbed or produced by changes inside an atom or nucleus. For example, gamma rays are produced by changes in the nucleus of an atom.

When electrons in an atom move down between energy levels, they emit EM waves.

Properties of radio waves (HT only)

Radio waves can be produced by **oscillations** in an electrical circuit.

When radio waves are absorbed by a receiver aerial, they may create an **alternating current** with the same frequency as the radio waves.

Uses of EM waves

EM waves have many practical applications, but exposure to some EM waves (such as those that are forms of ionising radiation) can have hazardous effects.

Radiation dose (in sieverts) is the risk of harm from exposure of the body to a particular radiation.

Type of EM wave	Use	Why is it suitable for this use? (HT only)	Hazards
radio waves	television and radio signals	• can travel long distances through air • longer wavelengths can bend around obstructions to allow detection of signals when not in line of sight	can penetrate the body and cause internal heating
microwaves	satellite communications and cooking food	• can pass through Earth's atmosphere to reach satellites • can penetrate into food and are absorbed by water molecules in food, heating it	
infrared	electrical heaters, cooking food, and infrared cameras	• all hot objects emit infrared waves – sensors can detect these to turn them into an image • can transfer energy quickly to heat rooms and food	can damage or kill skin cells due to heating
visible light	fibre optic communications	• short wavelength means visible light carries more information	can damage the retina
ultraviolet (UV)	energy efficient lights and artificial sun tanning	• carries more energy than visible light • some chemicals used inside light bulbs can absorb UV and emit visible light	can damage skin cells, causing skin to age prematurely and increasing the risk of skin cancer, and can cause blindness
X-rays	medical imaging and treatments	• pass easily through flesh, but not denser materials like bone • high doses kill living cells, so can be used to kill cancer cells – gamma rays can also be used to kill harmful bacteria	form of ionising radiation – can damage or kill cells, cause mutation of genes, and lead to cancers
gamma rays			

Key terms

Make sure you can write a definition for these key terms.

alternating current *electromagnetic wave* *electromagnetic spectrum*
oscillation *radiation dose* *reflection* *refraction* *transverse*

Chapter 12: Electromagnetic waves

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P12 questions		Answers
1	Are electromagnetic (EM) waves longitudinal or transverse waves?	Put paper here	transverse
2	Explain why EM waves are not mechanical waves.		they can travel through a vacuum (don't need a substance to travel through)
3	What do EM waves transfer from their source to an absorber?	Put paper here	energy
4	List the different types of waves in the EM spectrum in order of decreasing wavelength (increasing frequency).		radio, microwave, infrared, visible, ultraviolet, X-rays, gamma
5	Which part of the EM spectrum can humans see?	Put paper here	visible light
6	How can electromagnetic waves be produced?		changes inside an atom/atomic nucleus
7	How are gamma rays produced?		changes in the nucleus of an atom, for example during radioactive decay
8	How can radio waves be produced?	Put paper here	oscillations in an electrical circuit
9	How can we detect radio waves?		waves are absorbed and create an alternating current with the same frequency as the radio wave
10	What are radio waves used for?	Put paper here	transmitting television, mobile phone, and Bluetooth signals
11	What are microwaves used for?		satellite communications, cooking food
12	What is infrared radiation used for?		heating, remote controls, infrared cameras, cooking food
13	Which types of EM waves are harmful to the human body?	Put paper here	ultraviolet, X-rays, gamma rays
14	What are the hazards of being exposed to ultraviolet radiation?		damage skin cells, sunburn, increase risk of skin cancer, age skin prematurely, blindness
15	Why are X-rays used for medical imaging?	Put paper here	they pass through flesh but not bone
16	Why are gamma rays used for treating cancer and sterilising medical equipment?		high doses kill cells and bacteria

Chapter 13: Electromagnetism 1

Knowledge organiser

Magnets

Magnets have a north (N) and a south (S) pole.

When two magnets are brought close together, they exert a non-contact force on each other.

Repulsion – If the poles are the same (N and N or S and S), they will repel each other.

Attraction – If the poles are different (N and S or S and N), they will attract each other.

The force between a magnet and a magnetic material (iron, steel, cobalt, or nickel) is always attractive.

Magnetic fields

A **magnetic field** is the region around a magnet where another magnet or magnetic material will experience a force due to the magnet.

A magnetic field can be represented by magnetic field lines.

Field lines show the direction of the force that would act on a north pole at that point.

Field lines always point from the north pole of a magnet to its south pole.

A magnetic field's strength is greatest at the poles and decreases as distance from the magnet increases.

The closer together the field lines are, the stronger the field.

Induced and permanent magnets

A **permanent** magnet produces its own magnetic field which is always there.

An **induced** magnet is an object that becomes magnetic when it is placed in a magnetic field.

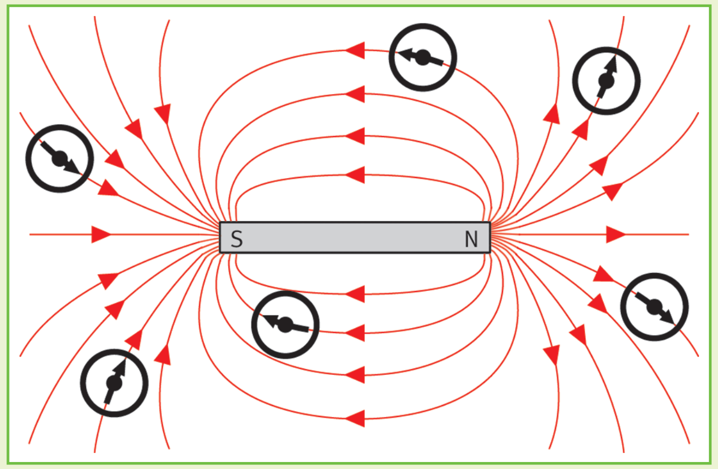
The force between an induced magnet and a permanent magnet is *always attractive* (it doesn't matter which pole of the permanent magnet the induced magnet is near).

If the induced magnet is removed from the magnetic field it will quickly lose most or all of its magnetism.

Plotting magnetic fields

A magnetic compass contains a small bar magnet that will line up with magnetic field lines pointing from north to south.

A compass can be used to plot the magnetic field around a magnet or an **electromagnet**:



If it is not near a magnet, a compass will line up with the Earth's magnetic field, providing evidence that the Earth's core is magnetic.

As a compass points towards a south pole, the magnetic pole near the Earth's geographic North Pole is actually a south pole.

Electromagnetism

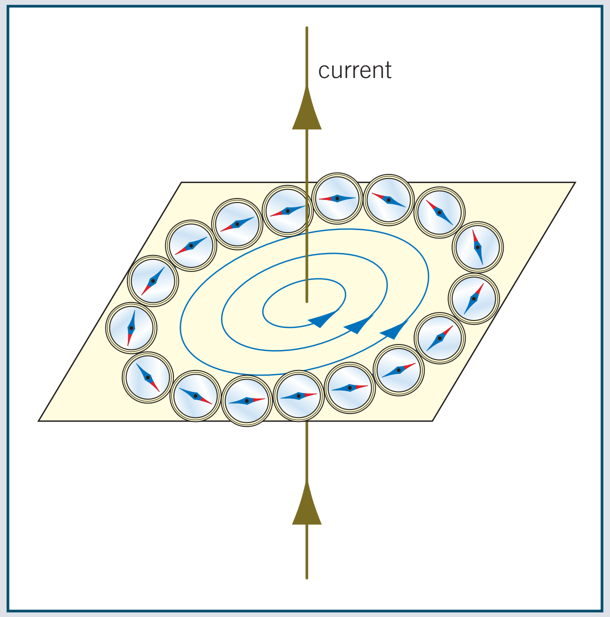
If an electric current flows through a wire (or other conductor), it will produce a magnetic field around the wire.

The field strength increases:

- with greater current
- closer to the wire.

Reversing the direction of the current reverses the direction of the field.

The field around a straight wire takes the shape of concentric circles at right angles to the wire:



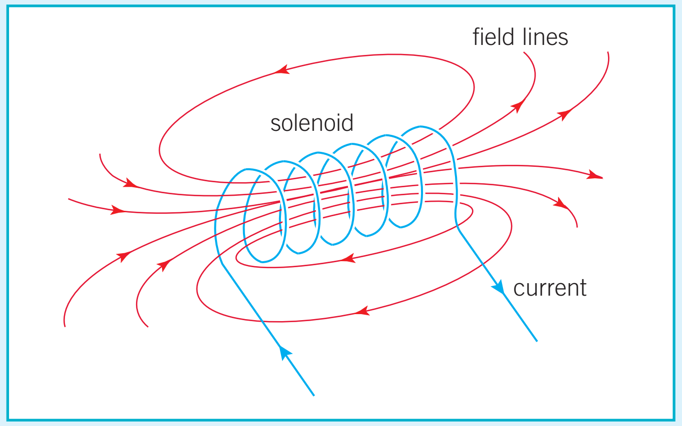
If the wire was gripped by someone's right hand so that the thumb pointed in the direction of the current, the fingers would curl in the direction of the magnetic field.

Solenoids

A **solenoid** is a cylindrical coil of wire.

Bending a current-carrying wire into a solenoid increases the strength of the magnetic field produced.

The shape of the magnetic field around a solenoid is similar to a magnetic field around a bar magnet.



Inside a solenoid the magnetic field is *strong* and *uniform*, which means it has the same strength and direction at all points.

The strength of the magnetic field around a solenoid can be increased by putting an iron core inside it.

If the wire was gripped by someone's right hand so that the fingers curl in the direction of the current in the coil, the thumb will point towards the north pole of the field.

Electromagnets are often solenoids with an iron core.

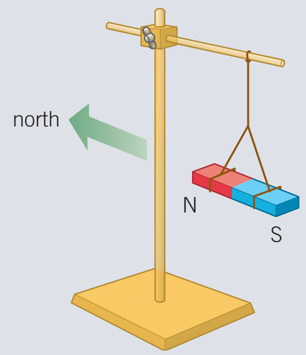
Advantages of electromagnets

- An electromagnet can be turned on and off.
- The strength of an electromagnet can be increased or decreased by adjusting the current.

Magnetic materials

Iron or steel objects, and some nickel and cobalt materials can be magnetised or demagnetised. Magnets made of steel tend to be more permanent as it does not lose its magnetism easily.

N-pole and S-pole can be identified by suspending a bar magnet, and using a second magnet to identify each pole.



Chapter 13: Electromagnetism 2

Knowledge organiser

The motor effect (HT only)

When a current-carrying wire (or other conductor) is placed in a magnetic field, it experiences a force.

The force is due to the interaction between the field created by the current in the wire and the magnetic field in which the wire is placed.

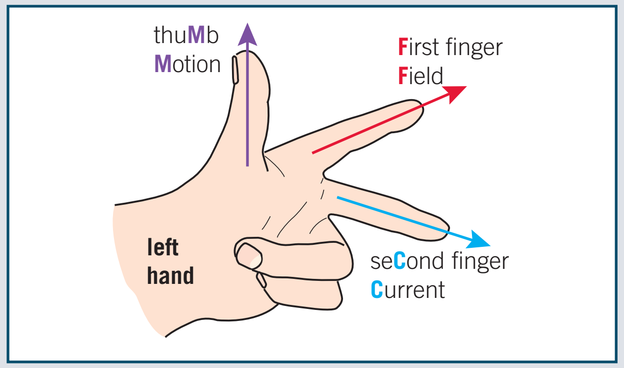
The magnet producing the field will experience an equal-sized force in the opposite direction.

The direction of the force is reversed if the current is reversed or if the direction of the magnetic field is reversed.

Fleming's left-hand rule (HT only)

The direction of the force/motion of the wire is always at right angles to both the current and the direction of the magnetic field it is within.

It can be worked out using Fleming's left-hand rule:



Magnetic flux density (HT only)

The **magnetic flux density** of a field is a measure of the strength of the magnetic field.

For a current-carrying wire at right angles to a magnetic field, the size of the force on it is given by the equation:

force (N) = magnetic flux density (T) × current (A) × length (m)

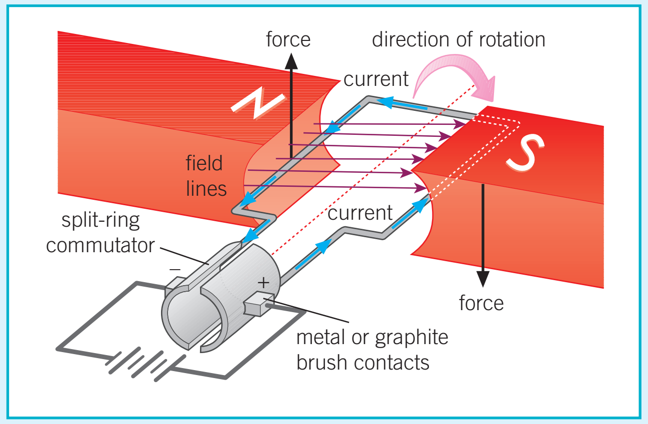
$$F = BIl$$

Electric motors (HT only)

A current-carrying coil of wire in a magnetic field will tend to rotate.

This is the basis of an electric motor.

The diagram below shows a simple motor made of one rectangular piece of wire.



When there is a current in the wire, it spins because:

- each side of the coil experiences a force due to being a current-carrying conductor in a magnetic field
- the forces on each side of the coil are in opposite directions.

The **split-ring commutator** keeps the motor spinning in the same direction.

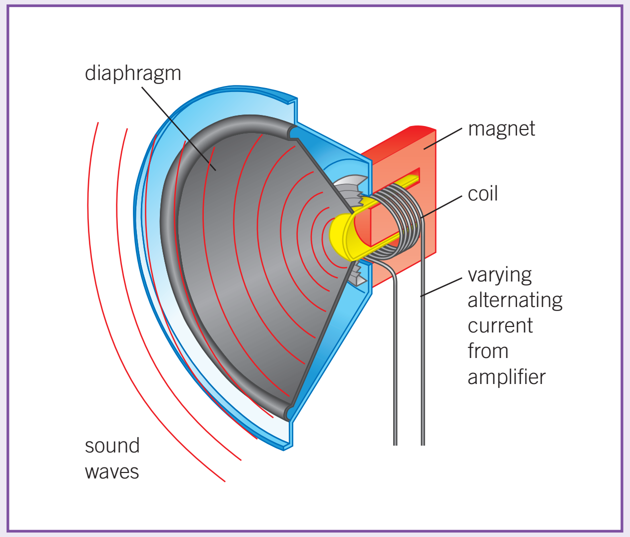
The ends of the wire swap contacts with the power supply every half turn, so current always flows in the same direction relative to the magnetic field.

The motor can be made to spin

- *faster* – by increasing the current in the coil or increasing the strength of the magnetic field.
- *in the opposite direction* – by reversing the direction of the current or reversing the direction of the magnetic field.

Loudspeakers

Moving-coil loudspeakers and headphones use the **motor effect** to convert changes of current in a coil of wire to changes of pressure in sound waves.



A coil of wire is placed inside a permanent magnet (so it is inside a magnetic field) and is attached to a diaphragm.

When a current flows through the coil, it experiences a force due to the motor effect.

This causes the diaphragm to move.

When the current changes direction, the force on the coil also changes direction, causing the diaphragm to move in the opposite direction.

Variations in the current make the coil and diaphragm vibrate.

These vibrations create variations of pressure in the air which form a sound wave.

The frequency of the sound wave produced is the same as the frequency of the alternating current supplied to the coil.

Key terms

Make sure you can write a definition for these key terms.

attraction, electromagnet, induced, magnetic field, magnetic flux density, motor effect, split-ring commutator, permanent, repulsion, solenoid

Chapter 13: Electromagnetism

Retrieval questions

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P13 questions	Answers
1	What is a magnetic field?	the region of space around a magnet where a magnetic material will experience a force
2	What happens when like and unlike poles are brought together?	like = repel, unlike = attract
3	What happens to the strength of the magnetic field as you get further away from the magnet?	decreases
4	Where is the magnetic field of a magnet strongest?	at the poles
5	In which direction do magnetic field lines always point?	north to south
6	What does the distance between magnetic field lines indicate?	strength of the field, closer together = stronger field
7	What is a permanent magnet?	material that produces its own magnetic field
8	What is an induced magnet?	material that becomes magnetic when it is put in a magnetic field
9	What does a magnetic compass contain?	small bar magnet
10	What is produced around a wire when an electric current flows through it?	magnetic field
11	What factors does the strength of the magnetic field around a straight wire depend upon?	size of current, distance from wire
12	What effect does shaping the wire into a solenoid have on the magnetic field strength?	increases strength of magnetic field
13	How can the strength of the magnetic field inside a solenoid be increased?	put an iron core inside
14	What does Fleming's left-hand rule show?	relative orientation of the force, current in the conductor, and magnetic field for the motor effect
15	What is the symbol for magnetic flux density and what unit is it measured in?	B, tesla (T)
16	What is the motor effect?	when a conductor placed in a magnetic field experiences a force
17	What causes the motor effect?	interaction between the magnetic field created by current in a wire and the magnetic field in which the wire is placed
18	What do loudspeakers and headphones do?	use the motor effect to convert variations in current in electrical circuits to pressure variations in sound waves

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