William Hulme's Grammar School
The best in everyone™
Part of United Learning

Y11 Physics
Knowledge Organiser

Separate Science (Triple)

Note: you could be tested on any of these skills on your GCSE paper 1 AND paper 2.

Working Scientifically Skills

Variables

In an experiment:

- The **independent** variable is what is changed
- The **dependent** variable is what is measured for each change of the independent variable.
- **Control variables** are kept the same so that you can compare your results, the experiment is a valid test.

Mean

To find a **mean**, add the values together and divide by the total by the number of values.

Example: calculate the mean of 3, 5, 1, 2, 6, 4, 2, 5, 7

Answer $= \frac{(3+5+1+2+6+4+2+5+6)}{10} = \mathbf{4}$

Repeatable

Measurements are **repeatable** when you repeat an experiment and get the same results. This has to be done by the same investigator and under the same conditions.

Reproducible

Measurements are **reproducible** if a different investigator repeats your experiment and gets similar results. This will be done with different equipment.

Anomalies

An **anomalous** result is a result that doesn't fit in with the pattern of the other results.

Anomalous values should be examined to try to identify the cause and, if a product of a poor measurement, ignored – including when calculating a mean.

Accuracy

An **accurate** measurement is one that is close to the true value.

Example

Group	Measurement of gravitational field strength (N/kg)
A	8.7
B	9.7
C	4.4
D	9.2

Gravitational field strength = 9.8 N/kg

Which group's data is most accurate?

- Group B
- because their result is closest to the true value

Precision

Measurements are precise if they cluster closely about the mean (they have a small **range**).

Example

Group A

Temperature of solution in °C						
Student 1	Student 2	Student 3	Student 4	Student 5	Mean	Range
46	43	45	44	47	45	43-47

Group B

Temperature of solution in °C						
Student 1	Student 2	Student 3	Student 4	Student 5	Mean	Range
44	46	45	44	46	45	44-46

Which group's data is more precise? Why?

- Group B
- because their results cluster more closely around the mean (it has a smaller range)

Errors

Error is the difference between a **measured** value and the **true** value of something.

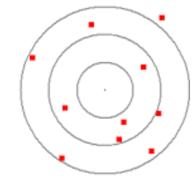
There are two main types of errors:

- **Random** error
- **Systematic** (and **zero**) error

NEVER SAY HUMAN ERROR in your GCSE papers

Random error

Random error causes readings to be **spread** about the true value, due to results **varying** in an unpredictable way from one measurement to the next.

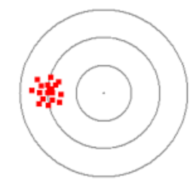


Random Error

To reduce the effect of random error, take **multiple** readings and then work out the **mean** (average) value. This also helps you spot **anomalies.**

Systematic error

Systematic error is when the results differ from the true value by a **consistent** amount for each reading.



Systematic Error

To remove systematic error, you can:

- **Reset** your equipment and **retake** the measurements.
- **Measure** the systematic error and add or take it away from your readings.

Zero error

Zero error is when a piece of equipment gives a reading other than zero when it should be zero. It is a type of systematic error.

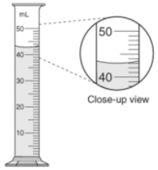
Working Scientifically Skills

Resolution

The resolution of a measuring instrument is the **<u>smallest</u>** change in a quantity that gives a change in the reading that can be seen.

For example, a thermometer with a mark at every 1.0 °C has a resolution of **<u>1.0 °C</u>**. It has a **<u>higher</u>** resolution than a thermometer with a mark at

Thermometer
resolution = 1 °C



Measuring cylinder
resolution = 1 ml

Voltmeter
resolution = 0.01 V

Range

The range is the **<u>difference</u>** between the highest and lowest values in a set of numbers.

Examples – calculate the range for:

1. 23, 27, 40, 18, 25 — range = 40 – 18 = **22**
2. 25, 26, 57, 15, 47 — range = 57 – 15 = **42**

Uncertainty

Uncertainty is the **<u>range</u>** of values a measurement could be.
It is written as your reading **±** the uncertainty.

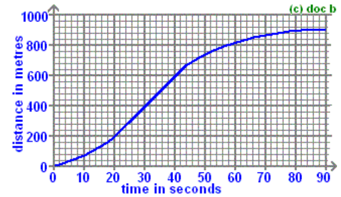
Example – the mass of a block is measured multiple times: 122 g , 120 g, 119 g, 118 g, 121 g
What is the uncertainty?

Range = 122 – 118 = 4

Uncertainty = $\frac{range}{2} = \frac{4}{2} = \pm \mathbf{2\ g}$

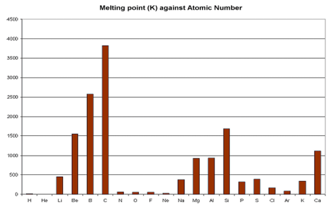
Continuous variables

Continuous variables can have values that can be given by **<u>counting</u>** (e.g. number of atoms) or by a **<u>measurement</u>** (e.g. force on a spring).
Continuous data is plotted on a **<u>line</u>** graph.



Categoric variables

Categoric variables have values that are **<u>labels</u>** (e.g. type of plant). Also known as: discontinuous or discrete variables
Categoric data is plotted on a **<u>bar</u>** chart

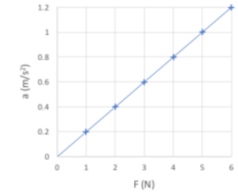


Examples:

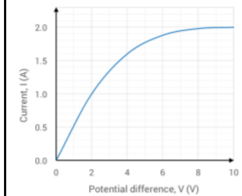
- Mass Continuous
- Temperature Continuous
- Colour Categoric
- Height Continuous
- Type of bacteria Categoric
- Type of metal Categoric
- Energy Continuous
- Velocity Continuous

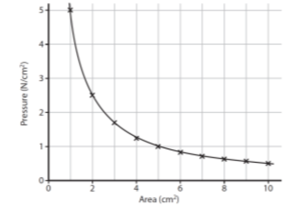
Graphs

- Linear graphs are a **<u>straight</u>** line:



- Non-linear graphs are **<u>not</u>** a straight line:





What makes a good graph? *SALLT!*

- **Scales** – going up by the same amount each time, constant spacing, covering all data
- **Axes** – independent variable on x-axis, dependent on y-axis
- **Labels** – and units
- **Line of best fit** – straight line or smooth curve
- **Title**

Significant Figures

When we round to significant figures, we start counting as soon as we reach a number that is not <u>zero</u>.

Working Scientifically Skills

Directly proportional

Directly proportional means that as one variable doubles, the other **doubles** too.
You can tell if a graph is directly proportional if it has:

- A **straight** line
- Going through the **origin** (0,0)

Proving a direct proportionality

A direct proportion can be written mathematically as:

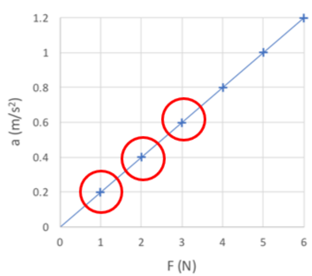
$$y \propto x$$

You can turn this into an equation (add an equals sign)

$$y = kx$$

where k is a constant of proportionality.
You can mathematically prove that the graph is directly proportional by taking **three** values from the graph, and showing that the constant of proportionality is the **same** for each point.

Example



a = kF   k = a/F

Point 1: k = 0.2/1 = 0.2

Point 2: k = 0.4/2 = 0.2

Point 3: k = 0.6/3 = 0.2

Therefore a and F are directly proportional to each other

Inversely proportional

Inversely proportional means as one variable doubles, the other **halves**. The graph for this is shown.

Proving an inverse proportionality

An inverse proportion can be written mathematically as:

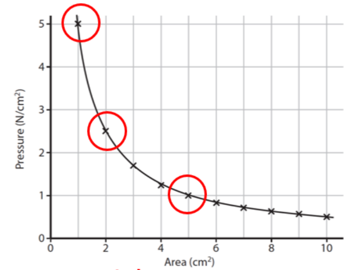
$$y \propto \frac{1}{x}$$

You can turn this into an equation (add an equals sign)

$$y = \frac{k}{x}$$

where k is a constant of proportionality.
You can mathematically prove that the graph is inversely proportional by taking **three** values from the graph, and showing that the constant of proportionality is the **same** for each point.

Example



p = k/A   k = pA

Point 1: k = 5 x 1 = 5

Point 2: k = 2.5 x 2 = 5

Point 3: k = 1 x 5 = 5

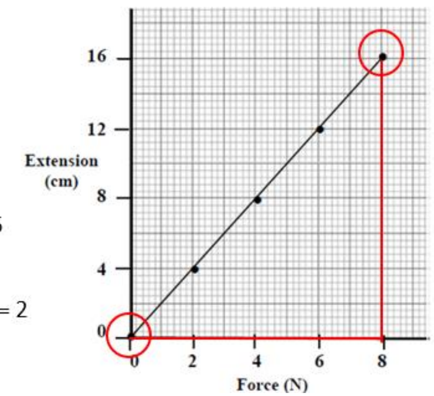
Therefore p and A are inversely proportional to each other

Gradients

Gradient = $\frac{\Delta y}{\Delta x} = \frac{change\ in\ y}{vhange\ in\ x}$

- Pick two easy to read points and draw a triangle
- Measure the Δy and the Δx
- Calculate gradient

Example



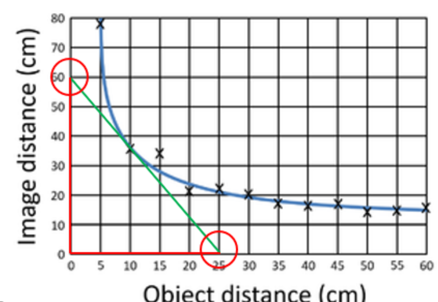
Δy = 16
Δx = 8

Gradient = 16/8 = 2

Finding the gradient for a point on a curve

Draw a tangent to the curve at the point you are interested in – the tangent will have the same gradient as the curve at that point

- Gradient = $\frac{\Delta y}{\Delta x}$
- Pick two easy to read points and draw a triangle
- Measure the Δy and the Δx and calculate gradient



Δy = 60
Δx = -25

Gradient = 60/-25 = -2.4

Working Scientifically Skills

Significant Figures

When we round to significant figures, we start counting as soon as we reach a number that is not <u>zero</u>.

Examples

1. Round 378 577 to 1 significant figures

Look at the first number, if it's more than 4 we round up.

Answer = 400 000

2. Round 378 437 to 3 significant figures

Look at the fourth number. It's less than 5, so we round down.

Answer = 378 000

3. Round 0.00289 to 2 significant figures

Look at the third non-zero number. It's more than 4 so we round up.

Answer = 0.0029

4. Round 0.002089 to 3 significant figures

Look at the fourth non-zero number. It's more than 4 so we round up.

Answer = 0.000209

5. Round 20 to 4 significant figures

We are starting with 2 digits. We need 4 digits in total. Add a decimal place and add zeroes on the end.

Answer = 20.00

Scientific method

Science progresses using the scientific method:

- Scientists **observe** something they don't understand
- They come up with a hypothesis or **model** – a possible explanation for what they've observed
- They **test** the hypothesis or model by gathering evidence through performing **experiments**
- They then share their findings in **peer-reviewed** journals
- If the hypothesis or model explains the evidence, then it is **accepted**. If it does not it is either **changed** or scrapped, and the process starts again.
- Accepted hypotheses are often called **theories** – they are not random guesses but a hypothesis that best explains the current evidence.
- If new evidence arises that cannot be explained using an existing model, then it will need to be modified or **replaced** with a model that does explain the evidence.

Peer review

Peer-review is when findings from experiments are published and shared with other scientists, so they can be checked.

Scientists can publish findings in <u>scientific journals</u> because:

- ✓ It's one of the ways communities of scientists find out what is going on in their field.
- ✓ It needs to be peer-reviewed before it can be published.
- ✓ It establishes their research as **credible** in the eyes of their peers and the public as it can detect false claims, inaccurate data and any **bias**.
- ✓ A newspaper may **distort** the facts.

Hazard vs. risk

A hazard is something that has the potential to cause **harm** or damage.

A risk is what could happen if you **encountered** the hazard.

Example

A high current flows through a wire.
What is the hazard, what is the risk?

- Hazard – wire could get hot
- Risk – Burn your skin

P1 – Energy

4.1.1 Energy changes in a system, and the ways energy is stored before and after such changes

4.1.1.1 Energy stores and systems

A system is an object or group of objects.

There are eight stores of energy:

- Chemical – The energy stored in chemical bonds, such as those between molecules. It is stored in food, batteries and muscles.
- Elastic potential – The energy stored when an object is stretched or squashed.
- Electrostatic – The energy stored when repelling charges have been moved closer together or when attracting charges have been pulled further apart.
- Gravitational potential – The energy stored in objects at height.
- Internal (thermal) – The energy stored in hot objects.
- Kinetic – The energy stored in moving objects.
- Magnetic – The energy stored when repelling poles have been pushed closer together or when attracting poles have been pulled further apart.
- Nuclear – The energy stored in the nucleus of an atom.

There are four ways energy is transferred:

- Electrical work – energy transferred by flowing electrical charges (current)
- Heating – energy transferred due to a temperature difference
- Mechanical work – energy transferred by forces moving objects.
- Radiation – energy transferred by waves.

When there is a change in a system, energy is transferred between stores using one of the four transfers.

When describing energy transfers, you need to identify:

- The object losing energy and the store that energy is being transferred away from, saying it is decreasing.
- The object gaining energy and the store energy is being transferred to, saying it is increasing.
- Which transfer is being used to transfer the energy between the stores.

When a ball is being projected upwards:

- The kinetic energy store of the ball is decreasing.
- The gravitational potential energy store of the ball is increasing.
- It is being transferred mechanically (gravity).

When a ball collides with a wall:

- The kinetic energy store of the ball is decreasing.
- The internal energy store of the surroundings is increasing.
- It is being transferred mechanically (force of wall on the ball) and by radiation (sound).

When a car is accelerating (speeding up):

- The chemical energy store of the fuel is decreasing.
- The kinetic energy store of the car is increasing.
- It is being transferred mechanically (thrust force).

When a car is decelerating (slowing down):

- The kinetic energy store of the car is decreasing.
- The thermal energy store of the surroundings is increasing.
- It is being transferred mechanically (friction force).

When a kettle is boiling water:

- The chemical energy store of the fuel in the power station is decreasing.
- The thermal energy store of the water is increasing.
- It is being transferred electrically.

4.1.1.2 Energy stores and systems

If an object accelerates (speeds up), its kinetic energy store increases. If it decelerates (slows down), its kinetic energy store decreases.

$$Kinetic\ energy = 0.5 \times mass \times (speed)^2$$

$$E_k = \frac{1}{2}mv^2$$

Kinetic energy (E_k) in joules (J)
Mass (m) in kilograms (kg)
Speed (v) in metres per second (m/s)

If an object is stretched or compressed, its elastic potential energy store increases. If it is released, its elastic potential energy store decreases.

$$\text{Elastic potential energy} = 0.5 \times \text{spring constant} \times (\text{extension})^2$$

$$E_e = \frac{1}{2}ke^2$$

Elastic potential energy (E_e) in joules (J)
Spring constant (k) in newtons per metre (N/m)
Extension (e) in metres (m)

This equation can only be used up to the limit of proportionality.

The spring constant is a measure of how stiff a spring is. The larger the spring constant the more force is needed to stretch it. The lower the spring constant the less force is needed to stretch it.

If an object is lifted up, its gravitational potential energy store increases. If it is lowered, its gravitational potential energy store decreases.

$$GPE = \text{mass} \times \text{gravitational field strength} \times \text{height}$$

$$E_p = mgh$$

Gravitational potential energy (E_p) in joules (J)
Mass (m) in kilograms (kg)
Gravitational field strength (g) in newtons per kilogram (N/kg)
Height (h) in metres (m)

4.1.1.3 Energy changes in systems

The amount of energy stored in or released from a system as its temperature changes can be calculated using the equation:

$$\text{change in thermal energy} = \text{mass} \times \text{specific heat capacity} \times \text{temperature change}$$

$$\Delta E = mc\Delta\theta$$

Change in thermal energy (ΔE) in joules (J)
Mass (m) in kilograms (kg)
Specific heat capacity in joule per kilogram per degrees Celsius. (J/kg °C)
Temperature change (Δθ) in degrees Celsius (°C)

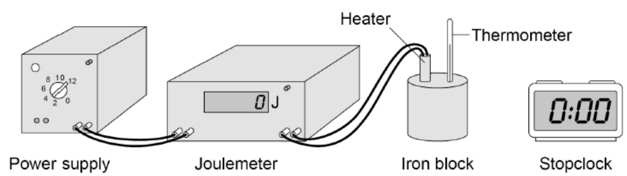
The specific heat capacity is the amount of energy required to raise the temperature of 1 kg of a substance by 1 °C.

The higher the specific heat capacity, the more energy is required to raise the temperature of 1 kg of a material. These materials warm up and cool down slowly.

The lower the specific heat capacity, the less energy is required to raise the temperature of 1 kg of a material. These materials warm up and cool down quickly.

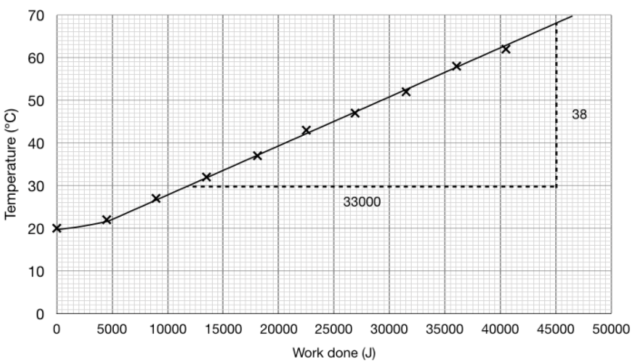
Required practical activity 1

Aim: investigation to determine the specific heat capacity of one or more materials.



1. Measure mass of block using a balance.
2. Measure initial temperature using a thermometer.
3. Turn on heater by turning on power supply. Start the stopwatch.
4. Record the temperature using the thermometer and the energy transferred using the joulemeter every minute for 15 minutes.
5. Plot a graph of temperature of the block against time.
6. Use the graph to work out a suitable change in temperature and energy transferred then use the equation ΔE = mcΔθ to calculate the specific heat capacity of the block.

- Leave the thermometer in the block for a few minutes before starting taking measurements to ensure the thermometer is at the same initial temperature as the block.
- The graph of temperature against time or energy transferred may not be a straight line at the start as it takes time for the heater to heat up.
- Add insulation to the block to reduce energy losses to the thermal store of the surroundings – this will lead to a more accurate reading of energy transferred and a more accurate specific heat capacity.



4.1.1.4 Power

Power is defined as the rate at which energy is transferred or the rate at which work is done.

$$\text{Power} = \frac{\text{energy transferred}}{\text{time}}$$

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

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

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

Power (P) in watts (W)
Energy transferred (E) in joules (J)
Time (t) in seconds (s)
Work done (W) in joules (J)

An energy transfer of 1 joule per second is equal to a power of 1 watt.

If motor A lifts a 5 kg block through the same height faster than motor B, it has a higher power as it has transferred the same amount of energy in a shorter time.

4.1.2 Conservation and dissipation of energy

4.1.2.1 Energy transfers in a system

In a closed system, energy cannot be created or destroyed – this is called the conservation of energy.

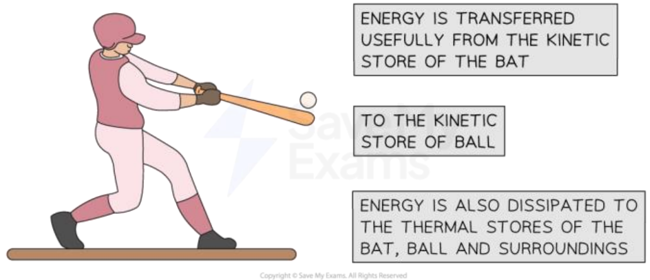
A closed system is a system where the total amount of energy remains constant.

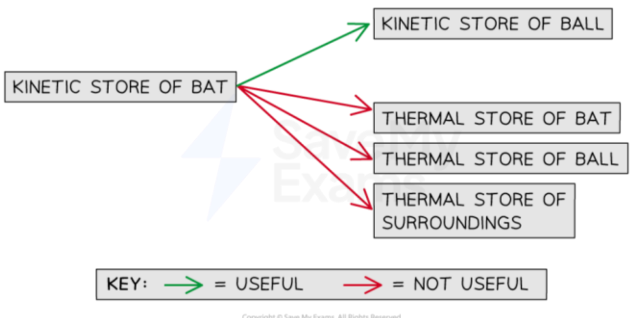
If the system is an open system, energy is dissipated (lost) to or gained from the surroundings.

Energy can be stored, transferred usefully, or dissipated (transferred to a store you don't want, normally to the thermal store of the surroundings – it is wasted).

In all system changes, energy is dissipated so that it is stored in less useful ways (it is wasted).

When hitting a ball with a bat:





Energy can be dissipated when a friction force is trying to stop an object moving. This can be reduced by lubricating parts that rub together.

Energy can be dissipated when heating an object – energy is transferred to the thermal store of objects we don't want to heat such as the surroundings. This can be reduced by adding insulation to the object we want to heat up.

Thermal energy always moves from hot objects to cold objects until the objects are in thermal equilibrium (same temperature). The bigger the temperature difference the higher the rate of energy transfer.

Conduction is the process of transferring energy by vibrating particles in a substance. Thermal conductivity is a measure of the **rate** at which energy is transferred through a material by conduction.

Materials that quickly transfer heat are called conductors. They have a high thermal conductivity. Materials that slowly transfer heat are called insulators. They have a low thermal conductivity.

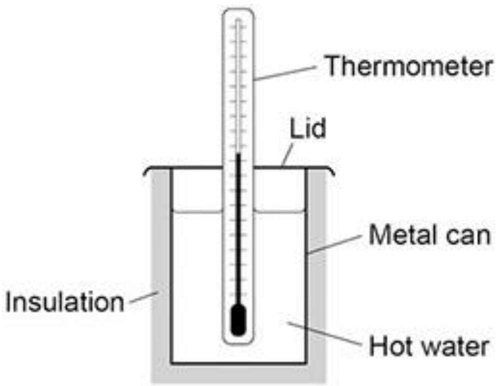
The higher the thermal conductivity of a material the higher the rate of energy transfer by conduction across the material. The thicker the material the lower the rate of energy transfer by conduction across the material.

Required practical activity 2

Aim: investigate the effectiveness of different materials as thermal insulators and the factors that may affect the thermal insulation properties of a material.

Activity 1: Comparing the effectiveness of different materials as thermal insulators

1. Wrap insulating material around a can.
2. Measure a fixed volume of boiling water using a measuring cylinder and add it to the can.
3. Place the lid on the top of the can.
4. Measure the initial temperature of the water using a thermometer.
5. Measure the final temperature of the water after a fixed amount of time and calculate the temperature change.
6. Repeat steps 1 – 4 using the same thickness of different insulating materials.



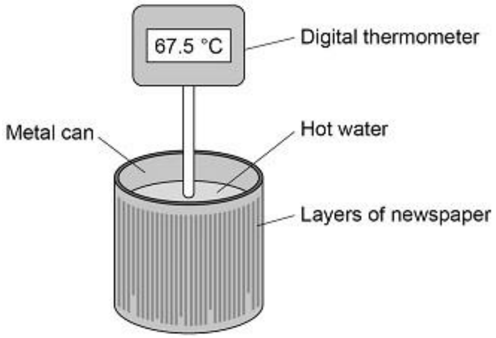
Independent variable – type of insulation.

Dependent variable – temperature change of the water.

Control variables – volume of water, initial temperature of water, thickness of insulation.

Activity 2: Comparing the effectiveness of different materials as thermal insulators

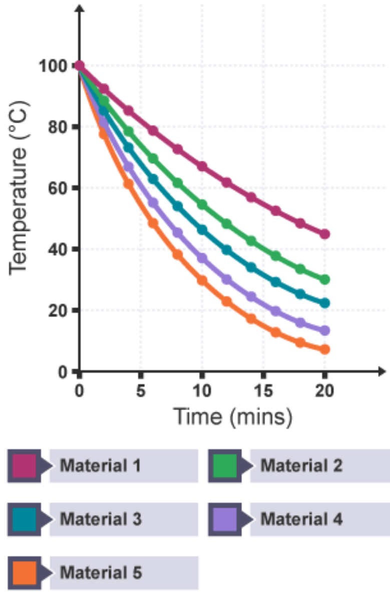
1. Wrap one layer of insulating material around a can.
2. Measure a fixed volume of boiling water using a measuring cylinder and add it to the can.
3. Place the lid on the top of the can.
4. Measure the initial temperature of the water using a thermometer.
5. Measure the final temperature of the water after a fixed amount of time and calculate the temperature change.
6. Repeat steps 1 – 4 adding an extra layer of insulating material every time.



Independent variable – number of layers of insulation.

Dependent variable – temperature change of the water.

Control variables – volume of water, initial temperature of water, type of insulation.



When energy is transferred, some is transferred usefully, and some energy is wasted or dissipated – often transferred to the thermal store of the surroundings.

Efficiency tells us the <u>proportion</u> of energy transferred usefully.

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

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

Efficiency is expressed as a decimal between 0 and 1 and has no units. Multiply it by 100 to turn it into a percentage between 0% and 100 %.

If a system has high efficiency, a large proportion of the energy is transferred usefully (little energy is wasted). If a system has a low efficiency, a small proportion of the energy is transferred usefully (lots of energy is wasted).

The efficiency of a device can be increased by:
- Lubricating it to reduce energy loss by friction (mechanical work).
- Reducing the resistance of components in an electrical circuit to reduce energy loss by heating.
- Streamlining an object to reduce energy loss by air resistance (mechanical work).
- Tightening loose parts in a machine to reduce energy loss by sound (radiation).

4.1.3 National and global energy resources

Energy resources are large stores of energy. The main uses of energy resources are:
- Transport
- Electricity generation
- Heating

A renewable energy resource is one that is being (or can be) replenished as it is used. A non-renewable energy resource is one that cannot be replenished as it is used.

Science has the ability to identify environmental issues arising from the use of energy resources but not always the power to deal with the issues because of political, social, ethical or economic considerations.

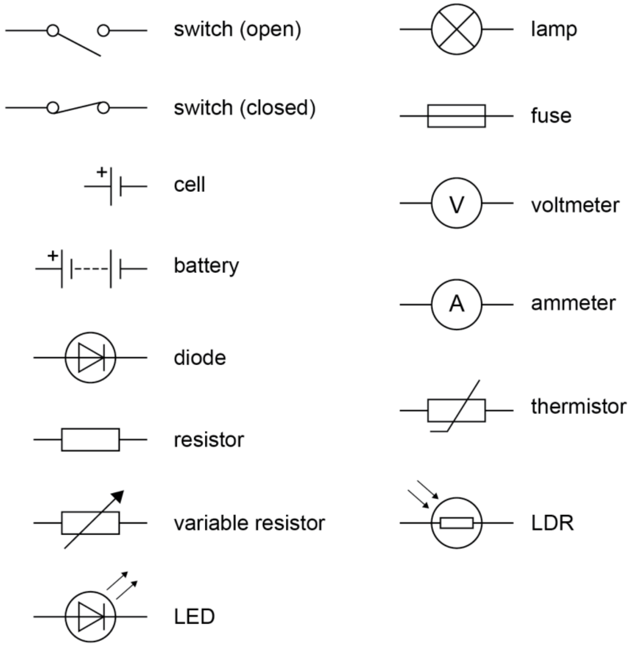
A reliable energy resource is predictable.

Energy resource	Description	Renewable or non-renewable	Advantages	Disadvantages
Fossil fuels (coal, oil, natural gas)	Burning fossil fuels (remains of living organisms) heats water to spin a turbine.	Non-renewable	- Reliable - Can produce large amounts of energy at short notice.	- Produces CO_2 that leads to global warming and climate change. - Burning coal releases sulfur dioxide which causes acid rain (natural gas does not do this).
Nuclear	Decaying radioactive materials (uranium or plutonium) heats water to spin a turbine.	Non-renewable	- Reliable - Can produce large amounts of energy at short notice. - Produces no CO_2 that leads to global warming and climate change. - Fuel is energy dense.	- Produces dangerous radioactive waste that can take thousands of years to decay.
Bio-fuel	Burning material from living things (such as wood) heats water to spin a turbine.	Renewable	- Produces no CO_2 overall (carbon neutral) that leads to global warming and climate change. - Won't run out as more can be grown.	- Takes up a lot of land that could be used for growing food. - Cutting down trees destroys habitats.
Wind	The movement of wind spins a turbine.	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Won't run out of wind	- Not reliable (not always windy) - Noisy and ugly - Not suitable to all locations - Dangerous to birds - Don't turn if wind is too strong or weak
Hydroelectric	Falling water stored behind a dam spins a turbine.	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Won't run out of water	- Floods large areas, destroying habitats
Geothermal	Heat from underground heats water to spin a turbine.	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Reliable - Won't run out of heat	- Very few suitable locations
Tidal	Moving water due to the tides spins a turbine.	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Reliable - Won't run out of tides	- Very few suitable locations - Can damage habitats and disrupt ecosystems
Solar	Generate electricity using sunlight.	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Won't run out of sunlight	- Not reliable (not always enough sunlight) - Take up space that could be used for growing food - Low useful power output so a lot are needed to generate sufficient electricity.
Waves	Moving water spins a turbine	Renewable	- Produces no CO_2 that leads to global warming and climate change. - Won't run out of water	- Not reliable

4.2.1 Current, potential difference and resistance

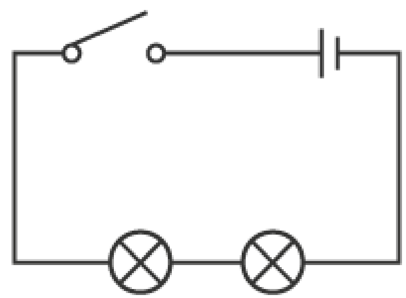
4.2.1.1 Standard circuit diagram symbols

Components are devices found in an electric circuit. Circuit diagrams use standard symbols for these components.



- Switch – turns the circuit on (closed) and off (open)
- Cell – a store of chemical energy that provides a source of potential difference.
- Battery – two or more cells.
- Resistor – a fixed resistor limits the flow of current. It has a fixed resistance.
- Variable resistor – A resistor with a slider that changes its resistance, changing the flow of current.
- Diode – allows current to flow in one direction only (the direction the triangle points)
- LED – Light Emitting Diode, a diode that emits light.
- Lamp – current heats the filament (wire) inside so that it gives out light.
- Fuse – contains a thin wire that melts if the current gets too high, breaking the circuit and stopping the flow of current.
- Voltmeter – measures potential difference.
- Ammeter – measure current.
- Thermistor – the resistance depends on temperature. As the temperature increases, its resistance decreases.
- LDR – Light Dependent Resistor. The resistance depends on light intensity. As the light intensity increases, its resistance decreases.

In a circuit diagram, wires are drawn as straight lines at 90° to each other.



4.2.1.2 Electrical charge and current

In a circuit there are charges all the way around the circuit. When the circuit is turned on, all the charges start to flow.

For electrical charge to flow, there must be:

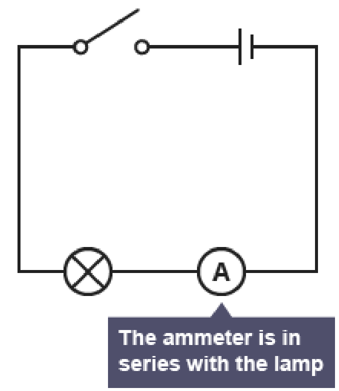
- A closed circuit (complete loop)
- A source of potential difference

Charge is a property of an object. Charged objects experience a force in an electric field. Objects can be positively charged, negatively charged, or neutral (no overall charge). Charge is measured in coulombs (C).

Current is the rate of flow of charge. It is measured in amps (A). In a circuit, the charged particles that flow are normally electrons.

Conventional current is defined as flowing from positive to negative.

Ammeters are used to measure current. Ammeters are placed in series (in the main loop) of the circuit.



$$Charge\ flow = current \times time$$
$$Q = It$$

Charge (Q) in coulombs (C)
Current (I) in amperes (shortened to amps) (A)
Time (t) in seconds (s)

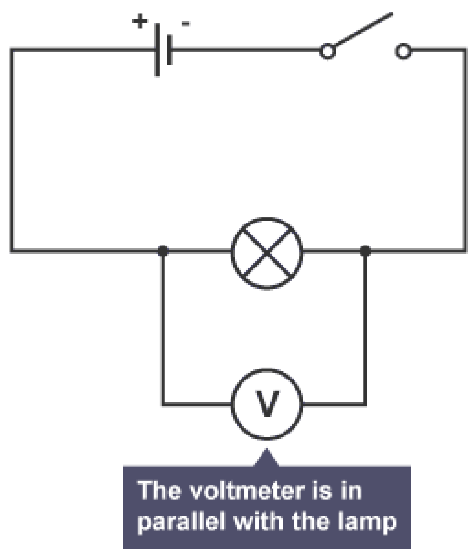
4.2.1.3 Current, resistance and potential difference

Potential difference is the amount of energy transferred per unit charge flowing from one point to another. It is measured in volts (V). Another name for potential difference is voltage.

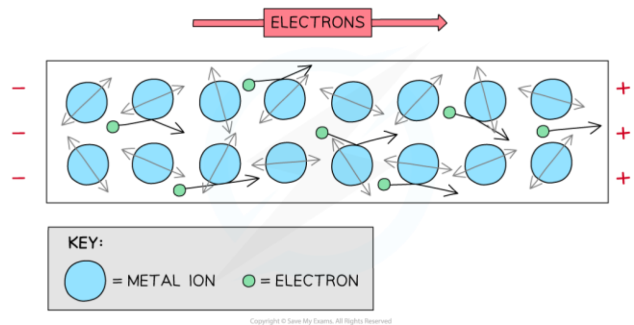
If a light bulb has a potential difference of 12 V across it, each coulomb of charge transfers 12 J of energy to the bulb.

To work out the potential difference between two points in a circuit, you have to compare the energy each coulomb of charge has at those points in the circuit.

Potential difference is measured using a voltmeter. Voltmeters go in parallel with (around) the component you want to measure.



Resistance is the opposition to the flow of current. As the electrons flow through the wire, they collide with the metal ions. This causes resistance.



The current through a component depends on both the resistance of the component and the potential difference across it.

For a constant potential difference:

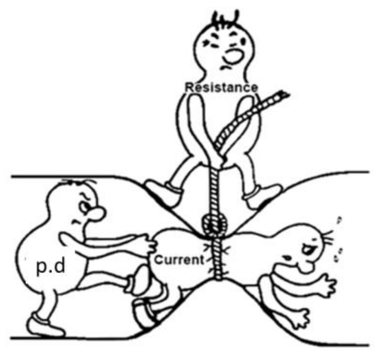
- The higher the resistance, the lower the current.
- The lower the resistance, the higher the current.

For a constant resistance:

- The higher the potential difference, the higher the current.
- The lower the potential difference, the lower the current.

Materials with a low resistance are called conductors.

Materials with a high resistance are called insulators.



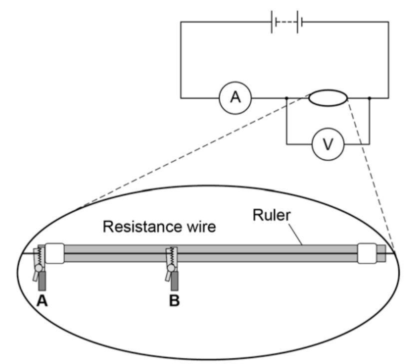
Resistance can be affected by temperature. The higher the temperature of the wire, the higher the resistance. This is because as the temperature increases, the metal ions in the wire gain energy and vibrate more. This means there are more collisions between the ions and the electrons as the electrons flow through the wire, increasing the resistance.

$$Potential\ difference = current \times resistance$$
$$V = IR$$

Potential difference (V) in volts (V)
Current (I) in amperes (A)
Resistance (R) in ohms (Ω)

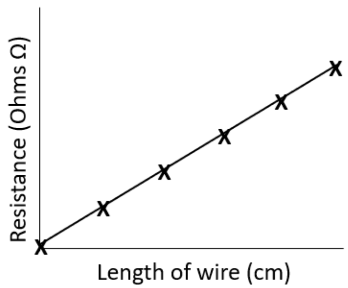
Required practical activity 3 – part 1

Aim: Use circuit diagrams to set up and check appropriate circuits to investigate the factors affecting the resistance of electrical circuits. This should include the length of wire at constant temperature.



Independent variable – length of wire
Dependent variable – resistance of wire
Control variables – type of wire, temperature of wire, diameter of wire, potential difference of the power supply.

1. Set up the circuit as shown, with an ammeter in the circuit and a voltmeter connected in parallel (around) the wire.
2. Move the crocodile clips so the wire is 10 cm long – use a ruler to measure the length. Measure the current using the ammeter and the potential difference using the voltmeter.
3. Repeat for 20, 30, 40, 50 cm.
4. Calculate resistance using R = V/I
5. Plot a graph of resistance against length.

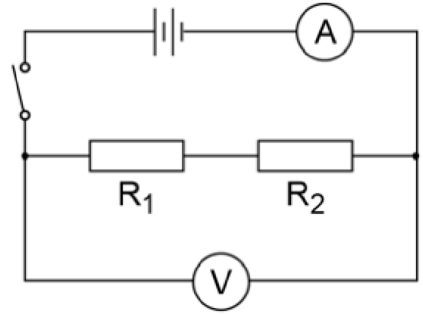


Resistance is directly proportional to length of wire.

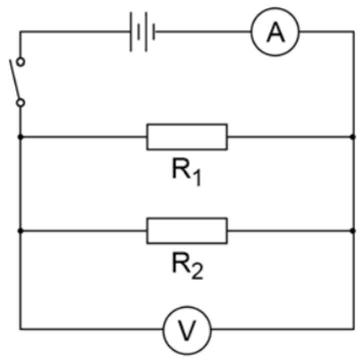
Turn off the circuit between readings and use a low current so that the wire does not get hot – this minimises the risk of burning yourself and keeps the temperature of the wire constant.

Required practical activity 3 – part 2

Aim: Use circuit diagrams to set up and check appropriate circuits to investigate the factors affecting the resistance of electrical circuits. This should include combinations of resistors in series and parallel.



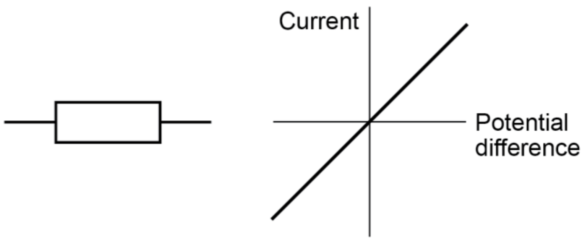
1. Set up circuit with two resistors of the same resistance in series.
2. Switch on the circuit and record the current with an ammeter and the potential difference with a voltmeter.
3. Calculate total resistance using R = V/I



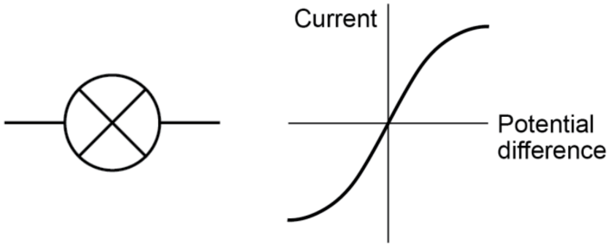
4. Set up circuit with two resistors of the same resistance in parallel.
5. Switch on the circuit and record the current with an ammeter and the potential difference with a voltmeter.
6. Calculate total resistance using R = V/I
7. Write a conclusion about the total resistance of adding resistors in series and parallel.

4.2.1.4 Resistors

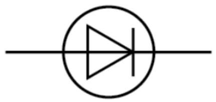
I-V graphs show the relationship between current and potential difference for different electrical components. The steeper the graph, the lower the resistance as R = V/I.

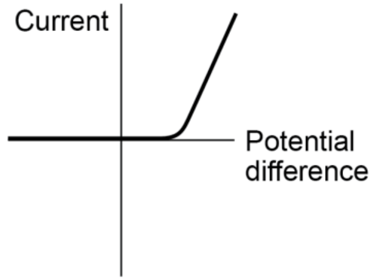


This is the I-V graph for an ohmic conductor. The current through an ohmic conductor (at a constant temperature) is directly proportional to the potential difference across it – this is known as Ohm's Law. This means the resistance remains constant as the current changes. Resistors are example of ohmic conductors. This is a linear graph as it is a straight line.



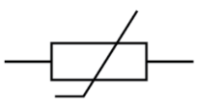
This is the I-V graph for a filament lamp. As the potential difference across the lamp increases, the current increases. The increase in current makes the temperature of the filament increase. This gives energy to the metal ions making them vibrate more meaning there are more collisions between the electrons and the metal ions. This increases the resistance. This results in the graph getting flatter. This is a non-linear graph as it is not a straight line.

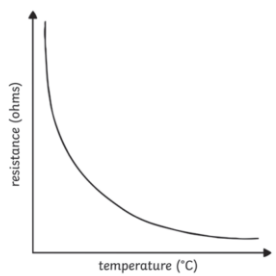




This is the I-V graph for a diode. The current through a diode flows in one direction only. The diode has a very high resistance in the reverse direction. This causes the negative side of the graph to always be at zero current. The positive side has current flowing after reaching a high enough potential difference. This is a non-linear graph as it is not a straight line.

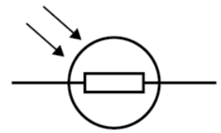
I-V graphs have both positive and negative potential differences and currents. To go from measuring positive to negative currents and potential differences, reverse the connections from your power supply so the potential difference acts in the opposite direction, making the current flow the opposite way around your circuit.

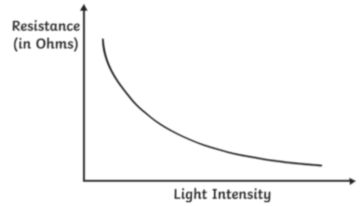




The resistance of a thermistor decreases as the temperature increases. The resistance increases as temperature decreases.

Thermistors can be used in circuits where you want to detect temperature changes such as in thermostats.



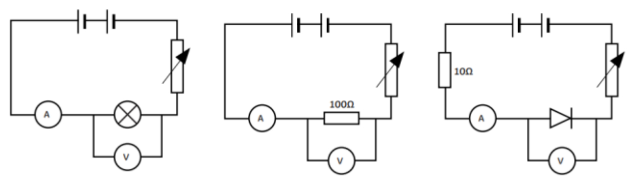


The resistance of an LDR decreases as the light intensity increases. The resistance increases as light intensity decreases.

LDRs can be used in circuits where you want to detect light intensity changes such as turning on streetlights when it gets dark.

Required practical activity 4

Aim: Use circuit diagrams to construct appropriate circuits to investigate the I–V characteristics of a variety of circuit elements, including a filament lamp, a diode and a resistor at constant temperature

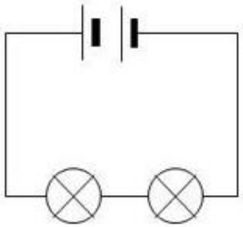


1. Set up the circuit with the resistor.
2. Adjust the variable resistor until you get the first reading for potential difference. Record the current from the ammeter and the potential difference from the voltmeter.
3. Adjust the variable resistor until you get the second reading for potential difference. Record the current from the ammeter and the potential difference from the voltmeter.
4. Repeat the previous step until you have taken all of your readings.
5. Swap the connections on the power supply and repeat step 3 until you get all of the needed negative readings.
6. Swap out the resistor for a filament lamp and then a diode and repeat all the steps again.
7. Plot a graph of current against potential difference to produce the three I-V characteristic graphs.

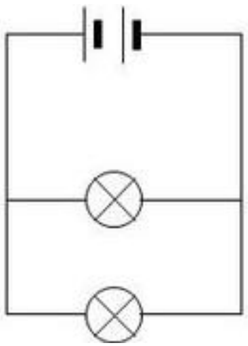
A low current should be used to avoid temperature increases in the resistor.

4.2.2 Series and parallel circuits

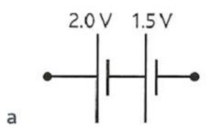
A series circuit has one path for the current to take (one loop).



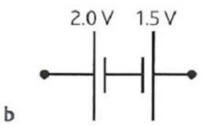
A parallel circuit has more than one path for the current to take (more than one loop).



The total potential difference of cells in series is the sum of their individual potential differences.



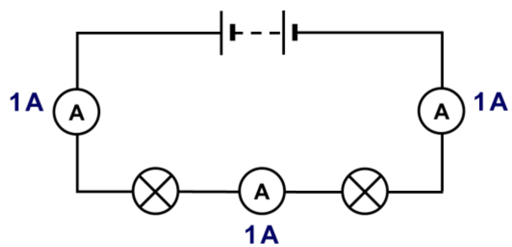
Total pd = 2.0 + 1.5 = 3.5 V



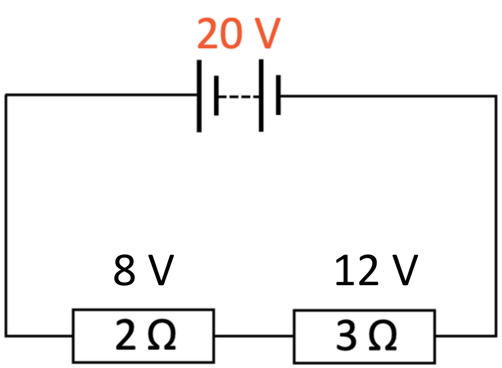
Total pd = 2.0 - 1.5 = 0.5 V

In a series circuit:

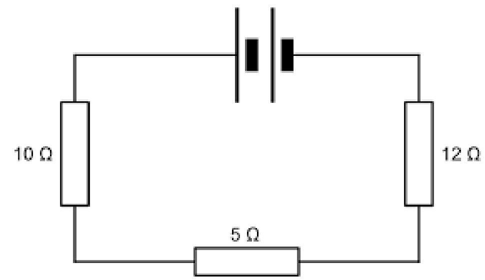
- The current is the same everywhere



- The total potential difference of the power supply is shared between the components in proportion to the resistance. The larger the resistance of a component, the greater share of the total potential difference it will have.



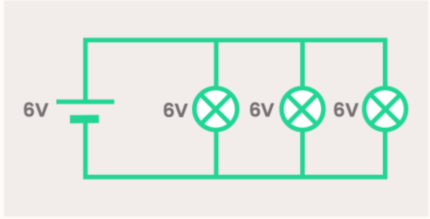
- The total resistance of two components in series is the sum of the resistance of each component. $R_{total} = R_1 + R_2$



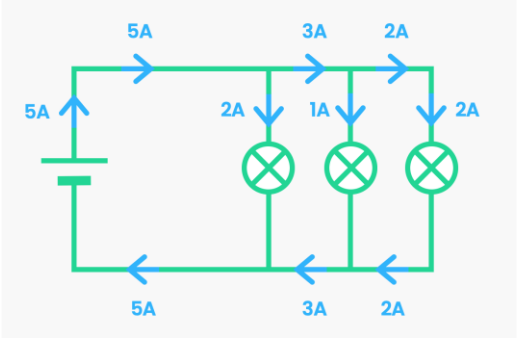
Total resistance = 10 + 5 + 12 = 27 Ω

In a parallel circuit:

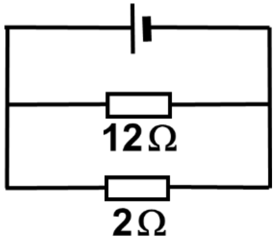
- The potential difference across each branch is the same.



- The total current through the whole circuit is the sum of the currents through each branch. The current in each branch depends on the resistance of the branch and the potential difference across it.



- The total resistance of two resistors is less than the resistance of the separate components.

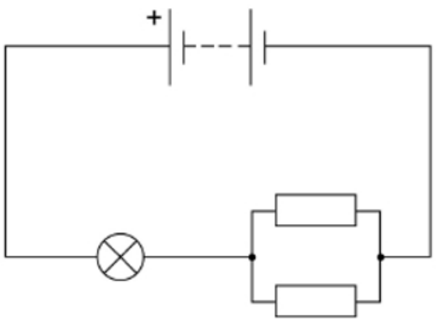


Total resistance < 2 Ω

When a component is added in parallel, the total resistance decreases. This is because adding an extra branch adds another path for current to flow. More current flows for the same potential difference, so the total resistance must have decreased.

Another way to find the total resistance of a circuit is to use $V = IR$ for the power supply.

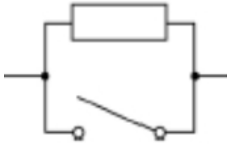
Some circuits include both series and parallel parts.



To solve calculation questions involving circuits, you need to use:

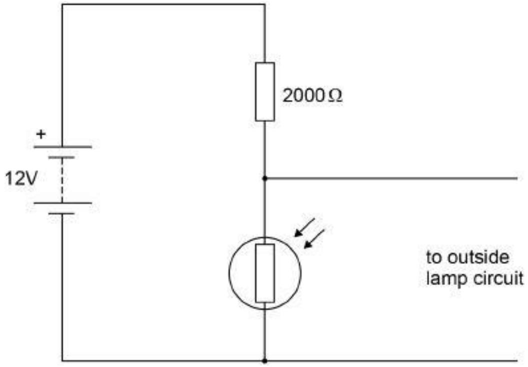
- Circuit rules
- $V = IR$

If a resistor is in parallel with a wire (which has no resistance), all of the current will flow through the wire and none through the component. This is called short circuiting.



The total resistance of the parallel components is zero so no potential difference is dropped across them. This means all the current flows through the wire and not the component being short circuited.

LDR and thermistors can be used in circuits to make components turn on and off with changes in the environment – sensing circuits.

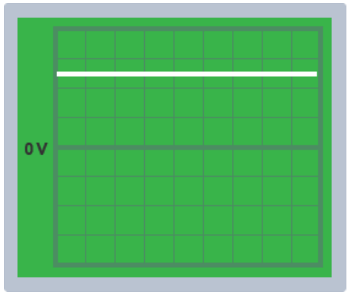


In this example, as the light intensity decreases, the resistance of the LDR increases.
The total resistance of the circuit increases and so the current in the circuit decreases.
The LDR now has a larger share of the total resistance and so gets a larger share of the potential difference. If a bulb is attached in parallel with the LDR, it will now have enough potential difference across it to turn on.

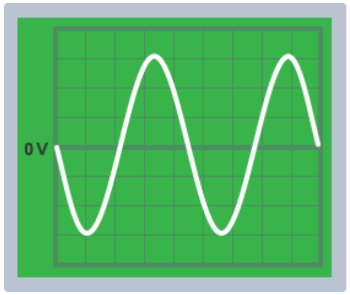
4.2.3 Domestic uses and safety

4.2.3.1 Direct and alternating potential difference

A direct potential difference has a constant polarity (acts in one direction only) – either always positive or always negative. In a complete circuit, it leads to a direct current (DC). Batteries and cells produce a direct potential difference.



An alternating potential difference regularly changes magnitude (size) and polarity (direction) from positive to negative. In a complete circuit, it leads to an alternating current (AC).



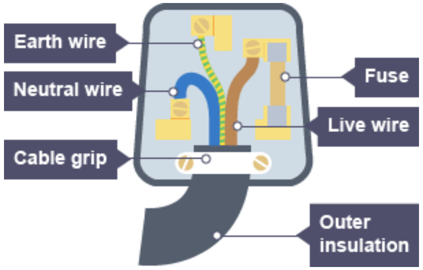
Mains electricity is an AC supply. In the United Kingdom the domestic electricity supply has a frequency of 50 Hz and a potential difference of about 230 V.

4.2.3.2 Mains electricity

Most electrical appliances are connected to the mains using a three-core cable. The three wires are:

- Live wire (brown) – held at a potential of 230 V. The live wire carries the alternating potential difference from the supply.
- Neutral wire (blue) – held at a potential of 0 V (earth potential). The neutral wire completes the circuit.
- Earth wire (green and yellow stripes) – held at a potential of 0 V (earth potential). The earth wire is a safety wire to stop the casing of an appliance becoming live. It only carries a current if there is a fault.

- B**L**ue – left
- B**R**own – right
- S**T**riped – top



The wires are always the same colours so you can easily identify them.

If you have a metal appliance and the earth wire comes loose and touches the metal casing, current will flow into the casing. If you touch the casing, there is a large potential difference between the casing (230 V) and you (0 V because you are earthed) and so current will flow through you giving you an electric shock. The Earth wire has a lower resistance than you so if the live wire comes loose, current will flow through the earth wire rather than you preventing an electric shock.

The live wire is dangerous even if it is not part of a complete circuit because if you touch it, there is a large potential difference between the wire (230 V) and you (0 V because you are earthed) and so current will flow through you to earth, giving you an electric shock.

4.2.4 Energy transfers

4.2.4.1 Power

Power in a circuit device is related to the potential difference across is and the current through it.

$$Power = potential\ difference \times current$$
$$P = VI$$

Power (P) in watts (W)
Current (I) in amperes (shortened to amps) (A)
Potential difference (V) in volts (V)

$$Power = (current)^2 \times resistance$$
$$P = I^2R$$

Power (P) in watts (W)
Current (I) in amperes (shortened to amps) (A)
Resistance (R) in ohms (Ω)

4.2.4.2 Energy transfers in everyday appliances

Everyday electrical appliances are designed to bring about energy transfers. The amount of energy an appliance transfers depends on how long the appliance is switched on for and the power of the appliance. Work is done when charge flows in a circuit.

$$Energy\ transferred = power \times time$$
$$E = Pt$$

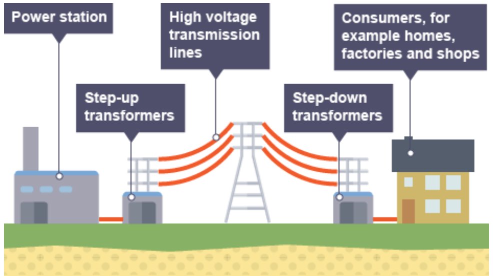
Energy transferred (E) in joules (J)
Power (P) in watts (W)
Time (t) in seconds (s)

$$Energy\ transferred = charge\ flow \times potential\ difference$$
$$E = QV$$

Energy transferred (E) in joules (J)
Charge flow (Q) in coulombs (C)
Potential difference (V) in volts (V)

4.2.4.3 The National Grid

The National Grid is a system of cables and transformers linking power stations to consumers. Electrical power is transferred from power stations to consumers using the National Grid.



Step-up transformers increase the potential difference and decrease the current. This reduces energy loss to the surroundings by heating in the cables, increasing the efficiency of the system as more energy is transferred usefully.

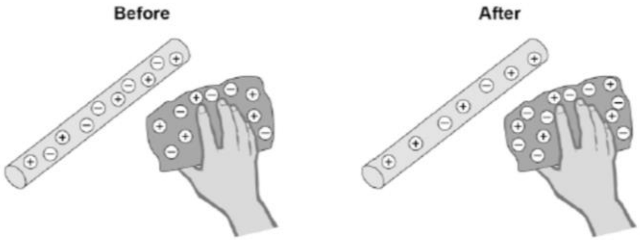
Step-down transformers decrease the potential difference and increase the current. This makes it safe to use in the home.

4.2.5 Static electricity

4.2.5.1 Static charge

All materials have a mixture of positive nuclei and negative electrons and so have a neutral charge

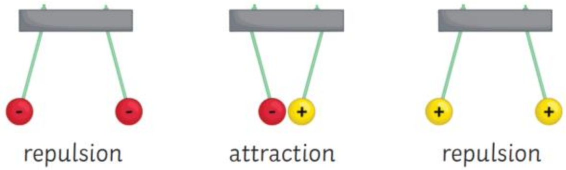
When certain insulating materials are rubbed against each other they become electrically charged. Negatively charged electrons are transferred from one material to the other by friction. The material that gains electrons becomes negatively charged as it has more negative electrons than positive protons. The material that loses electrons is left with an equal in size positive charge – it has more positive protons than negative electrons.



When two electrically charged objects are brought close together, they exert a force on each other.

- Like chargers repel
- Opposite charges attract

These electrostatic forces are non-contact forces as they can be applied when the objects are not touching.

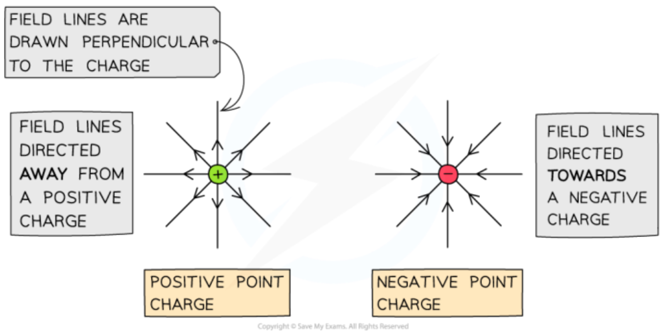


4.2.5.2 Electric fields

A charged object creates an electric field around itself. The electric field is strongest close to the charged object. The further away from the charged object, the weaker the field.

The strength of the field can be shown by the density of the field lines – the closer together the field lines, the stronger the field and the electric force. The further apart the field lines the weaker the field and the electric force.

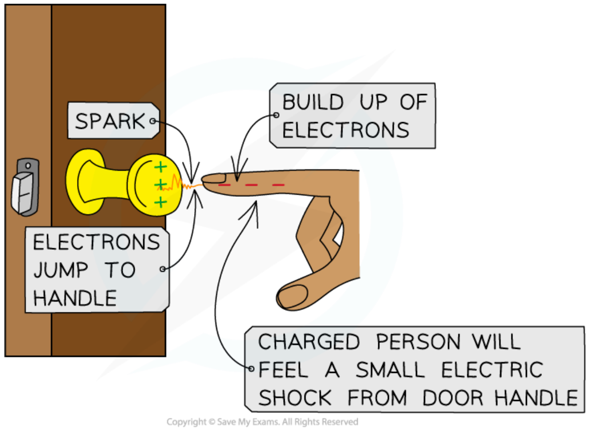
Field lines should be drawn evenly distributed around a charge, perpendicular to the surface of the charge, with arrows.



The field lines show the direction of the electric force on a positive charge – this means the field lines point away from a positive charge and towards a negative charge.

A second charged object placed in the field experiences a force. The force gets stronger as the distance between the objects decreases because the field lines are getting closer together.

If there is a build-up of charge in one place, like in a high-voltage cable, sparking can occur. Around the object will be a strong electric field. If it is strong enough, the air atoms can be ionised – the electrons are ripped off the atoms allowing the air to become a conductor. There is a large potential difference between the charged object and earth (or the object that is earthed) and so the charges flow through the air to earth. This is called sparking.



P3 – Particle model of matter

4.3.1 Changes of state and the particle model

4.3.1.1 Density

Density is the mass per unit volume of a material. It is a measure of how tightly packed the particles are in a substance.

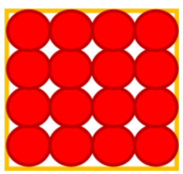
$$Density = \frac{mass}{volume}$$

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

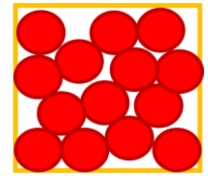
Density (ρ) in kilograms per metre cubed (kg/m^3)
Mass (m) in kilograms (kg)
Volume (V) in metres cubed (m^3)

Sometimes density is measured in g/cm^3.

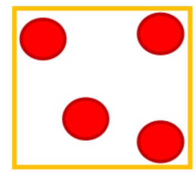
Solids

Diagram	
Arrangement of particles	Ordered Touching
Movement of particles	Vibrate about a fixed position
Energy of particles	Low
Forces of attraction	Strong
Density	High – little space between the particles

Liquids

Diagram	
Arrangement of particles	Random Touching
Movement of particles	Free to move around each other
Energy of particles	Greater energy
Forces of attraction	Weaker
Density	Medium – small space between the particles

Gases

Diagram	
Arrangement of particles	Random Not touching
Movement of particles	Free to move at a range of speeds in random directions
Energy of particles	High energy
Forces of attraction	Very weak
Density	Low – lots of space between the particles

Solids cannot be poured and don't take the shape of the container as there are strong forces of attraction holding the particles together, so they are not free to move. Liquids and gases can be poured and take the shape of the container as there are weaker forces of attraction holding the particles together, so they are free to move.

Solids and liquids cannot be compressed because the particles are touching each other. Gases can be compressed because the particles have space between them so they can be pushed closer together.

Required practical activity 5

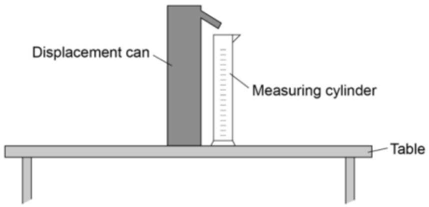
Aim: use appropriate apparatus to make and record the measurements needed to determine the densities of regular and irregular solid objects and liquids.

Practical 1 – density of a regularly shaped object

1. Measure the mass of the object using a balance.
2. Measure the length, width and height of the object using a 30 cm ruler. Vernier callipers or a micrometer could be used for a more accurate measurement as they have a higher resolution.
3. Calculate the volume of the object using the equation volume = length x width x height.
4. Calculate the density of the object using the equation $\rho = \frac{m}{V}$.

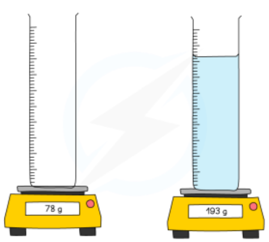
Practical 2 – density of an irregularly shaped object

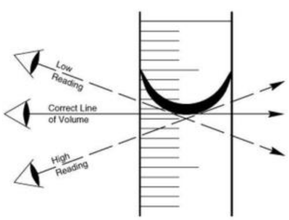
1. Measure the mass of the object using a balance.
2. Fill a displacement can with water up to the spout and place a measuring cylinder beneath the spout.
3. Carefully lower the object into the displacement can so it completely submerged.
4. Measure the volume of displaced water – this is equal to the volume of the object.
5. Calculate the density of the object using the equation $\rho = \frac{m}{V}$.



Practical 3 – density of a liquid

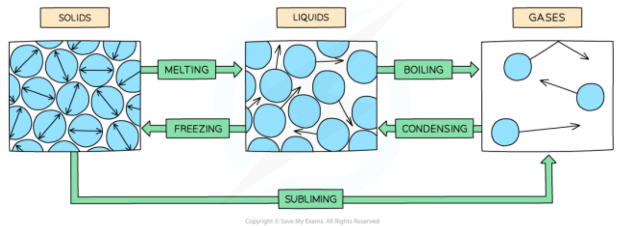
1. Measure the mass of an empty measuring cylinder.
2. Pour 100 cm^3 of the liquid into the measuring cylinder and record the mass of the liquid and the measuring cylinder. Measure the volume from eye level.
3. Calculate the mass of the liquid by doing mass of liquid and cylinder – mass of empty cylinder.
4. Calculate the density of the object using the equation $\rho = \frac{m}{V}$.

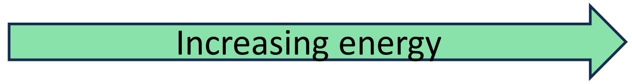




4.3.1.2 Changes of state

When an object is heated or cooled, energy is transferred to or from the object. This can cause it to change state.



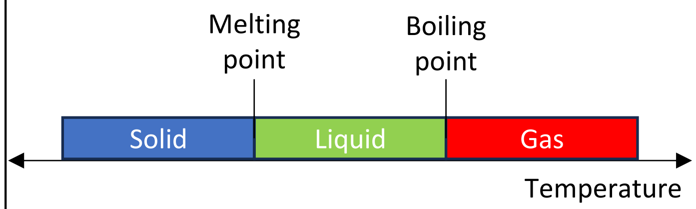


Boiling is an active process. People actively apply energy to a liquid to turn it into a gas using a heater such as a kettle. Evaporation is a passive process. The liquid slowly absorbs energy from the surrounding area so that some of its particles gain enough energy to escape the liquid.

The melting point is the temperature at which a substance changes from a solid to liquid (melts) or liquid to solid (freezes).

The boiling point is the temperature at which a substance changes from a liquid to gas (boils) or gas to liquid (condenses).

If a substance is below the melting point, it is a solid.
If a substance is between the melting point and the boiling point, it is a liquid.
If a substance is above the boiling point, it is a gas.



Throughout all of these changes the number of particles does not change, just their spacing and arrangement. As a result, the total mass does not change – mass is conserved.

Changes of state are physical changes which differ from chemical changes because the material recovers its original properties if the change is reversed.

4.3.2 Internal energy and energy transfers

4.3.2.1 Internal energy

Energy is stored inside a system by the particles (atoms and molecules) that make up the system. This is called internal energy.

Internal energy is the total kinetic energy and potential energy of all the particles (atoms and molecules) that make up a system.

Kinetic energy is the energy stored due to the motion of the particles.
Potential energy is the energy stored due to the position of the particles relative to each other.

Heating changes the energy stored within the system by increasing the energy of the particles that make up the system. When you heat a system, you either raise the temperature of the system or change its state.

P3 – Particle model of matter

The temperature of a substance is related to the average kinetic energy of the particles. When you heat a substance and its temperature increases, the kinetic energy of the particles increases increasing the substance's internal energy.

When you heat a substance and it changes state, the potential energy of the particles increases so the particles can overcome the forces of attraction. This increases the substance's internal energy. This is because the arrangement of the particles is changing.

When you heat or cool a substance you either change the kinetic energy and temperature of the substance or the potential energy and state of the substance, never both at the same time.

4.3.2.2 Temperature changes in a system and specific heat capacity

If the temperature of the system increases, the increase in temperature depends on the mass of the substance heated, the type of material and the energy input to the system.

$$change\ in\ thermal\ energy = mass \times specific\ heat\ capacity \times \text{temperature change}$$

$$\Delta E = mc\Delta\theta$$

Change in thermal energy (ΔE) in joules (J)
Mass (m) in kilograms (kg)
Specific heat capacity in joule per kilogram per degrees Celsius. (J/kg °C)
Temperature change (Δθ) in degrees Celsius (°C)

Temperature change = final temp. – initial temp.

The specific heat capacity is the amount of energy required to raise the temperature of 1 kg of a substance by 1 °C.

The higher the specific heat capacity, the more energy is required to raise the temperature of 1 kg of a material. These materials warm up and cool down slowly.

The lower the specific heat capacity, the less energy is required to raise the temperature of 1 kg of a material. These materials warm up and cool down quickly.

4.3.2.3 Changes of state and specific latent heat

When a change of state occurs, the energy supplied changes the internal energy but not the temperature – the energy is being used to overcome the forces of attraction between the particles (potential energy), not changing their kinetic energy (and temperature).

The energy needed for a substance to change state is called latent heat.

The specific latent heat of a substance is the amount of energy required to change the state of one kilogram of the substance with no change in temperature.

$$Energy\ for\ a\ change\ of\ state = mass \times specific\ latent\ heat$$

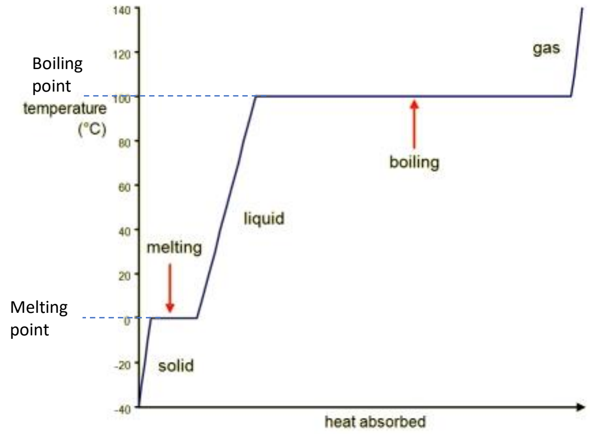
$$E = mL$$

Energy (E) in joules (J)
Mass (m) in kilograms (kg)
Specific latent heat (L) in joules per kilogram (J/kg)

Substances have two specific latent heats depending if they are changing between solid and liquid or between liquid and gas.

- Specific latent heat of fusion – change of state from solid to liquid (or liquid to solid).
- Specific latent heat of vaporisation – change of state from liquid to gas (or gas to liquid)

If you heat or cool a substance, you produce a heating or cooling curve.

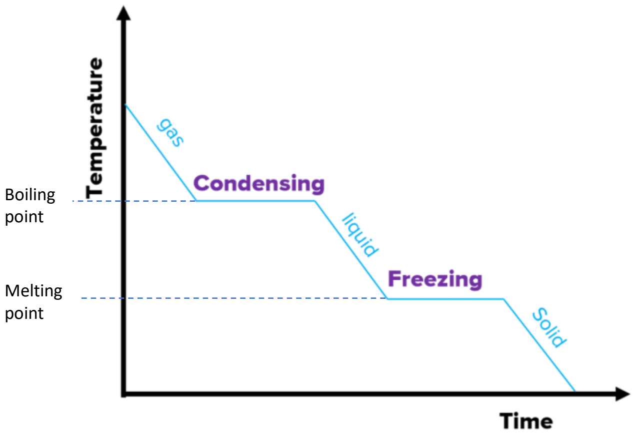


When a substance is being heated, its internal energy increases as energy is being added to the system.

Heating either:

- Increases the kinetic energy of the particles, increasing the temperature (sloped parts of graph) – use the specific heat capacity equation to calculate energy transferred.
- Increases the potential energy of the particles, changing the state with no temperature change (flat parts of graph) – use the specific latent heat equation to calculate energy transferred.

P3 – Particle model of matter



When a substance is being cooled, its internal energy decreases as energy is being removed from the system.

Cooling either:

- Decreases the kinetic energy of the particles, decreasing the temperature (sloped parts of graph) – use the specific heat capacity equation to calculate energy transferred.
- Decreases the potential energy of the particles, changing the state with no temperature change (flat parts of graph) – use the specific latent heat equation to calculate energy transferred.

If you heat or cool a substance and it changes temperature and changes state, you have to use both the specific heat capacity equation and the specific latent heat equation.

Solids have a low internal energy as the particles have little kinetic energy (only vibrate) and little potential energy (particles are close together).

Gases have a high internal energy as the particles have lots of kinetic energy (move quickly) and high potential energy (particles are spread apart).

4.3.3 Particle model and pressure

4.3.3.1 Particle motion in gases

The molecules of a gas are in constant random motion.

The temperature of the gas is related to the average kinetic energy of the molecules. The higher the temperature, the higher the average kinetic energy of the particles.

Gas pressure is the force per unit area exerted on the walls of a container by collisions from the particles.

Changing the temperature of a gas, held at constant volume, changes the pressure exerted by the gas.

- Heating a gas causes its temperature to increase as energy is transferred to the particles.
- Since the temperature increases, the particles have gained kinetic energy.
- This makes the particles move faster.
- There are more frequent collisions between the particles and the walls of the container.
- This increases the force with which the particles collide with the walls, increasing the force on the walls from the particles.
- Pressure increases as pressure is the force per unit area and there is a greater force on the same area.

4.3.3.2 Pressure in gases

A gas can be compressed or expanded by pressure changes. The pressure produces a net force at right angles to the wall of the gas container (or any surface).

Increasing the volume of a container in which a gas is contained, at constant temperature, can lead to a decrease in pressure.

- As the volume increases, the number of collisions between the particles and the walls of the container per second decreases – there are less frequent collisions. This is because the particles have to travel further between collisions with the walls, increasing the time between collisions.
- This decreases the force on the walls from the particles.
- Pressure decreases as pressure is the force per unit area and there is a lower force on the same area.

For a fixed mass of gas held at a constant temperature:

$$Pressure \times volume = constant$$
$$pV = constant$$

Pressure (p) in pascals (Pa)

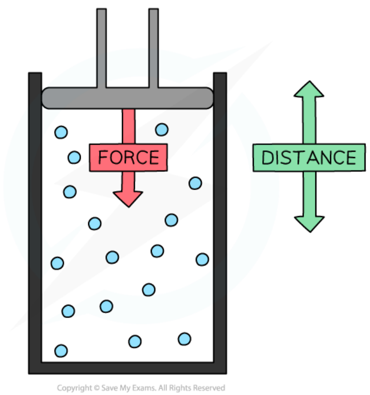
Volume (V) in metres cubed (m^3)

The constant is a constant for that gas. If you multiply the pressure of a gas and its volume, you will get a constant. If you then change the pressure of the gas, the volume will also change. If you multiply the new pressure by the new volume, you will get that same constant.

4.3.3.3 Increasing the pressure of a gas

Work is the transfer of energy by a force.

Doing work on a gas by compressing it increases the kinetic energy of the particles. This makes them move faster and causes an increase in temperature.



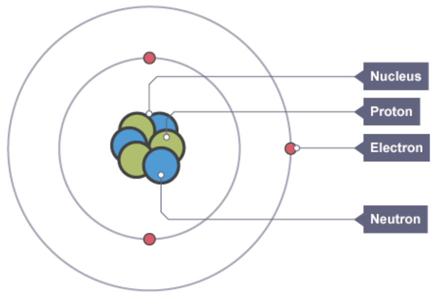
If you use a bicycle pump, you do work on the gas as you pump up the tyre. This transfers energy to the particles, increasing their kinetic energy and their temperature making the bicycle pump increase in temperature.

P4 – Atomic Structure

4.4.1 Atoms and isotopes

4.4.1.1 The structure of an atom

Atoms are very small, having a radius of about 1×10^{-10} metres.



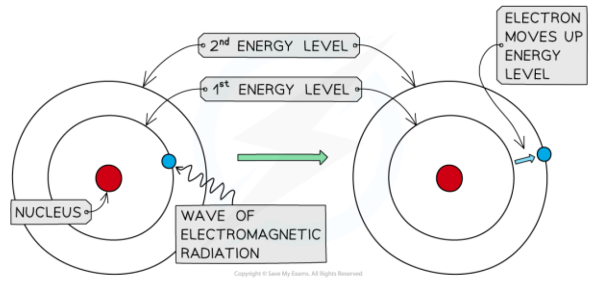
The basic structure of an atom is a positively charged nucleus composed of both protons and neutrons surrounded by negatively charged electrons.

Particle	Location	Relative charge	Relative mass
Proton	Nucleus	+1	1
Neutron	Nucleus	0	1
Electron	Energy levels (shells) around the nucleus	-1	Very small

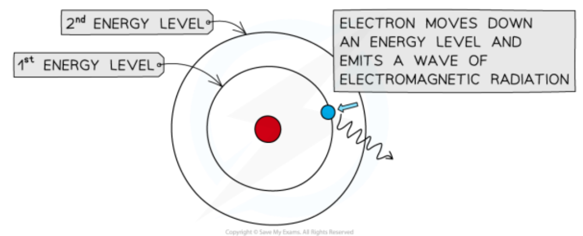
The radius of a nucleus is less than 1/10 000 of the radius of an atom. Most of the mass of an atom is concentrated in the nucleus.

The electrons are arranged at different distances from the nucleus (different energy levels).

Electrons can change which energy level they are in. If they absorb electromagnetic radiation, they move to a higher energy level further away from the nucleus.



They can then emit electromagnetic radiation and move to a lower energy level closer to the nucleus.



4.4.1.2 Mass number, atomic number and isotopes

Atoms have no overall electrical charge (they are neutral). This means that in an atom the number of electrons is equal to the number of protons in the nucleus (the positive protons cancel out the negative electrons to make the atom neutral overall).

All atoms of a particular element have the same number of protons e.g. hydrogen always has 1 proton, helium always has 2 protons.

(Mass number) (Atomic number) $^{23}_{11}\text{Na}$

Atoms can be represented as their element symbol with two numbers: the atomic number and the mass number.

The atomic number is the number of protons (and therefore also the number of electrons) in the atom.

The mass number is the number of protons and neutrons in the nucleus of the atom.

To calculate the number of neutrons in an atom, you need to do:

Number of neutrons = mass number – atomic number

In the example above, there are:

- 11 protons (atomic number)
- 11 electrons (same as number of protons)
- 12 neutrons (mass number – atomic number)

Atoms of the same element always have to have the same number or protons but can have different numbers of neutrons.

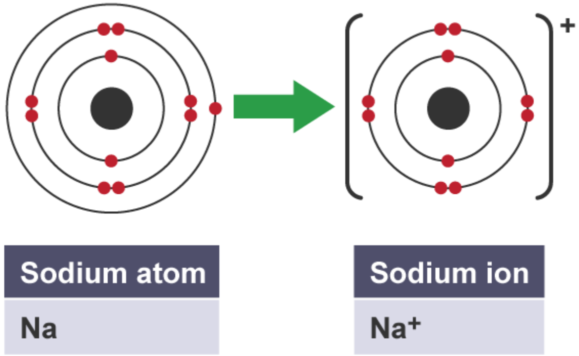
Atoms with the same number of protons but a different number of neutrons are called isotopes.

Protons: 3 Neutrons: 3	Protons: 3 Neutrons: 4	Protons: 3 Neutrons: 5

Lithium-6, lithium-7, and lithium-8 are all isotopes of lithium – they all have 3 protons but different numbers of neutrons.

If an atom loses or gains an electron, it becomes charged – atoms with a charged are called ions.

Atoms turn into positive ions if they lose one or more outer electron(s).



4.4.1.3 The development of the model of the atom

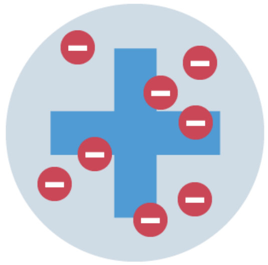
New experimental evidence may lead to a scientific model being changed or replaced.

Dalton model

Before the discovery of the electron, atoms were thought to be tiny spheres that could not be divided – the Dalton model.

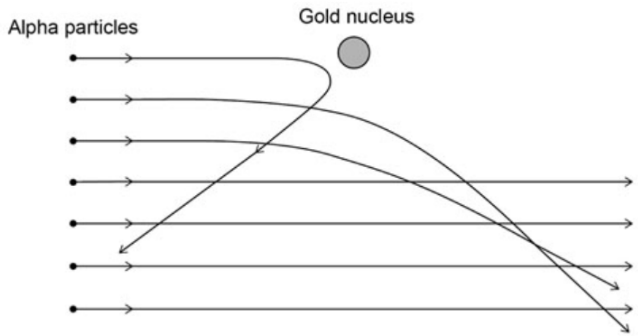
Plum pudding model

J. J. Thomson then discovered the negative electron. Since atoms are neutral, this suggested there also had to be a positive charge inside atoms. This led to the plum pudding model of the atom. The plum pudding model suggested that the atom is a ball of positive charge with negative electrons embedded in it.



Nuclear model

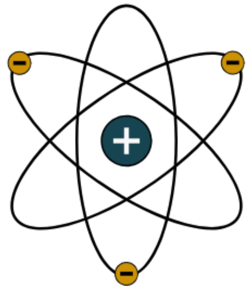
Rutherford performed an experiment where he fired positively charged alpha particles at very thin gold leaf. If the plum pudding model was correct, all of the alpha particles should pass through the gold. This is not what happened – the old model could not explain the results, so the model was changed to explain the new evidence.



The results from the alpha particle scattering experiment were:

- Most of the alpha particles passed through – this suggests most of an atom is empty space.
- A small number of alpha particles rebounded – this suggests that the mass of the atom is concentrated at the centre called the nucleus.
- A few alpha particles were deflected from their paths – this suggests that the nucleus is positively charged. Like charges repel. Alpha particles are positively charged so the nucleus must also be positive to repel the alpha particles.

The plum pudding model was replaced with the nuclear model where electrons orbit around a positive nucleus.



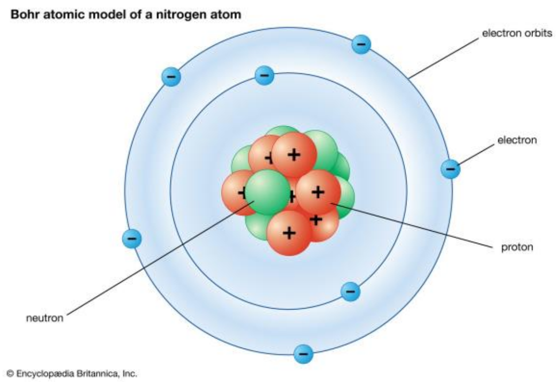
Bohr model

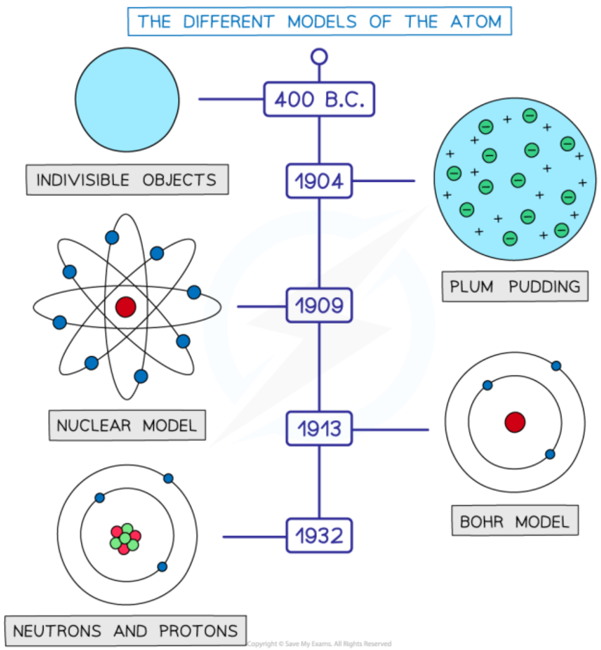
Niels Bohr adapted the nuclear model by suggesting that electrons orbit the nucleus at specific distances. The theoretical calculations of Bohr agreed with experimental observations.

Later experiments led to the idea that the positive charge of any nucleus could be subdivided into a whole number of smaller particles, each particle having the same amount of positive charge. The name proton was given to these particles.

P4 – Atomic Structure

The experimental work of James Chadwick provided the evidence to show the existence of neutrons within the nucleus. This was about 20 years after the nucleus became an accepted scientific idea.



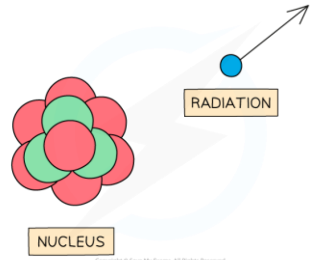


4.4.2 Atoms and nuclear radiation

4.4.2.1 Radioactive decay and nuclear radiation

Some atomic nuclei are unstable – this is normally because they either have too many particles in the nucleus or too many neutrons compared to protons.

To become stable, the nucleus gives out radiation. This is a random process called radioactive decay. Random means you cannot predict when a nucleus will decay.



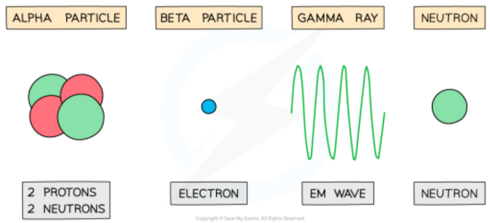
Activity is the rate at which a source of unstable nuclei decays (the number of decays per second). It is measured in becquerels (Bq). The higher the activity, the more dangerous the object as there is more radiation being emitted each second.

Measurements of activity of a sample can be slightly different – this is because radioactive decay is a random process.

Count-rate is the number of decays recorded each second by a detector (e.g. Geiger-Muller tube). Count-rate is normally less than the activity as not all the radiation emitted is detected – some is absorbed before reaching the detector, not all radiation is emitted towards the detector.

There are four main types of radiation:

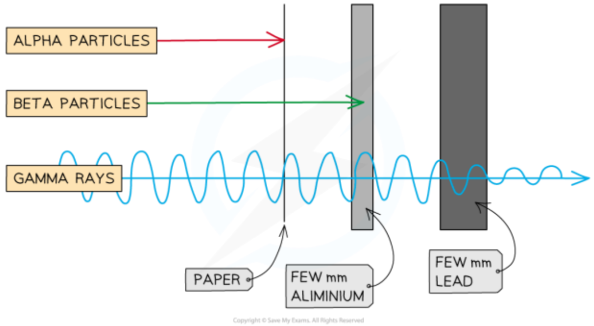
- an alpha particle (α) – this consists of two neutrons and two protons, it is the same as a helium nucleus.
- a beta particle (β) – a high speed electron ejected from the nucleus as a neutron turns into a proton.
- a gamma ray (γ) – electromagnetic radiation from the nucleus.
- a neutron (n).



Radiation can be classified by its:

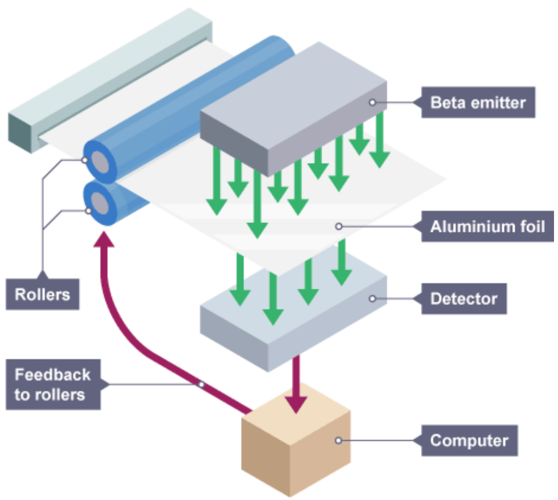
- Ionising power – its ability to remove electrons from atoms, a measure of how dangerous it is. The higher the charge, the more ionising the radiation.
- Penetrating power – a measure of how far it can travel before being absorbed.

	Alpha (α)	Beta (β)	Gamma (γ)
Made of	2 protons 2 neutrons	Electron	EM radiation
Charge	+2	-1	0
Range in air	Few cm	1 metre	Infinite
Penetration	Low – stopped by paper/skin	Medium – stopped by a few mm of aluminium	High – stopped by several cm of lead/thick concrete
Ionisation	High	Medium	Low



Different types of radiation can be used for different purposes depending on its properties.

For example, if I want to measure the thickness of aluminium foil, I can use beta. Alpha won't work as it is not penetrating enough to pass through foil so none would be detected. Gamma won't work as it is too penetrating and all of it will pass through the foil. Beta will work – as the thickness of the foil changes, the amount of beta radiation penetrating through will change, changing the amount detected. You can tell the thickness of the foil based on the amount of beta radiation detected.



4.4.2.2 Nuclear equations

Nuclear equations are used to represent radioactive decay.

In a nuclear equation an alpha particle may be represented by the symbol:

$$^{4}_{2}\text{He}$$

Emitting an alpha particle reduces the mass number by 4 as the nucleus loses four particles and reduces the atomic number by 2 as the nucleus loses two protons. A new element is produced as the number of protons is changing.

$$^{219}_{86}\text{radon} \longrightarrow {}^{215}_{84}\text{polonium} + {}^{4}_{2}\text{He}$$

Tip: Make sure the numbers before the arrow balance the numbers after the arrow. In this case:

- 219 = 215 + 4
- 86 = 84 + 2

In a nuclear equation a beta particle may be represented by the symbol:

$$^{0}_{-1}\text{e}$$

In beta decay, a neutron turns into a proton, emitting an electron. Emitting a beta article does not change the mass number as the nucleus has the same number of protons + neutrons (3 neutrons, 2 protons becomes 2 neutrons, 3 protons – you start and end with 5 particles in the nucleus).

Beta decay increase the atomic number by 1 as the nucleus gains a proton.

A new element is produced as the number of protons is changing.

$$^{14}_{6}\text{carbon} \longrightarrow {}^{14}_{7}\text{nitrogen} + {}^{0}_{-1}\text{e}$$

Tip: Make sure the numbers before the arrow balance the numbers after the arrow. In this case:

- 14 = 14 + 0
- 6 = 7 – 1

In gamma decay, electromagnetic radiation is released form the nucleus, not particles. The nucleus does not change mass or charge, so no decay equation is needed.

You will not need to identify the element from the atomic number so you will not need a periodic table, all you need to do is be able to balance the numbers.

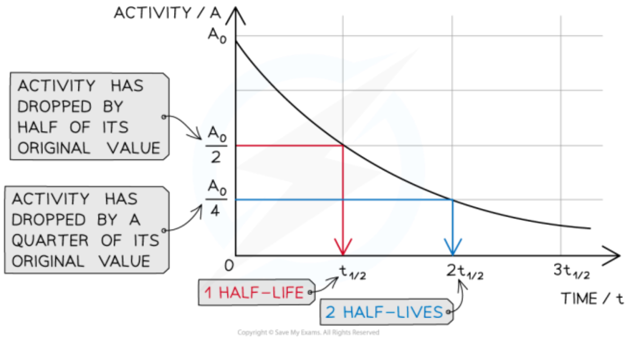
4.4.2.3 Half-lives and the random nature of radioactive decay

Radioactive decay is random – that means you cannot predict when an individual unstable nucleus will decay, or which nucleus will decay. What you can know is the probability a nucleus will decay in a period of time.

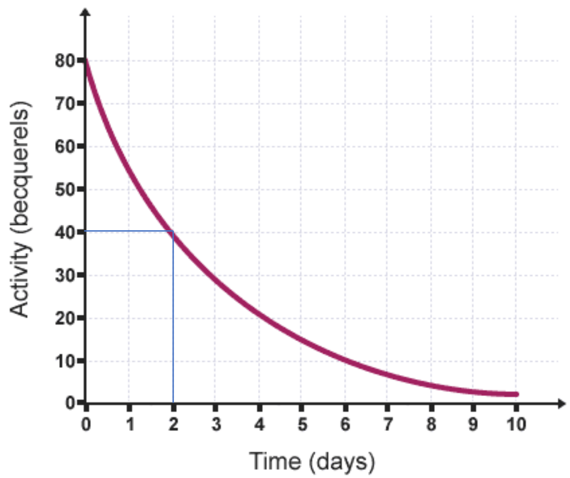
The half-life of a radioactive isotope is the time it takes for the number of nuclei of the isotope in a sample to halve, or the time it takes for the count rate (or activity) from a sample containing the isotope to fall to half its initial level.

If you started with 100 nuclei, the half-life would be the time taken until there were half of the nuclei left, 50. It would then take the same amount of time to half again to 25 left, one half-life.

Each isotope has a different half-life which is a constant value e.g. the half-life of urainium-235 is 704 million years. It will take 704 million years to go from 100 % of the nuclei to 50 %, then another 704 million years to go from 50 % to 25 %. The longer the half-life, the more stable the isotope.



To find the half-life from a graph, look at the original activity or number of nuclei. Half that number and see how long it took to half.



The initial activity is 80 Bq. After one half-life there will be 40 Bq, so the half-life is 2 days. It will take another 2 days to go from 40 Bq to 20 Bq.

You need to be able to calculate the net decline in a radioactive emission and express it as a ratio.

Example:
The half-life of cobalt-60 is 5 years. If there are 100 g of cobalt-60 in a sample, how much will be left after 15 years?

If the half-life is five years, then 15/5 = 3 half-lives have passed.

If you started with 100 g, then after 3 half-lives:

$$100 \xrightarrow{1} 50 \xrightarrow{2} 25 \xrightarrow{3} 12.5$$

12.5 g would be left after three half-lives

As a ratio of what was present originally compared to what was left, this would be 100:12.5 or 8:1.

If the half-life graph has number of atoms on the x-axis and time on the y-axis, then the gradient of the graph is the number of decays per second, the activity. The gradient can be found by drawing a tangent to the curve.

4.4.2.4 Radioactive contamination

Radioactive contamination is the unwanted presence of materials containing radioactive atoms on other materials. The hazard from contamination is due to the radiation emitted during the decay of the contaminating atoms.

The type of radiation emitted affects the level of hazard.

If the unstable nuclei are inside the body, alpha would be most dangerous as it will be absorbed by the body and is the most ionising. Gamma would be the least dangerous as it is the most penetrating, so most radiation would just leave the body and won't be absorbed, and it is the least ionising.

If the unstable nuclei are outside the body, alpha would be least dangerous as it is the least penetrating so wouldn't be able to enter the body. Gamma would be the most dangerous as it is the most penetrating, so could enter the body and ionise the DNA in your cells.

If the DNA in your cells is ionised, it can damage the DNA leading to mutations which increases the risk of cancer. The more ionising the radiation, the greater the risk of cancer.

To minimise the risk of contamination, you need to prevent the radioactive atoms from getting on or inside you – wear a suit and mask, don't touch the material with your hands.

Irradiation is the process of exposing an object to ionising radiation.

The irradiated object does not become radioactive. To become radioactive, the atom needs an unstable nucleus. An irradiated atom can lose electrons (become ionised), the radiation does not change the stability of the nucleus.

Irradiation is used to sterilise medical equipment and food – the radiation can kill any bacteria on the object.

Suitable precautions must be taken to protect against any hazard that the radioactive source used in the process of irradiation may present.

To minimise the risk of irradiation, you need to minimise the dose of radiation received – use a shield to block radiation, stand far away from the source, minimise your exposure time.

It is important for the findings of studies into the effects of radiation on humans to be published and shared with other scientists so that the findings can be checked by peer review.

Peer review is the process by which other scientists look at the findings of your research and check to see if it is correct.

Good scientific research is peer-reviewed and published in a journal. This allows other scientists to learn from your research and allows them to check its accuracy. Scientific journals should be non-biased unlike other places of publication like newspapers that are not always peer-reviewed.

4.4.3 Hazards and uses of radioactive emissions and of background radiation

4.4.3.1 Background radiation

Background radiation is radiation that exists around us all of the time. It comes from:

- natural sources such as rocks and cosmic rays from space.
- man-made sources such as the fallout from nuclear weapons testing and nuclear accidents.

The level of background radiation and radiation dose may be affected by occupation and/or location. Some places have rocks that release radioactive gases so will be exposed to higher levels of background radiation. If you work at a nuclear power station, you will be exposed to a higher level of background radiation.

The amount of radiation received by a person is called the dose. Radiation dose is measured in sieverts (Sv).

$$1000 \text{ mSv} = 1 \text{ Sv}$$

Note: You do not need to remember that dose is measured in sieverts. You do need to convert between millisieverts and sieverts and make conclusions from given data about the risks and consequences of exposure to radiation.

4.4.3.2 Different half-lives of radioactive isotopes

Radioactive isotopes have a very wide range of half-life values, some very short and some very long.

The half-life affects the level of hazard of the isotope.

If you have two radioactive sources that contain the same number of nuclei and emit the same type of radiation, one with a long half-life and one with a short-half-life, the source with the short half-life will initially be more dangerous. Since it has a short half-life, a lot of the nuclei will be decaying each second (it has a high activity) so you will be exposed to a lot of radiation – you will receive a large dose. However, the short half-life means the risk of harm decreases quickly.

The source with the longer half-life will have a lower activity as fewer nuclei are decaying each second due to the longer half-life. This means you will be exposed to less radiation each second. However, you will be exposed to radiation for a longer time due to the longer half-life.

4.4.3.3 Uses of nuclear radiation

Nuclear radiations are used in medicine for the:

- exploration of internal organs – a radioactive source is injected into the body and taken up to part of the body you want to look at. The radiation is emitted from that part of the body and can be detected, letting you image that part of the body.
- control or destruction of unwanted tissue – nuclear radiation is ionising which can kill cells like cancer cells.

When evaluating the use of a radioactive source, you need to think about:

- Half-life
- Ionising power
- Penetrating power

For medical tracers, you want a short half-life, so the body isn't unnecessarily exposed to ionising radiation.

You would want to use a gamma source as it is highly penetrating so can escape the body and be detected and is also weakly ionising, so it minimises the risk of cancer.

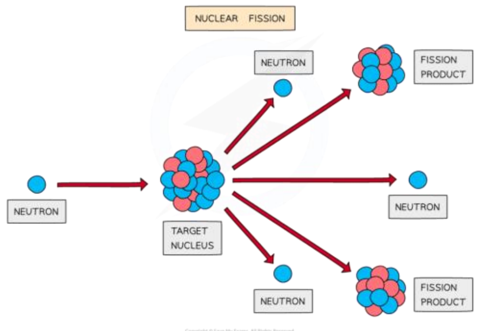
Using ionising radiation is risky in medicine as it increases the risk of cancer. However, the benefits of imaging part of the body or destroying cancer cells can outweigh the increased risk of cancer making it worthwhile.

4.4.4 Nuclear fission and fusion

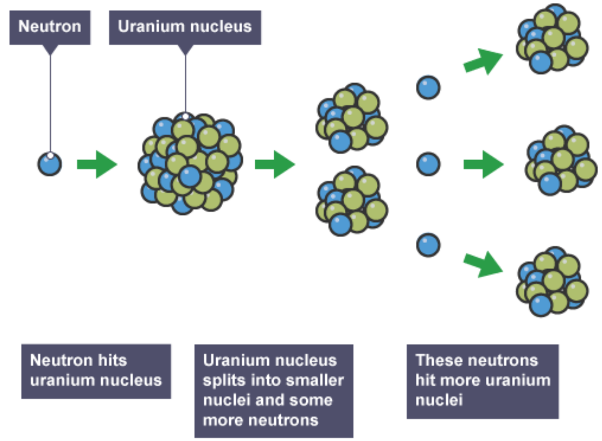
4.4.4.1 Nuclear fission

Nuclear fission is the splitting of a large and unstable nucleus (e.g. uranium or plutonium). This can happen spontaneously, but it is rare. Usually for fission to occur the unstable nucleus must absorb a neutron.

The nucleus undergoing fission splits into two smaller nuclei, roughly equal in size, and emits two or three neutrons plus gamma rays. Energy is released by the fission reaction. All of the fission products have kinetic energy.



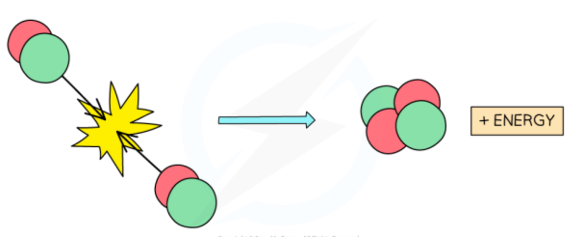
The neutrons may go on to start a chain reaction – the two or three neutrons start another fission reaction which produces more neutrons, which starts more fission reactions, which release more neutrons and so on.



The chain reaction is controlled in a nuclear reactor to control the energy released. The explosion caused by a nuclear weapon is caused by an uncontrolled chain reaction.

4.4.4.2 Nuclear fusion

Nuclear fusion is the joining of two light nuclei to form a heavier nucleus. In this process some of the mass may be converted into the energy of radiation.



4.5.1 Forces and their interactions

4.5.1.1 Scalar and vector quantities

A physical quantity is something that can be measured.

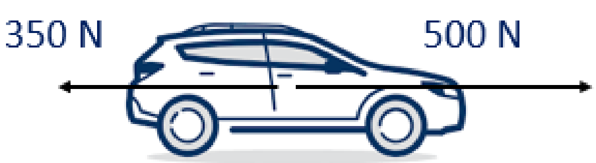
Scalar quantities have magnitude (size) only.
Examples of scalar quantities include:

- Temperature
- Mass
- Energy
- Volume
- Power
- Density
- Distance
- Speed

Vector quantities have both magnitude and direction.
Examples of vector quantities include:

- Force
- Acceleration
- Momentum
- Displacement
- Velocity

A vector quantity may be represented by an arrow. The length of the arrow represents the magnitude, and the direction of the arrow the direction of the vector quantity.



4.5.1.2 Contact and non-contact forces

A force is a push or pull that acts on an object due to the interaction with another object. Forces can change the speed, direction or shape of an object.

All forces between objects are either contact or non-contact forces.

Contact forces are forces that are applied when the objects are physically touching.
Examples of contact forces are:

- Air resistance – Force which slows objects when moving through air.
- Friction – Force which slows objects rubbing together.
- Normal contact – Force between two solid objects that are touching. It acts at 90° to the plane of contact.
- Tension – force transmitted through a rope, string or wire when pulled by forces acting on each end.
- Thrust – force causing an object to move
- Upthrust – upward push of a fluid on an object.

Non-contact forces are forces that are applied when the objects are not physically touching.

Examples of non-contact forces are:

- Gravitational force – the attractive force between two objects with mass.
- Electrostatic force – the attractive or repulsive force between charged objects.
- Magnetic force – the attractive or repulsive force between magnetic poles.

4.5.1.3 Gravity

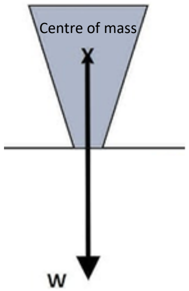
Mass is related to the amount of matter in an object. It will be the same everywhere in the universe.

Weight is the force acting on an object due to gravity. The force of gravity close to the Earth is due to the gravitational field around the Earth. The weight of an object depends on the gravitational field strength at the point where the object is.

$$Weight = mass \times gravitational\ field\ strengh$$
$$W = mg$$

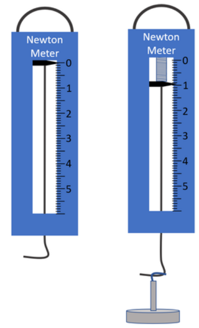
Weight (W) in newtons (N)
Mass (m) in kilograms (kg)
Gravitational field strength (g) in newtons per kilogram (N/kg)

The weight of an object and the mass of an object are directly proportional.



The weight of an object may be considered to act at a single point referred to as the object's centre of mass.

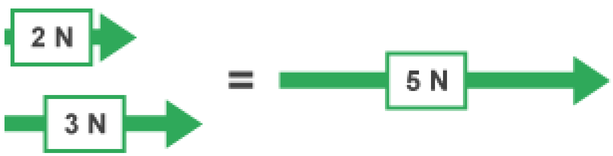
Weight is measured using a calibrated spring-balance (a newtonmeter).



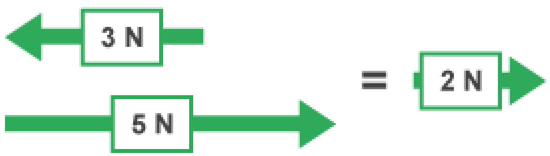
4.5.1.4 Resultant forces

A number of forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together. This single force is called the resultant force.

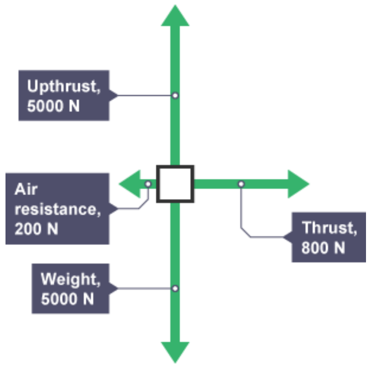
Two forces that act in the same direction produce a resultant force that is greater than either individual force – the magnitudes are added together.



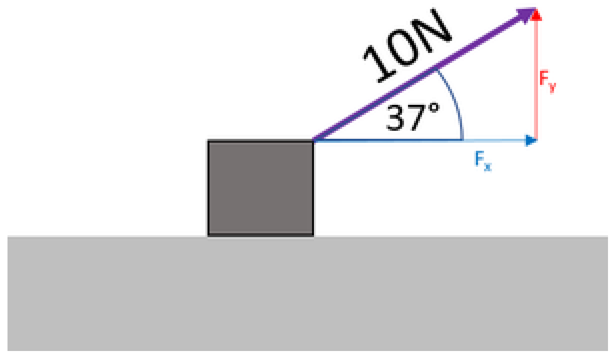
Two forces that act in opposite directions produce a resultant force that is smaller than either individual force – subtract the magnitude of the smaller force from the magnitude of the larger force.



Free body diagrams are used to describe situations where several forces act on an object.

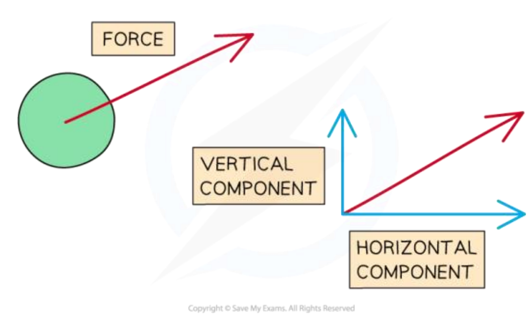


A single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.



Rules ('tip to tail'):

- Decide a suitable scale for your diagram.
- Draw the vector to scale in the direction stated – use a ruler to draw its length and a protractor to draw it at the correct angle.
- Resolve the force into horizontal and vertical components by turning your vector into a right-angled triangle.
- Measure the length of each component with a ruler.
- Convert length to force using your scale to find the magnitude of each component.



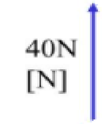
Vector diagrams are used to calculate resultant forces that are not acting directly opposite each other, on a straight line.

Rules ('tip to tail'):

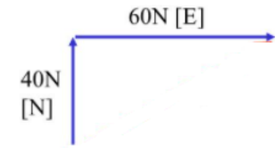
- Draw first vector to scale, in the direction stated.
- Draw second vector, from the tip of the first one in the direction stated.
- Join the two lines in a triangle and measure the resulting line.
- Convert length to force using your scale – this is the resultant force.
- Measure the angle using a protractor

Example:
Two forces act on a toy boat – 40 N acting north, 60 N acting east. Calculate the resultant force and state the direction.

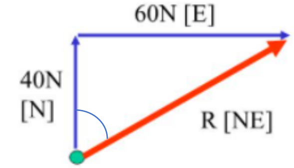
Draw the first vector to scale



Draw 2nd vector from tip of the first one using the same scale.



3. Join the two lines. Measure the resulting line. Use a protractor to measure the angle.



Resultant force = 72 N, 56° from vertical.

4.5.2 Work done and energy transfer

When a force causes an object to move through a distance work is done on the object. So a force does work on an object when the force causes a displacement of the object.

$$Work\ done = force \times distance$$
$$W = Fs$$

Work done (W) in joules (J)

Force (F) in newtons (N)

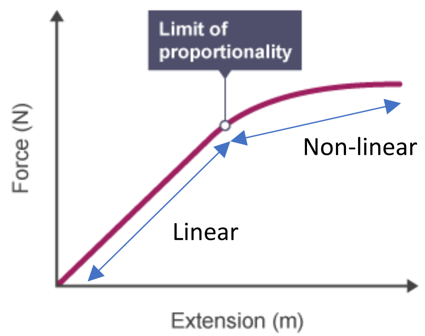
Distance (s) in metres (m)

The distance in the equation is the distance moved along the line of action of the force (the direction the force is acting).

Work done can also be measured in newton-metres (N m). 1 joule = 1 newton-metre.

One joule of work is done when a force of one newton causes a displacement of one metre.

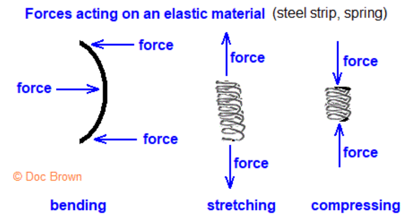
Work done against the frictional forces acting on an object causes a rise in the temperature of the object



4.5.3 Forces and elasticity

Forces can stretch, compress and bend objects.

To change the shape of an object, more than one force has to be applied.



A change of an object's shape is called deformation. There are two types of deformation:

- Elastic deformation – when object return to their original shape when the forces are removed.
- Inelastic deformation – when the object does not return to its original shape when the forces are removed.

Hooke's law says that the extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded ($F \propto e$).

The limit of proportionality is the point where if more force is added, the object may extend but will not return to its original shape when the forces are removed.

$$Force = spring\ constant \times extension$$
$$F = ke$$

Force (F) in newtons (N)

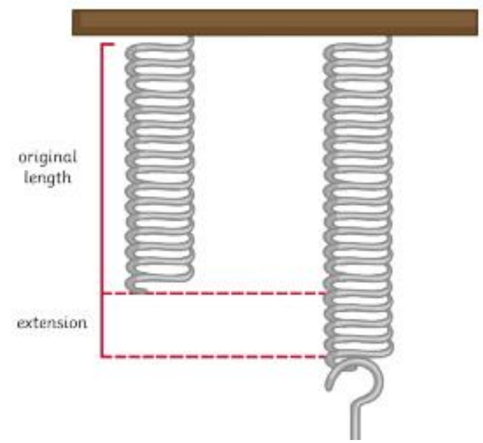
Spring constant (k) in newtons per metre (N/m)

Extension or compression (e) in metres (m)

The spring constant is a measure of how stiff a spring is. The larger the spring constant the more force is needed to stretch it. The lower the spring constant the less force is needed to stretch it.

Extension is the change in Length of the object.

Extension = new length – original length



A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not inelastically deformed, the work done on the spring and the elastic potential energy stored are equal.

$$Elastic\ potential\ energy$$
$$= 0.5 \times spring\ constant \times (extension)^2$$
$$E_e = \frac{1}{2}ke^2$$

Elastic potential energy (E_e) in joules (J)

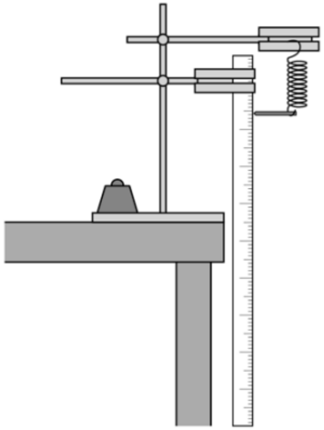
Spring constant (k) in newtons per metre (N/m)

Extension or compression (e) in metres (m)

Required practical activity 6

Aim: investigate the relationship between force and extension for a spring.

- IV – Force on spring
- DV – extension of spring
- CV – spring constant of spring, diameter of spring, original length of spring



Method

1. Set up your apparatus making sure that:

• the ruler is vertical. The zero on the scale needs to be at the same height as the top of the spring

• the splint is attached securely to the bottom of the spring. Make sure that the splint is horizontal and that it rests against the scale of the ruler.

2. Measure original length of the spring and record this.

3. Attach a 100 g mass (1 N) – record the new length of the spring.

4. Continue adding 100 g masses recording the length each time, up to a total of 700 g.

5. Work out the extension for each mass using:

final length – original length

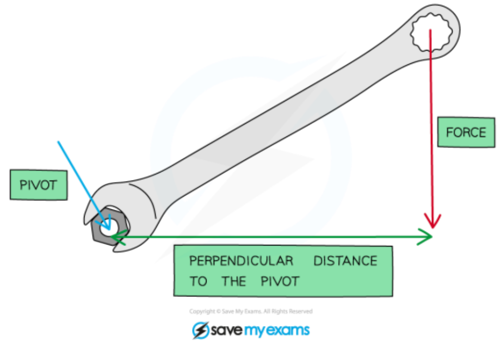
6. Plot a line graph with extension (m) on the x-axis and force (N) on the y-axis. Calculate the spring constant of your spring.

4.5.4 Moments, levers and gears

A force or a system of forces may cause an object to rotate. The turning effect of a force is called the moment of the force.

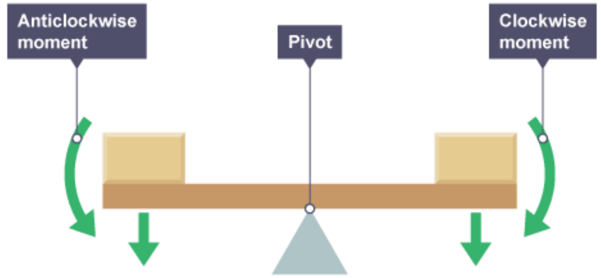
$$Moment\ of\ a\ force = force \times distance$$
$$M = Fd$$

Moment of a force (M) in newton-metres (N m)
Force (F) in newtons (N)
Distance (d) is the perpendicular distance from the pivot to the line of action of the force in metres (m).

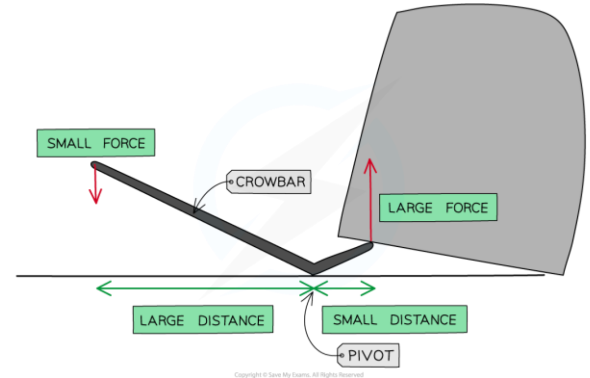


The line of action of the force is a line in the direction the force acts.

If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot.

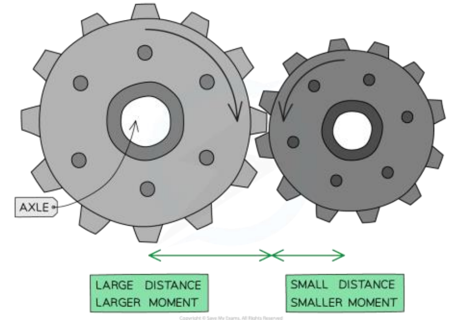


A simple lever and a simple gear system can both be used to transmit the rotational effects of forces.



Levers increase the size of a force acting on an object to make the object turn more easily. A small force at a large distance from the pivot makes a large force a small distance from the pivot.

Gears consist of a wheel with a toothed edge rotating on an axle. The teeth of one gear interlock with the teeth of another gear, transmitting the force. They multiply the effect of a turning force using moments.



The forces is the same on both gears, but the moment is different as the teeth are different distances from the pivot. Their speed of rotation will also be different.

4.5.5 Pressure and pressure differences in fluids

4.5.5.1 Pressure in a fluid

4.5.5.1.1 Pressure in a fluid 1

A fluid can be either a liquid or a gas.

Pressure in a fluid acts in all directions. This causes a force normal (at right angles) to any surface in the fluid.

The pressure at the surface of a fluid can be calculated using the equation:

$$Pressure = \frac{force\ normal\ to\ a\ surface}{area\ of\ that\ surface}$$

$$p = \frac{F}{A}$$

Pressure (p) in pascals (Pa)
Force (F) in newtons (N)
Area (A) in metres squared (m^2)

4.5.5.1.2 Pressure in a fluid 2

The pressure due to a column of liquid can be calculated using the equation:

$$pressure = height \times density \times gravitational\ field\ strength$$

$$p = h\rho g$$

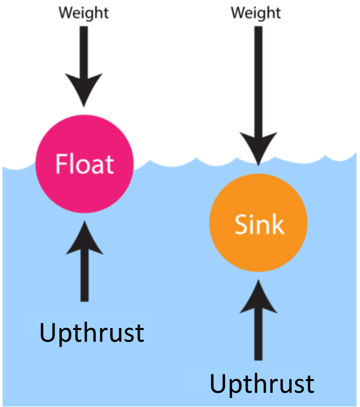
Pressure (p) in pascals (Pa)
Height of the column (h) in metres (m)
Density (ρ) in kilograms per metre cubed (kg/m^3)
Gravitational field strength (g) in newtons per kilogram (N/kg)

In a liquid, the pressure increases with the height of the column of liquid above that point. This is because pressure in a liquid is caused by the weight of the liquid pushing against objects immersed in the liquid. As the liquid becomes deeper, the mass of liquid (and hence the weight) increases which causes the pressure to increase.

In a liquid, the pressure increases as the density of the liquid increases. This is because a more dense liquid has more particles per unit volume so there are more collisions with the object per second. This exerts a larger force per unit area on the object, increasing the pressure.

A partially (or totally) submerged object experiences a greater pressure on the bottom surface than on the top surface because they're at different depths. This creates a resultant force upwards. This force is called the upthrust.

If the upthrust is less than the weight of the object, the object will sink. If the upthrust is larger than the weight of the object, the object will float.



4.5.5.2 Atmospheric pressure

The atmosphere is a thin layer (relative to the size of the Earth) of air round the Earth. The atmosphere gets less dense with increasing altitude.

Air molecules colliding with a surface create atmospheric pressure. The number of air molecules (and so the weight of air) above a surface decreases as the height of the surface above ground level increases. So as height increases there is always less air above a surface than there is at a lower height. So atmospheric pressure decreases with an increase in height.

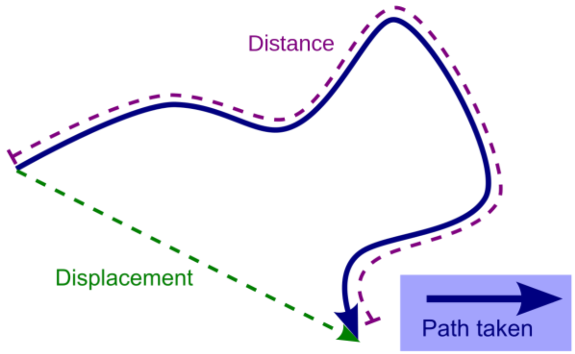
4.5.6 Forces and motion

4.5.6.1 Describing motion along a line

4.5.6.1.1 Distance and displacement

Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.

Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity.



4.5.6.1.2 Speed

Speed does not involve direction. Speed is a scalar quantity.

The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing. The speed at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled. Typical values may be taken as:

- Walking ~ 1.5 m/s
- Running ~ 3 m/s
- Cycling ~ 6 m/s
- Car – 10 to 30 m/s
- Plane – 200 to 250 m/s

The speed of sound and the speed of the wind also vary. A typical value for the speed of sound in air is 330 m/s.

$$Distance\ travelled = speed \times time$$
$$s = vt$$

Distance (s) in metres (m)
Speed (v) in metres per second (m/s)
Time (t) in seconds (s)

To calculate the average speed, you divide the total distance travelled by the time taken.

4.5.6.1.3 Velocity

The velocity of an object is its speed in a given direction. Velocity is a vector quantity

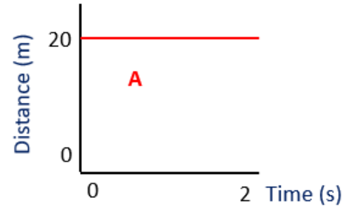
When an object moves in a circle at a constant speed, its direction constantly changes. A change in direction causes a change in velocity. This is because velocity is a vector quantity - it has an associated direction as well as a magnitude.

4.5.6.1.4 The distance-time relationship

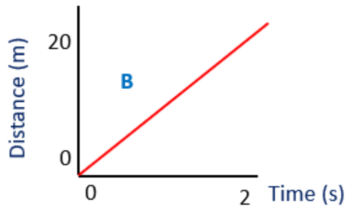
If an object moves along a straight line, the distance travelled can be represented by a distance–time graph.

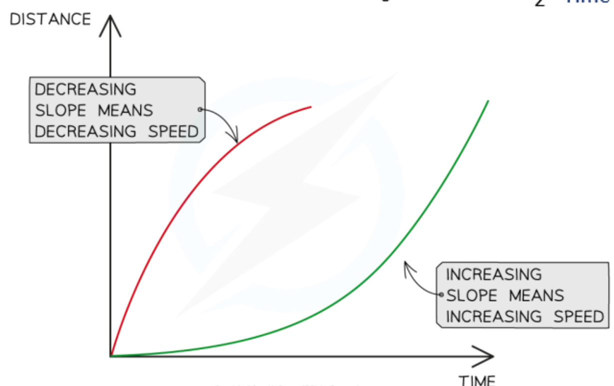
The speed of an object can be calculated from the gradient of its distance–time graph. The steeper the gradient, the faster the object.

Object is stationary (distance not changing)

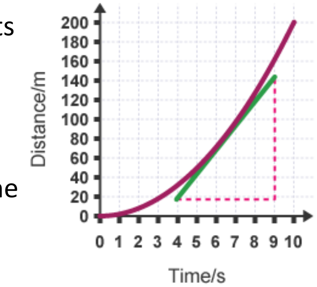


Object is travelling at a constant speed (constant gradient).





If an object is accelerating, its speed at any particular time can be determined by drawing a tangent and measuring the gradient of the distance–time graph at that time.



4.5.6.1.5 Acceleration

Acceleration is the rate of change of velocity.

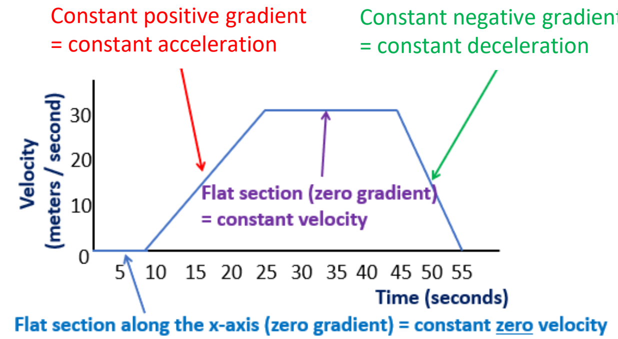
$$Acceleration = \frac{change\ in\ velocity}{time\ taken}$$

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

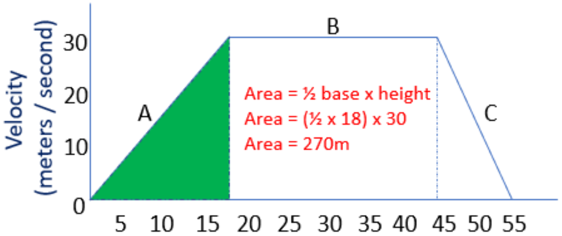
Acceleration (a) in metres per second squared (m/s^2)
Change in velocity (Δv) in metres per second (m/s)
Time (t) in seconds (s)

An object that speeds up is accelerating. An object that slows down is decelerating.

The acceleration of an object can be calculated from the gradient of a velocity–time graph



The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph.



If the velocity-time graph is curved, you can estimate the distance travelled by counting the squares under the graph.

$$(final\ velocity)^2 - (initial\ velocity)^2 = 2 \times acceleration \times distance$$

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

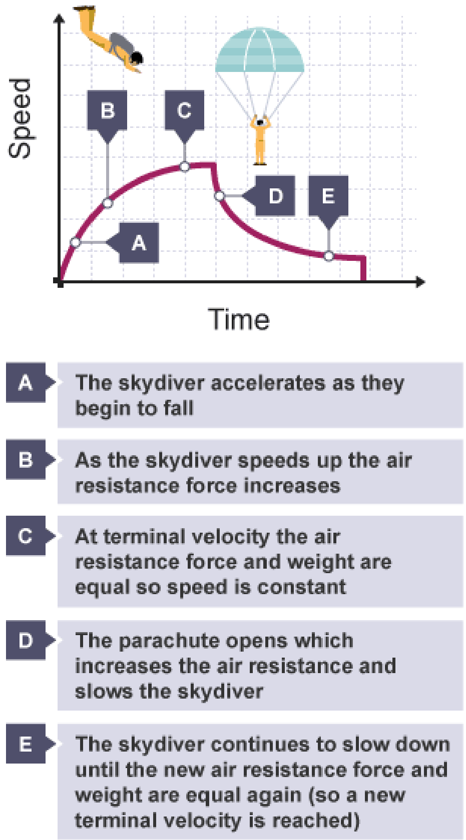
Final velocity (v) in metres per second (m/s)
Initial velocity (u) in metres per second (m/s)
Acceleration (a) in metres per second squared (m/s^2)
Distance (s) in metres (m)

Near the Earth's surface any object falling freely under gravity has an acceleration of about 9.8 m/s^2.

An object falling through a fluid initially accelerates due to the force of gravity. Eventually the resultant force will be zero and the object will move at its terminal velocity.

The size of the drag force on an object depend on its speed and area. The higher the speed, the larger the drag forces. The higher the area, the larger the drag forces.

1. At the start, the object accelerates downwards due to the force of gravity. There are initially very small drag forces as the object has only just started moving. The weight is greater than the drag forces so there is a large resultant force downwards.
2. As the object's speed increases drag forces increase. Weight does not change. The resultant force decreases so the acceleration is smaller.
3. At terminal velocity, the weight of the object due to gravity is balanced by the frictional forces, and the resultant force is zero.

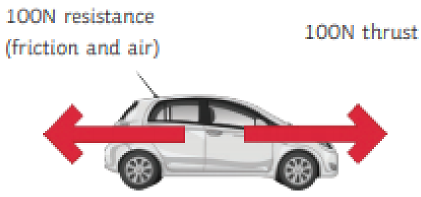


4.5.6.2 Forces, accelerations and Newton's Laws of motion

4.5.6.2.1 Newton's First Law

If the resultant force acting on an object is zero and:

- the object is stationary, the object remains stationary.
- the object is moving, the object continues to move at the same speed and in the same direction. So the object continues to move at the same velocity.



When a vehicle travels at a steady speed the resistive forces balance the driving force. The velocity (speed and/or direction) of an object will only change if a resultant force is acting on the object.

The tendency of objects to continue in their state of rest or of uniform motion is called inertia.

4.5.6.2.2 Newton's Second Law

If a resultant force acts on an object, the object will accelerate in the direction of the resultant force.

The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object.

$$Resultant\ force = mass \times acceleration$$
$$F = ma$$

Force (F) in newtons (N)

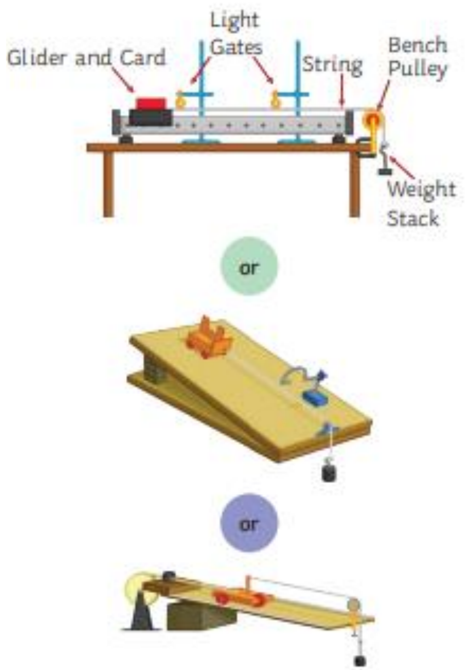
Mass (m) in kilograms

Acceleration (a) in metres per second squared (m/s^2)

Inertial mass is a measure of how difficult it is to change the velocity of an object. Inertial mass is defined as the ratio of force over acceleration.

Required practical activity 7

Aim: investigate the effect of varying the force on the acceleration of an object of constant mass, and the effect of varying the mass of an object on the acceleration produced by a constant force.



Measuring the effect of force on acceleration at constant mass

Independent variable = force applied

Dependent variable = acceleration of car

Control variables = mass of car and surface car is on.

1) Place the car on a ramp. Incline the ramp until the car just does not move. This is to remove as much of the effect of friction as possible.
2) Set up a light gate at the end of the ramp.
3) Place a 1 N weight on the pulley attached to the glider and let go.
4) Record the acceleration from the light gate.
5) Repeat the experiment several times, decreasing the weight on the pulley each time (e.g. 0.8 N, 0.6 N, 0.4 N etc.) Place the removed mass onto the car to keep the mass of the system constant.

Measuring the effect of mass on acceleration with a constant force

Independent variable = mass of glider

Dependent variable = acceleration of glider

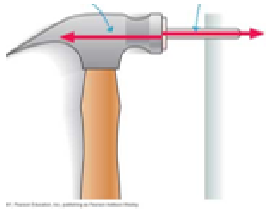
Control variables = force applied and surface car is on

1) Place the glider on the track. Switch on the air blower and adjust until the glider just doesn't move. This is to remove as much of the effect of friction as possible.
2) Set up a light gate at the end of the air track.
3) Add a 10 g mass onto the glider. Place a 1 N weight on the pulley attached to the glider and let go.
4) Record the acceleration from the light gate
5) Repeat the experiment several times, increasing the mass on the glider each time (e.g. 20 g, 30 g, 40 g etc.) whilst keeping the weight (1 N) on the pulley constant

4.5.6.2.3 Newton's Third Law

Whenever two objects interact, the forces they exert on each other are equal in magnitude and opposite in direction.

e.g. a hammer hitting a nail
The hammer exerts a force on the nail, and the nail exerts an equal and opposite force on the hammer.



4.5.6.3 Forces and braking

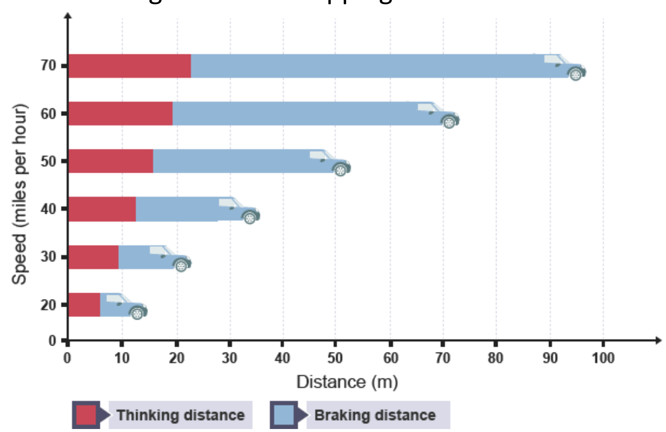
4.5.6.3.1 Stopping distance

$$Stopping\ distance = thinking\ distance + braking\ distance$$

Thinking distance – the distance the vehicle travels during the driver's reaction time

Braking distance – the distance the vehicle travels under the braking force.

For a given braking force, the greater the speed of the vehicle the greater the stopping distance.

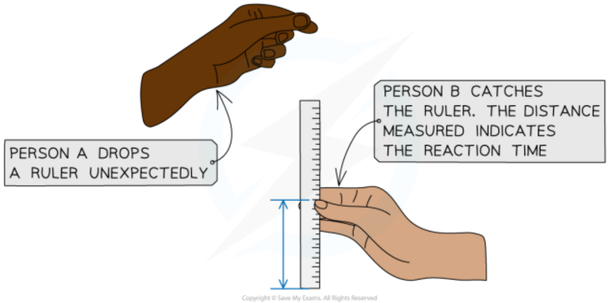


4.5.6.3.2 Reaction time

Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s.

A driver's reaction time (and therefore thinking distance) can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver's ability to react.

Reaction time can be measured using experiments.



4.5.6.3.3 Factors affecting braking distance 1

The braking distance of a vehicle can be affected by adverse road and weather conditions (wet, icy) and poor condition of the vehicle (tyres, brakes).

4.5.6.3.4 Factors affecting braking distance 2

When a force is applied to the brakes of a vehicle, work done by the friction force between the brakes and the wheel reduces the kinetic energy store of the vehicle and increases the internal/thermal energy store of the brakes, causing the temperature of the brakes increases.

The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance.

The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control.

4.5.7 Momentum

4.5.7.1 Momentum is a property of moving objects

$$Momentum = mass \times velocity$$
$$p = mv$$

Momentum (p) in kilogram metre per second (kg m/s)
Mass (m) in kilograms (kg)
Velocity (v) in metres per second (m/s)

4.5.7.2 Conservation of momentum

In a closed system, the total momentum before an event is equal to the total momentum after the event. This is called conservation of momentum.

A closed system is a system where the total amount of energy remains constant.

When completing conservation of momentum calculations:

1. Calculate the total momentum before the collision
2. Calculate the total momentum after the collision
3. Put them equal to each other
4. Rearrange to find the required variable

In an explosion, the total momentum before is zero, so the total momentum after also has to be zero.

4.5.7.2 Changes in momentum

When a force acts on an object that is moving, or able to move, a change in momentum occurs.

If you substitute $a = \frac{\Delta v}{t}$ into $F = ma$, you get:

$$Force = \frac{change\ in\ momentum}{time\ taken}$$

$$F = \frac{m\Delta v}{\Delta t}$$

Force (F) in newtons (N)
Mass (m) in kilograms (kg)
Velocity (v) in metres per second (m/s)
Time (t) in seconds (s)

Force is equal to the rate of change of momentum.

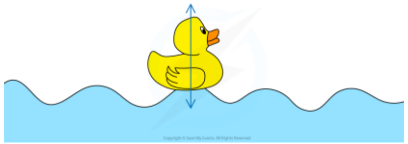
To decrease the force in a collision, you need to increase the time taken for the collision to occur. This decreases the rate of change of momentum, reducing the force on the object.

Air bags, seat belts, gymnasium crash mats cycle helmets and cushioned surfaces for playgrounds all use this principle to reduce the force on people to reduce the risk of injury.

4.6.1 Waves in air, fluids and solids

4.6.1.1 Transverse and longitudinal waves

Waves are repeated vibrations that transfer energy but not matter. The medium is the material through which the wave travels.

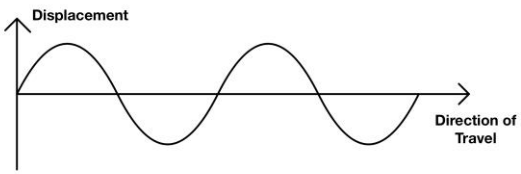


Ripples on the surface of water are an example of a wave. A toy duck floating on the water shows that the wave involves vibrations but doesn't transfer matter, just the energy – the duck vibrates but does not move anywhere overall, the matter is not transferred just the energy.

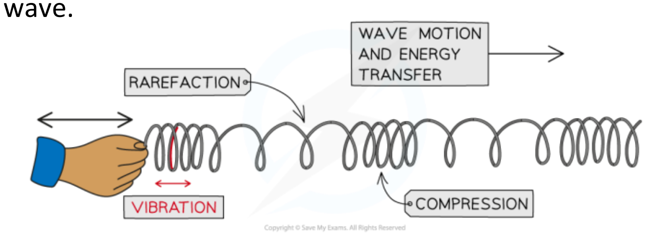
Sound waves in air are an example of a wave. If you stand in front of a speaker, you do not feel a breeze as you hear the music – this shows that the air is transferring the energy (you hear the music) but not the matter (there is no breeze).

There are two types of wave: transverse and longitudinal.

The vibrations of transverse waves are perpendicular to the direction of energy transfer (the direction the wave moves). Examples of transverse waves include ripples on the surface of water and electromagnetic waves like light.



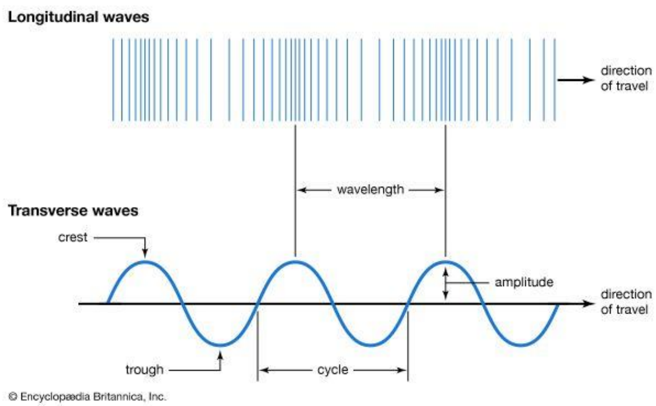
The vibrations of longitudinal waves are parallel to the direction of energy transfer (the direction the wave moves). An example of a longitudinal wave is a sound wave.



The points in a longitudinal wave where the particles are close together are called compressions.

The points in a longitudinal wave where the particles are spaced apart are called rarefactions.

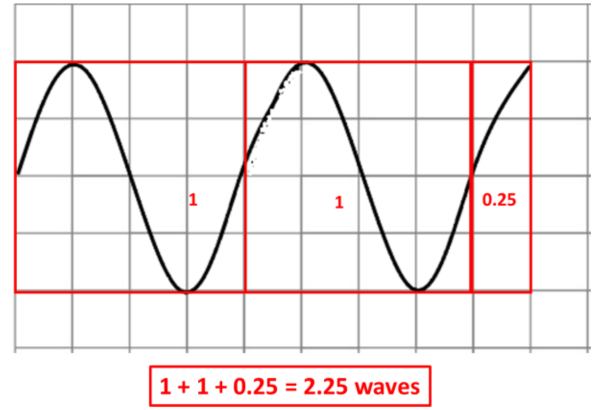
4.6.1.2 Properties of waves



The wavelength of a wave is the distance from one point on a wave to the next identical point on a wave. This is normally measured from the peak/crest (top) or trough (bottom) of a wave but can be measured from any point on the wave to the next identical point. In a longitudinal wave it is normally measured from one compression to the next compression.

The amplitude of a wave is the maximum displacement (distance) of a point on a wave away from its undisturbed position (the middle of the wave).

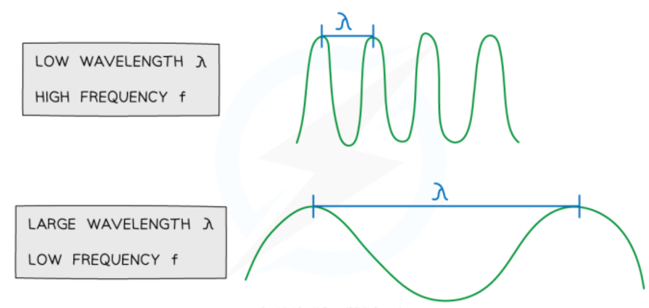
The number of waves in an image is the number of complete cycles shown.



The frequency of a wave is the number of waves passing a point in one second.

10 waves in one second, frequency = 10 waves per second.

10 waves in two seconds, frequency = 5 waves per second.



P6 – Waves

The period is the time taken for one full cycle of a wave.

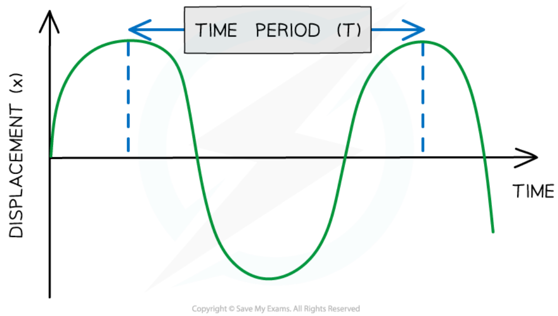
$$Period = \frac{1}{frequency}$$

$$T = \frac{1}{f}$$

Period (T) in seconds (s)

Frequency (f) in hertz (Hz)

If a wave has an x-axis with time on it instead of distance, you can measure the period from the graph by finding the time for one cycle of the wave.



The wave speed is the speed at which the energy is transferred (or the wave moves) through the medium.

$$Wave\ speed = frequency \times wavelength$$
$$v = f\lambda$$

Wave speed (v) in metres per second (m/s)

Frequency (f) in hertz (Hz)

Wavelength (λ) in metres (m)

To measure the speed of sound:

1. Have two people stand at least 100 m apart, measured with a trundle wheel or tape measure.
2. One person should bang together two blocks of wood.
3. The second person should start the timer when they see the block collide and stop the timer when they hear the sound.
4. Repeat the experiment multiple times and calculate a mean time.
5. Use the equation speed = distance ÷ time to calculate the speed of the sound.

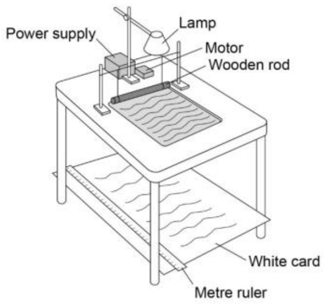
Note: If you are reflecting the sound off a wall and listening for an echo, the distance travelled is double the distance to the wall as the wave has travelled to the wall and back again.

The velocity, wavelength and frequency of sound waves are inter-related. If one of them changes from as the wave travels from one medium to another, the others will change e.g. A sound wave has a constant frequency as it travels from one medium to another. If its speed decreases when it enters the new medium, the wavelength must also decrease (see the wave speed equation).

Required practical activity 8

Aim: make observations to identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid and take appropriate measurements.

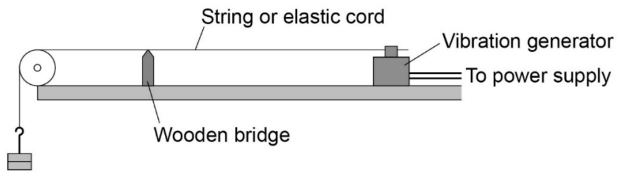
Experiment 1: ripple tank



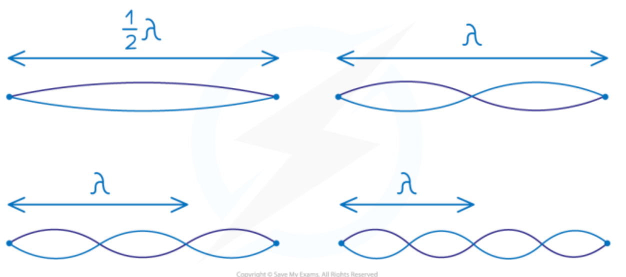
1. Set up the equipment as shown and turn on the motor to produce low frequency waves so that they are able to be counted.
2. Adjust the lamp until pattern is seen clearly on white screen underneath
3. Use a ruler to measure the length of a number of waves (e.g. 10) and divide the length by the number of waves to give wavelength. Either take a photo or use a stroboscope to freeze the image of the waves to make the measurement. One wave is one light band and one dark band.
4. Record the waves using a camera or mobile phone. Count the number of waves passing a point in 10 seconds using a stopwatch and slowing the recording down.
5. Divide the number of waves counted by the time to give frequency (or read the frequency from the frequency generator if available).
6. Use v = fλ to calculate the wave speed.

Note: the speed of the wave could be measured by dividing the length of the tank by the time it took one wave to cross the tank.

Experiment 2: waves in a solid



1. Set up the equipment as shown.
2. Turn on the vibration generator and adjust the position of the wooden bridge until the first wave appears – the wave should look like it is not moving.
3. Use a metre ruler to measure across as many half wavelengths (one loop) as possible. Divide this length by the number of half wavelengths and multiply by two to calculate the wavelength.



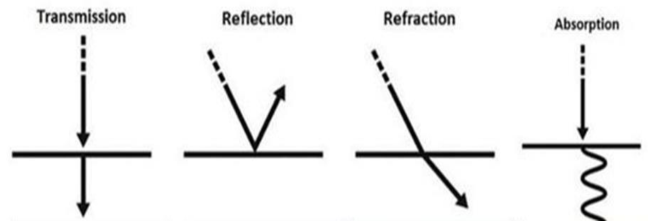
4. The frequency of the wave can be read from the vibration generator.
5. Calculate speed using $v = f\lambda$.
6. Repeat for different frequencies.

It can be difficult to measure the wavelength and frequency in these experiments. If you measure across multiple waves and divide by the number of wavelengths or measure the number of waves in 10 seconds, then divide by 10 to find the frequency, this can improve the accuracy of your readings.

4.6.1.3 Reflection of waves

When reaching a boundary between two different materials, waves can be:

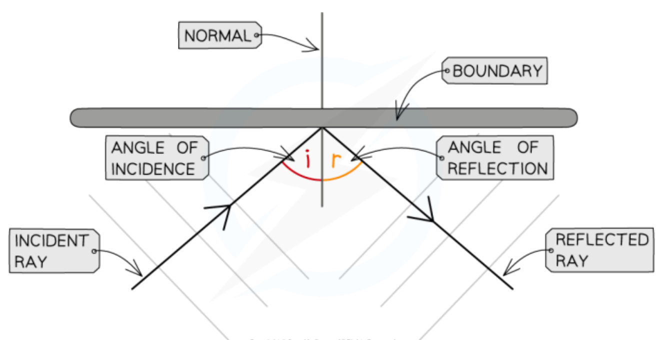
- Reflected (bounce back)
- Absorbed (energy taken in)
- Transmitted (pass through)
- Refracted (change direction while passing through)



A ray diagram shows how waves travels, including what happens when it reaches a surface.

In a ray diagram, you draw each ray as:

- a straight line.
- with an arrowhead pointing in the direction that the light travels.



In a ray diagram for reflection, you need to draw the:

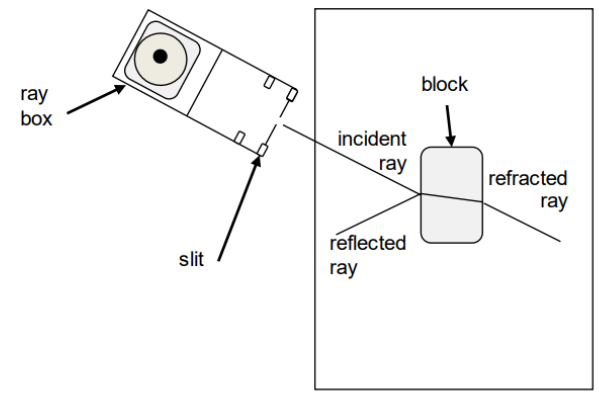
- Normal – a line drawn at right angles to the surface.
- Incident ray – the wave coming towards the surface.
- Angle of incidence – the angle between the incident ray and the normal.
- Reflected ray – the wave travelling away from the surface after reflection.
- Angle of reflection – the angle between the reflected ray and the normal.

The law of reflection states that:

angle of incidence = angle of reflection

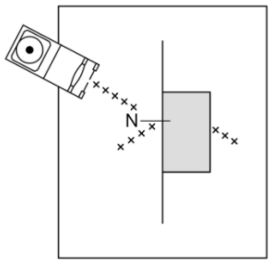
Required practical activity 9

Aim: investigate the reflection of light by different types of surface and the refraction of light by different substances.

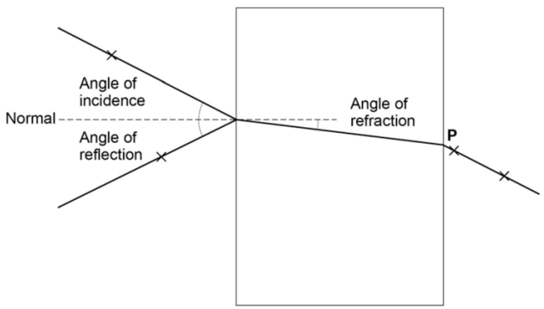


1. Place a glass block on a piece of paper and draw around it.
2. Use a protractor to draw in a normal line at right angles to the surface of the block.
3. Set up the ray box so that a narrow ray of light is produced.
4. Use the ray box to direct a ray of light at the point where the normal meets the block at an angle to the normal.

5. Mark the path of the incident ray, reflected ray and outgoing ray with crosses.



6. Remove the block and join up the crosses with solid lines to show the path of all the light rays. Label the diagram.



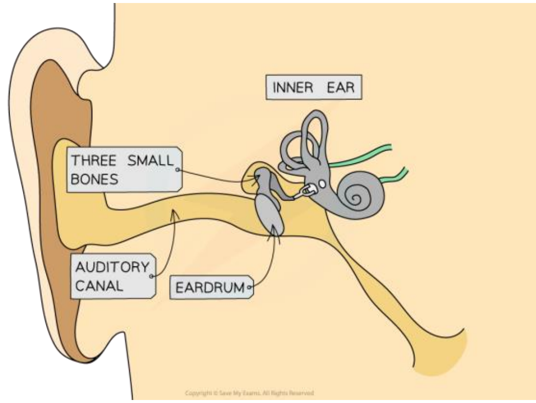
7. Measure with a protractor: the angle of incidence, the angle of reflection, the angle of refraction.
8. Repeat the experiment with a block made of a different material such as Perspex.

The main source of error is the width of the ray. If the width isn't narrow, it will be harder to judge where the centre of the beam is adding inaccuracy to the reading of your angles as there is a larger uncertainty in the measurements.

4.6.1.4 Sound waves

Sound waves are vibrations of air particles. They travel at 330 m/s in air. When a sound wave comes into contact with a solid, those vibrations can be transferred to the solid e.g. when sound waves make a drinking glass vibrate.

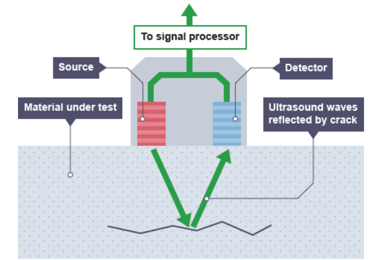
Within the ear, sound waves cause the ear drum and other parts to vibrate which causes the sensation of sound. The conversion of sound waves to vibrations of solids works over a limited frequency range. This restricts the limits of human hearing to a range of 20 Hz to 20 kHz.



4.6.1.5 Waves for detection and exploration

Ultrasound waves have a frequency higher than the upper limit of hearing for humans (20 kHz).

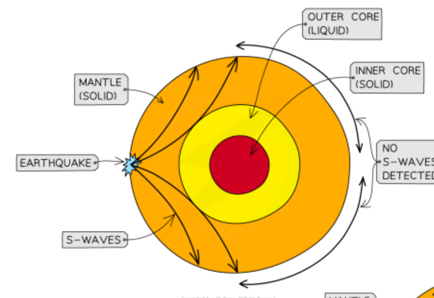
Ultrasound waves are partially reflected when they meet a boundary between two different media. The time taken for the reflections to reach a detector can be used to determine how far away such a boundary is using speed = distance ÷ time. This allows ultrasound waves to be used for both medical and industrial imaging.

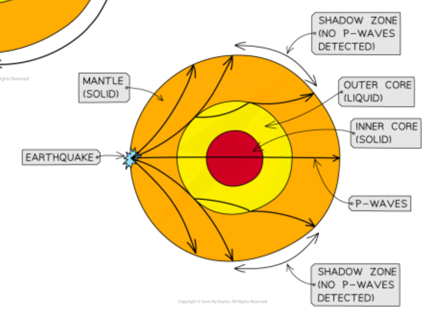


Seismic waves are produced by earthquakes.

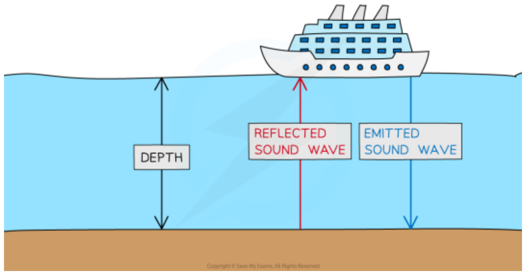
- P-waves are longitudinal seismic waves. P-waves travel at different speeds through solids and liquids.
- S-waves are transverse seismic waves. S-waves cannot travel through a liquid but can travel through solids.

The way that P-waves and S-waves travel through the Earth after earthquakes provided new evidence that led to discoveries about parts of the Earth which are not directly observable such as the structure and size of the Earth's core e.g. Transverse waves can't travel through liquids. Transverse S-waves don't travel through the outer core suggesting it is a liquid.





Echo sounding using high frequency sound waves is used to detect objects in deep water and measure water depth. When calculating depths using echo sounding, make sure to divide the distance travelled by the wave by two as the wave has travelled there and back again, double the depth.



4.6.2 Electromagnetic waves

4.6.2.1 Types of electromagnetic waves

Electromagnetic waves are transverse waves that transfer energy from the source of the waves to an absorber.

Electromagnetic waves form a continuous spectrum. All types of electromagnetic wave travel at the same velocity (the speed of light) through a vacuum (space) or air (3×10^8 m/s).

The waves that form the electromagnetic spectrum are grouped in terms of their wavelength and their frequency.

Long wavelength → Short wavelength

Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays

Low frequency → High frequency

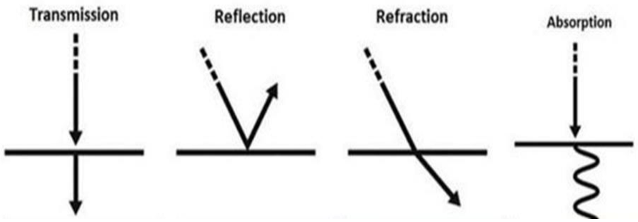
Our eyes only detect visible light and so detect a limited range of electromagnetic waves.

In the visible spectrum, red has the longest wavelength while violet has the shortest wavelength.

4.6.2.2 Properties of electromagnetic waves 1

When reaching a boundary between two different materials, waves can be:

- Reflected (bounce back)
- Absorbed (energy taken in)
- Transmitted (pass through)
- Refracted (change direction while passing through)

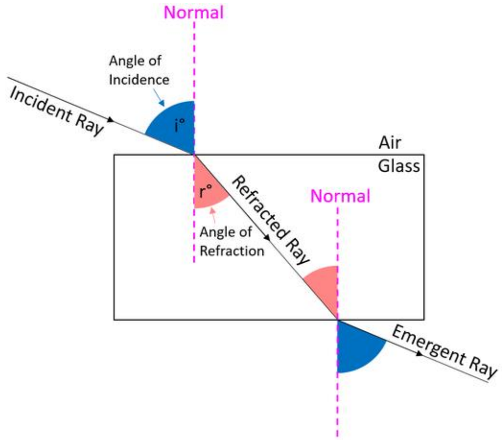


Different substances may absorb, transmit, refract or reflect electromagnetic waves in ways that vary with wavelength e.g. glass transmits visible light but absorbs ultraviolet light.

Waves can refract (change direction) when travelling from one medium to another. This is because the wave is changing velocity as it goes from one medium to another.

When going from a less dense to a more dense medium (e.g. air to glass), a wave slows down and bends towards the normal.

When going from a more dense to a less dense medium (e.g. glass to air), a wave speeds up and bends away from the normal.

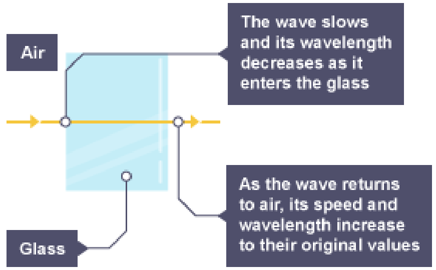


In a ray diagram for refraction, you need to draw the:

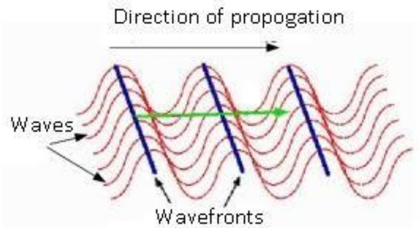
- Normal – a line drawn at right angles to the surface.
- Incident ray – the wave coming towards the surface.
- Angle of incidence – the angle between the incident ray and the normal.
- Refracted ray – the wave travelling into the new medium that has changed direction,
- Angle of refraction – the angle between the refracted ray and the normal.

Note that the emergent ray is parallel to the incident ray.

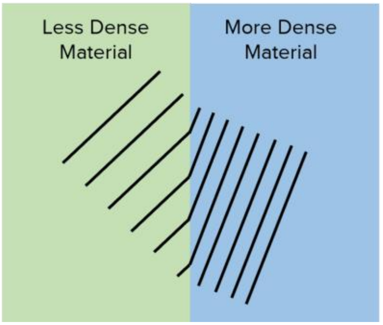
If the wave travels along the normal (the angle of incidence is 0°), the wave slows down but does not change direction.



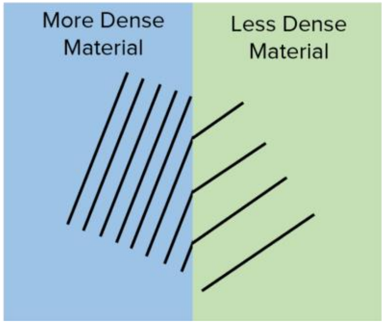
Refraction can be explained using wavefronts. Wavefronts are lines connecting the peaks (or troughs) of waves.



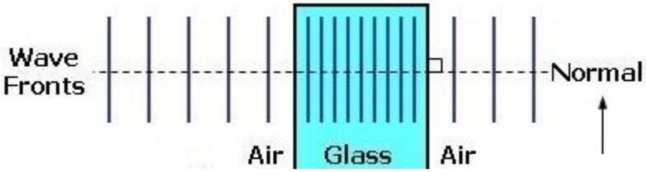
When a wave goes from a less dense medium to a more dense medium (like air to water) at an angle, one side of the wavefront enters the new medium first and slows down while the other side keeps moving at the original faster speed. One side changing speed before the other causes the wave to change direction (bend towards the normal) and the wavelength to decrease.



When a wave goes from a more dense medium to a less dense medium (like water to air) at an angle, one side of the wavefront enters the new medium first and speeds up while the other side keeps moving at the original slower speed. One side changing speed before the other causes the wave to change direction (bend away from the normal) and the wavelength to increase.



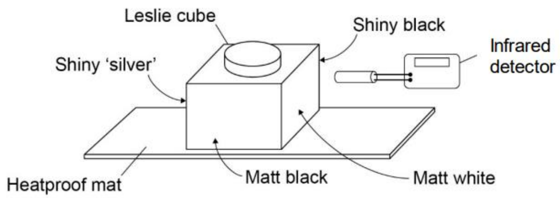
When a wave enters a new medium along the normal (angle of incidence = 0°), all parts of the wavefront enter the new medium at the same time and so the whole wave speeds up or slows down at the same time. This means there is no change in direction, just a change in wavelength.



Required practical activity 10

Aim: investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.

A Leslie cube is a metal cube with different colour sides which are either shiny or matt.



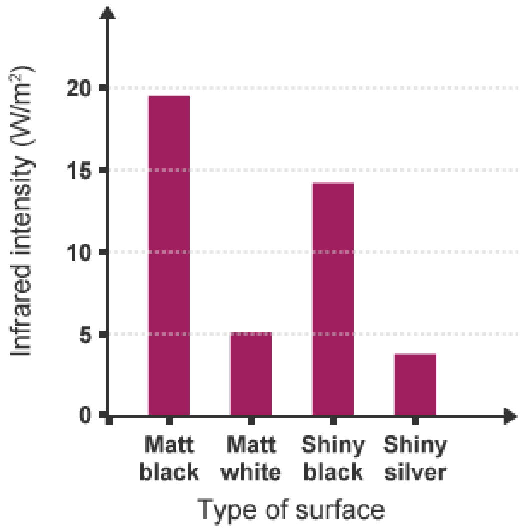
Independent variable – surface colour.

Dependent variable – infrared radiation emitted by surface.

Control variable – distance between the surface and the infrared detector.

1. Place Leslie cube on a heat proof mat.
2. Once the kettle has boiled, fill the Leslie cube with hot water and put on the lid
3. Hold the infrared thermometer 5 cm from the first surface.
4. Record the infrared radiation emitted by the surface.
5. Repeat the experiment three times on each surface and calculate mean for each surface.

An advantage of using a Leslie cube instead of individual flasks of different colours is all the sides will be the same temperature as they're all in contact with the same hot water.

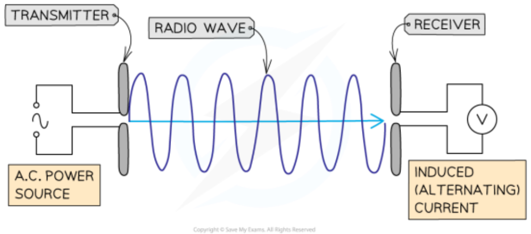


All objects emit and absorb infrared radiation.

- An object at constant temperature is absorbing radiation at the same rate as it is emitting radiation.
- The temperature of an object increases when it absorbs radiation faster than it emits radiation.
- The temperature of an object decreases when it emits radiation faster than it absorbs radiation.
- The greater the temperature difference, the greater the rate of emission and absorption of infrared radiation.

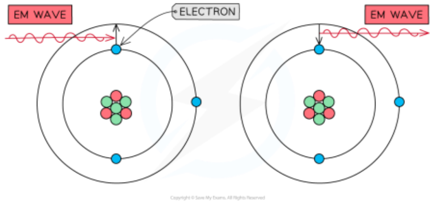
4.6.2.3 Properties of electromagnetic waves 2

Radio waves can be produced by an alternating current in a transmitter. The radio wave will have the same frequency as the alternating current.



When radio waves are absorbed by a receiver, they make the electrons in the receiver vibrate, inducing an alternating current with the same frequency as the radio wave in the receiver.

Changes in atoms and the nuclei of atoms can result in electromagnetic waves being generated or absorbed over a wide frequency range.



Electrons can absorb electromagnetic waves and move to a higher energy level. They then drop down to a lower energy level, releasing electromagnetic radiation. This can happen up to X-rays.

Gamma rays originate from changes in the nucleus of an atom, not the electron energy levels.

Ultraviolet waves, X-rays and gamma rays (high energy electromagnetic waves) can have hazardous effects on human body tissue as this radiation is ionising – it can remove electrons from atoms. If the DNA in your cells is ionised, it can lead to mutations which cause an increased risk of cancer.

The effects depend on the type of radiation and the size of the dose.

Radiation dose (measured in sieverts, Sv) is a measure of the risk of harm resulting from an exposure of the body to the radiation.

$$1000 \text{ mSv} = 1 \text{ Sv}$$

The size of the dose depends on how long you are exposed to the ionising radiation – the longer the time the larger the dose.

Note: You do not need to remember that dose is measured in sieverts. You do need to convert between millisieverts and sieverts and make conclusions from given data about the risks and consequences of exposure to radiation.

Radio waves, microwaves, infrared, and visible light (low energy electromagnetic waves) are non-ionising so do not lead to an increased risk of cancer.

Some risks of high energy electromagnetic waves include:

- Ultraviolet waves can cause skin to age prematurely and increase the risk of skin cancer.
- X-rays and gamma rays are ionising radiation that can cause the mutation of genes and cancer.

4.6.2.4 Uses and applications of electromagnetic waves

Electromagnetic waves have many practical applications including:

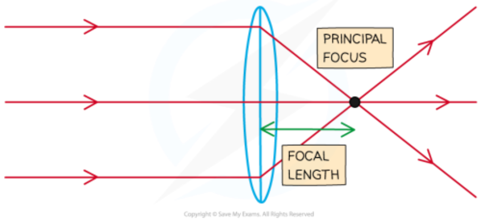
- Radio waves – television and radio, communications
- Microwaves – satellite communications as they can pass through the atmosphere, cooking food, phone signals, Wi-Fi
- Infrared – electrical heaters, cooking food, infrared cameras
- Visible light – fibre optic communications (e.g. internet)
- Ultraviolet – energy efficient lamps, sun tanning
- X-rays – medical imaging and treatments like imaging bones. X-rays are absorbed by dense tissues (like bone) and metals, but they can pass through soft tissue like skin and muscle. This produces a shadow on the film, showing an image of the bones.
- Gamma rays – medical imaging and treatments, sterilising equipment.

4.6.2.5 Lenses

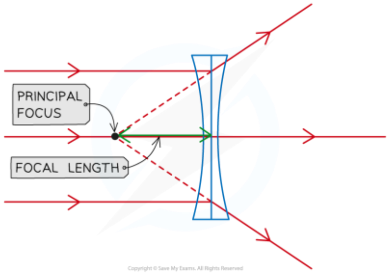
A lens forms an image by refracting light.

There are two types of lenses:

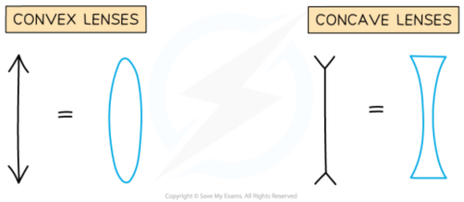
- Convex lens – parallel rays of light are brought to a focus at the principal focus. The distance from the lens to the principal focus is called the focal length.

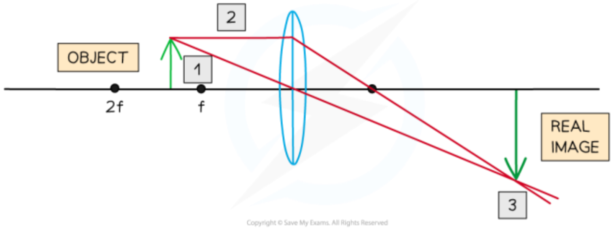


- Concave lens – parallel rays of light diverge away from the principal focus. The distance from the lens to the principal focus is called the focal length



Ray diagrams are used to show the formation of images by convex and concave lenses. In ray diagrams, convex and concave lenses are represented by symbols:





A ray diagram will contain a lens and the object (where the light rays are coming from) drawn as an arrow. The object will be a certain distance away from the lens, normally measured in focal lengths e.g. one focal length from the lens, between one and two focal lengths from the lens. All light ray come from the top of the object.

To draw a lens diagram:

1. Draw a light ray from the top of the object through the centre of the lens in a straight line (it is not refracted).
2. Draw a light ray from the top of the object parallel to the axis to the lens. Then draw a straight line from the lens through the principal focus.
3. Draw in the image from the axis to the point where the light rays meet – this is the top of the image.

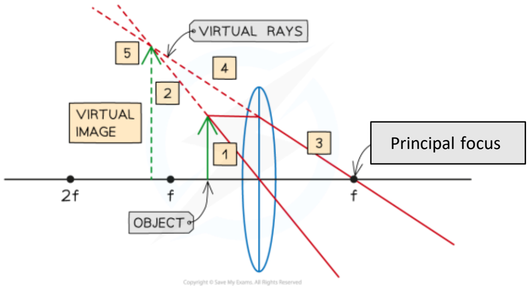
The image can be described as:

- Magnified (bigger) or diminished (smaller)
- Upright or inverted (upside down)
- Real or virtual

A real image is an image that is formed when light rays converge and meet each other and can be projected onto a screen. They are always on the opposite side of the lens to the object.

A virtual image is an image that is formed when the light rays do not meet but appear to meet behind the lens and cannot be projected onto a screen. They are always on the same side of the lens as the object.

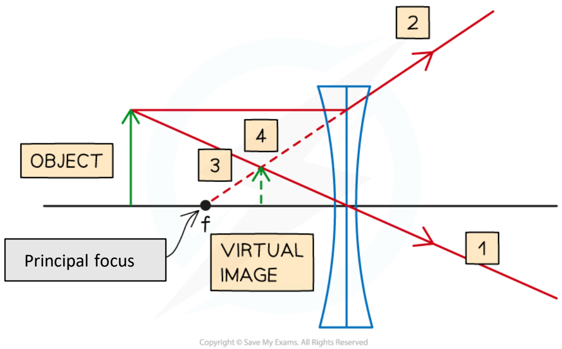
The image formed in the first example is magnified (bigger), inverted (upside down) and real (on the opposite side of the lens to the object). An object further away than the focal length will always form a real image.



Sometimes the light rays will not converge if the object is closer than the focal length.

1. Draw a light ray from the top of the object through the centre of the lens in a straight line (it is not refracted).
2. Draw a dashed line backwards following the line.
3. Draw a light ray from the top of the object parallel to the axis to the lens. Then draw a straight line from the lens through the principal focus.
4. Draw a dashed line backwards following the line.
5. Draw in the image from the axis to the point where the light rays meet – this is the top of the image.

The image formed in this example is magnified (bigger), upright and virtual (on the same side of the lens to the object).



To draw a lens diagram for a concave lens:

1. Draw a light ray from the top of the object through the centre of the lens in a straight line (it is not refracted).
2. Draw a light ray from the top of the object parallel to the axis to the lens. Then draw a straight line from the lens diverging away from the principal focus.
3. Draw a dashed line backwards following the line.
4. Draw in the image from the axis to the point where the light rays meet – this is the top of the image.

The image formed in this example is diminished (smaller), upright and virtual (on the same side of the lens to the object).

The image produced by a concave lens is always virtual. The image produced by a convex lens can be virtual or real.

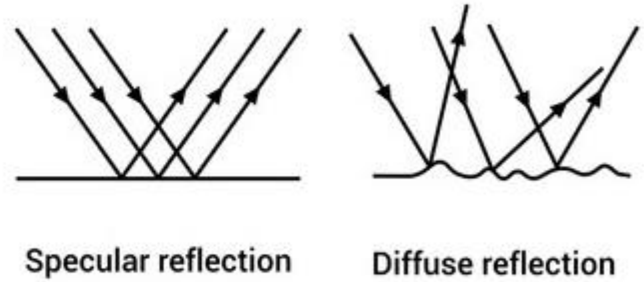
The magnification produced by a lens can be calculated using the equation:

$$Magnification = \frac{image\ height}{object\ height}$$

Magnification is a ratio so has no units. The units of image and object height can be any unit for height, as long as it is the same for both image and object height e.g. both millimetres or both centimetres.

4.6.2.6 Visible light

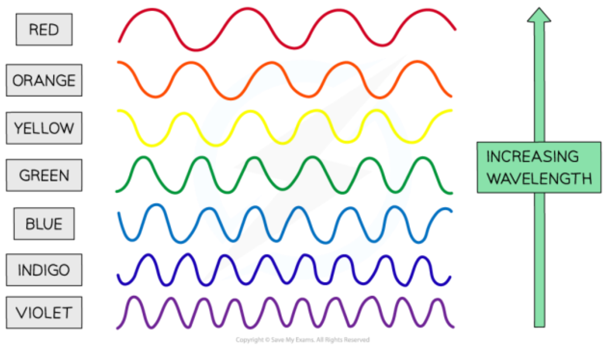
Reflection from a smooth surface in a single direction is called specular reflection. Reflection from a rough surface causes scattering: this is called diffuse reflection.



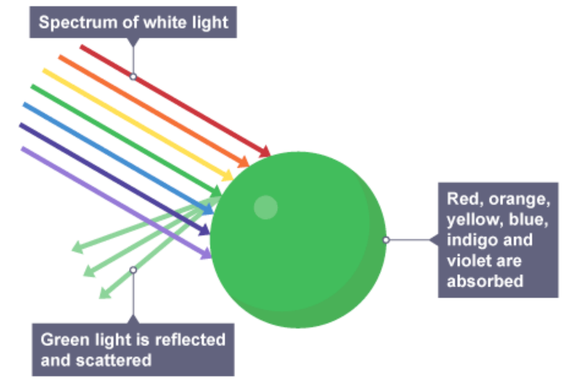
Materials are either:

- Transparent – light can transmit through the material.
- Translucent – light is transmitted but the rays are scattered.
- Opaque – light is absorbed or reflected by the material; it is not transmitted.

Each colour within the visible light spectrum has its own narrow band of wavelength and frequency. White light is a mixture of all wavelengths (all colours) of visible light.

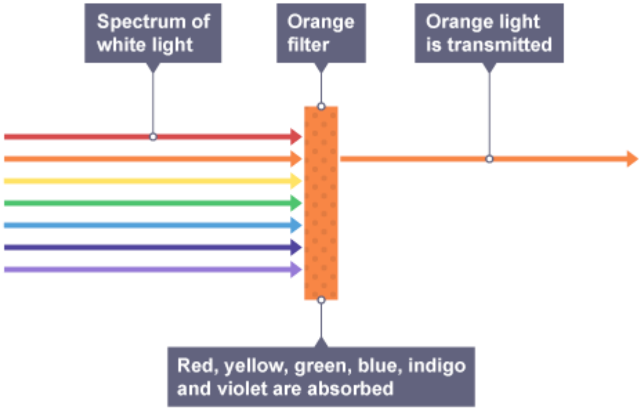


The colour of an opaque object is determined by which wavelengths of light are more strongly reflected. Wavelengths that are not reflected are absorbed. A green object appears green because green light is reflected, all the other colours are absorbed.



If all wavelengths are reflected equally the object appears white. If all wavelengths are absorbed the objects appears black.

Colour filters work by absorbing certain wavelengths (and colour) and transmitting other wavelengths (and colour). An orange filter transmits orange light but absorbs all the other colours.



A blue object that is looked at through a red filter will appear black as the blue light reflected from the blue object will not be transmitted through the red filter, it is absorbed.

4.6.3 Black body radiation

4.6.3.1 Emission and absorption of infrared radiation

All bodies (objects), no matter what temperature, emit and absorb infrared radiation. The hotter the body, the more infrared radiation it radiates in a given time.

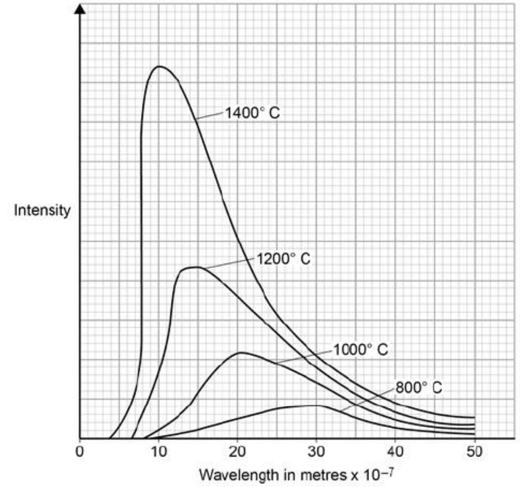
A perfect black body is an object that absorbs all of the radiation incident on it. A black body does not reflect or transmit any radiation.

Since a good absorber is also a good emitter, a perfect black body would be the best possible emitter.

4.6.3.2 Perfect black bodies and radiation

All objects emit radiation with a range of wavelengths.

As objects change temperature, they emit different amounts of radiation (intensity) and different wavelengths of radiation.



The intensity and wavelength distribution of any emission depends on the temperature of the body.

- The higher the temperature, the greater the intensity.
- The higher the temperature, the lower the peak wavelength.

All objects emit and absorb infrared radiation.

- An object at constant temperature is absorbing radiation at the same rate as it is emitting radiation.
- The temperature of an object increases when it absorbs radiation faster than it emits radiation.
- The temperature of an object decreases when it emits radiation faster than it absorbs radiation.

The temperature of the Earth depends on many factors including: the rates of absorption and emission of radiation, reflection of radiation into space.

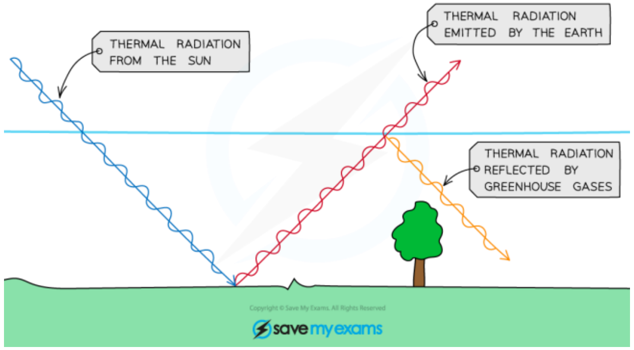
The local temperature of the Earth changes during the day due to the absorption, emission and reflection of radiation from the Sun by the ground and clouds.

During the day more radiation is absorbed than emitted so the Earth increases in temperature.

During the night more radiation is emitted than absorbed so the Earth decreases in temperature.

Radiation can also be reflected off bodies like ice sheets and clouds, reducing the radiation absorbed by the Earth.

If it is cloudy at night, the clouds reflect infrared radiation back at the Earth and prevent it being radiated to space making the night warmer.



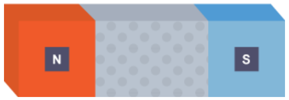
Infrared radiation is also absorbed and reflected by greenhouse gases in the atmosphere making the Earth warmer than it would be without them.

P7 – Magnetism and electromagnetism

4.7.1 Permanent and induced magnetism, magnetic forces and fields

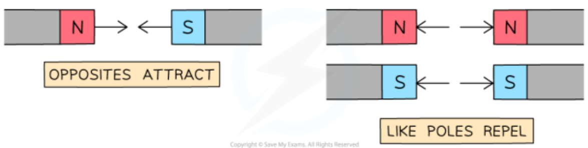
4.7.1.1 Poles of a magnet

The ends of a magnet are called poles – the north pole and the south pole. The poles of a magnet are the places where the magnetic forces are strongest.



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

- Two like poles repel each other.
- Two unlike poles attract each other.

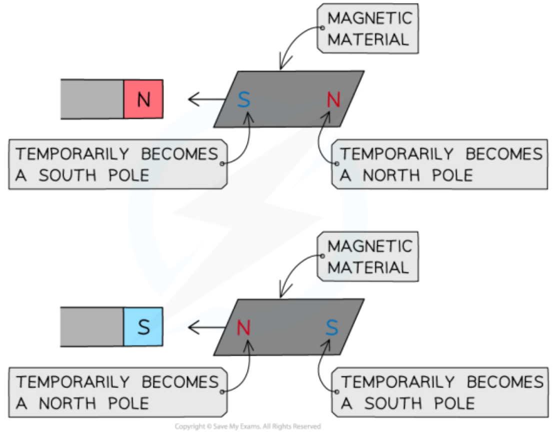


Attraction and repulsion between two magnetic poles are examples of non-contact force.

A permanent magnet produces its own magnetic field – it is always a magnet.

An induced magnet is a material that becomes a magnet when it is placed in a magnetic field. Induced magnetism always causes a force of attraction. When removed from the magnetic field an induced magnet loses most/all of its magnetism quickly.

If a magnetic material is brought towards a north pole, it will induce a south pole at that end of the magnetic material. If it is brought towards a south pole, it will induce a north pole at that end of the magnetic material.



4.7.1.2 Magnetic fields

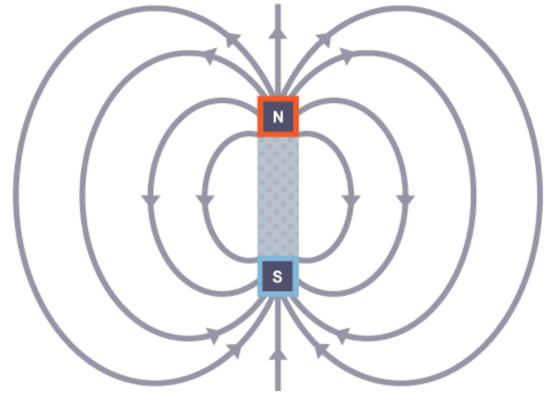
Magnetic materials are not magnets but are affected by magnetic fields. Magnetic materials include:

- Iron
- Steel
- Cobalt
- Nickel

Magnetic materials are always attracted to both poles of a magnet and will become induced magnets. Permanent magnets can either be attracted or repelled by another magnet depending on which pole is brought close to the permanent magnet. Non-magnetic materials are not affected by magnets.

The region around a magnet where a force acts on another magnet or on a magnetic material is called the magnetic field.

The magnetic field of a bar magnet looks like this:



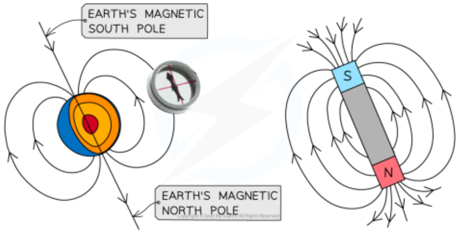
Magnetic field lines always point from the north pole to the south pole.

The direction of the magnetic field at any point is given by the direction of the force that would act on another north pole placed at that point – repelled from a north pole, attracted to a south pole. The direction of the field is shown by the arrows.

The strength of a magnetic field is determined by the density of the field lines (how close the lines are together). The closer the field lines, the stronger the field and the stronger the force. This is why the forces are strongest at the poles – the field lines are close together at the poles.

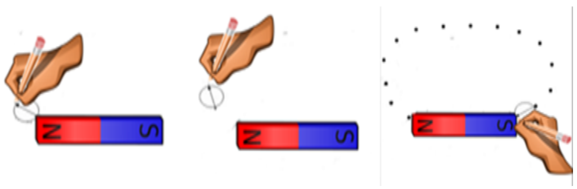
The strength of the magnetic field changes with distance. The further you get from a magnet, the weaker the field because the field lines are getting further apart.

A magnetic compass contains a small bar magnet. The Earth has a magnetic field. The compass needle always points in the same direction (north) because it aligns itself with the Earth's magnetic field – this provides evidence that the Earth has a magnetic field. The Earth's core, which is made from iron and nickel, produces this magnetic field.



A magnetic compass can be used to plot and draw the magnetic field lines around a magnet as a compass always aligns itself with the direction of a magnetic field (it points along the field lines).

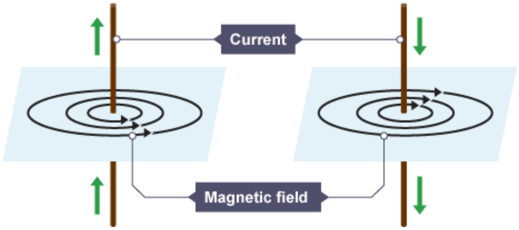
1. Place the bar magnetic in centre of paper.
2. Place a plotting compass at one end of the magnet.
3. Put a pencil dot at the place the compass arrow is pointing to.
4. Move the compass to line up the tail of the compass needle to the dot you just made.
5. Repeat until you reach the other end of the magnet.
6. Join the dots using a line – this is the magnetic field line. Mark on the direction the arrow pointed – it should run from north to south.
7. Repeat for other positions along the magnet.



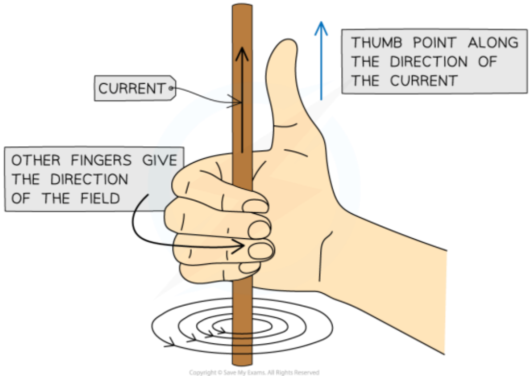
4.7.2 The motor effect

4.7.2.1 Electromagnetism

When a current flows through a conducting wire a magnetic field is produced around the wire in concentric circles. You can show this by placing compasses around a current-carrying wire.



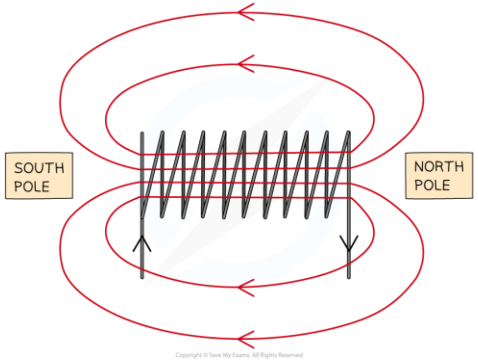
To work out the direction of the field, use the right-hand grip rule. Grab the wire with your right hand, with your thumb pointing in the direction of the current. Your fingers will wrap around the wire in the direction of the field.



As the distance from the wire increases, the field lines get further apart. This shows that as the distance from the wire increases, the magnetic field strength decreases.

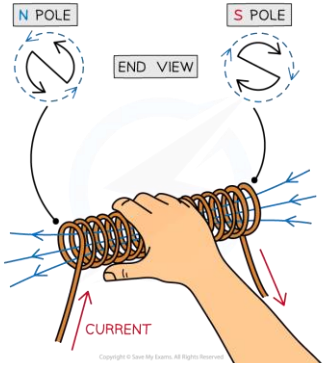
Another way to increase the field strength is to increase the current.

A solenoid is a coil of wire. When a current-carrying wire is shaped into a solenoid, the magnetic fields interact to form an overall magnetic field in the shape of a bar magnet's magnetic field.



The magnetic field inside a solenoid is strong (the field lines are close together) and uniform (the field lines are the same distance apart).

To work out the direction of the field of a solenoid, use the right-hand grip rule. Grab the solenoid with your right hand with your fingers pointing along the direction the current flows. This time your fingers represent the direction the current flows, and your thumb point in the direction of the field (flowing out of the north pole).

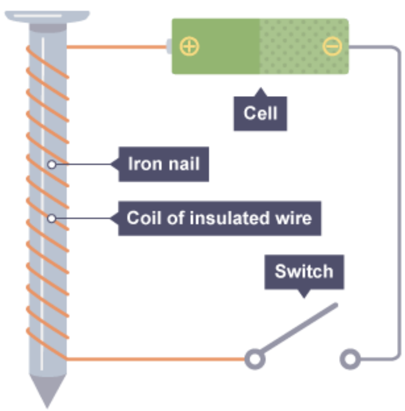


Just like with a bar magnet, the further you get from the solenoid, the weaker the field because the field lines get further apart. If you reverse the current, the field will also reverse direction.

To increase the field strength of a solenoid, you can:

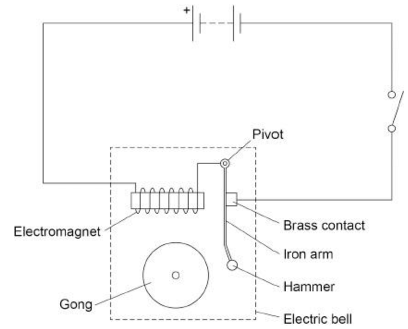
- Increase the current flowing through the wire.
- Increase the number of turns in the coil.
- Insert an iron core through the centre of the coils – the iron core becomes an induced magnet (it becomes magnetised), making the field stronger.

A solenoid with an iron core through the centre of it is called an electromagnet.



The benefits of an electromagnet compared to a permanent magnet is that you can easily change its strength and you can switch it on and off.

You need to be able to interpret diagrams of electromagnetic devices in order to explain how they work. Examples include electric bells, electromagnet locks and electromagnetic switches.

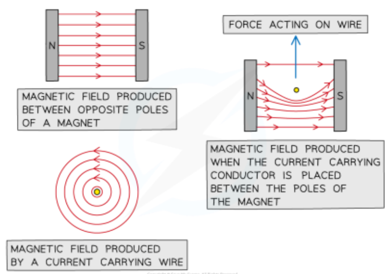


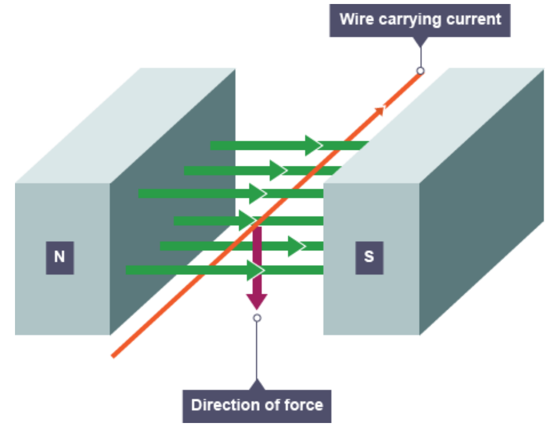
For example, an electric bell:

- The switch is closed causing a current to flow in the circuit
- A magnetic field is created around the electromagnet.
- An attractive force acts on the iron arm, causing it to move towards the electromagnet.
- The iron arm moves away from the brass contact and hits the gong.
- This breaks the circuit, removing the force on the arm which swings back to its original position.
- This completes the circuit, and the process repeats itself.

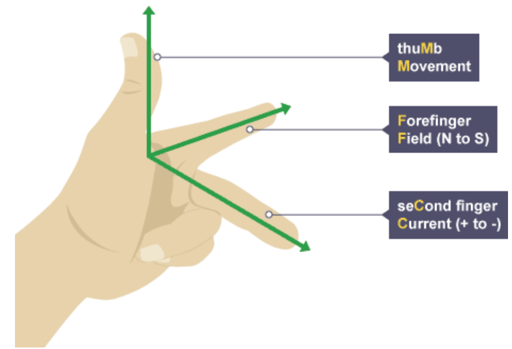
4.7.2.2 Fleming's left-hand rule

When a conductor carrying a current is placed in a magnetic field, the magnet producing the field and the magnetic field around the conductor interact, exerting a force on each other. This is called the motor effect.





Fleming's left-hand rule can be used to work out the direction of the force due to the motor effect.



- Thu<u>M</u>b – <u>M</u>otion due to the <u>force</u>
- <u>F</u>irst finger – <u>F</u>ield (points from north to south)
- Se<u>C</u>ond finger – <u>C</u>urrent (flows from positive to negative)

Each digit is at right angles to each other.

The force from the motor effect is maximum when the current is perpendicular to the field. If the current and magnetic field are parallel, the two fields don't interact and there is no force.

To increase the size of the force due to the motor effect, you can:

- Increase the current
- Increase the magnetic field strength by using stronger magnets
- Increase the length of wire in the field

The direction of the force can be reversed by:

- Reversing the direction of the current.
- Reversing the direction of the magnetic field by reversing the poles of the magnet.

For a conductor at right angles to a magnetic field and carrying a current:

$$Force = magnetic\ flux\ density \times current \times length$$
$$F = BIl$$

Force (F) in newtons (N)

Magnetic flux density [another name for field strength] (B) in tesla (T)

Current (I) in amperes [shortened to amps] (A)

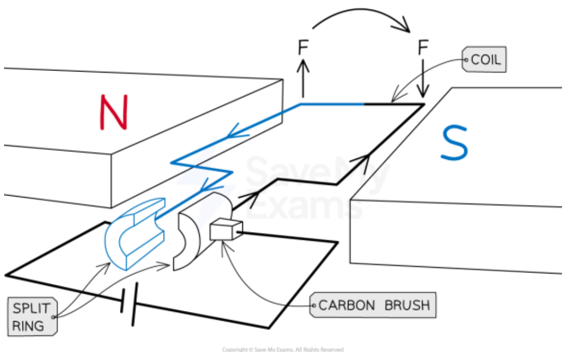
Length (l) in metres (m)

4.7.2.3 Electric motors

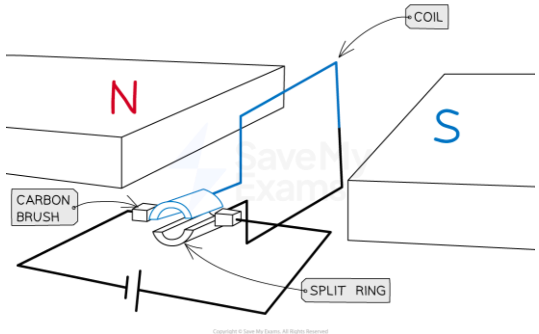
A coil of wire carrying a current in a magnetic field tends to rotate. This is the basis of an electric motor.

A motor consists of a coil of wire (which is free to rotate) positioned in a uniform magnetic field. The coil of wire, when horizontal, forms a complete circuit with a cell. The coil is attached to a split-ring commutator (a circular tube of metal split in two). This split ring is connected in a circuit with the cell via contact with conducting carbon brushes.

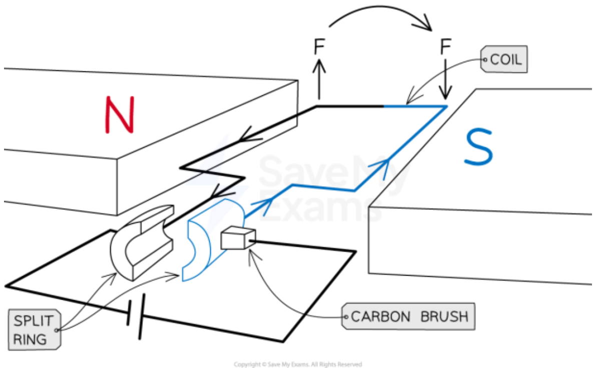
- Current flows in opposite directions down each side of the coil that is perpendicular to the magnetic field (up the dark side on the right, down the light side on the left).
- The magnetic field created around the current-carrying wire interacts with the field from the permanent magnet.
- This applies a force on each side of the coil by the motor effect that act in opposite directions.
- The forces cause moments that act in the same direction, making the coil rotate.



- Once the coil has rotated 90°, the split-ring commutator is no longer in contact with the brushes. No current flows through the coil so no forces act.
- Even though no force acts, the momentum of the coil causes the coil to continue to rotate.



- The split-ring commutator reconnects with the carbon brushes and current flows through the coil again
- The current in the coil has reversed direction (up the light side on the right, down the dark side on the left).
- However, the two halves of the rotating split-ring commutator have swapped from one carbon brush to the other (the dark side is now on the left and the light side is now on the right).
- This means that the current still flows up the right side of the coil and down the left side of the coil.
- This keeps the forces in the same direction which keeps the coil rotating.



To increase the force on the motor:

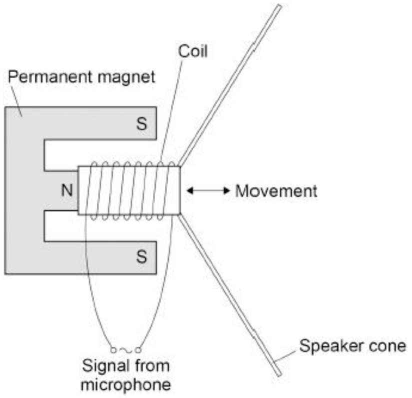
- Increase the current in the coil.
- Increase the magnetic field strength by using a stronger magnet.
- Add more turns to the coil.

The direction of rotation of the coil can be changed by:

- Reversing the direction of the current.
- Reversing the direction of the magnetic field by reversing the poles of the magnet.

4.7.2.4 Loudspeakers

Loudspeakers and headphones use the motor effect to convert variations in current in electrical circuits to the pressure variations in sound waves.



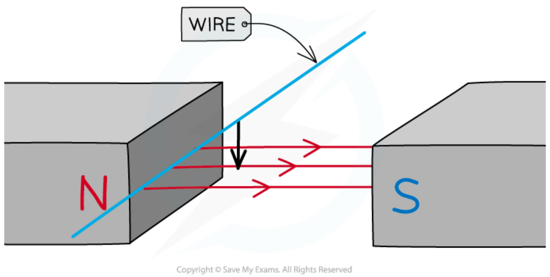
- Alternating current (AC) flows through the coil.
- Current creates a magnetic field around the coil which interacts with the permanent magnetic field.
- This produces a force by the motor effect. The size of the current affects the size of the force.
- This makes the coil and the cone move out.
- The current changes direction, making the force change direction.
- The coil and the cone move in.
- Every time the current changes direction, the force on the cone changes direction – it vibrates.
- The cone vibrations cause pressure variations in the air, which are sound waves.
- The frequency of the AC is the same as the frequency of the sound waves.

4.7.3 Induced potential, transformers and the National Grid

4.7.3.1 Induced potential

If an electrical conductor experiences a changing magnetic field (the conductor cuts through the magnetic field lines), a potential difference is induced across the ends of the conductor. This is called the generator effect.

The conductor can experience a changing magnetic field (cut through magnetic field lines) if it moves through a magnetic field or if the magnetic field around it changes.



If the conductor is part of a complete circuit, a current is induced in the conductor.

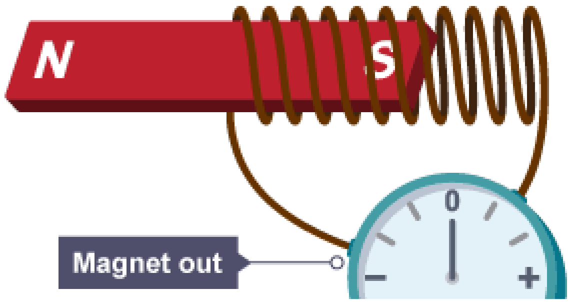
Note: The motor effect and generator effect are opposites – in the motor effect, current and magnetic field are used to create motion. In the generator effect, motion and magnetic field are used to create current/potential difference.

To increase the induced potential difference, you can:

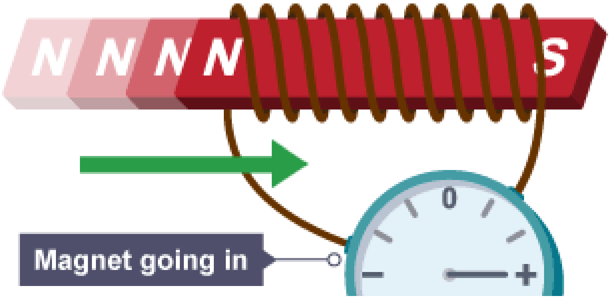
- Increase the speed at which the wire or magnet move – this increases the number of field lines the conductor cuts through each second.
- Increase the number of turns of a coil – this increases the number of field lines the conductor cuts through each second.
- Increase the strength of the magnetic field – this increases the number of field lines the conductor cuts through each second.

The direction of the induced potential difference depends on

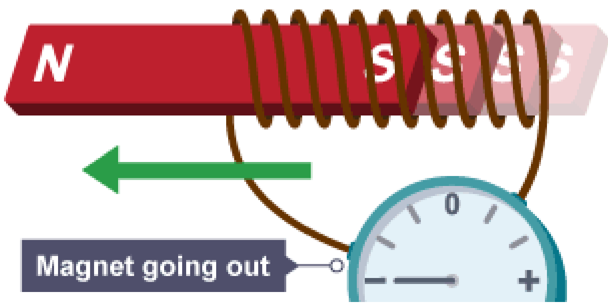
- the direction the conductor or magnet moves. If you reverse the direction of movement, the direction of the induced potential difference reverses.
- The orientation of the poles. The induced potential difference will be a different direction if you move a north pole towards a coil of wire compared to moving a south pole towards a coil of wire.



In this example, a magnet is stationary inside a coil of wire. There is no change in magnetic field (the coil doesn’t cut through any field lines) so there is no induced potential difference.

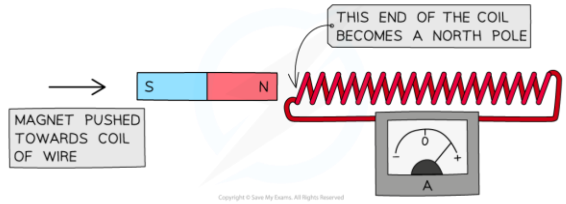


In this example, a magnet is moving into the coil of wire. There is a change in magnetic field (the coil cuts through field lines) so there is an induced potential difference.

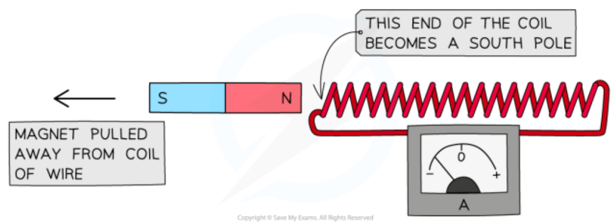


In this example, a magnet is moving out of the coil of wire. There is a change in magnetic field (the coil cuts through field lines) so there is an induced potential difference. The magnet is moving in the opposite direction to the previous example so the induce potential difference is in the opposite direction.

If there is a complete circuit, a current is induced in the circuit. An induced current generates a magnetic field that opposes the original change, either the movement of the conductor or the change in magnetic field.



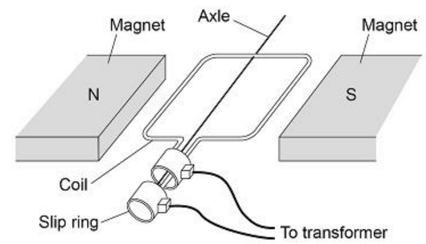
In this example, a magnet is moved towards the coil. There is a change in magnetic field (the coil cuts through field lines) so there is an induced potential difference. A current is induced because there is a complete circuit. Current flowing through the solenoid creates a magnetic field in the solenoid – this magnetic field always opposes the motion that creates it so the magnetic field will try to stop the magnet moving into the coil. Since a north pole is moving towards the coil, a north pole will be induced at the end of the coil the magnet is moving into – like poles repel so this will ty to stop the movement of the magnet.

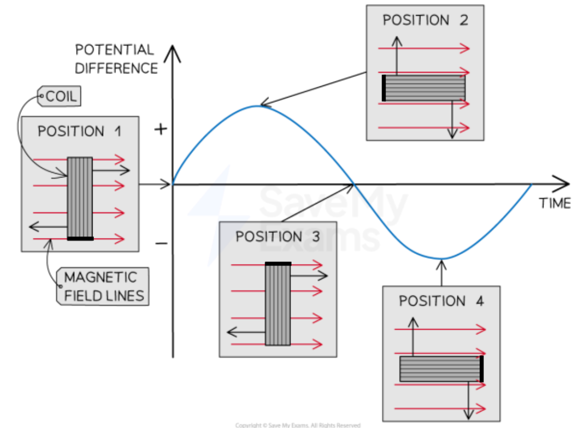


In this example, a magnet is moved away from the coil. There is a change in magnetic field (the coil cuts through field lines) so there is an induced potential difference. A current is induced because there is a complete circuit. Current flowing through the solenoid creates a magnetic field in the solenoid – this magnetic field always opposes the motion that creates it so the magnetic field will try to stop the magnet moving away from the coil. Since a north pole is moving away from the coil, a south pole will be induced at the end of the coil the magnet is moving into – opposite poles attract so this will ty to stop the movement of the magnet.

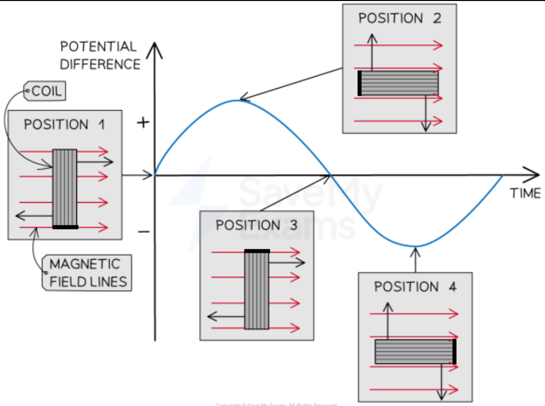
4.7.3.2 Uses of the generator effect

An alternator is used to generate alternating current. It consists of a coil of wire attached to a slip-ring commutator that is made rotate inside a magnetic field. The slip-ring commutator provides continuous contact with the coil and the brushes/circuit – one side of the coil always is connected to one ring, and the other side is always connected to the other ring.



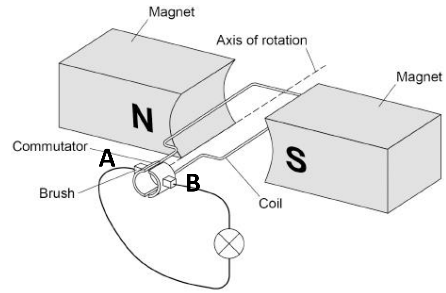


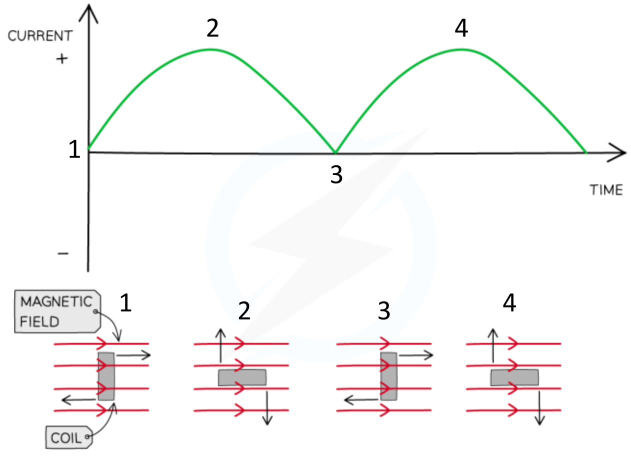
- The coil shown above rotates from position 1 to position 2. As it rotates, one side of the coil moves up through the field (dark side) and one side moves down through the field (light side). The coil experiences a changing magnetic field (it cuts through field lines) which induces a potential difference. Since this is a complete circuit, a current is induced in the coil.



- The coil rotates 90° to position 3. Both sides of the coil move parallel to the field so do not cut any field lines – there is no changing magnetic field. This means there is no induced potential difference so no induced current.
- The coil rotates 90° to position 4. As it rotates, one side of the coil moves up through the field (light side) and one side moves down through the field (dark side). The coil experiences a changing magnetic field (it cuts through field lines) which induces a potential difference. Since this is a complete circuit, a current is induced in the coil. Since the sides of the coil are moving the opposite way through the field, the induced potential difference is in the opposite direction and so the induced current is in the opposite direction.
- Because there is continuous contact with the slip-ring commutators (each side of the coil is always connected to the same ring), the current in the circuit is also now in the opposite direction – alternating current.
- The coil rotates 90° back to position 1. Both sides of the coil move parallel to the field so do not cut any field lines – there is no changing magnetic field. This means there is no induced potential difference so induced current.

A dynamo is used to generate direct current. It consists of a coil of wire attached to a split-ring commutator that is made rotate inside a magnetic field. The split-ring commutator does not provide continuous contact with the coil and the brushes/circuit.





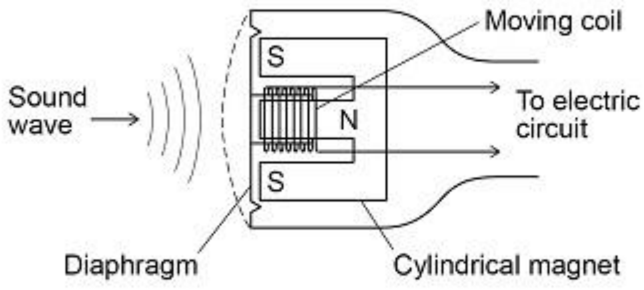
- The coil shown above rotates from position 1 to position 2. As it rotates, one side of the coil moves up through the field (connected to side A of the split-ring commutator) and one side moves down through the field (connected to side B of the split-ring commutator). The coil experiences a changing magnetic field (it cuts through field lines) which induces a potential difference. Since this is a complete circuit, a current is induced in the coil.
- The coil rotates 90° to position 3. Both sides of the coil move parallel to the field so do not cut any field lines – there is no changing magnetic field. This means there is no induced potential difference so no induced current.
- The coil rotates 90° to position 4. As it rotates, one side of the coil moves up through the field and one side moves down through the field. The coil experiences a changing magnetic field (it cuts through field lines) which induces a potential difference. Since this is a complete circuit, a current is induced in the coil.
- Each half-revolution, the two ends of the coil swap from one brush to the other.
- The split ring commutator means that the side moving up is still connected to side A of the split-ring commutator and the side moving down is still connected to side B of the split-ring commutator. This means the induced potential difference is in the same direction as before and so the induced current flows in the same direction as before. This means we get direct current as the direction is not changing.
- The coil rotates 90° back to position 1. Both sides of the coil move parallel to the field so do not cut any field lines – there is no changing magnetic field. This means there is no induced potential difference so induced current.

If you spin an alternator or dynamo faster:
- The induced potential difference and current increase, increasing the amplitude of the graph.
- The frequency increases – you get more complete cycles per unit time, squashing the graph along the x-axis.

With both the alternator and the dynamo, there is an induced current in the coil. This means a magnetic field is induced around the coil which opposes the motion that is making it – it tries to stop the coil rotating. If you disconnect the circuit so it is not a complete circuit, only a potential difference is induced (no induced current). This means there is no magnetic field induced which tries to oppose the rotation of the coil, making the coil easier to rotate.

4.7.3.3 Microphones

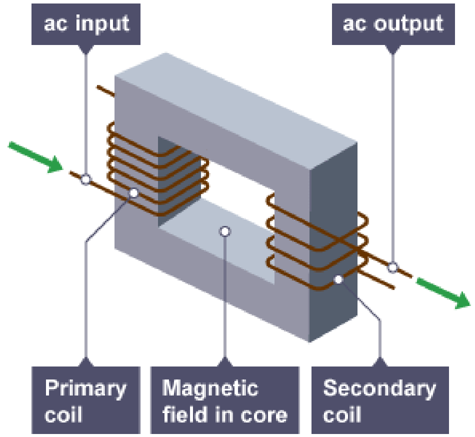
Microphones use the generator effect to convert the pressure variations in sound waves into variations in current in electrical circuits.



- Sound waves hit the diaphragm and cause it to vibrate.
- This makes the coil vibrate through the magnetic field of the magnet.
- The movement of the coil through a magnetic field induces a potential difference by the generator effect (the coil is cutting the magnetic field lines as it vibrates).
- Since there is a complete circuit current is induced in the coil.
- Since the coil is vibrating, the direction it moves is constantly changing. This means the direction of the induced potential difference and induced current changes is also constantly changing – it produces an alternating current in the circuit.
- The frequency of the potential difference is the same as the frequency of the sound waves.

4.7.3.4 Transformers

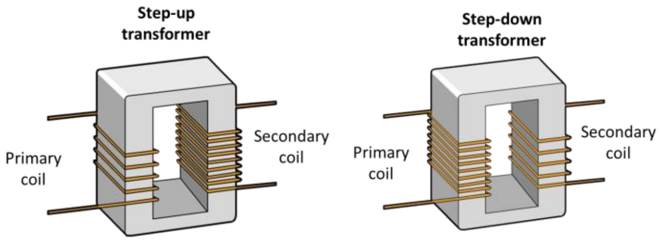
A basic transformer consists of a primary coil and a secondary coil wound on an iron core.



Current comes in at the primary coil and goes out from the secondary coil.

Iron is used as the material for the core as it is easily magnetised.

- An alternating current is supplied to the primary coil. The current is constantly changing direction so there is a magnetic field induced in the primary coil that is also constantly changing direction.
- The iron core is easily magnetised (becomes an induced magnet) and demagnetised, so the changing magnetic field passes through it and is guided into the secondary coil.
- The secondary coil experiences a changing magnetic field and so a potential difference is induced in the secondary coil. This magnetic field is constantly changing direction, so the potential difference is also changing direction – it is an alternating potential difference.
- Since there is a complete circuit, an alternating current is induced in the secondary coil.



If there are more turns in the secondary coil than the primary coil, it is a step-up transformer.

If there are more turns in the primary coil than the secondary coil, it is a step-down transformer.

A step-up transformer:
- Increases the potential difference
- Decreases the current

A step-down transformer:
- Decreases the potential difference
- Increases the current

The ratio of the potential differences across the primary and secondary coils of a transformer V_p and V_s depends on the ratio of the number of turns on each coil, n_p and n_s.

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

Potential difference in the primary coil (V_p) in volts (V)

Potential difference in the secondary coil (V_s) in volts (V)

Number of turns in the primary coil (n_p)

Number of turns in the secondary coil (n_s)

The number of turns of the coils can be adjusted to change how much the output potential difference is increased or decreased.

If transformers were 100% efficient, the electrical power output would equal the electrical power input – power into the primary coil would equal power out of the secondary coil.

Power = potential difference x current (P = VI). So:

$$Power\ input = power\ output$$
$$V_p I_p = V_s I_s$$

Potential difference in the primary coil (V_p) in volts (V)

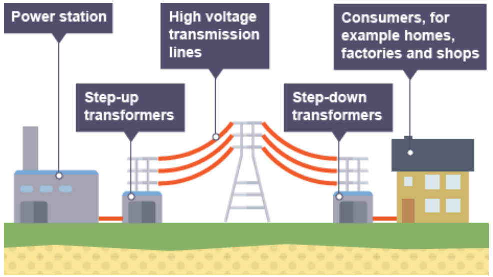
Current in the primary coil (I_p) in amps (A)

Potential difference in the secondary coil (V_s) in volts (V)

Current in the secondary coil (I_s) in amps (A)

Power input and output in watts (W).

The National Grid is a system of cables and transformers linking power stations to consumers. Electrical power is transferred from power stations to consumers using the National Grid.



Step-up transformers increase the potential difference and decrease the current. This reduces energy loss to the surroundings by heating in the cables, increasing the efficiency of the system as more energy is transferred usefully.

Step-down transformers decrease the potential difference and increase the current. This makes it safe to use in the home.

P8 – Space physics

4.8.1 Solar system; stability of orbital motions; satellites

4.8.1.1 Our solar system

The Solar System contains anything that is influenced by the Sun's gravity. The Solar System includes:

- One star, the Sun.
- Eight planets that orbit the Sun. A planet is an objects that has a gravitational field strong enough to make it spherical and has cleared its orbital path of other objects.
- Dwarf planets that orbit the Sun. The gravitational field of a dwarf planet is not strong enough to clear its orbital path, so there may be other objects in its orbit around the Sun.
- Satellites – objects that orbit planets. These can be natural satellites like moons or artificial satellites. The Moon that orbits the Earth is an example of a natural satellite. Other planets also have moons.

Our solar system is a small part of the Milky Way galaxy. A galaxy is a system of millions or billions of stars, together with dust and gas, held together by gravitational attraction.

The Sun was formed from a cloud of dust and gas (nebula) pulled together by gravitational attraction.

As the nebula collapses under its own gravity, gravitational potential energy is transferred to kinetic energy, increasing the temperature and density.

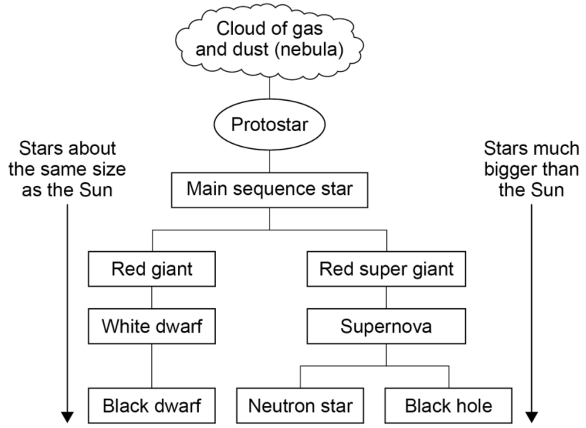
This is known as a protostar.

When the temperature is hot enough nuclear fusion of hydrogen into helium begins and the protostar becomes a main sequence star.

Main sequence stars are stable because the forces are balanced – the fusion reactions lead to an equilibrium between the gravitational collapse of a star and the expansion of a star due to fusion energy.

4.8.1.2 The life cycle of a star

A star goes through a life cycle. The life cycle is determined by the size of the star.



Same size as the Sun

When all the hydrogen has been used up in the fusion process, the star starts to shrink and heat up due to reduced expansion due to fusion energy.

When it gets hot enough, helium begins to fuse to make heavier elements and the star expands to become a red giant.

Once the heavier nuclei have fused, fusion stops and the star becomes unstable and ejects its outer layers into space. The core collapses and heats up, becoming a white dwarf star.

The star will eventually cool to the point of no longer emitting light – this is called a black dwarf star.

Much bigger than the Sun

When all the hydrogen has been used up in the fusion process, the star starts to shrink and heat up due to reduced expansion due to fusion energy.

When it gets hot enough, heavier nuclei begin to fuse to make heavier elements and the star expands to become a red super giant.

Once the heavier nuclei have fused up to iron, fusion stops and the core of the star collapses suddenly causing a gigantic explosion called a supernova.

Fusion processes in stars produce all of the naturally occurring elements. Elements heavier than iron are produced in a supernova. Supernovae distribute these elements throughout the universe.

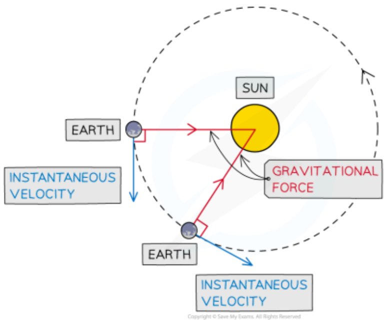
At the centre of the supernova, a very dense object called a neutron star forms made of neutrons.

If the star has a large enough mass, the force between the neutrons can't overcome gravity and they will collapse to form a black hole.

4.8.1.3 Orbital motion, natural and artificial satellites

Gravity provides the force that allows planets and satellites (both natural and artificial) to maintain their circular orbits.

For a satellite orbiting in a circle, the resultant force (gravity) always acts towards the centre of the circle, the planet. This is perpendicular to the velocity of the satellite.



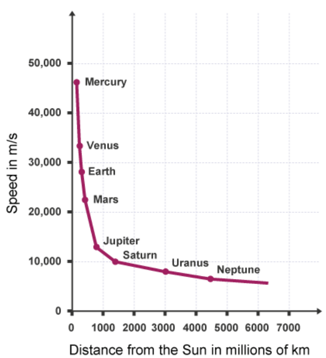
Since there is a resultant force on the satellite, the satellite will accelerate towards the planet. This changes the direction of the velocity but not its magnitude as the force is perpendicular to the velocity. This changes the velocity vector which is acceleration.

The closer to a star or planet you are, the stronger the force of gravity is.

The stronger the force, the faster the object must move to stay in a stable orbit.

If the speed of the object increases, the radius of stable orbit must decrease so it can have a stronger force of gravity to prevent it flying off into space.

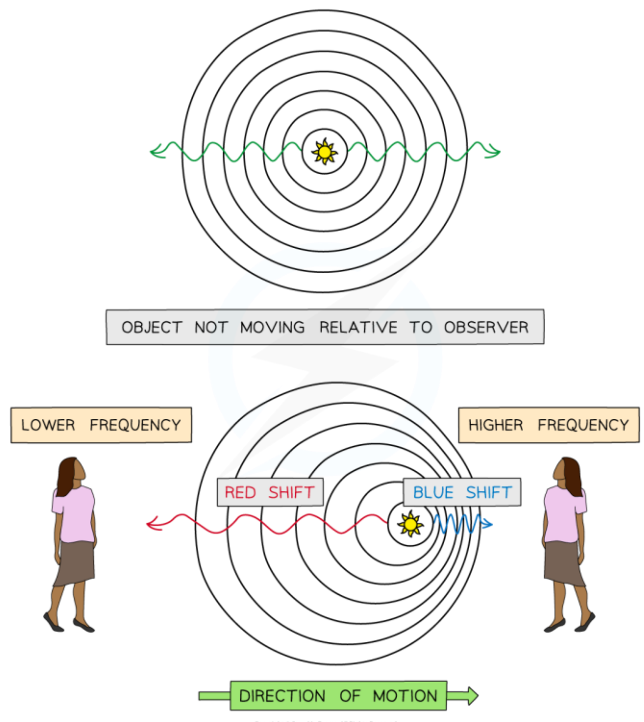
If the speed of the object decreases, the radius of stable orbit must increase so it can have a weaker force of gravity to prevent crashing into the object it is orbiting.



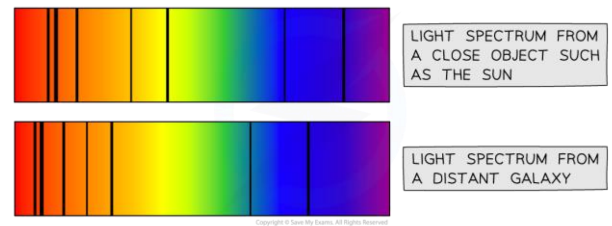
4.8.2 Red-shift

When a moving object emits waves, the wavelength of the wave gets stretched if it is moving away from you or squashed if it is moving towards you.

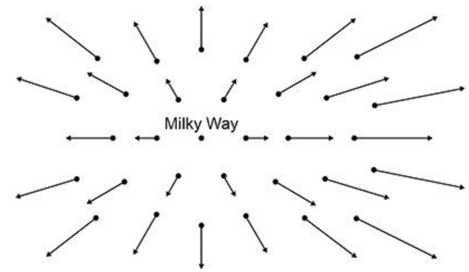
If the observed wavelength of visible light is increased due to an object moving away from the observer, it moves towards the red end of the electromagnetic spectrum.



There is an observed increase in the wavelength of light from most distant galaxies.



The further away the galaxies, the faster they are moving and the bigger the observed increase in wavelength. This effect is called red-shift.



This suggests that space itself (the universe) is expanding. This suggests that at some time in the past, all space and matter started at the same point. This suggests the universe had a beginning which led to the Big Bang theory.

The Big Bang theory suggests that the universe began from a very small region that was extremely hot and dense.

Since 1998 onwards, observations of supernovae suggest that distant galaxies are receding ever faster – the rate of expansion of the universe is increasing.

There is still much about the universe that is not understood, for example dark mass and dark energy. If there are new observations or evidence that don't fit the model, the theories and models have to change.