

AQA Physics (Combined Science) Unit 6.1: Energy

Required Practical

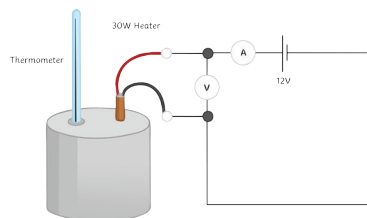
Investigating Specific Heat Capacity

independent variable – material

dependent variable – specific heat capacity

control variables – insulating layer, initial temperature, time taken

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



Method:

- Using the balance, measure and record the mass of the copper block in kg.
- Wrap the insulation around the block.
- Put the heater into the large hole in the block and the block onto the heatproof mat.
- Connect the power pack and ammeter in series and the voltmeter across the power pack.
- Using the pipette, put a drop of water into the small hole.
- Put the thermometer into the small hole and measure the temperature.
- Switch the power pack to 12V and turn it on.
- Read and record the voltmeter and ammeter readings – during the experiment, they shouldn't change.
- Turn on the stop clock and record the temperature every minute for 10 minutes.
- Record the results in the table.
- Calculate work done and plot a line graph of work done against temperature.

Equations

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

$$E_p = mgh$$

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

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

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

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

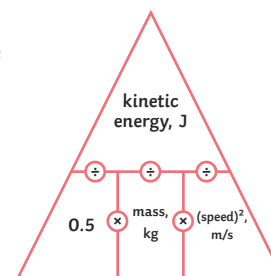
Kinetic and Potential Energy Stores

Movement Energy

$$\text{kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed}^2$$

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

(J) (kg)(m/s)

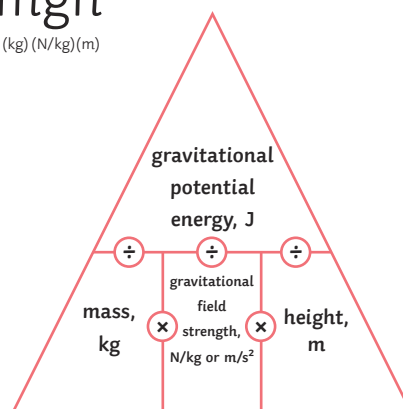


When something is off the ground, it has gravitational potential energy

gravitational potential energy = mass × gravitational field strength × height

$$E_p = mgh$$

(J) (kg) (N/kg)(m)



When an object falls, it loses gravitational potential energy and gains kinetic energy.

Stretching an object will give it elastic potential energy.

$$\text{elastic potential energy} = \frac{1}{2} \times \text{spring constant} \times \text{extension}^2$$

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

(J) (N)(m)

Transferring Energy by Heating

Heating a material transfers the energy to its thermal energy store - the temperature increases.

E.g. a kettle: energy is transferred to the thermal energy store of the kettle. Energy is then transferred by heating to the water's thermal energy store. The temperature of the water will then increase.

Some materials need more energy to increase their temperature than others.

change in thermal energy = mass × specific heat capacity × temperature change

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

(J) (kg) (J/kg °C) (°C)

Specific heat capacity is the amount of energy needed to raise the temperature of 1kg of a material by 1°C.



Energy Stores and Systems

Energy Stores	
kinetic	Moving objects have kinetic energy.
thermal	All objects have thermal energy.
chemical	Anything that can release energy during a chemical reaction.
elastic potential	Things that are stretched.
gravitational potential	Anything that is raised.
electrostatic	Charges that attract or repel.
magnetic	Magnets that attract or repel.
nuclear	The nucleus of an atom releases energy.

Energy can be transferred in the following ways:

mechanically – when work is done;

electrically – when moving charge does work;

heating – when energy is transferred from a hotter object to a colder object.

Conservation of Energy

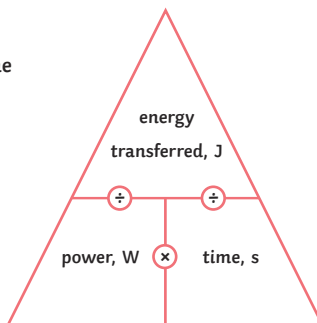
Energy can never be created or destroyed, just transferred from one form to another. Some energy is transferred usefully and some energy gets transferred into the environment. This is mostly wasted energy.

Power

Power is the rate of transfer of energy – the amount of work done in a given time.

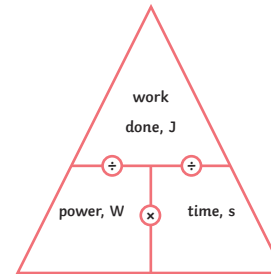
power = energy transferred ÷ time

$$P (W) = E (J) \div t (s)$$



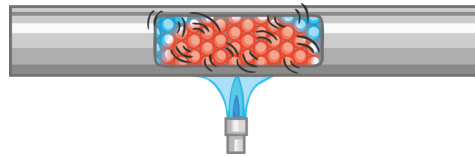
power = work done ÷ time

$$P (W) = W (J) \div t (s)$$



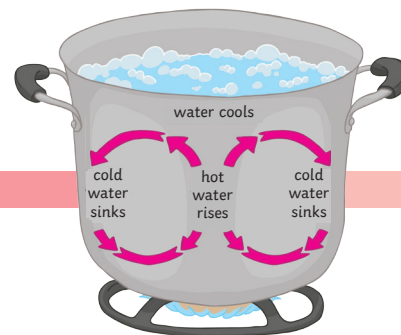
Energy Transfer

Lubrication reduces the amount of friction. When an object moves, there are frictional forces acting. Some energy is lost into the environment. Lubricants, such as oil, can be used to reduce the friction between the surfaces.



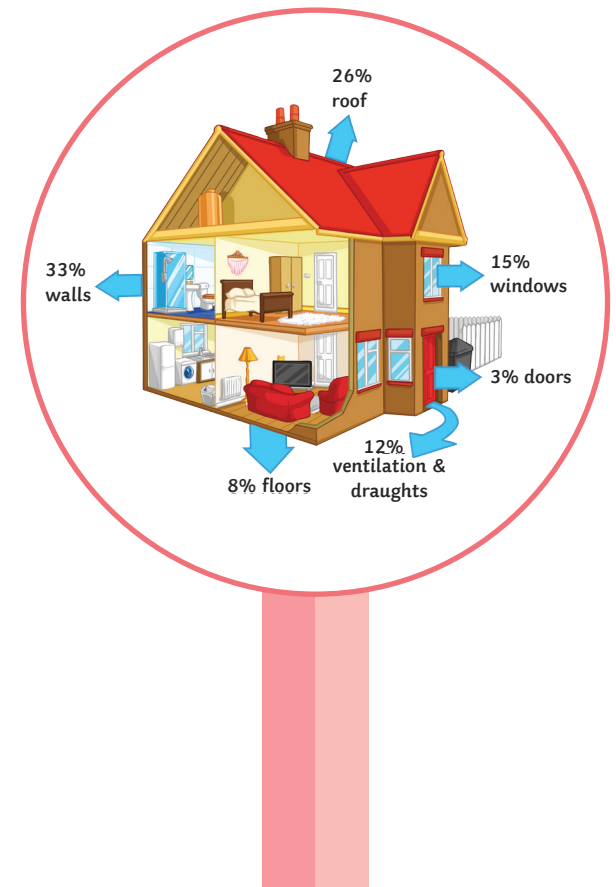
Conduction – when a solid is heated, the particles vibrate and collide more, and the energy is transferred.

Convection – when a liquid or a gas is heated, the particles move faster. This means the liquid or gas becomes less dense. The denser region will rise above the cooler region. This is a convection current.



Insulation – reduces the amount of heat lost. In your home, you can prevent heat loss in a number of ways:

- thick walls;
- thermal insulation, such as:
- loft insulation (reducing convection);
- cavity walls (reduces conduction and convection);
- double glazing (reduces conduction).

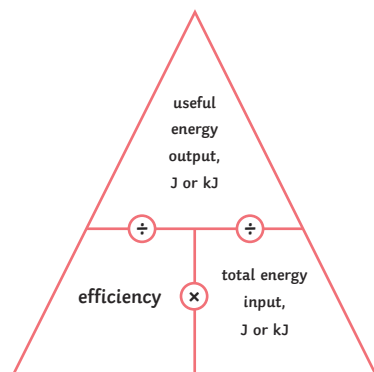


Efficiency

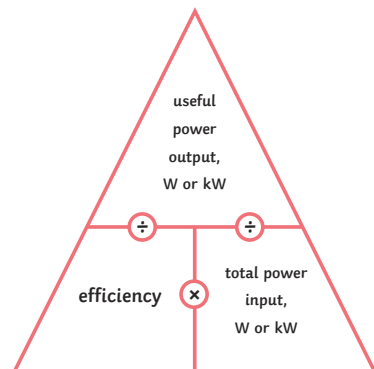
When energy is transferred, some energy is wasted. The less energy that is wasted during the transfer, the more efficient the transfer.

There are two equations to calculate efficiency:

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



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



Some energy is always wasted. Nothing is 100% efficient.

Efficiency

Non-renewable – coal, oil, gas - they will all run out, they damage the environment, but provide most of the energy.

Renewable – they will never run out, can be unreliable and do not provide as much energy.

Energy Resource	Advantages	Disadvantages
solar – using sunlight	Renewable, no pollution, in sunny countries it is very reliable.	Lots of energy needed to build, only works during the day, cannot increase power if needed.
geothermal – using the energy of hot rocks	Renewable and reliable as the rocks are always hot. Power stations have a small impact on environment.	May release some greenhouse gases and only found in specific places.
wind – using turbines	Renewable, no pollution, no lasting damage to the environment, minimal running cost.	Not as reliable, do not work when there is no wind, cannot increase supply if needed.
hydroelectric – uses a dam	Renewable, no pollution, can increase supply if needed.	A big impact on the environment. Animals and plants may lose their habitats.
wave power – wave powered turbines	Renewable, no pollution.	Disturbs the seabed and habitats of animals. Unreliable.
tidal barrages – big dams across rivers	Renewable, very reliable, no pollution.	Changes the habitats of wildlife, fish can be killed in the turbines.
biofuels	Renewable, reliable, carbon neutral.	High costs, growing biofuels may cause a problem with regards to space, clearance of natural forests.
non-renewable – fossil fuels	Reliable, enough to meet current demand, can produce more energy when there is more demand.	Running out, release CO ₂ , leading to global warming, and also release SO ₂ which causes acid rain.

Trends in energy resources – most of our electricity is generated by burning fossil fuels and nuclear. The UK is trying to increase the amount of renewable energy resources. The governments are aware that non-renewable energy resources are running out; targets of renewable resources have been set. Electric and hybrid cars are also now on the market.

However, changing the fuels we use and building renewable power plants cost money. Many people are against the building of the plants near them and do not want to pay the extra in their energy bills. Hybrid and electric cars are also quite expensive.



Electricity – Separate Science

Required Practical

Investigating Resistance in a Wire

Independent variable: length of the wire.

Dependent variable: resistance.

Control variables: type of metal, diameter of the wire.

Conclusion: As the length of the wire increases, the resistance of the wire also increases.

Investigating Series and Parallel Circuits with Resistors

Independent variable: circuit type (series, parallel).

Dependent variable: resistance.

Control variables: number of resistors, type of power source.

Conclusion: Adding resistors in series increases the total resistance of the circuit. In a parallel circuit, the more resistors you add, the smaller the resistance.

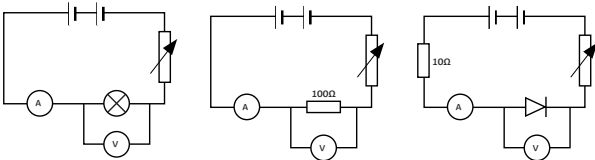
Investigating I-V Relationships in Circuits (Using a filament bulb, ohmic conductor, diode.)

Independent variable: potential difference/volts (V).

Dependent variable: current (A).

Control variable: number of components (e.g. 1 filament bulb, 1 resistor), type of power source.

Set up the circuits as shown below and measure the current and the potential difference.



Draw graphs of the results once collected.

Equations and Maths

Equations

Charge: $Q = It$

Potential difference: $V = IR$

Energy transferred: $E = Pt$

Energy transferred: $E = QV$

Power: $P = VI$

Power: $P = I^2R$

Maths

$1\text{ kW} = 1000\text{ W}$

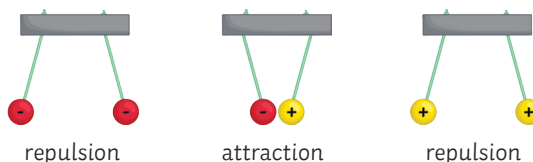
$0.5\text{ kW} = 500\text{ W}$

$50\,000\text{ W} = 50\text{ kW}$

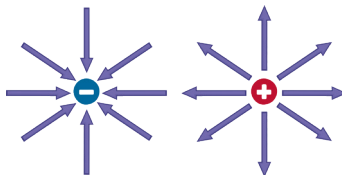
Static

A build-up of static is caused by friction. When materials are rubbed together, the electrons move from one to the other. One material becomes positively charged and the other is negatively charged. The positive charges do not move.

Too much static can cause a spark. If the potential difference is large enough, the electrons can jump across the gap - this is the spark.



Electric charges create an **electric field**. The closer you get to the object, the **stronger** the field. The electric field can be shown by drawing field lines, they go from **positive to negative**.

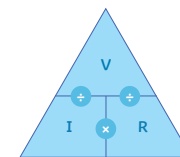


If a charged object is placed near the field, it will experience a force. The force becomes stronger as the charged object gets closer.

Resistance

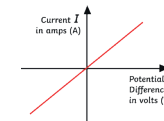
voltage (V) = current (A) × resistance (Ω)

$V = IR$

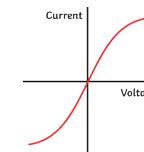


Graphs of I-V Characteristics for Components in a Circuit

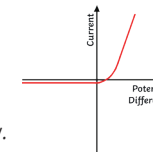
1. **Ohmic conductor:** the current is directly proportional to the potential difference - it is a straight line (at a constant temperature).



2. **Filament lamp:** as the current increases, so does the temperature. This makes it harder for the current to flow. The graph becomes less steep.



3. **Diode:** current only flows in one direction. The resistance is very high in the other direction which means no current can flow.



Current and Circuit Symbols

Current: the flow of electrical charge.

Potential difference (voltage): the push of electrical charge.

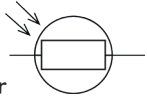
Resistance: slows down the flow of electricity.

cell		closed switch		fuse	
resistor		ammeter		LDR	
battery		voltmeter		LED	
variable resistor		bulb		thermistor	
open switch		diode			

Electricity – Separate Science

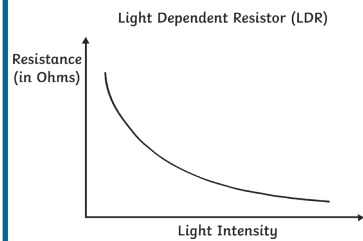
Circuit Devices

LDR – Light Dependent Resistor

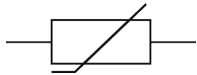


An LDR is dependent on light intensity. In bright light the resistance falls and at night the resistance is higher.

Uses of LDRs: outdoor night lights, burglar detectors.

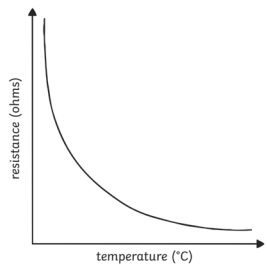


Thermistor



A thermistor is a temperature dependent resistor. If it is hot, then the resistance is less. If it becomes cold, then the resistance increases.

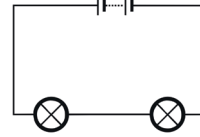
Uses of thermistors: temperature detectors.



Series and Parallel Circuits

Series Circuits

Once one of the components is broken then all the components will stop working.



$$V_{\text{total}} = V_1 + V_2$$

$$I_1 = I_2 = I_3$$

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

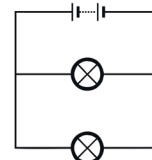
Potential difference – the total p.d. of the supply is shared between all the components.

Current – wherever the ammeter is placed in a series circuit the reading is the same.

Resistance – In a series circuit, the resistance will add up to make the total resistance.

Parallel Circuits

They are much more common - if one component stops working, it will not affect the others. This means they are more useful.



Potential Difference – this is the same for all components. $V_1 = V_2$

Current – the total current is the total of all the currents through all the components. $I_{\text{total}} = I_1 + I_2 + I_3$

Resistance – adding resistance reduces the total resistance.

Charge

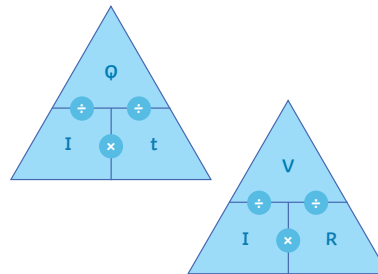
Electric current is the flow of electric charge. It only flows when the circuit is complete.

The **charge** is the current flowing past a point in a given time. Charge is measured in **coulombs (C)**.

Calculating Charge

charge flow (C) =
current (A) × time (s)
 $Q = It$

potential difference =
current × resistance
 $V (V) = I (A) \times R (\Omega)$

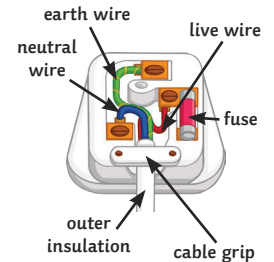


Electricity in the Home

AC – alternating current. Constantly changing direction - UK mains supply is 230V and has a frequency of 50 hertz (Hz).

DC – direct current. Supplied by batteries and only flows in one direction.

Cables – most have three wires: live, neutral and earth. They are covered in plastic insulation for safety.



Live wire – provides the potential difference from the mains.

Neutral wire – completes the circuit.

Earth wire – protection. Stops the appliance from becoming live. Carries a current if there is a fault.

Touching the live wire can cause the current to flow through your body. This causes an electric shock.

Energy Transferred – this depends on how long the appliance is on for and its power.

$$\text{energy transferred (J)} = \text{power (W)} \times \text{time (s)} \quad E = Pt$$

Energy is transferred around a circuit when the charge moves.

$$\text{energy transferred (J)} = \text{charge flow (C)} \times \text{potential difference (V)} \quad E = QV$$

$$\text{power (W)} = \text{potential difference (V)} \times \text{current (A)} \quad P = VI$$

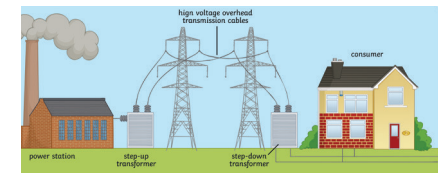
$$\text{power (W)} = \text{current}^2 (\text{A}) \times \text{resistance } (\Omega) \quad P = I^2R$$

The National Grid

The National Grid is a system of **cables** and **transformers**. They transfer electrical power from the power station to where it is needed. Power stations are able to change the amount of electricity that is produced to meet the demands. For example, more energy may be needed in the evenings when people come home from work or school. Electricity is transferred at a low current, but a high voltage so less energy is being lost as it travels through the cables.

Step-up transformers – increase the voltage as the electricity flows through the cables.

Step-down transformers – decrease the potential difference to make it safe.



AQA Physics (Separate Science) Unit 3: Particle Model of Matter

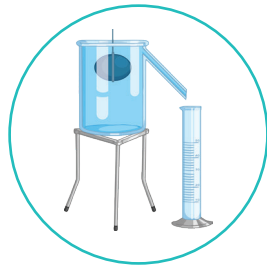
Required Practical

Measuring the density of a regularly shaped object:

- Measure the mass using a balance.
- Measure the length, width and height using a ruler.
- Calculate the volume.
- Use the density ($\rho = m/V$) equation to calculate density.

Measuring the density of an irregularly-shaped object:

- Measure the mass using a balance.
- Fill a eureka can with water.
- Place the object in the water - the water displaced by the object will transfer into a measuring cylinder.
- Measure the volume of the water. This equals the volume of the object.
- Use the density ($\rho = m/V$) equation to calculate density.



Density

Density is a measure of how much mass there is in a given space.

$$\text{Density (kg/m}^3\text{)} = \text{mass (kg)} \div \text{volume (m}^3\text{)}$$

A more dense material will have more particles in the same volume when compared to a less dense material.

Example

The density of an object is 8050 kg/m^3 and it has a volume of 3.4 m^3 . What is its mass in kg?

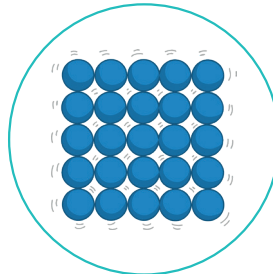
$$8050 = \text{mass} \div 3.4$$

$$8050 \times 3.4 = \text{mass}$$

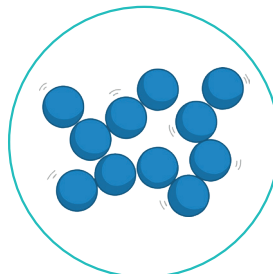
$$27\,370 \text{ kg}$$

States of Matter

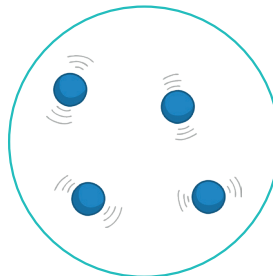
Solids have strong forces of attraction between the particles. The particles are held together very closely in a fixed, regular arrangement. The particles do not have much energy and can only vibrate.



Liquids have weaker forces of attraction between the particles. The particles are close together, but can move past each other. They form irregular arrangements. They have more energy than particles in a solid.

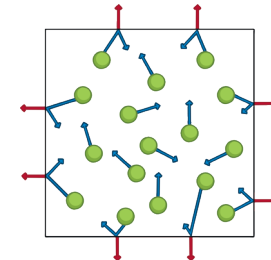


Gases have almost no forces of attraction between the particles. The particles have the most energy and are free to move in random directions.

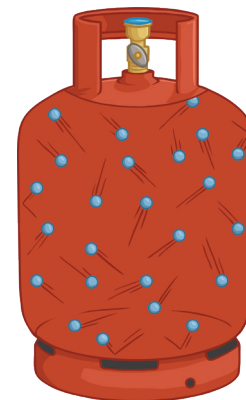


Motion in Gas Particles

Gas particles move about randomly, at high speed. They intercept other gas particles and anything else that is in the way. When this occurs, a pressure is exerted. If the gas is within a sealed container, pressure occurs when the gas particles hit the walls of the container. They produce a force at right angles to the wall of the container.

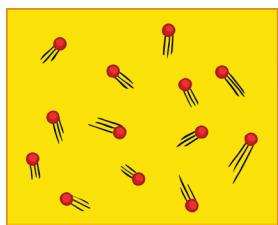


If the temperature of the gas increases, then the pressure will also increase. The hotter the temperature, the more kinetic energy the gas particles have. They move faster, colliding with the sides of the container more often.

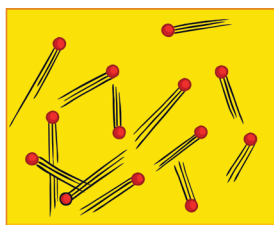


Internal Energy

Particles within a system have kinetic energy when they vibrate or move around. The particles also have a potential energy store. The total internal energy of a system is the kinetic and potential energy stores.



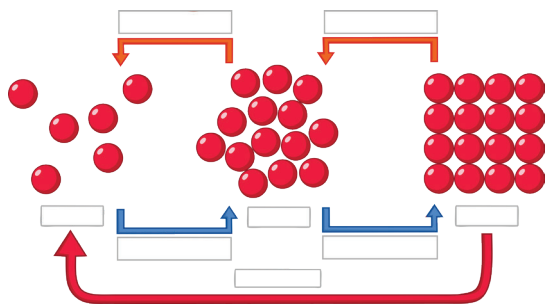
Low Temperature



High Temperature

If the system is heated, the particles will gain more kinetic energy, so increasing the internal energy.

Changing State

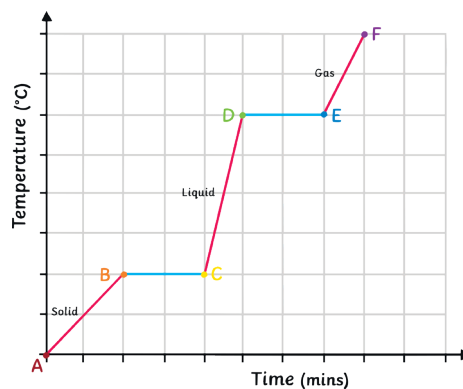


If a system gains more energy, it can lead to a change in temperature or change in state. If the system is heated enough, then there will be enough energy to break bonds.

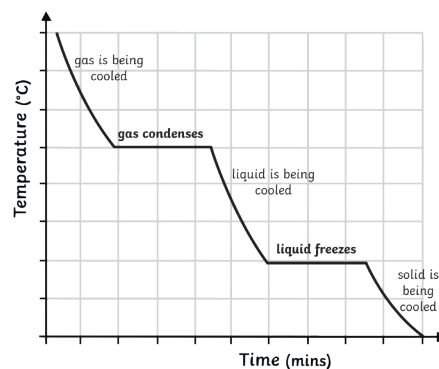
When something changes state, there is no chemical change, only physical. No new substance is formed. The substance will change back to its original form. The number of particles does not change and mass is conserved.

Specific Latent Heat

Energy is being put in during melting and boiling. This increases the amount of internal energy. The energy is being used to break the bonds, so the temperature does not increase. This is shown by the parts of the graph that are flat.



When a substance is condensing or freezing, the energy put in is used to form the bonds. This releases energy. The internal energy decreases, but the temperature does not go down.



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

Specific latent heat is the amount of energy needed to change 1kg of a substance from one state to another without changing the temperature. Specific latent heat will be different for different materials.

- solid $\rightarrow$ liquid - specific latent heat of **fusion**
- liquid $\rightarrow$ gas - specific latent heat of **vaporisation**

Specific Latent Heat Equation

The amount of energy needed/released when a substance of mass changes state.

$$\text{energy (E)} = \text{mass (m)} \times \text{specific latent heat (L)}$$

$$E = mL$$



Pressure in Gases

Heating

Heating up the gas particles provides them with more energy to move more quickly. This means they are likely to collide more frequently with other particles. This, in turn, increases the pressure.

Volume

If the volume of the container is increased, the number of collisions will decrease. This causes an overall decrease in pressure.

The equation for a fixed mass and a constant temperature is as follows (you will be given this in the exam):

$$P \times V = \text{constant}$$

P = pressure (Pa)

V = volume (m^3)

If the volume increases, the pressure decreases.

If the volume decreases, the pressure increases.

If the pressure of a gas changes, the volume of the gas can also change. A helium-filled balloon, once released, will rise into the atmosphere; the pressure outside of the balloon will decrease. The volume of the balloon will increase (due to less pressure outside the balloon), meaning the pressure inside the balloon will decrease.

Work Done on a Gas (Higher Tier Only)

Work done on a gas causes it to gain internal energy and so will increase the temperature. Pumping up the tyre of a bicycle involves doing work and this will increase the temperature of the gas inside the bicycle tyre.



Atomic Structure Knowledge Organiser – Foundation and Higher Separate Science

Developing the Model of the Atom

Scientist	Time	Contribution
John Dalton	Start of 19th century	Atoms were first described as solid spheres.
JJ Thomson	1897	Thomson suggested the plum pudding model – the atom is a ball of charge with electrons scattered within it.
Ernest Rutherford	1909	Alpha Scattering experiment – Rutherford discovered that the mass is concentrated at the centre and the nucleus is charged. Most of the mass is in the nucleus. Most atoms are empty space.
Niels Bohr	Around 1911	Bohr theorised that the electrons were in shells orbiting the nucleus.
James Chadwick	Around 1940	Chadwick discovered neutrons in the nucleus.

Isotopes

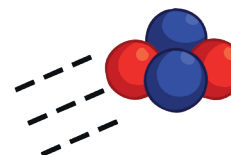
An isotope is an element with the same number of protons but a different number of neutrons. They have the same atomic number, but different mass numbers.

Isotope	Protons	Electrons	Neutrons
${}^1_1\text{H}$	1	1	0
${}^2_1\text{H}$	1	1	1
${}^3_1\text{H}$	1	1	2

Some isotopes are unstable and, as a result, decay and give out radiation. Ionising radiation is radiation that can knock electrons off atoms. Just how ionising this radiation is, depends on how readily it can do that.

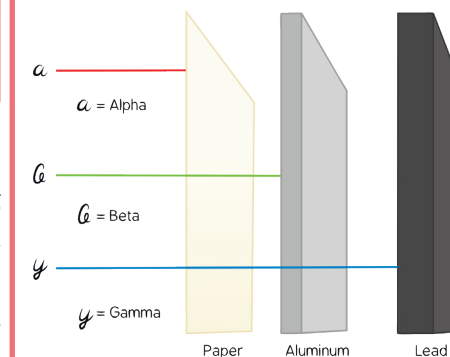
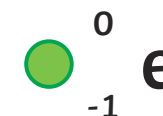
Alpha

Alpha radiation is an alpha particle emitted from the nucleus of a radioactive nuclei. It is made from two protons and two neutrons. They can't travel too far in the air and are the least penetrating – stopped by skin and paper. However, they are highly ionising because of their size.



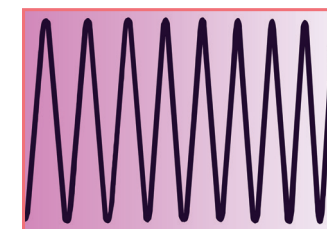
Beta

Beta radiation is a fast moving electron that can be stopped by a piece of aluminium. Beta radiation is emitted by an atom when a neutron splits into a proton and an electron.



Gamma

A gamma wave is a wave of radiation and is the most penetrating – stopped by thick lead and concrete.



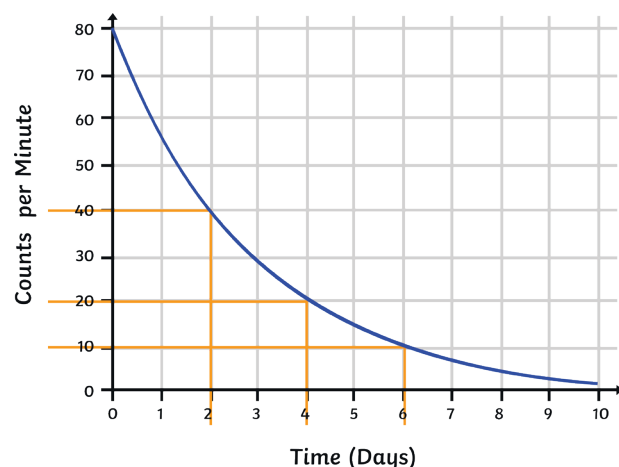
Half-life

The half-life is the time taken for the number of radioactive nuclei in an isotope to halve.

Radioactivity is a random process – you will not know which nuclei will decay. Radioactive decay is measured in becquerels Bq. 1 Bq is one decay per second.

Radioactive substances give out radiation from their nucleus.

A graph of half-life can be used to calculate the half-life of a material and will always have this shape:



Judging from the graph, the radioactive material has a half-life of two days.

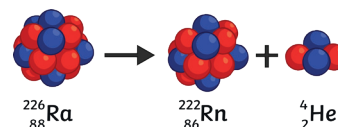
Irradiation

Irradiation occurs when materials are near a radioactive source. The source is sometimes placed inside a lead-lined box to avoid this.

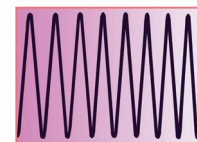
People who work with radioactive sources will sometimes stand behind a lead barrier, be in a different room or use a remote-controlled arm when handling radioactive substances.

Alpha Decay Equations

An alpha particle is made of two protons and two neutrons. The atomic number goes down by two and its mass number decreases by four.

**Gamma rays**

There is no change to the nucleus when a radioactive source emits gamma radiation. It is the nucleus getting rid of excess energy.

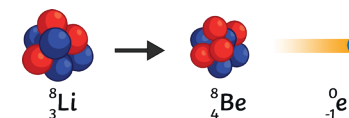
**Contamination**

When unwanted radioactive atoms get onto an object, it is possible for the radioactive particles to get inside the body.

Protective clothing should be worn when handling radioactive material.

Beta Decay Equations

A neutron turns into a proton and releases a an electron. The mass of the nucleus does not change but the number of protons increases.



Alpha radiation is more dangerous inside the body. It is highly ionising and able to cause a lot of damage. Outside the body it is less dangerous because it cannot penetrate the skin.

Beta radiation is less dangerous inside the body as some of the radiation is able to escape. Outside the body it is more dangerous as it can penetrate the skin.

Gamma radiation is the least dangerous inside the body as most will pass out and it is the least ionising. Gamma is more dangerous outside the body as it can penetrate the skin.



Background Radiation

This comes from natural sources like rocks, food and air. It also comes from man-made sources such as nuclear weapons, nuclear waste or nuclear accidents. The dose of radiation people receive varies dependent on how close they are to the source. Too much exposure to radiation can cause radiation poisoning. Radiation dosage is measured in **sieverts (Sv)**.

1000 millisieverts (mSv) = 1 sievert (Sv)

Uses of Nuclear Radiation

Although radiation can be dangerous, it also has its uses. The risks are always considered when using radiation. Gamma sources can be used as a medical tracer in the human body; isotopes can be injected or swallowed. As the isotope goes around the body, it can be monitored and medical issues can be spotted. Gamma radiation is emitted out of the body and does not cause the cells to become ionised. The isotope used will have a short half-life so it does not stay inside the body for too long. Tracers can be used to diagnose potentially life-threatening conditions which otherwise would not be spotted. The risk of using the radioactive tracer is much less than the risk of the condition they may diagnose.

Fission

Nuclear fission is the splitting of large radioactive nuclei into smaller ones. A neutron is absorbed by a large unstable radioactive nucleus. Next, the nucleus splits into smaller nuclei. As this happens, more neutrons and energy are released. The neutrons released go on to cause more reactions. This is called a chain reaction.

Fission is carried out in a nuclear reactor in order to generate energy. It is controlled by control rods which, when they are lowered down, slow down the reaction process. When they are raised, the reaction speeds up again. If this process is not controlled, then a nuclear weapon has been produced.

Different Half-Lives of Radioactive Isotopes

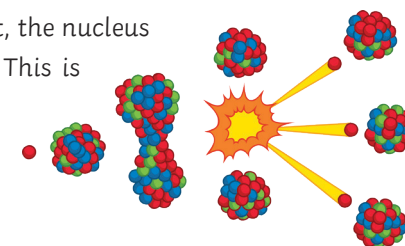
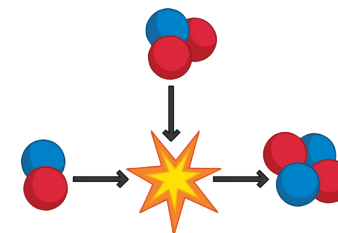
All radioactive isotopes have different half-lives. Some are very short and others are much longer. The uses of these will depend on the half-life. For example, you would use an isotope with a short half-life as a medical tracer so it is not in the body for too long.

Radiotherapy

High doses of radiation can be used to treat cancer. Gamma rays are focused directly onto the cancer cell, killing the cancer cell but not killing too many healthy cells. The damage to the healthy cells that may be close to the cancer can cause the patient to feel ill. However, killing the cancer cell makes it worth it.

Fusion

Nuclear fusion is the joining together of smaller radioactive nuclei to make a larger atom. Fusion occurs in the sun. This whole process releases a lot of energy, much more than fission. However, a very high temperature and pressure is needed for fusion to occur, so it is not used in the production of energy yet.



AQA GCSE Physics (Separate Science) Unit 5: Forces

Scalar and Vector Quantities

A **scalar** quantity has **magnitude** only. Examples include temperature or mass.

A **vector** quantity has both **magnitude** and **direction**. Examples include velocity.

Speed is the scalar magnitude of **velocity**.

A vector quantity can be shown using an **arrow**. The size of the arrow is relative to the magnitude of the quantity and the direction shows the associated direction.

Contact and Non-Contact Forces

Forces either **push** or **pull** on an object. This is as a result of its interaction with another object.

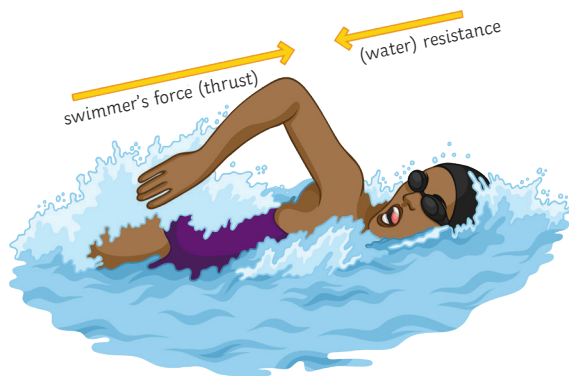
Forces are categorised into two groups:

Contact forces – the objects are touching e.g. friction, air resistance, tension and contact force.

Non-contact forces – the objects are not touching e.g. gravitational, electrostatic and magnetic forces.

Forces are calculated by the equation: **force (N) = mass (kg) × acceleration (m/s²)**

Forces are another example of a **vector quantity** and so they can also be represented by an **arrow**.



Gravity

Gravity is the natural phenomenon by which any object with mass or energy is drawn together.

- The **mass** of an object is a scalar measure of how much matter the object is made up of. Mass is measured in **kilograms (kg)**.
- The **weight** of an object is a vector measure of how gravity is acting on the mass. Weight is measured in **newtons (N)**.

$$\text{weight (N)} = \text{mass (kg)} \times \text{gravitational field strength (N/kg)}$$

(The gravitational field strength will be given for any calculations. On earth, it is approximately 9.8N/kg).

An object's **centre of mass** is the point at which the weight of the object is considered to be acting. It does not necessarily occur at the centre of the object.

The **mass** of an object and its **weight** are **directly proportional**. As the mass is increased, so is the weight. Weight is measured using a **spring-balance** (or **newton metre**) and is measured in **newtons (N)**.

Resultant Forces

A **resultant force** is a single force which replaces several other forces. It has the same effect acting on the object as the combination of the other forces it has replaced.

The forces acting on this object are represented in a **free body** diagram. The arrows are relative to the magnitude and direction of the force.

The car is being pushed to the left by a force of 30N. It is also being pushed to the right by a force of 50N.



The **resultant force** is $50\text{ N} - 30\text{ N} = 20\text{ N}$

The 20N resultant force is pushing to the right, **so the car will move right**.

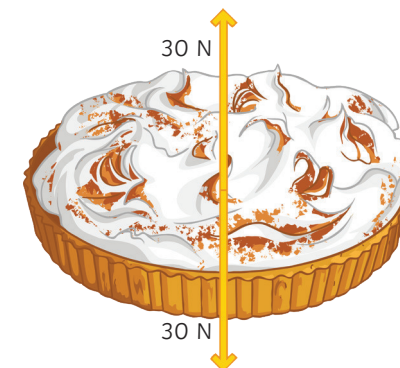
When a resultant force is not zero, an object will **change speed** (accelerate or decelerate) or **change direction** (or both).

When an object is stationary, there are still forces acting upon it.

In this case, **the resultant force is $30\text{ N} - 30\text{ N} = 0\text{ N}$** .

The forces are in **equilibrium** and are **balanced**.

When forces are balanced, an object will either **remain stationary** or if it is moving, it will continue to move at a **constant speed**.

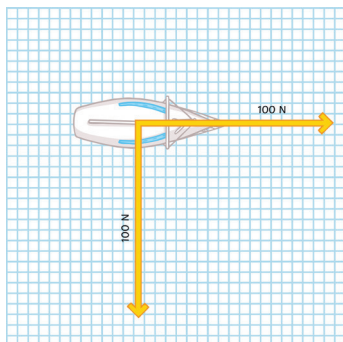


Resultant Forces

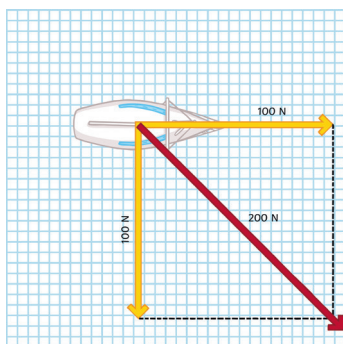
A **scale vector diagram** can be used to calculate **resultant forces** that are not acting directly opposite of one another, on a straight line.

Worked example 1:

A boat is being pulled toward the harbour by two winch motors. Each motor is pulling with a force of 100N and they are working at right angles to one another.



To find the resultant force, you would first draw construction lines from the end of each arrow parallel to the other force arrow.



Remember that the size of the arrow is representative of the size of the force being exerted.

Where the construction lines intercept indicates the direction of the resultant force: from the centre of mass through the intercept.

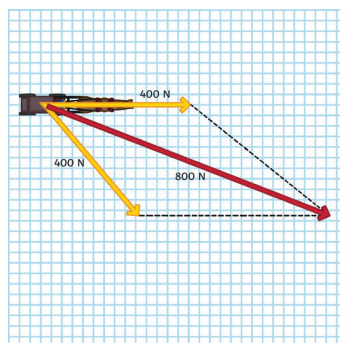
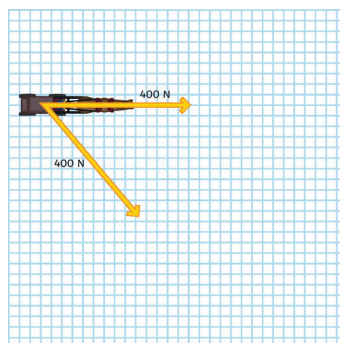
The resultant force is the sum of the forces acting so in this example, that is 200N.

Measure the size of the arrows and make sure you draw your resultant force arrow to the correct scale so it represents the resultant force size.

Worked example 2:

A horse-drawn carriage is pulled by two horses at 400N each. One of the horses is pulling in a different direction to the other horse. Show the resultant force and direction of the horse-drawn carriage.

As before, you will need to draw construction lines from the end of each force arrow and parallel to the other one. The intercept represents the direction of the resultant force. The resultant force is the sum of the individual forces so in this example, it is 800N.



Work Done and Energy Transfer

When a force acts on an object and makes it move, there is **work done** on the object. This movement requires energy. The **input energy** could be from fuel, food or electricity for example.

The energy is **transferred to a different type of energy** when the work is done. Not all the energy transfers are useful, sometimes energy is **wasted**. For example, when car brakes are applied, some energy is wastefully transferred as heat to the surroundings. Work done against the force of **friction** always causes a **temperature rise** in the object.

Work done is calculated by this equation:

work done [energy transferred] (J) = force (N) × distance moved (in the direction of the force) (m)

Worked example

A man's car has broken down and he is pushing it to the side of the road. He pushes the car with a force of 160N and the car is moved a total of 8m. Calculate the energy transferred.

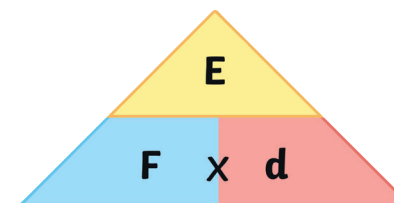
$$E = F \times d$$

$$E = 160 \times 8$$

$$E = 1280\text{J}$$

1 joule of energy is transferred for every 1 newton of force moving an object by a distance of 1 metre.

$$1\text{J} = 1\text{Nm}$$



AQA GCSE Physics (Separate Science) Unit 5: Forces

Required Practical Investigation Activity 6: Investigate the Relationship Between Force and Extension for a Spring

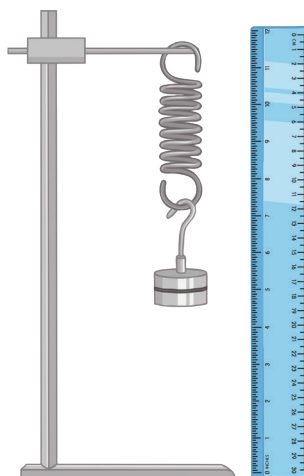
$$F = k \times e$$

force applied (N) = spring constant (N/m) $\times$ extension (m)

You should be familiar with the equation above and the required practical shown to the right.

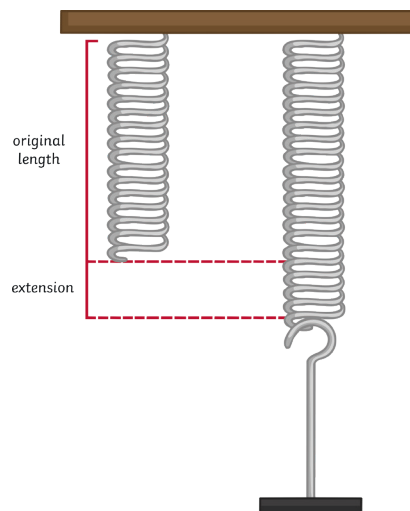
The spring constant is a value which describes the elasticity of a material. It is specific to each material. You can carry out a practical investigation and use your results to find the spring constant of a material.

1. Set up the equipment as shown.
2. Measure the original length of the elastic object, e.g. a spring, and record this.
3. Attach a mass hanger (remember the hanger itself has a weight). Record the new length of the spring.
4. Continue to add masses to the hanger in regular intervals and record the length each time.



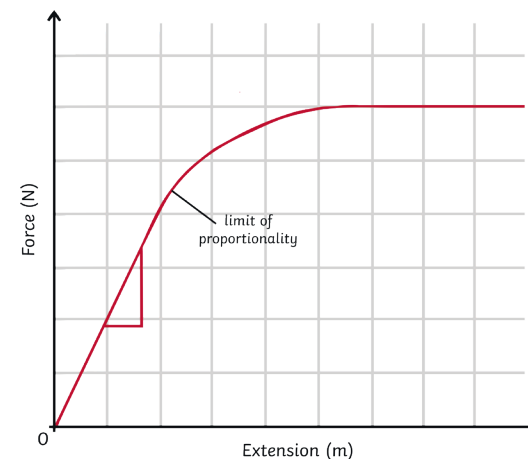
Once you have your results, you can find the extension for each mass using this formula: **spring length – original length**

The data collected is continuous so you would plot a **line graph** using the x-axis for extension (m) and the y-axis for force (N). As a result of Hooke's Law, you should have a **linear graph**. The **gradient of the graph is equal to the spring constant**. You can calculate it by rearranging the formula above or by calculating the gradient from your graph.



Spring Constant and Hooke's Law

Hooke's Law describes that the extension of an elastic object is **proportional** to the force applied to the object. However, there is a maximum applied force for which the extension will still increase proportionally. If the **limit of proportionality** is exceeded, then the object becomes **permanently deformed** and can no longer return to its original shape. This can be identified on a graph of extension against force when the gradient stops being linear (a straight line) and begins to **plateau**. The limit is shown on the graph above and this is the specific object's **elastic limit**.



Forces and Elasticity

When work is done on an elastic object, such as a spring, the energy is stored as elastic potential energy.

When the force is applied, the object changes shape and stretches. The energy is stored as elastic potential and when the force is no longer applied, the object returns to its original shape. The stored elastic potential energy is transferred as kinetic energy and the object recoils and goes back to its original shape.



AQA GCSE Physics (Separate Science) Unit 5: Forces

Work Done: Elastic Objects

Work is done on elastic objects to **stretch** or compress them.

To calculate the work done (**elastic potential energy** transferred), use this equation:

$$E (J) = 0.5 \times k \times e^2$$

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

You might need to use this equation also: $F = k \times e$

Worked example:

A bungee jumper jumps from a bridge with a weight of 800N. The elastic cord is stretched by 25m. Calculate the work done.

Step 1: find the spring constant using $F = k \times e$

Rearrange to $k = F \div e$

$$800 \div 25 = 32\text{N/m}$$

Step 2: use the value for k to find the elastic potential energy (work done) using $E (J) = 0.5 \times k \times e^2$

$$0.5 \times 32 \times 25^2$$

$$E = 10\,000\text{J}$$

Moments, Levers and Gears

A moment is the turning effect produced by a force. To find the size of a moment, use the equation:

$$\text{moment (Nm)} = \text{force (N)} \times \text{distance (m)}$$

Remember that the distance is the perpendicular distance from the pivot to the line of action of the force.

Worked example:

A crowbar is being used to lift a manhole cover. Calculate the moment produced.

$$M = F \times d$$

$$M = 10 \times 0.4$$

$$m = 40\text{Nm}$$

To increase the turning effect achieved without increasing the amount of force applied, you would need to increase the distance between the force and the pivot.

For example, if the crowbar in the example above was 0.5m, then the moment would be:

$$M = F \times d$$

$$M = 10 \times 0.5$$

$$M = 50\text{Nm}$$

Levers can be used to increase the effect of a force applied, acting as a force multiplier. Some everyday examples include:

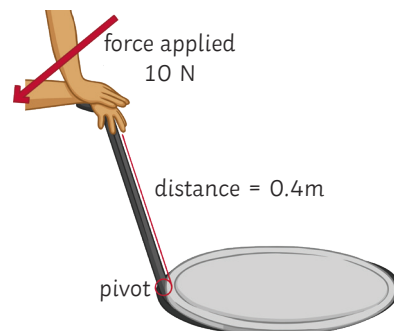
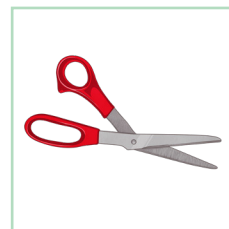
spanner



wheelbarrow



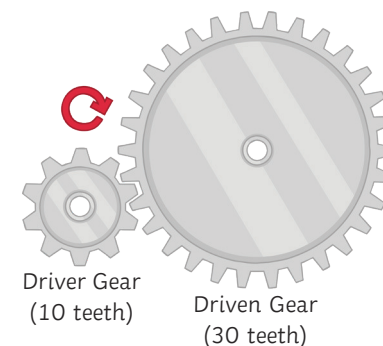
pair of scissors



A force multiplier makes it easier to do work because the same force applied at a greater distance from the pivot increases the moment produced.

A **gear** is a wheel which has 'teeth' around the circumference.

The teeth of different gears lock together and the gear can turn on an **axle**, turning the other gears it is connected to. Where the teeth meet, they must move in the same direction. This means that the gears rotate in **opposite directions**. If one gear is turning clockwise, it will turn the connected gear anticlockwise.



When gears are connected, the **same force** is applied to each; however, if they are different sizes, they will produce **different moments**. This is because the moment is calculated using the distance from the pivot (the radius of the gear) and if the gear is smaller, it will move a shorter distance. If the gear is larger, it will move a greater distance.

Worked example:

A gear has a radius of 0.25m. It turns a second gear with a radius of 1.5m. The moment of the smallest gear is 30Nm. Calculate the moment of the largest gear.

Step 1: calculate the force using $M = F \times d$

Rearrange to $F = M \div d$

$$F = 30 \div 0.25$$

$$F = 120\text{N}$$

Step 2: use the force to calculate the moment of the larger gear.

$$M = F \times d$$

$$M = 120 \times 1.5$$

$$M = 180\text{Nm}$$



AQA GCSE Physics (Separate Science) Unit 5: Forces

Balanced Moments

When the anticlockwise moment on an object is equal to the clockwise moment, the **resultant moment** is zero and the object does not move or turn.

To balance moments: **total anticlockwise moments = total clockwise moments**

Worked example:

An elephant sits on a seesaw. It has a weight of 750N and is sat 2.5m from the pivot. A mouse with a weight of 60N is sitting on the other side of the seesaw. The seesaw is balanced.

What distance is the mouse from the pivot?

Step 1:	Step 2:	Step 3:
Calculate the anticlockwise moment.	total anticlockwise moments = total clockwise moments	Use the value calculated for the moment to find the distance on the clockwise side.
$M = F \times d$	$1875\text{Nm} = 1875\text{Nm}$	rearrange: $d = M \div F$
$= 750\text{N} \times 2.5\text{m}$		$d = 1875 \div 60$
$= 1875\text{Nm}$		$d = 31.25\text{m}$

Pressure and Pressure Difference in Fluids

A **fluid** is any material in a state of matter which flows; it is a **liquid** or a **gas**.

The pressure in a fluid causes a force at a **right angle** (normal) to the surface.

The pressure is calculated using the equation:

$$\text{pressure (Pa)} = \frac{\text{force (N)}}{\text{surface area (m}^2\text{)}}$$

Worked example:

Find the pressure exerted by an elephant on a frozen pond. The force exerted by the elephant is 4500N and the area of the pond is 30m².

$$p = 4500 \div 30$$

$$p = 150\text{Pa}$$

Pressure in Fluids

You can find the pressure produced by a column of liquid using the equation:

$$\text{pressure (Pa)} = \text{height of column (m)} \times \text{density of liquid (kg/m}^3\text{)} \times \text{gravitational field strength (N/kg)}$$

The more water above an object, then the greater the force applied and the greater the pressure exerted. Scuba divers have to monitor the pressure as they dive to ensure they are not endangering their lives by going too deep.

This can be demonstrated by placing holes in a bucket or other container of water at two different heights.

Water leaking from the hole higher up the bucket will be at a lower pressure than water leaking from the hole lower in the bucket.

When an object is **submerged partially**, it will have a greater pressure on the bottom surface than on the top surface (there is more water behind the force acting upwards). This creates an upwards resultant force called **upthrust** and this is what causes an object to float.



Atmospheric Pressure

Surrounding the earth is a layer of **air** called the **atmosphere**. Compared to the size of the planet, this layer is relatively thin. The air becomes less dense the farther from the planet's surface you are (with increasing **altitude**).

When the air molecules collide with the surface of the earth, pressure is exerted and this is called **atmospheric pressure**. The amount of air molecules above a surface **decreases** with **altitude** and so the **pressure exerted** also **decreases** with increasing height.

Velocity

Velocity is a **vector** quantity. It is the **speed** of an object in a given **direction**.

Circular Motion (Higher tier only)

Objects moving in a **circular path** don't go off in a straight line because of a **centripetal** force caused by another force acting on the object.

For example, a car driving around a corner has a centripetal force caused by **friction** acting between the surface of the road and the tyres. When the Earth orbits around the Sun, it is held in orbit by **gravity** which causes the centripetal force.

When an object is moving in a circular motion, its **speed** is **constant**. Its **direction changes** constantly and because direction is related to **velocity**, this means that the velocity of the object is constantly changing too. The changes in velocity mean that the object is **accelerating**, even though it travels at a constant speed.

The acceleration occurs because there is a **resultant force** acting on the object. In this case, the resultant force is the velocity, which is greater than the centripetal force acting.



AQA GCSE Physics (Separate Science) Unit 5: Forces

Forces and Motion: Distance vs Displacement

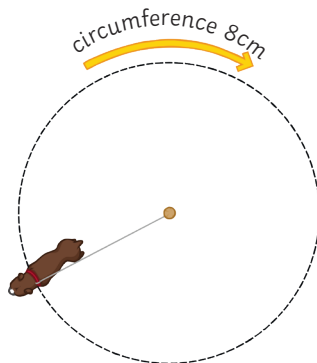
Distance is a **scalar** quantity. It measures how far something has moved and does not have any associated direction.

Displacement is a **vector** quantity. It measures how far something has moved and is measured in relation to the direction of a straight line between the starting and end points.

E.g. A dog is tethered to a post. It runs 360° around the post three times. Each 360° lap is 8m

$$\text{distance} = 8 \times 3 = 24\text{m}$$

displacement = 0m (The dog is in the same position as when it started.)



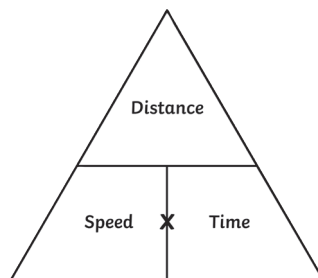
Speed

You should be able to recall the typical speed of different transportation methods.

Activity	Typical Value
walking	1.5m/s
running	3m/s
cycling	6m/s
driving a car	25mph (40km/h)
train travel	60mph (95km/h)
aeroplane travel	550mph (885km/h)
speed of sound	330m/s

These values are average only. The speed of a moving object is rarely constant and always fluctuating.

$$\text{speed} = \text{distance} \div \text{time}$$



You should be able to use this equation and rearrange it to find the distance or time.

Worked example:

John runs 5km. It takes him 25 minutes. Find his average speed in metres per second.

Step 1: convert the units

$$\text{km} \rightarrow \text{m} (\times 1000) = 5000\text{m}$$

$$\text{min} \rightarrow \text{s} (\times 60) = 1500\text{s}$$

Step 2: calculate $s = d \div t$

$$s = 5000 \div 1500$$

$$s = 3.33\text{m/s}$$

Worked example 2:

Zi Xin has driven along the motorway. Her average speed is 65mph. She has travelled 15 miles. How long has her journey taken? Give your answer in minutes.

Step 1: calculate $t = d \div s$

$$t = 15 \div 65$$

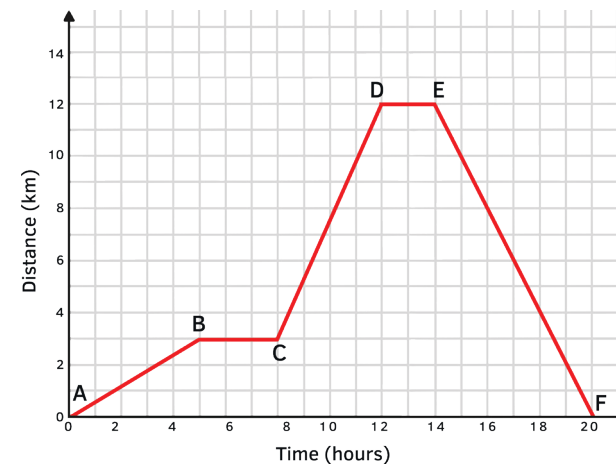
$$t = 0.23 \text{ (hours)}$$

Step 2: convert units

$$\text{hr} \rightarrow \text{min} (\times 60) = 13.8 \text{ minutes}$$

Distance-Time and Velocity-Time Graphs

When an object travels in a **straight line**, we can show the distance which has been covered in a **distance-time graph**.



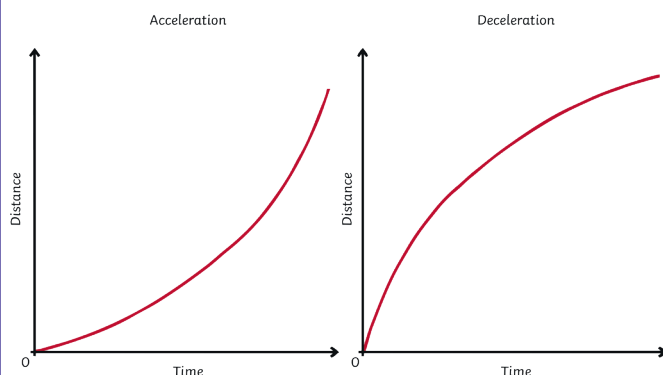
You should be able to understand what the features of the two types of graph can tell you about the motion of an object.

Graph Feature	Distance-Time Graph	Velocity-Time Graph
x-axis	time	time
y-axis	distance	velocity
gradient	speed	acceleration (or deceleration)
plateau	stationary (stopped)	constant speed
uphill straight line	steady speed moving away from start point	acceleration
downhill straight line	steady speed returning to the start point	deceleration
uphill curve	acceleration	increasing acceleration
downhill curve	deceleration	increasing deceleration
area below graph		distance travelled



AQA GCSE Physics (Separate Science) Unit 5: Forces

Changing Speed on a D-T graph



When the graph is a **straight line**, it is representing a **constant speed**. A **curve** represents a changing speed, either **acceleration** or **deceleration**. The speed at any given point can be calculated by drawing a **tangent** from the curve and finding the **gradient** of the tangent.

Terminal Velocity

When an object begins moving, the force **accelerating** the object is much greater than the force resisting the movement. A resistant force might be **air resistance** or **friction**, for example.

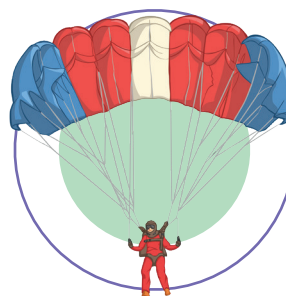
As the **velocity** of the object increases, the force **resisting** the movement also increases. This causes the acceleration of the object to be reduced gradually until the forces become **equal** and are **balanced**. This doesn't cause the object to stop moving. As the object is already in motion, balanced forces mean it will continue to move at a **steady speed**. This steady speed is the maximum that the object can achieve and is called the **terminal velocity**.

The terminal velocity of an object depends on its shape and weight. The shape of the object determines the amount of resistant force which can act on it. For example, an object with a large surface area will have a greater amount of resistance acting on it.

Consider a skydiver and his parachute. When the skydiver first jumps from the aeroplane, he has a small area where the air resistance can act. He will fall until he reaches a terminal velocity of approximately 120mph.



After the skydiver releases his parachute, the shape and area has been changed and so the amount of air resistance acting is increased. This causes him to decelerate and his terminal velocity is reduced to about 15mph. This makes it a much safer speed to land on the ground.



Acceleration

Acceleration can be calculated using the equation:

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

Worked example:

A dog is sitting, waiting for a stick to be thrown. After the stick is thrown, the dog is running at a speed of 4m/s. It has taken the dog 16s to reach this velocity. Calculate the acceleration of the dog.

$$a = \Delta v \div t$$

$$a = (4-0) \div 16$$

$$A = 0.25\text{m/s}^2$$

Changes in velocity due to acceleration can be calculated using the equation below. This equation of motion can be applied to any moving object which is travelling in a **straight line** with a **uniform acceleration**.

$$\text{Final velocity}^2 \text{ (m/s)} - \text{initial velocity}^2 \text{ (m/s)} = 2 \times \text{acceleration (m/s}^2\text{)} \times \text{displacement (m)}$$

or

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

Worked example:

A bus has an initial velocity of 2m/s and accelerates at 1.5m/s² over a distance of 50m. Calculate the final velocity of the bus.

$$\text{Step 1: rearrange the equation: } v^2 - u^2 = 2as$$

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

$$\text{Step 2: insert known values and solve}$$

$$v^2 = (2 \times 1.5 \times 50) + 2^2$$

$$v^2 = (150) + 4$$

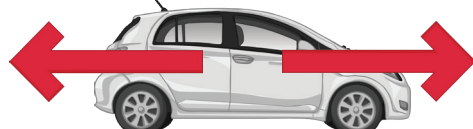
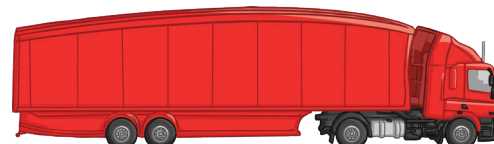
$$v^2 = 154$$

$$v = \sqrt{154}$$

$$v = 12.41\text{m/s}$$



AQA GCSE Physics (Separate Science) Unit 5: Forces

Stopping Distance	Newton's Laws of Motion: Newton's First Law	Newton's Laws of Motion: Newton's Second Law	Momentum
The stopping distance of a vehicle is calculated by: stopping distance = thinking distance + braking distance Reaction time is the time taken for the driver to respond to a hazard. It varies from 0.2s to 0.9s between most people. Reaction time is affected by: • tiredness • drugs • alcohol • distractions You can measure human reaction time in the lab using simple equipment: a metre ruler and stopwatch can be used to see how quickly a person reacts and catches the metre ruler. The data collected is quantitative and you should collect repeat readings and calculate an average result.	If the resultant force acting on an object is zero... • a stationary object will remain stationary. • a moving object will continue at a steady speed and in the same direction. 100N resistance (friction and air) 100N thrust  Inertia – the tendency of an object to continue in a state of rest or uniform motion (same speed and direction).	The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to the mass of the object resultant force (N) = mass (kg) × acceleration (m/s²) Inertial mass – how difficult it is to change an objects velocity. It is defined as the ratio of force over acceleration. Newton's Laws of Motion: Newton's Third Law When two objects interact, the forces acting on one another are always equal and opposite. For example, a book laid on a table is being acted upon by at least two forces: the downward pull of gravity and the upward reaction force from the table surface. The forces are equal and opposite so the book does not move. We describe the forces as being balanced.	momentum (N) = mass (kg) × velocity (m/s) The law of conservation of mass (in a closed system) states that the total momentum before an event is equal to the total momentum after an event. Worked example: Calculate the momentum of a 85kg cyclist travelling at 7m/s. $p = m \times v$ $p = 85\text{kg} \times 7\text{m/s}$ $p = 595\text{kg m/s}$ Worked example: 2 
Braking Distance			
The braking distance is the distance travelled by a vehicle once the brakes are applied and until it reaches a full stop. Braking distance is affected by: • adverse weather conditions (wet or icy) • poor vehicle condition (brakes or tyres) When force is applied to the brakes, work is done by the friction between the car wheels and the brakes. The work done reduces the kinetic energy and it is transferred as heat energy, increasing the temperature of the brakes. increased speed = increased force required to stop the vehicle increased braking force = increased deceleration Large decelerations can cause a huge increase in temperature and may lead to the brakes overheating and the driver losing control over the vehicle	30mph 9m14m23m 40mph 12m24m36m 50mph 15m38m53m 60mph 18m55m73m 70mph 21m75m96m Distance (metres) Braking distance Thinking distance		
A lorry with a mass of 12 000kg, travelling at 20m/s, collides with a stationary car with a mass of 1500kg. After the collision, the vehicles move off together. Calculate their velocity. Step 1: find the momentum of each vehicle before the collision. Calculate the momentum of the lorry: $p = m \times v$ $p = 12\,000 \times 20 = 240\,000\text{kg m/s}$ Calculate the momentum of the car: $p = m \times v$ $p = 1500 \times 0 = 0\text{kg m/s}$			



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Step 2: find the total momentum before the collision.
total momentum before = $240\,000 + 0 = 240\,000\text{kg m/s}$

Step 3: use the law of conservation of momentum and rearrange the equation.

total momentum before collision = total momentum after collision

$$\frac{p}{m} = v$$

$240\,000\text{kg m/s} \div (12\,000 + 1500) = 17.78\text{m/s}$.

Worked example: 3

A cannon fires a 5kg cannonball at a velocity of 90m/s. The cannon recoils at a velocity of 2m/s after the explosion. Calculate the mass of the cannon.

Step 1: find the total momentum before the explosion.

$p = m \times v$ (for the cannonball)

$p = 5 \times 90 = 450\text{kg m/s}$

Although you don't have all the information to calculate the momentum of the cannon, you know it is zero because it is stationary and therefore has a velocity of zero. Since momentum is mass $\times$ velocity, you know the momentum will be zero regardless of the mass.

total momentum before = 450kg m/s

Step 2: use the law of conservation of momentum and rearrange the equation.

total momentum before explosion = total momentum after explosion

$$\frac{p}{v} = m$$

$450\text{kg m/s} \div 2\text{m/s} = 225\text{kg}$

Changes in Momentum

When a force acts on a **moving** or **moveable** object there is a **change of momentum**.

The equations for calculating **force** and **acceleration** can be combined:

$$F = m \times a \text{ and } a = (v - u) \div t$$

To give:

force(N) = change in momentum (kg m/s) $\div$ time taken (s)

or

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

This equation tells you that the **force is equal to the rate of change of momentum** in the object.

Car Safety Features

When people are travelling in a moving car, they have momentum. If the car were to crash and become stationary all of a sudden, the passengers would lose all their momentum. This would result in a large force being exerted; therefore, it is important to change the momentum gradually.

This is done by the seatbelts and the air bags which are fitted into vehicles.

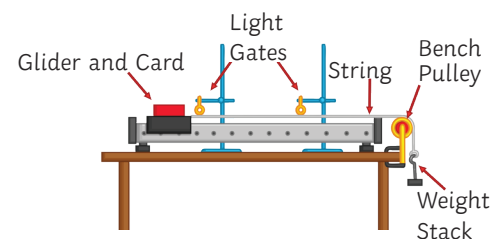
An airbag is also designed to reduce the momentum. The air bag is filled with air as it is deployed and has a small hole inside. As the person makes contact with the airbag, the air is slowly released from the hole and the person is slowed down more gradually.

The force exerted on the passenger is reduced because the time taken to slow them down is increased.

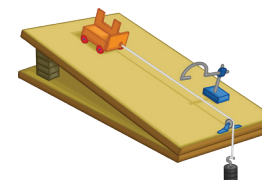
Required Practical Investigation 7

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.

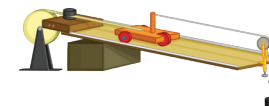
You may be given any of the following apparatus set-ups to conduct these investigations:



or



or



Something is a **fair test** when **only** the independent variable has been allowed to affect the dependent variable.

The independent variable was **force**.

The dependent variable was **acceleration**.

The control variables were:

- **same total mass**
- **same surface/glider/string/pulley (friction)**
- **same gradient if you used a ramp**

