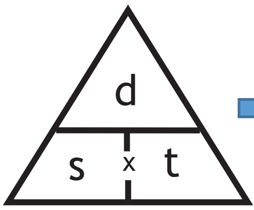
Unit 6.1 - Motion

Calculating Speed

Speed is defined as the distance moved per unit time, and hence, the equation for speed is :

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

$$s = \frac{d}{t}$$



...and the other two forms of the equation are :

$$d = s \times t$$

$$t = \frac{d}{s}$$

Distance is measured in	**metres (m)**
Time is measured in	**seconds (s)**
Speed is measured in	**metres per seconds (m/s)**

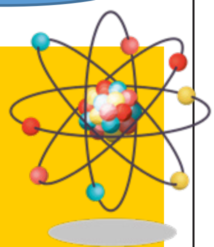
Example 1

If a school bus moves 1600 metres at an average speed of 12.5 m/s, how long did the journey take ?

$$t = \frac{d}{s} = \frac{1600}{12.5} = 128 \text{ s}$$

Look !! Since it's **time** we're calculating, the answer must have units of **seconds.**

Example 2



An electron in orbit around an atom moves at a speed of 2500 km/s !
How far would it travel (in a straight line) if it moved at this speed for 1 minute ?

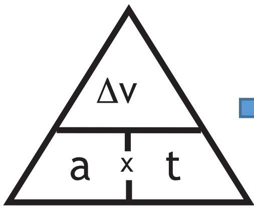
$d = s \times t = 2\,500\,000 \times 60 = 1.5 \times 10^8$ m (Almost 4 times around the Earth !)

Look !! It's safer to use all values in metres and seconds (rather than km and minutes).
So, 2500 km/s = 2500 x 1000 = 2 500 000 m/s

Calculating Acceleration

Another equation you'll need is the one for acceleration.
Acceleration is defined as the change in velocity (or speed) per second :

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



...and the other two forms of the equation are :

$$\Delta v = a \times t$$

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

> *Info. ! Notice the triangle symbol (∞) in front of the "v". It's the Greek letter 'delta'. In this case it means 'change in'.*

Change in velocity is measured in **metres per second (m/s)**
Time is measured in **seconds (s)**
Acceleration is measured in **metres per second^2 (m/s^2)**

Example 1

A cyclist increases her speed from 5m/s to 19m/s in 7 seconds.
What is her acceleration?

$$a = \frac{\Delta v}{t} = \frac{(19-5)}{7} = \frac{14}{7} = 2\ \text{m/s}^2$$

Example 2

An oil tanker can decelerate at a maximum rate of 0.04 m/s^2. How long will the tanker take to come to a complete stop if initially travelling at a speed of 12 m/s ?

$$t = \frac{\Delta v}{a} = \frac{(12)}{0.04} = 300\ \text{s}$$

(A full 5 minutes !)

Example 3

A football moving forwards at a speed of 12.4 m/s, is kicked forwards so that its speed increases. The acceleration of the ball is 48.0 m/s^2, which lasts for 0.45 s. What's the final speed of the ball after this acceleration ?

Change in speed, $\Delta v = a \times t = 48.0 \times 0.45 = 21.6$ **m/s**

So, final speed $= 12.4 + 21.6 =$ **34.0 m/s**

Motion graphs

The motion of an object can be shown on one of two types of graphs : distance-time or velocity-time graphs (sometimes called speed-time graphs).

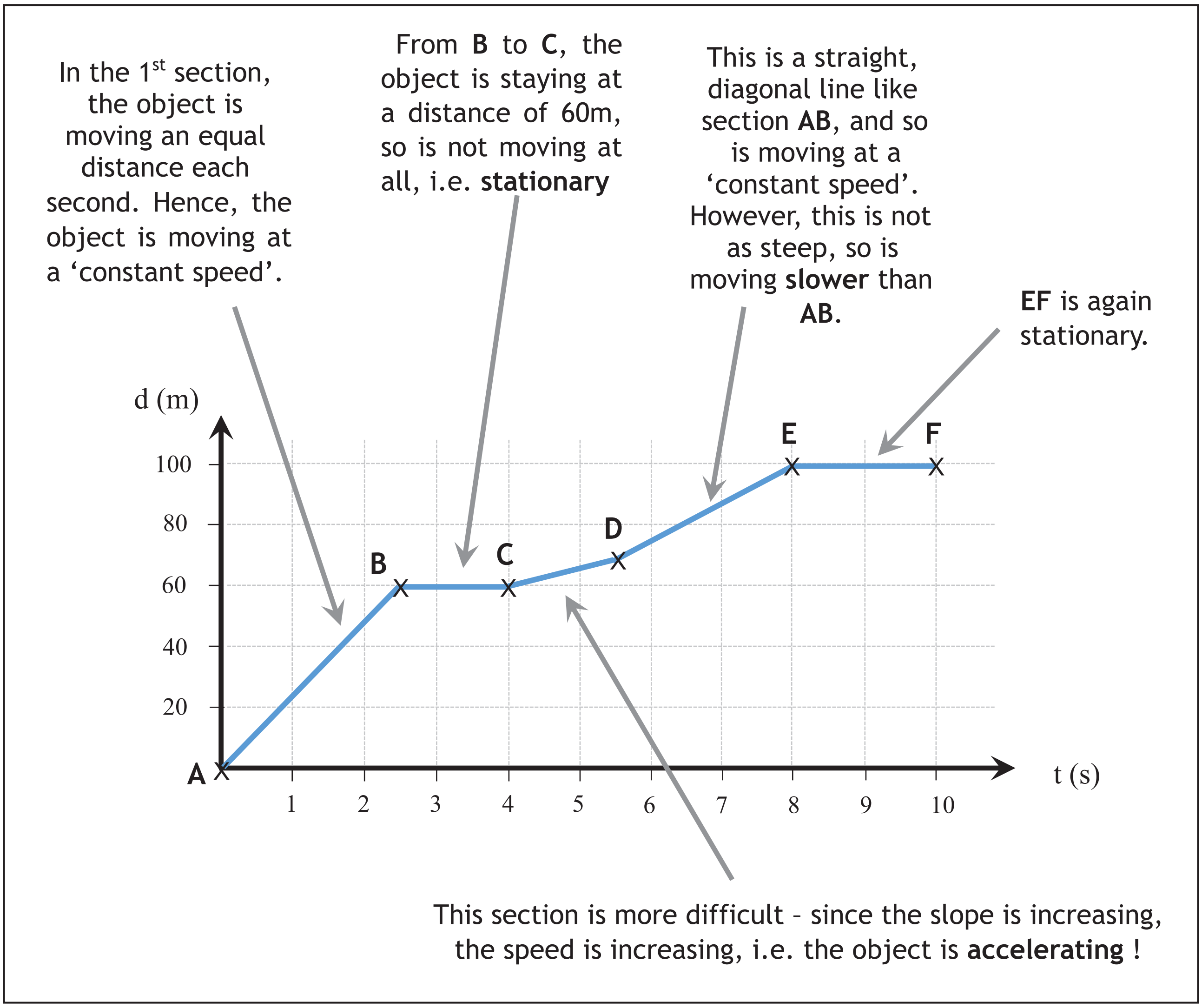
Distance - time graphs

There's ONE rule for a d-t graph :

The 'steepness' (or more correctly 'slope' or 'gradient') of this graph indicates the speed of the object.

So,

a STEEP line ➔ a high speed
a less steep line ➔ a lower speed
a flat/horizontal line ➔ not moving



Motion graphs

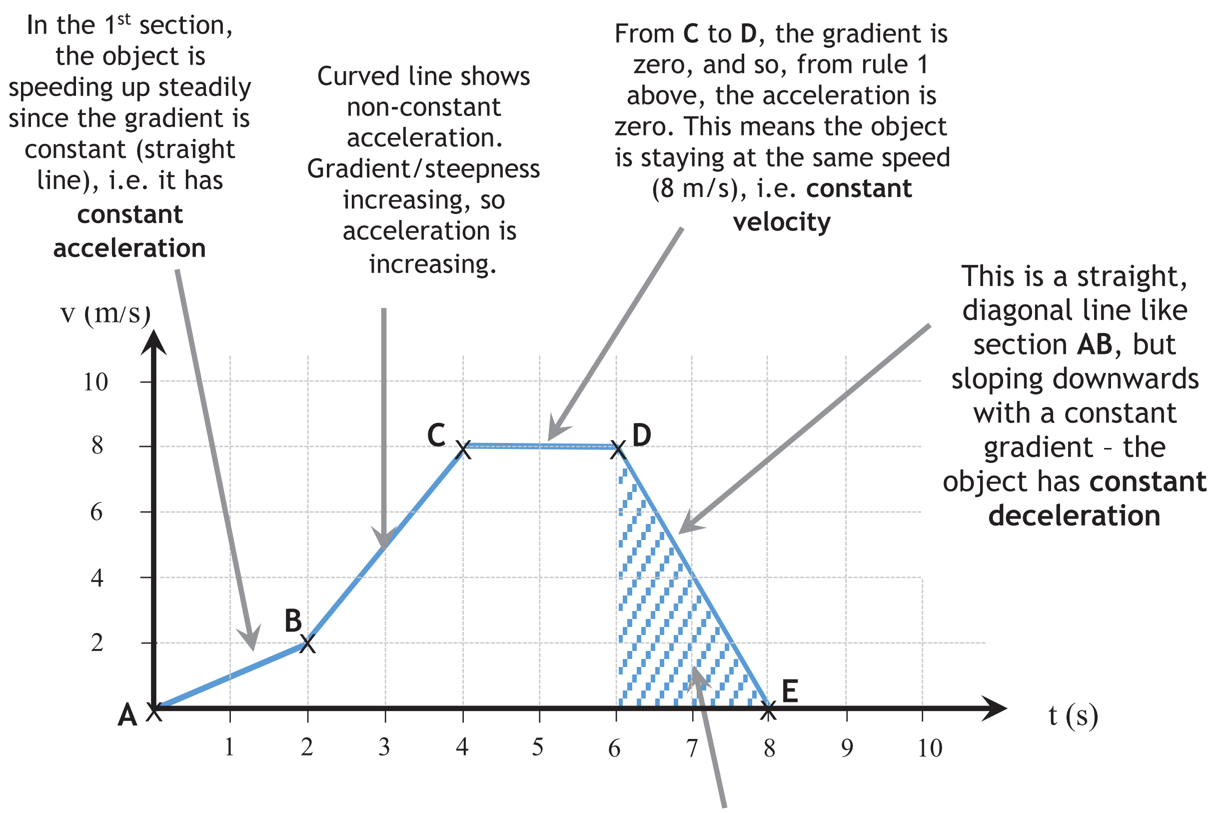
Velocity - time graphs

(or 'speed-time' graphs)

There are TWO rules for a v-t graph :

1. The slope/gradient is equal to the acceleration.

2. The area under the graph is equal to the distance travelled.



The distance travelled in any section can be calculated from the area below the line, in this case the area of the shaded triangle :

Distance = area $= \frac{\text{base x height}}{2} = \frac{2 \times 8}{2} = \frac{16}{2} =$ **8 metres**

Calculating the average/mean acceleration in section BC :

$a = \frac{\Delta v}{t} = \frac{8-2}{2} = \frac{6}{2} = 3 \text{ m/s}^2$

NOTE : Calculating the average speed in a sloping section is easy !! Since only straight line sections are used for this, it's simply half way between the start and end speed for that section e.g. for section DE, the average speed is 4 m/s (half way between 8 m/s and 0 m/s)

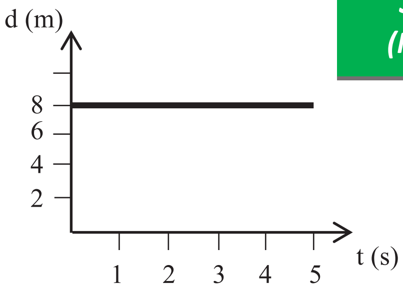
Motion graphs

The motion of an object can be shown on one of two types of graphs : distance-time or velocity-time graphs (sometimes called speed-time graphs).

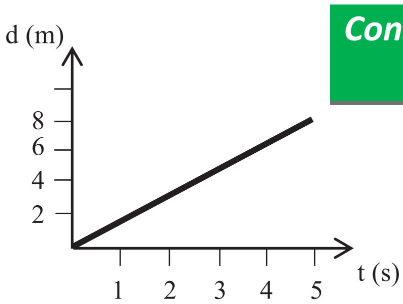
It's important that you learn what the shape of each type of graph tells you about the object's motion :

Distance - time graphs

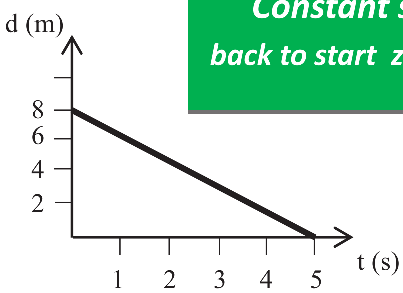
Stationary
(Not moving)



Constant speed
(forwards)

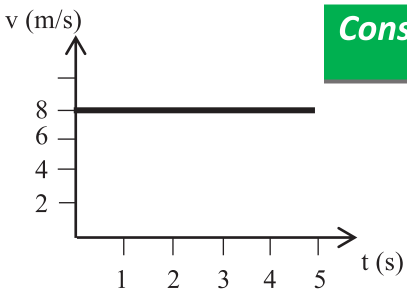


Constant speed –
back to start zero metres)

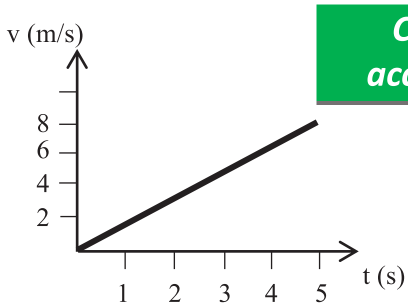


Velocity - time graphs

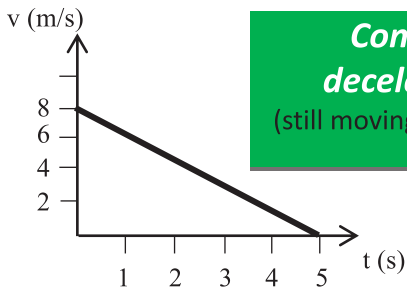
Constant speed



Constant acceleration



Constant deceleration
(still moving forwards !!)



Stopping distance & Car Safety

Many road accidents happen because people often underestimate the distance needed to slow a car until it stops – **the stopping distance.** The stopping distance is in two distinct parts :

Stopping distance	**=**	**Thinking distance**	**+**	**Braking distance**

Thinking distance = the distance travelled whilst reacting to a situation (before the driver applies the brakes)

Braking distance = the distance travelled whilst the brakes are applies (car is slowing down)

Reaction **time** is closely linked to thinking distance as follows :

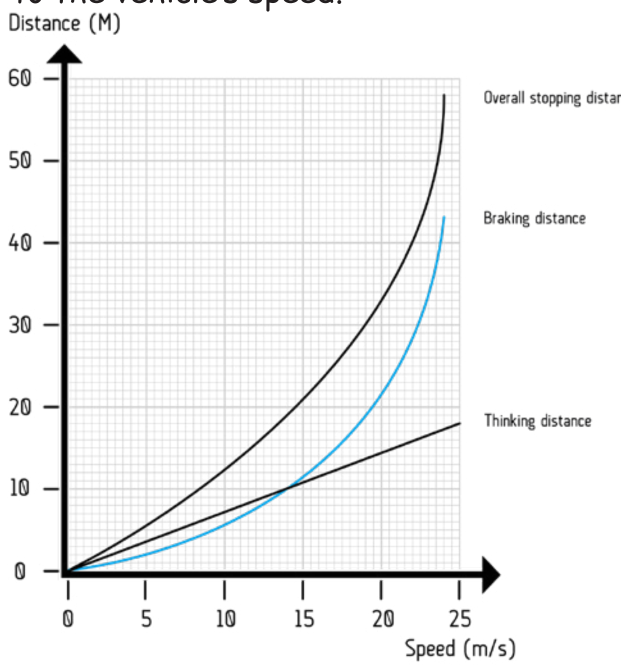
Thinking distance = speed x reaction time (d = s x t)

So, although a person's reaction time is not much affected by speed, the thinking distance is – look at these calculations at two different speed, 20 m/s, and 40 m/s, with a typical reaction time of 0.4 s,

@ 20 m/s	Thinking distance	= 20 x 0.4 = 8m
@ 40 m/s	Thinking distance	= 40 x 0.4 = 16m

So, thinking distance is directly proportional to the vehicle's speed. Braking distance also increases with the vehicle's speed. However, they're not proportional (see the blue line on the graph ➔).
(In fact, doubling the vehicle's speed quadruples the braking distance, since the speed is squared in the KE equation).

To find the overall stopping distance at a particular speed, just add the thinking distance and the braking distance values at that speed.



Unit 6.2 - Newton's laws (Forces)

Forces

A force is a **push** or a **pull** acting on an object. There are many different types of force, e.g. friction, air-resistance, weight , upthrust, **but they are always measured in newtons, or N.**

Sir Isaac Newton came up with three laws of motion, all of which describe the effect that forces have on things.

Before looking at these three laws, it's necessary to understand the term 'resultant force' first.

Resultant force

Usually, more than one force is acting on an object, like in the 'tug-of-war' below. In order to work out the effect of these forces on the object, we need to calculate what's known as '**resultant force**'.

Remember that all forces have a direction, unless of course they're zero.
If forces act in the same direction ➔ add; if opposite ➔ subtract.

In the above example, the **resultant force** , RF = 490 – 450 = **40N** 🡐

What's the **resultant** force in the example below ?

Answer : RF = 0 (zero) N, 39N🡐 + 24N🡐 = 63N 🡐 (then 63-63 = 0)

Newton’s 1st law

A body will remain at rest or continue to move at a constant velocity unless acted upon by an external (resultant) force.

In effect, this is like saying that if the forces are balanced, the object will remain stationary or keep moving at a constant velocity.

In the example on the right the cyclist keeps a steady forwards force by pushing on the pedals.

If the backward forces like air-resistance are equal to the forward force, the resultant force is then zero, and so the cyclist will keep moving at a constant speed.

This law also brings about the idea of **‘inertia’**. **Inertia** is the resistance of any object to any change in its motion (including a change in direction). In other words, it is the tendency of objects to keep moving in a straight line at constant speed. So, a large object with a lot of mass, e.g. a cruise ship, will be very difficult to move, accelerate, decelerate, change its direction, etc. (because of its ‘inertia’).

Newton's 2nd law

In situations where the **mass** is constant, Newton's 2nd law can be simplified :

$$F = \frac{\Delta (mv)}{t} = m \frac{\Delta v}{t} = m \times a$$

$$F = m\,a$$

So, the acceleration is directly proportional to the resultant force.
If the resultant force doubles, the acceleration doubles.

Where F = **resultant** force, m = mass, and a = acceleration

Mass & Weight

Mass is a measure of how much 'matter' or material an object has.
It's measured in **kg.**

Weight is a measure of how large the force of gravity is on an object.
It is measured in **N.**

Clearly, mass and weight are not the same !!

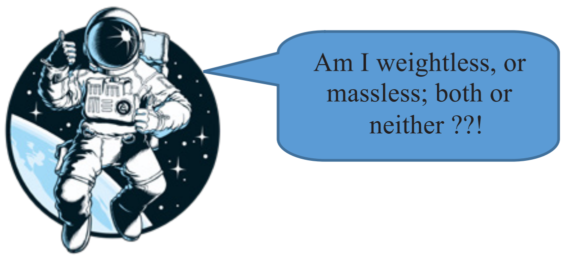
Mass does NOT depend on the location of the object, i.e. consider a 1 litre bottle of water - it has a mass of 1kg. If this bottle were taken to the surface of Mars, its **mass** would still be 1kg (as long as no water is taken out of the bottle !).

However, since there's less gravity on Mars, the **weight** of the bottle is less on Mars than here on Earth.

Since weight is a type of force, we can apply the force equation to calculate it :

$$F = m \times a$$

$$W = m \times g$$



where W = weight = 'force of gravity
m = mass
g = gravitational field strength / acceleration due to gravity

Here on the Earth's surface the value of 'g' is 10 N/kg. You will have to learn this equation, as it does not appear in the equation list at the start of the examination paper !

$$W = m \times 10$$

Newton's laws

Example

A water rocket of mass 2.5kg is launched from the surface of the Earth. It produces a steady thrust of 75N. Calculate the acceleration at the start.

Weight of rocket , W = m x g = 2.5 x 10 = 25 N

So, resultant force on the rocket = 75 – 25 = 50N (↑)

acceleration, $a = \dfrac{\text{resultant force}}{\text{mass}} = \dfrac{50}{2.5} = 20\ \text{m/s}^2$

Newton's 3rd law

In an interaction between 2 bodies, A and B, the force exerted by body A on body B is equal and opposite to the force exerted by body B on body A.

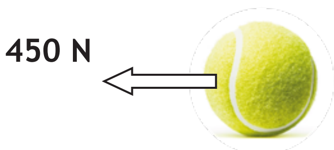
No force can act alone.
Remember that the action/reaction pair of forces are **always** on different objects, and so **never** 'cancel' out !

The racquet pushes the ball **forwards** with a force of 450N. Therefore, by Newton's 3rd law, the ball pushes the racquet **backwards** with an equal force.

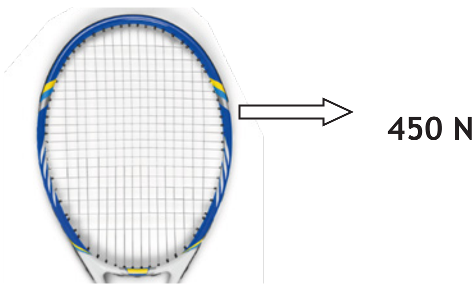
Note : one force is on the racquet, the other on the ball, so they don't 'cancel'.

The effect of these **two resultant forces** is that both objects **accelerate** in opposite directions. It may be easier to draw a **free body diagram** - a diagram that shows the forces acting on any **ONE** object at a time :

Here's the free body diagram for the tennis ball :



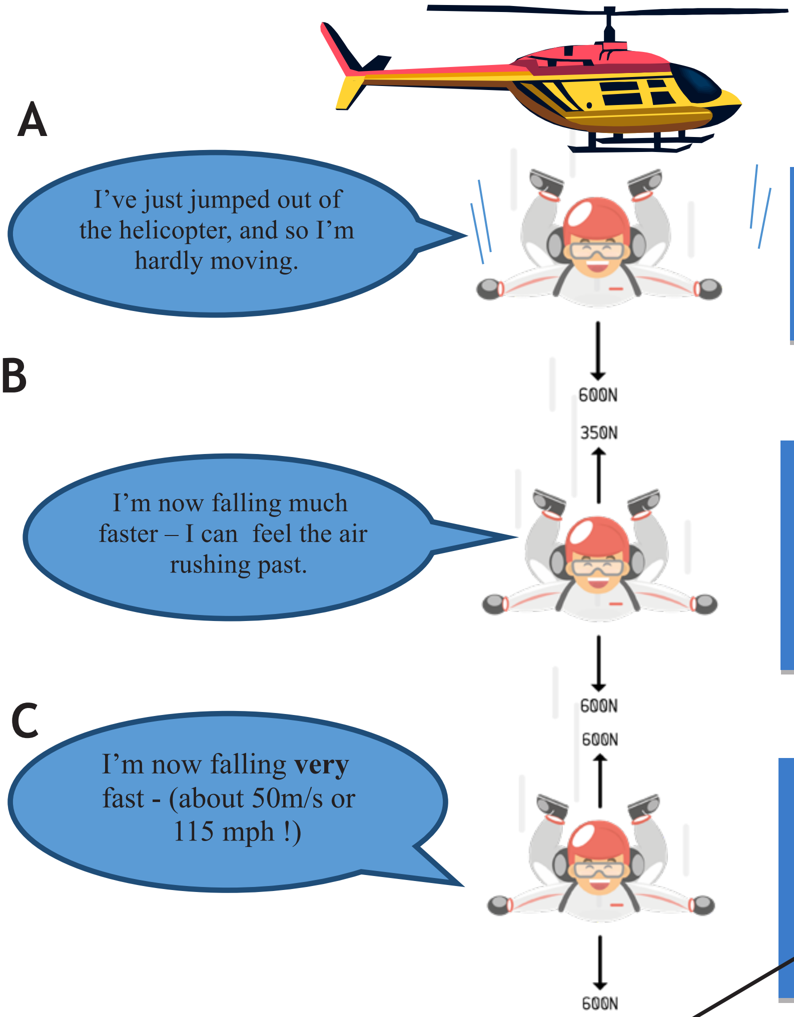
Here's the free body diagram for the racquet :



Note : Other forces like gravity and air-resistance have not been shown on these diagrams !

Applying Newton's laws

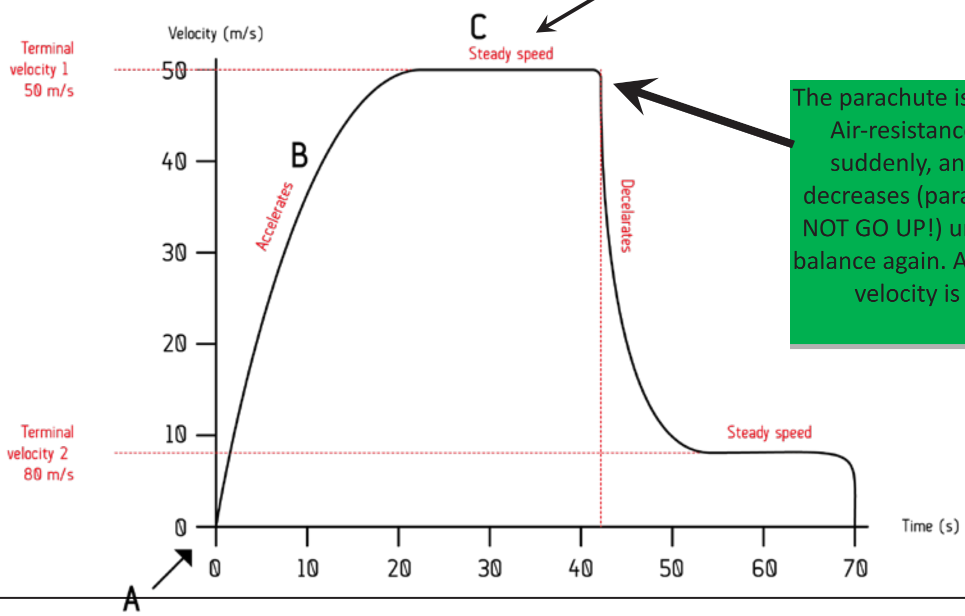
Examination questions on forces often deal with the idea of 'terminal velocity'. This idea involves a situation whereby, initially, the forces may be unbalanced (so Newton's 2nd law is used) but later become balanced (➔ Newton's 1st law).



Air-resistance is zero, and so Newton's 2nd law states that the skydiver will **accelerate** downwards.

As the speed increases, so does the air-resistance. (The weight remains constant).Newton's 2nd law states that the skydiver will still **accelerate**, but not as much as before.

Eventually, the skydiver's speed is high enough such that the air-resistance is equal to the weight. Resultant force is zero, so zero acceleration. (Newton's 1st law) - **terminal velocity**



The parachute is opened here. Air-resistance increases suddenly, and so speed decreases (parachutist DOES NOT GO UP!) until the forces balance again. A new terminal velocity is reached.

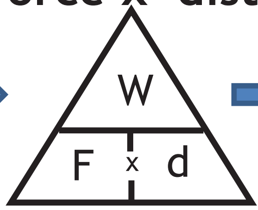
Unit 6.3 - Work done & Energy

Work Done

Doing 'work' in Physics means something very specific - it means a force is acting on an object causing some energy to be transferred. Work is calculated like this :

Work done = Force x distance

W = F x d



...and the other two forms of the equation are :

$$F = \frac{W}{d}$$

$$d = \frac{W}{F}$$

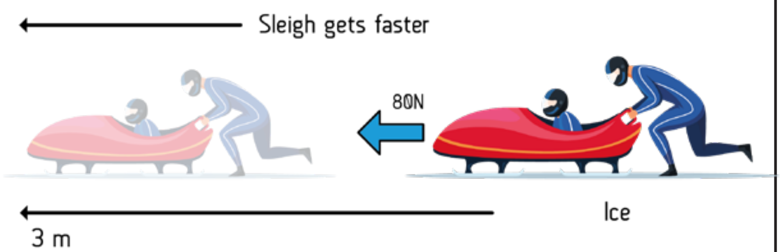
Work, W, (or energy transferred) is measured in **joules** (J)
Force, F, is measured in **newtons (N)**
Distance, d, is measured in **metres, (m)**

It's very important to remember the following fact :

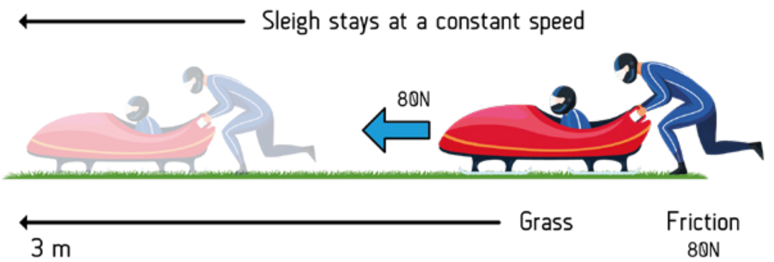
Work done = energy transferred

In correct terms, we should say that "Work done on an object is always equal to the energy transferred to or by the object". Here are 2 examples to explain this :

The force (by the person that's pushing) is doing work on the sleigh. This 240 J of work done is transferred to the sleigh, so it gains 240 J of kinetic energy - it speeds up.



The force is again doing the same amount of work on the sleigh, and so 240 J of energy must have gone somewhere !
This time, however, there's friction. The frictional force is equal to the pushing force. The work done (240 J) is transferred/wasted as heat and sound (not extra kinetic).



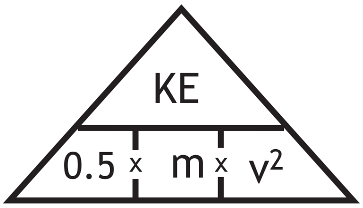
Work Done & Energy transfers

There are a number of different energy types, although all can be thought of as either kinetic or potential.

Kinetic Energy (KE) is the energy of a moving object.

Here's the equation to calculate KE :

$$\text{Kinetic energy} = \frac{\text{mass x speed}^2}{2} \qquad KE = \tfrac{1}{2} m v^2$$



In order to find the speed of an object of known mass and KE, the above equation is re-arranged like this :

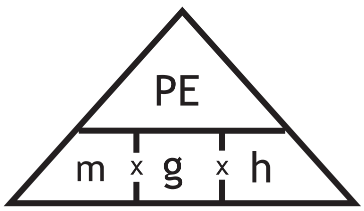
$$v = \sqrt{\frac{2\ KE}{m}} \quad \text{or} \quad v = \sqrt{\frac{KE}{0.5\ m}}$$

Using the triangle

(Gravitational) Potential Energy (PE) is the energy an object has because of its position (usually its height above ground, or some other reference point).

Here's the equation to calculate PE :

Change in potential energy = mass x gravitational field strength x change in height $\qquad$ **PE = mgh**

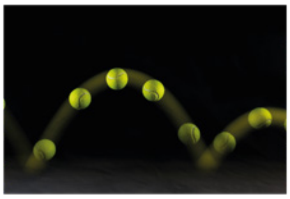


PE	is measured in	joules, J
m	is measured in	kilograms, kg
g	is measured in	N/kg (or m/s^2)
h	is measured in	metres, (m)

Work Done & Energy transfers

The **law of conservation of energy** states that energy can't be created or destroyed, only transferred from one form to another.

Hence, when an object, e.g. a ball, falls towards the ground, its gravitational potential energy (PE) decreases as it is transferred into kinetic energy (KE).



However, for all everyday situations, friction and air-resistance tend to act on moving objects, which change some of the energy into heat & sound. This is why a bouncing ball can never bounce back to the same height - some of its energy changes to heat and sound, mainly each time it strikes the floor, but also almost continuously by air-resistance.

For objects falling downwards

$$PE_{loss} = KE_{gain} + W$$

For objects thrown upwards

$$KE_{loss} = PE_{gain} + W$$

where **W** = work done by air-resistance and/or friction

Notice that the above are both 'conservation of energy' word equations. If the exam. question says that air-resistance and friction can be ignored, then just write one of the above word equation without the 'work done', '**W**'.

Also, remember that if there is some energy lost from the moving object through frictional forces, i.e. '**W**' is NOT zero, then you can also use this equation for work done :

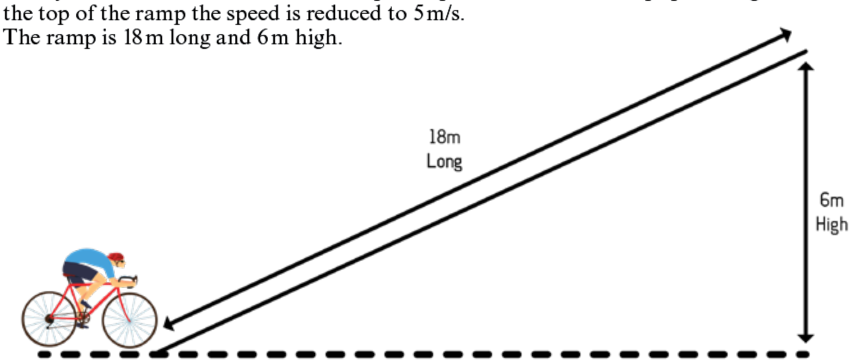
Work = Force x distance

$$W = F \times d$$

Example 1(P2, Jan 2012) - Answers at bottom of page !!

HINTS !!

A cyclist and cycle have a total mass of 90 kg.
The cyclist reaches the bottom of a ramp at a speed of 13 m/s and stops pedalling. On reaching the top of the ramp the speed is reduced to 5 m/s.
The ramp is 18 m long and 6 m high.



(a) By using the equations

$$\text{kinetic energy} = \frac{mv^2}{2} \text{ and potential energy} = mgh$$

where g = 10 N/kg, calculate:

(i) the kinetic energy of the cyclist (and cycle) at the bottom of the ramp. [2]

Kinetic energy = ... J

(ii) the **total energy** at the top of the ramp. [4]

Simply add the KE_{top} and the PE.

Total energy = ... J

(b) Use your answers to part *(a)* and an equation from page 2 to calculate the frictional force acting against the cyclist up the ramp. [3]

Find the difference between the energy of the cyclist at the bottom and at the top - this 'difference' is equal to the **work done** by frictional forces.

Frictional force = ... N

Answers

(a) (i) $KE_{bottom} = 0.5\ m\ v^2 = 7610$ J

(ii) $E_{total} = KE_{top} + PE = 1130 + 5400 = 6530$ J

(b) **Expected method**

$W_{friction} = KE_{bottom} - E_{total} = 1080$ J

Friction = $W_{friction}$ / distance = 60 N

(b) **Alternative method**

$KE_{loss} = PE_{gain} + W_{friction}$

hence, $W_{friction} = KE_{loss} - PE_{gain} = 1080$ J

Friction = $W_{friction}$ / distance = 60 N

Work Done & Energy transfers

Example 2 (P2, June 2012) - Answers at bottom of page !!

A cruise ship's engines produce a constant thrust of 1.6×10^6 N. It has a mass of 1.2×10^8 kg.

(a) Use the equation

$$\text{acceleration} = \frac{\text{resultant force}}{\text{mass}}$$

to calculate the ship's initial acceleration. [2]

Acceleration = ... m/s^2

(b) Once at sea, the ship's speed increases from 5 m/s to 9 m/s over a distance of 2400 m. By using the equations

$$\text{work} = \text{force} \times \text{distance}$$

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

(i) calculate the work done by the ship's engines over the 2400 m travelled at sea, [2]

Work done = ... J

(ii) calculate the increase in the ship's kinetic energy. [2]

K.E. increase = ... J

(iii) Use your answers to parts (i) and (ii) to calculate the mean work done against the ship as its speed increases. Hence find the value of the mean drag force acting against the ship. [3]

Mean work done = ... J

Mean drag force = ... N

HINTS !!

'Initial acceleration' means 'at the start', when the ship isn't moving fast enough to experience any friction or air-resistance. This means that you can assume the resultant force is equal to the 'thrust'.

Look up the equation for 'work done'.

Calculate the KE **twice** - once for each speed, then find the difference.

Calculate the difference between the work done by the engines and the KE gain. This is the work done by the frictional forces.

Answers

(a) a = 0.013 m/s^2

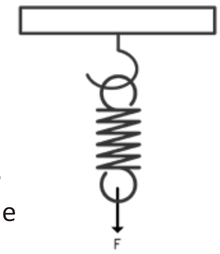
(b) (i) W_{engine} = 3.84×10^9 J

(ii) KE_{gain} = KE_{final} - $KE_{initial}$ = 3.36×10^9 J

(iii) W_{drag} = 4.80×10^8 J ; hence, **Drag** = W_{drag} / distance = 2.00×10^5 **N**

Stretching materials

Hooke's Law



When a force is applied to a material that is attached at one end, or if forces are applied at both ends of the material in opposite directions, the material will EXTEND (stretch). Some materials, like a metal spring, will stretch in a very uniform, and hence predictable way, and follow this equation :

$$F = k\ x$$

where,	F =	force	measured in	newtons, N
	k =	spring constant	measured in	N/m
	x =	extension	measured in	metres, m

(This is known as "Hooke's Law")

This equation into words : **The extension of a material is directly proportional to the force.**

Energy stored in a stretched material

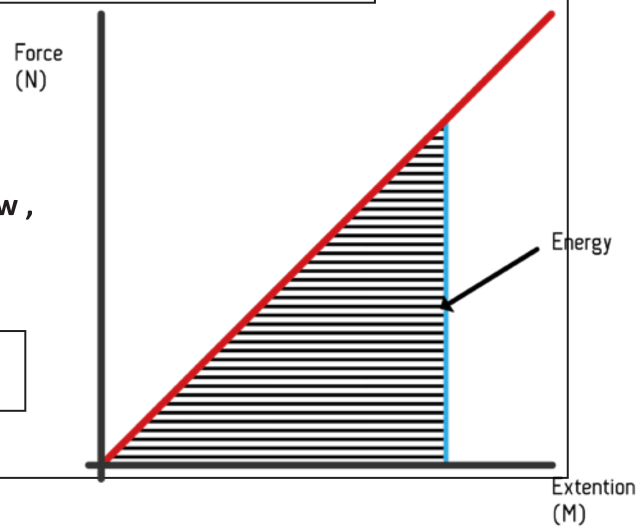
You may recall that **"energy transferred = work done"**, so if we want to know how much elastic potential energy a stretched spring has, we only need to find how much work was done stretching it !

Work done is always equal to the area under a Force-extension graph.

So, for a material obeying Hooke's Law, this is simply the area of a triangle.

Energy stored in a stretched spring obeying Hooke's Law ,

$$EPE = ½\ F\ x$$

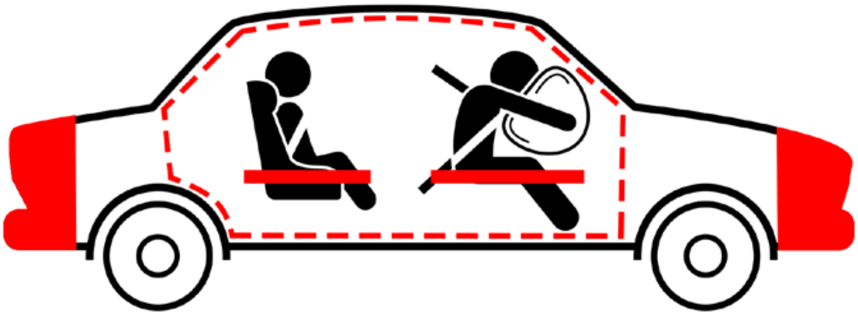


Stopping distance & Car Safety

There are many safety features in modern cars/vehicles – some are shown in the picture. ➔

The main features are :

1) Seat belts
2) Crumple zones
3) Airbags
4) Side-impact bars
5) Passenger cell



Feature	What it is	How it works
Seat belt	A strong belt strapped around the body	Prevents the person being thrown forwards in a crash
Crumple zone	A section that deforms/ compresses on impact	Decreases the deceleration, and so the force
Airbag	A bag that inflates rapidly in front of the person during a crash	Acts as a cushion to prevent the head of the passenger from hitting the front/side of the inside of the car
Side-impact	Strong bars inside the car doors	Strengthens the doors to better protect the passengers from another car hitting from the side
Passenger cell	A rigid cage around the passengers	Protects the passengers from impacts in all directions, but especially from a collapsing roof (when the car's upside-down)

Car manufacturers intentionally crash cars with dummies inside to assess the effectiveness of various safety features.

The idea behind crumple zones and airbags is to reduce the **force** on passengers during a crash.

Since Force = $\frac{work\ done}{distance}$, if you increase the distance over which the energy is transferred, it will reduce the force.

Example: a person is sitting inside a moving car. The car is moving with a speed of 30 m/s. The person's mass is 75kg. Calculate the person's kinetic energy.

$$KE = 0.5\ m\ v^2 = 0.5 \times 75 \times 900 = 33\ 750\ J$$

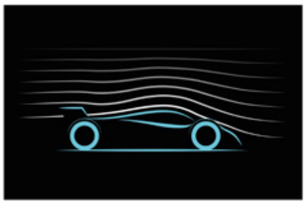
The car deforms a little during the collision. This means the passengers reduce their speed over a certain distance. In a car without a proper 'crumple zone', this distance is about 40cm. **With** a crumple zone it increases to 60cm. The seat belt also stretches a little, so increases these distances by 4cm. Calculate the force acting on the passeneger in a normal car, and then in a car with a crumple zone. If the person travelling in the car has 33,750 J of kinetic energy before the collision. The work done happens over a distance of 0.64m with a crumple zone.

Grym = W / x = 33750 / 0.64 = 52 734 N (With crumple zone)

Grym = W / x = 33750 / 0.44 = 76 705 N (No crumple zone)

Therefore the force on the occupant is much less when a crumple zone is used.

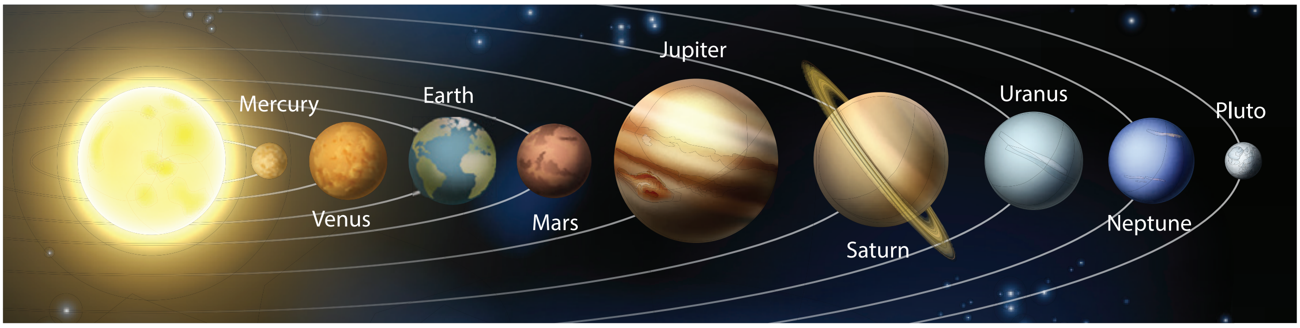
Improving the efficiency of vehicles.

Feature	Picture	How it works.
Aerodynamic losses		Cars are designed to reduce aerodynamic losses by using more streamlined designs. This allows the car to move through the air as easily as possible.
Rolling resistance		Rolling resistance is reduced by having correctly inflated tyres and using materials which don't heat up as much as they are squashed.
Idling losses		Stop-start systems reduce idling losses. If the car is stopped in traffic the engine shuts down automatically and then re-starts automatically when the accelerator is pressed
Inertial losses		Inertial losses are reduced by having lighter cars. Materials such as carbon fibre are used instead of metals for parts of the bodywork.

Unit 6.4 – Stars and planets

The Solar System.

The planets all move in an orbit around the Sun. The order of the planets is: **Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune, (Pluto is a 'dwarf planet').**

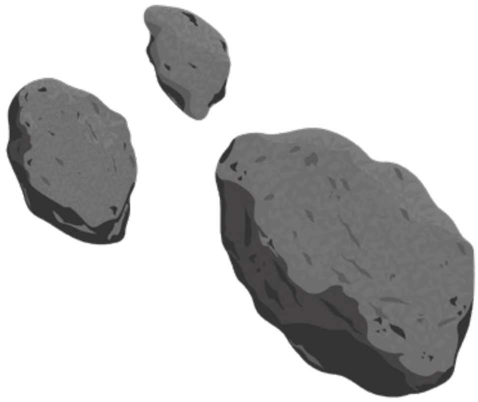


The planets seen above are shown to the correct scale according to their relative sizes, but are far from scale in terms of their distances from the Sun.
(On the scale shown, the Earth should be about 15metres away from the Sun !!)

Mercury, Venus, Earth and Mars are rocky planets, the rest are gas giants. Most of the planets have moons which are in orbit around them. Saturn and Jupiter have the greatest number of moons because they have the strongest gravitational pull.

Asteroids.

Asteroids are lumps of rock which are in orbit around the Sun but are too small to be called planets. The asteroid belt is located between Mars and Jupiter and contains a number of dwarf planets. Ceres is largest of these with a diameter of 587 miles.



Comets.

Comets are lumps of ice and dust which are in a highly elliptical orbit around the Sun. They travel very far out of our solar system and take a number of years to return closer to the Sun. Halley's Comet is one of the most famous, it has an orbital period of about 75 years.

Scale and distances in space.

Astronomical Unit (AU): The mean distance from the centre of the Earth to the centre of the Sun. . . . .

$$1\text{AU} = 1.496 \times 10^{11}\text{m}$$

The light year (l-y): the **distance** light travels in one year.

$$1 \text{ l-y} = 9.46 \times 10^{15}\text{m}$$

http://htwins.net/scale2

The Earth - our home !
Diameter = 12,800 km.
The closest object to us in space is the Moon. (It's about 30 Earth diameters away).

Our star - the Sun. All objects in the solar system orbit around the Sun.
It's about 100 times as big as the Earth.

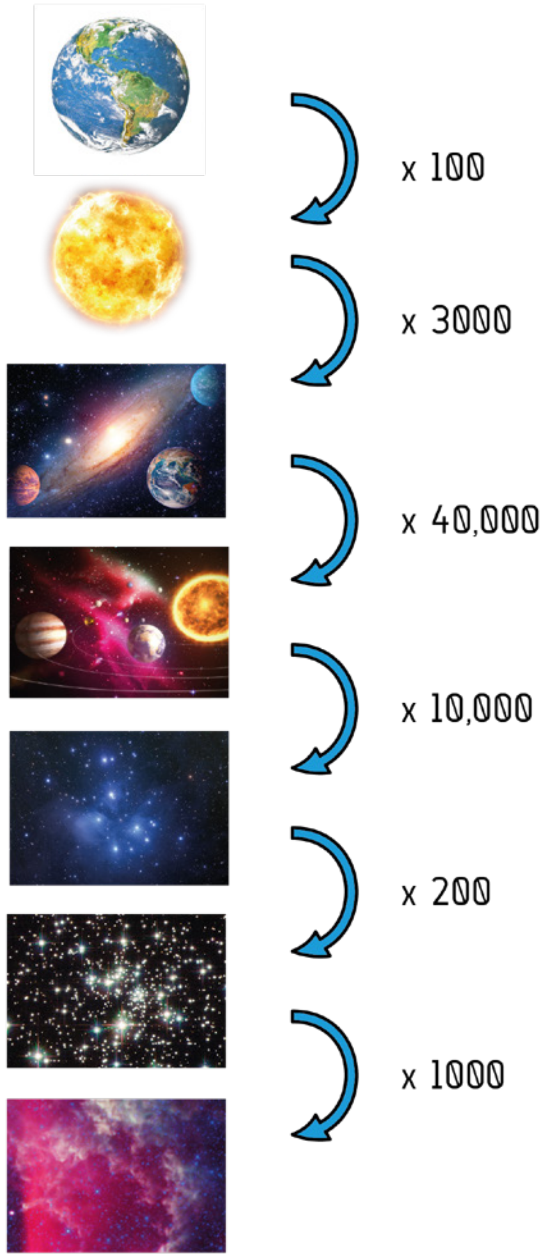
Our solar system.
The picture at the top of this page shows what it contains. Diameter ~ 100 AU (1 AU = Earth-Sun distance, $1.5\text{x}10^{11}$m)

Outside the solar system there's a lot of empty space. The nearest stars are about 4 light years away, and all spaced out about the same distance within the galaxy.

A cluster of stars is known as a galaxy. Our galaxy is called the 'Milky Way'. It's about 90,000 light years across. (1 l.y. = 63 000 AU = $9.5\text{x}10^{15}$m).

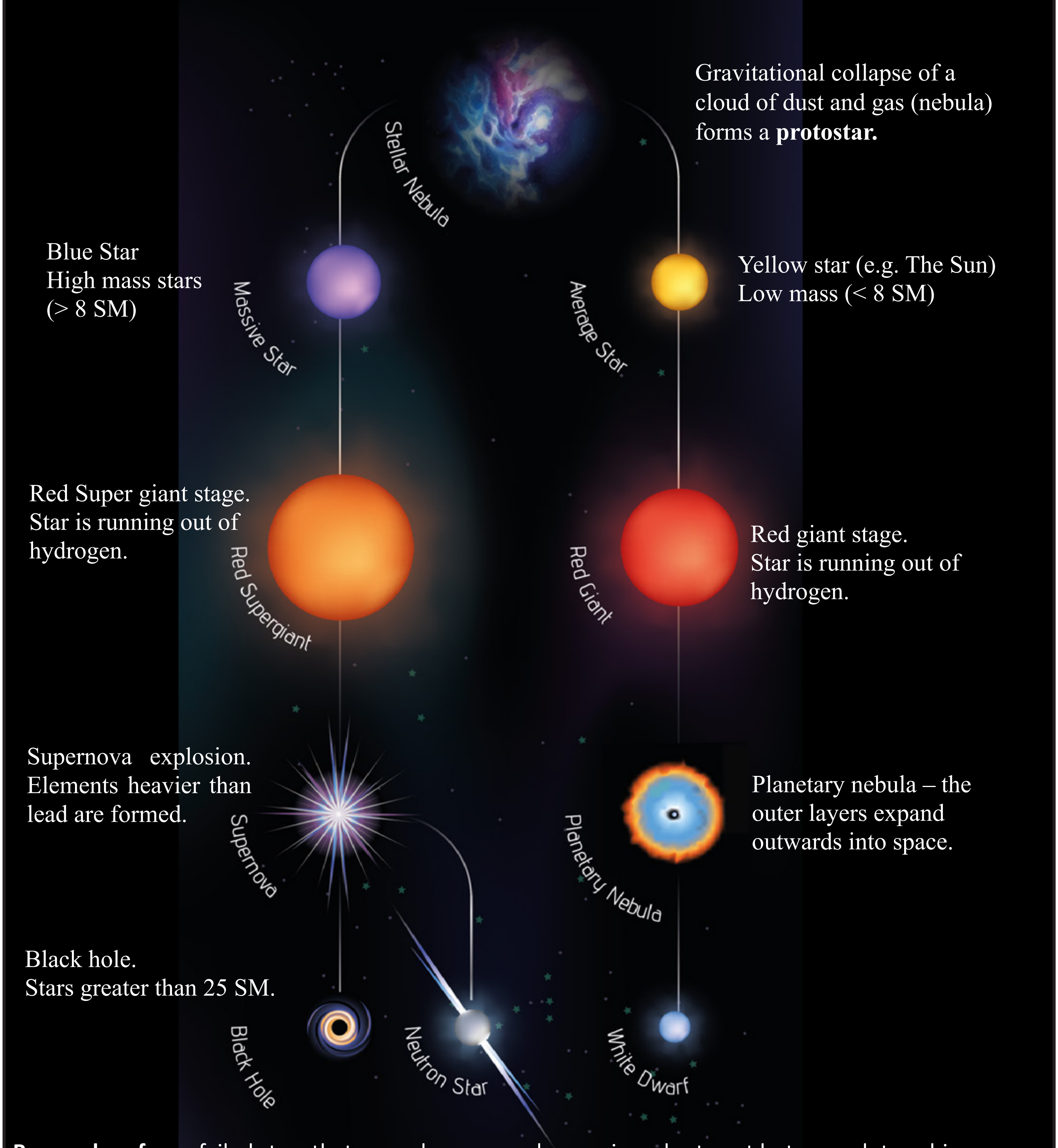
The picture (➔), taken by the Hubble telescope shows a large 'cluster' of galaxies !

The known universe is made of many billions of galaxies. The string-like patterns seen are called 'filaments' - colossal clusters of millions of galaxies !



Life cycle of the stars.

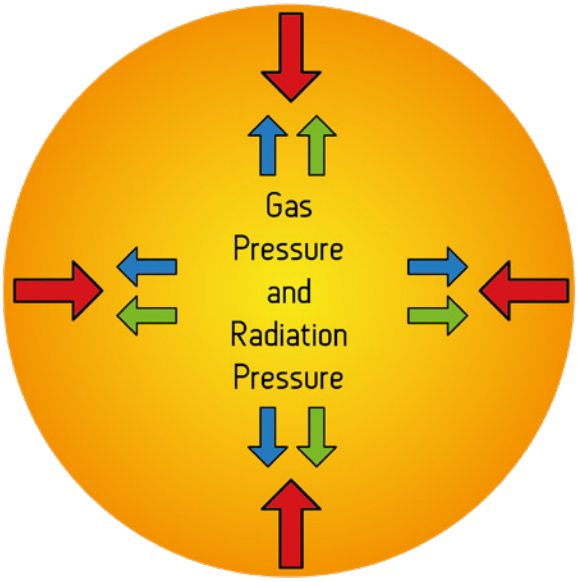
The diagram below shows the possible life cycle for stars of different masses. **SM** stands for **Solar Masses**. If a star is 3SM then it is 3 times the mass of the Sun.



Brown dwarfs are failed stars that never have enough mass in order to get hot enough to achieve nuclear fusion.

Red dwarf stars: these are low mass stars that **do** achieve nuclear fusion. They are not very bright and have very long lifetimes. They are main sequence stars.

Forces within a star.



There are 2 forces at acting inside a star.

1. ***Inward force of gravity***
2. ***Outward: combination of gas and radiation pressure.***

Gas pressure: caused by rapid random motion of particles in the sun.

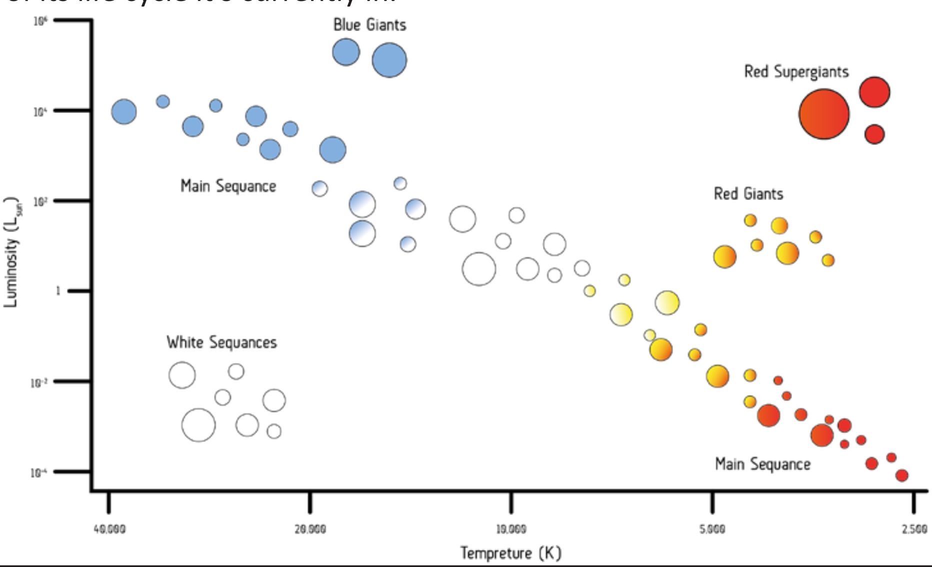
Radiation pressure: caused by light hitting the particles.

For most of the life of a star it is in a stable state in which the inward force of gravity on any part of the star is balanced (equal) by a force due to the increasing pressure towards the centre.

If the pressure in the middle ***falls***, this will cause a star to ***shrink*** – this will cause the pressure to rise once more until a new equilibrium is established with the smaller core. If the pressure increases, the star will ***expand.***

Main sequence stars.

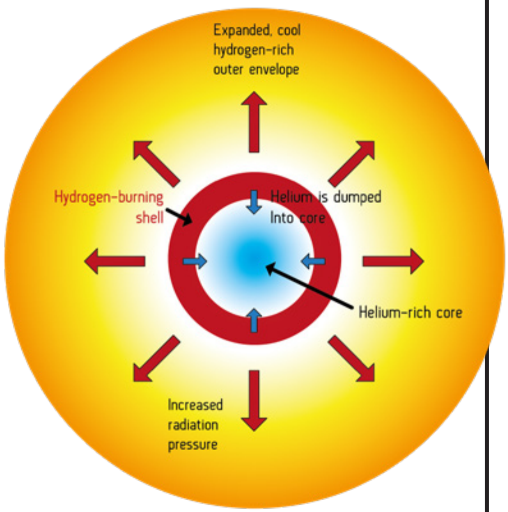
Main sequence stars fuse ***hydrogen*** to ***helium*** in their cores.
The colour of a star depends upon the temperature of the star. Our sun is a yellow star which is one of the most common type. Surface temperature is 5800˚C. Stable lifetime is around 10,000 million years.
The diagram below is a Hertzsprung-Russell diagram. In general, where a star is on the diagram relates to which stage of its life cycle it's currently in.



End of main sequence stage.

Once a star has exhausted (run out) of its supply of hydrogen the temperature of the star's core will decrease as nuclear fusion ceases. This means that the gravitational force is greater than the gas and radiation pressure causing the core to shrink.

Fusion of helium will then soon start in the core as the temperature increases due to gravitational collapse, once again resulting in an increase in gas and radiation pressure. The fusion reactions are now much more 'fierce' than before (higher temp.), and so the increased gas and radiation pressure causes the star's outer layers to expand – the star is now a **red giant.**



Hydrogen Shell Burning on the Red Giant Branch

At the end of the main sequence stage of our Sun the:

- Light elements (Hydrogen and Helium) fuse in the centre
- Centre is exhausted of light elements – nuclear reactions stop, causing pressure to drop
- Star nucleus shrinks, making density and temperature go up, allowing heavier elements to fuse
- Meanwhile the lighter elements continue fusing in a shell around the nucleus
- Stars like the Sun never reach sufficient temperatures to fuse elements heavier than oxygen
- The outer layers of the star are pushed off by the radiation pressure of the core – enriching the interstellar medium with heavier elements.
- A very dense core remains known as a white dwarf (1 teaspoon has a mass of 5 tons).

Useful website http://aspire.cosmic-ray.org/Labs/StarLife/

A new beginning !

All the material from a supernova mixes up with interstellar dust and gas. The shockwave from a supernova can also 'kickstart' the collapse of a nebula. The effect then is that the dust and gas in a nebula (now enriched with heavier elements from the supernova) contracts over time.
As the nebula (or part of it) contracts, the 'gravitational collapse' converts gravitational potential energy into kinetic energy, i.e. the dust and gas becomes hotter and hotter.

M16 : AKA "The eagle nebula – pillars of creation".

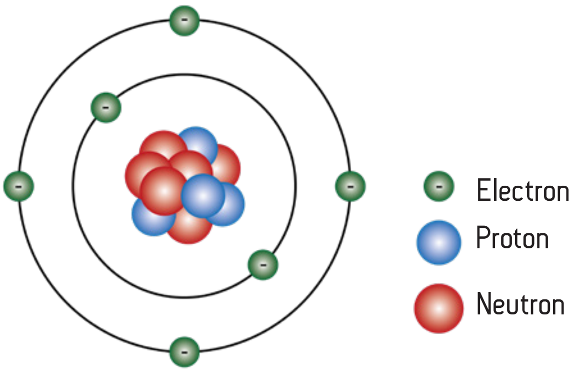
Eventually the temperature at the heart of the nebula reaches a sufficiently high temperature and density for fusion to start – a star is born !

During formation rocks tended to gather close to the Sun and formed the rocky planets whilst gaseous substances gathered together at distances further away and formed the gas planets.

Unit 6.5 - Types of radiation

Nuclear physics.

To understand what radioacivity is you must understand what makes an atom radioactive.



The atom consists of:

6 protons

6 neutrons

6 electrons

$^{A}_{Z}X$ where X is the symbol for the element

Proton number (or Atomic number) (Z) - This tells us the number of protons in the atom/nucleus.

Nucleon number (aka Mass Number) (A)- This tells us the number of protons and neutrons in the atom/nucleus.

A mathematical formula to calculate the number of neutrons 'N' in terms of A and Z. . . . .

$$N = A - Z$$

Example: $^{7}_{3}Li$ of protons = 3

Number of neutrons 'N' = A - Z = 7 - 3 = 4

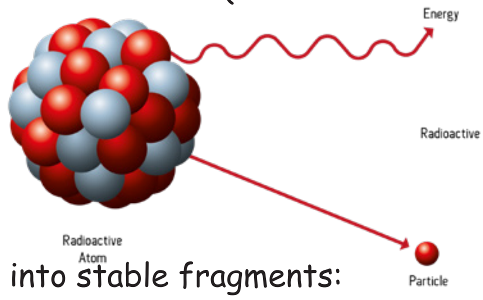
Isotopes: These are atoms of the same element which have the same number of protons but a different number of neutrons. They have the same proton number and differing nucleon number.

Example. Iodine-123 $^{123}_{53}I$ and iodine-131 $^{131}_{53}I$ are isotopes. Iodine-123 has 53 protons and 70 neutrons whereas iodine-131 has 53 protons and 78 neutrons.

The higher the proton number of the element the more neutrons the element will have compared to protons.

RADIOACTIVE DECAY

Why is an atom radioactive? If an atom has an imbalance of protons and neutrons in the nucleus it will be also be UNSTABLE. (This does **not** mean an equal number of protons and neutrons).



The nucleus tries to become stable by breaking up into stable fragments: **RADIOACTIVE DECAY.** Carbon has three common isotopes ^{12}C, ^{13}C a ^{14}C. Carbon-14 is radioactive because it has an imbalance of protons and neutrons.

$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e$$

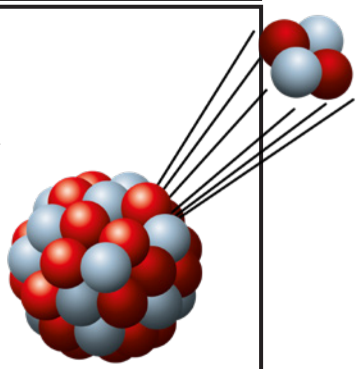
Carbon will **emit radiation** to try and make itself stable, a nitrogen nucleus is formed in the process. This process is called **RADIOACTIVE DECAY**.

There are 3 types of radiation emitted from the nucleus.

Information	**Alpha (α)**	**Beta (β)**	**Gamma (γ)**
Symbol	$^{4}_{2}He$	$^{0}_{-1}e$	γ
What is it?	 A helium nucleus (2 protons and 2 neutrons).	 Fast moving/ high energy electron.	 High energy electromagnetic wave.
What can stop it? Penetrating power.	Thin sheet of paper, skin or few cm of air	Few mm of aluminium or up to a metre of air.	Several cm of lead or very thick concrete.
Ionising power	Very high - most damaging inside the body.	Medium	Low (compared with alpha and beta). Easily passes through the body.

Balancing nuclear equations.

Alpha decay $^{4}_{2}He$



During alpha decay the number of protons decreases by 2 and the number of neutrons decreases by 2. Therefore the proton number decreases by 2 and the nucleon number decreases by 4.

General equation:

$$^{A}_{Z}X \longrightarrow \ ^{A-4}_{Z-2}X' + \ ^{4}_{2}He$$

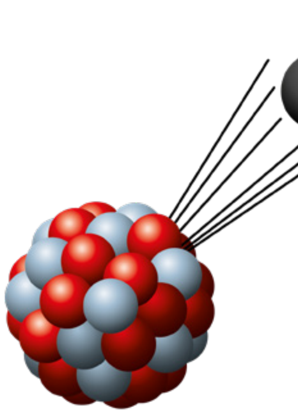
$$^{238}_{92}U \longrightarrow \ ^{234}_{90}Th + \ ^{4}_{2}He$$

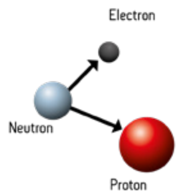
Balance the following nuclear equations by calculating the value of a, b, c and d.

1. $^{241}_{95}Am \longrightarrow \ ^{a}_{b}Np + \ ^{4}_{2}He$

2. $^{236}_{84}Po \longrightarrow \ ^{c}_{d}Pb + \ ^{4}_{2}He$

Beta decay.





During beta decay the number of protons increases by 1 and the number of neutrons decreases by 1. Therefore the proton number increases by 1 and the nucleon number stays the same

General equation:

$$^{A}_{Z}X \longrightarrow \ _{Z+1}^{A}X' + \ ^{0}_{-1}e$$

$$^{16}_{8}O \longrightarrow \ ^{16}_{9}F + \ ^{0}_{-1}e$$

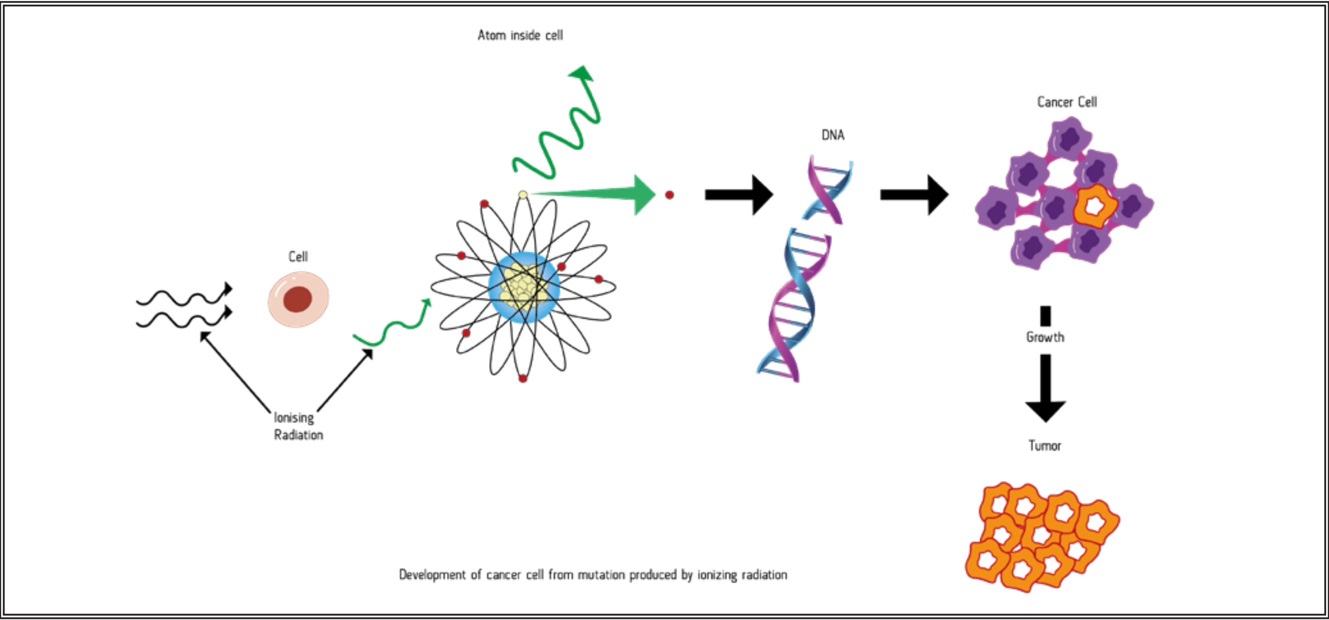
Balance the following nuclear equations by calculating the value of a, b, c and d.

1. $^{a}_{b}H \longrightarrow \ ^{2}_{2}He + \ ^{0}_{-1}e$
2. $^{63}_{28}Ni \longrightarrow \ ^{c}_{d}Cu + \ ^{0}_{-1}e$

a=2, b=1, c=63, d=29

Ionising radiation.

Ionising:- some particles and electromagnetic waves (both are radiation) have enough energy to rip electrons away from atoms and molecules. Ions are formed which can interact with cells in the body and ***damage DNA/cells***. This damage can lead to the formation of cancer.

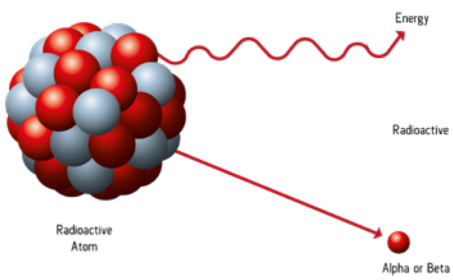


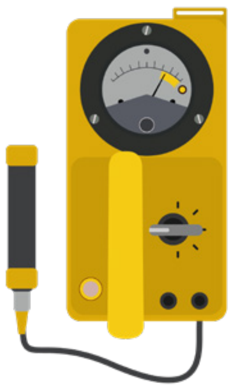
Ionising radiation include: alpha, beta, gamma, x-rays and ultraviolet.

Non-ionising radiation: visible light, infrared, microwave and radio waves.

Radioactive decay:

Some atoms are unstable and so we say that they are radioactive. They try to become stable emitting alpha, beta or gamma radiation. The process of atoms undergoing radioactive decay is totally **random** and **spontaneous**. There is no way of telling **when** or **which** atom will decay in a radioactive material.





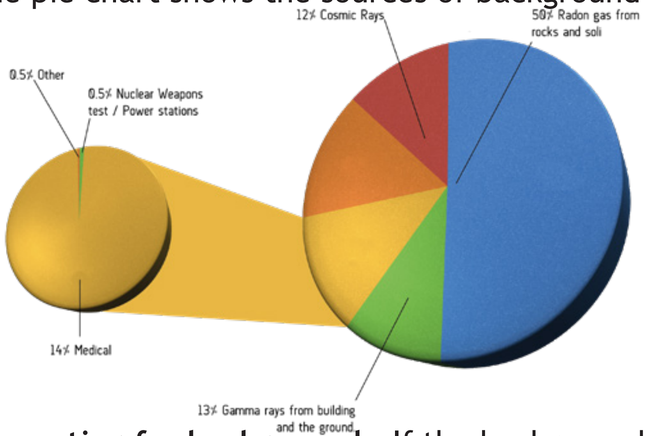
A Geiger counter can be used to measure the ionising radiation. To gain greater accuracy when measuring radioactive decay we must do 2 things:

1. **Repeat the experiment and calculate the average.**

2. **Carry out the experiment over a longer period of time.**

Background radiation.

Background radiation: background radiation is all around as radioactive atoms emit alpha, beta and gamma radiation. Most of the background radiation comes from natural sources. The pie chart shows the sources of background radiation.



<u>Natural sources</u>: Radon, Cosmic radiation (from space), radon, rocks, food and buildings. Background radiation varies with altitude as at higher altitudes there will be more cosmic radiation.

<u>Artificial sources</u>: medical and nuclear industry.

Correcting for background : If the background count was 30 counts per minute (30 count/minute) then if we are measuring the activity of a radioactive source we must ***subtract*** the background count rate. If the count rate was therefore measured to be 150 count/minute what is the count rate from the radiation source?

Radiation from **source only**	=	150	-	30	=	120
		(total)		(background)		(radiation from source)

Determining the type of radiation emitted by a radioactive source

<u>Example question:</u> Various materials are placed between the Geiger tube and the radioactive material. The following information is recorded about the radioactive material. The count rate has ***not been corrected*** for background.

	No absorber	Paper absorber	Sheet of **aluminium**	20cm of **lead**
Count rate detected (counts/s)	250	50	50	0.5

Question: determine the type and amount of each radiation emitted by the radioactive material.

1^{st} point: the count drops from 250 to 50 with a shielding of paper. This indicates the presence of alpha radiation. Count rate alpha = 250 – 50 = 200 count/s.

2^{nd} point: placing aluminium in front has no effect so there's no beta present.

3^{rd} point: the lead decreases the count/s so must be gamma radiation present.
Count rate gamma = 50 – 0.5 = 49.5 count/s.

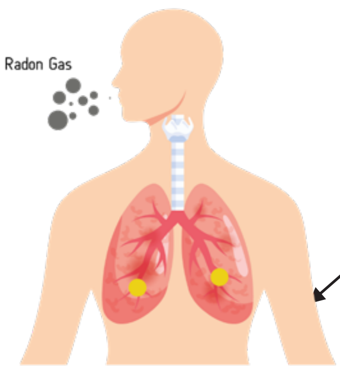
4^{th} point: Background count = 0.5 count/s. All (almost) gamma radiation should be stopped by 20cm of lead.

Summary: **alpha** = 200 count/s, **beta** = 0 count/s, **gamma** = 49.5 count/s, **background** = 0.5 count/s

Radon Gas.

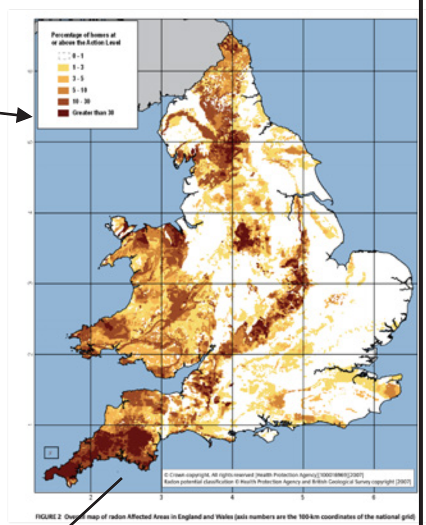
Radon gas is formed when uranium in volcanic rocks like granite undergoes radioactive decay to form radium and then the radium decays to radon gas. High levels of radon gas can lead to lung cancer.

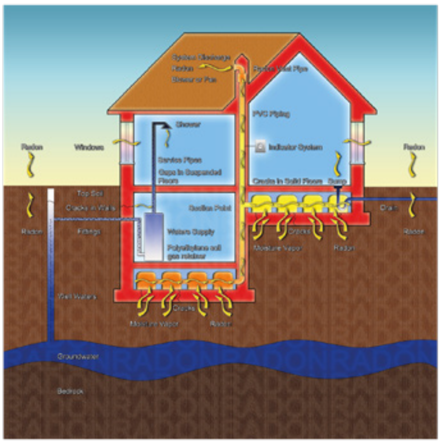
Uranium-238 Solid → α → Radium 226 Solid → α → Radon 222 Gas → α → Polonium 218 Solid



The radon gas is an ***alpha emitter*** which is the worst kind as it the most **highly ionising** and does the most damage if it gets ***inside*** the body.

The dark areas on the map are places with higher levels of radon gas. Radon gas enters your home through the ***gaps/ cracks*** in the floor.





If the level of radon is above 200 Bq/m^3, (1 Becquerel is decay per second) then action should be taken to reduce the levels of radon in your home:

1. *Improve ventilation by opening windows.*
2. *Fitting air bricks to improve under floor ventilation.*
3. *Install a fan to extract radon gas from a sump underneath the house.*

Radiation dose.

Measuring the received dose of radiation: The higher the radiation received can increase your risk of developing cancer. Scientists can measure the dose in units of **sievert** (Sv). One sievert is a large dose and therefore they use **milisievert** (mSv).

The higher the dose received the more damage has been done.
The dose received depends upon two things:

1. **The type of radiation (alpha, beta or gamma)**
2. **The amount of radiation received.**

Over the world the average dose received is 2.4 milisievert (0.0024Sv) a year. Some places in Cornwall receive doses of 7.8 mSv.

Available scientific evidence does not indicate any cancer risk or immediate effects at doses below 100 mSv a year. At low levels of exposure, the body's natural repair mechanisms seem to be adequate to ***repair radiation damage*** to cells soon after it occurs.

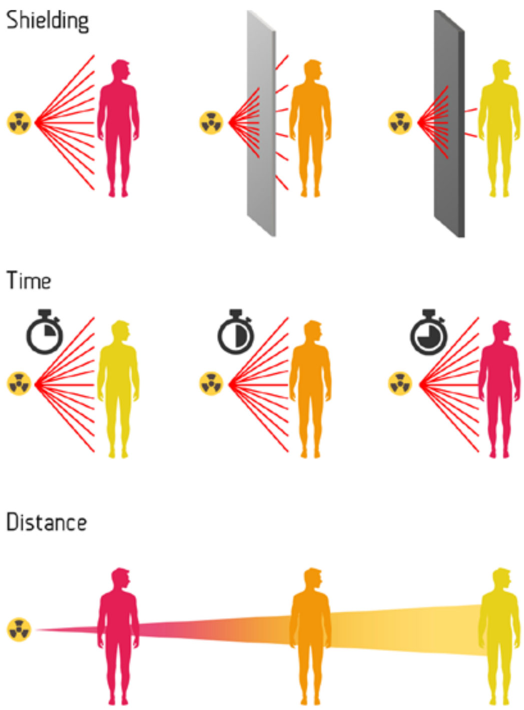
Protecting against radiation

There are ***four ways*** in which people are protected from identified radiation sources:

1. **Limiting time**. In the workplace situations, dose is reduced by limiting exposure time.

2. **Distance**. The intensity of radiation decreases with distance from its source.

3. **Shielding.** Barriers of lead, concrete or water give good protection from high levels of penetrating radiation such as gamma rays. Intensely radioactive materials are therefore often stored or handled under water, or by remote control in rooms constructed of thick concrete or lined with lead.



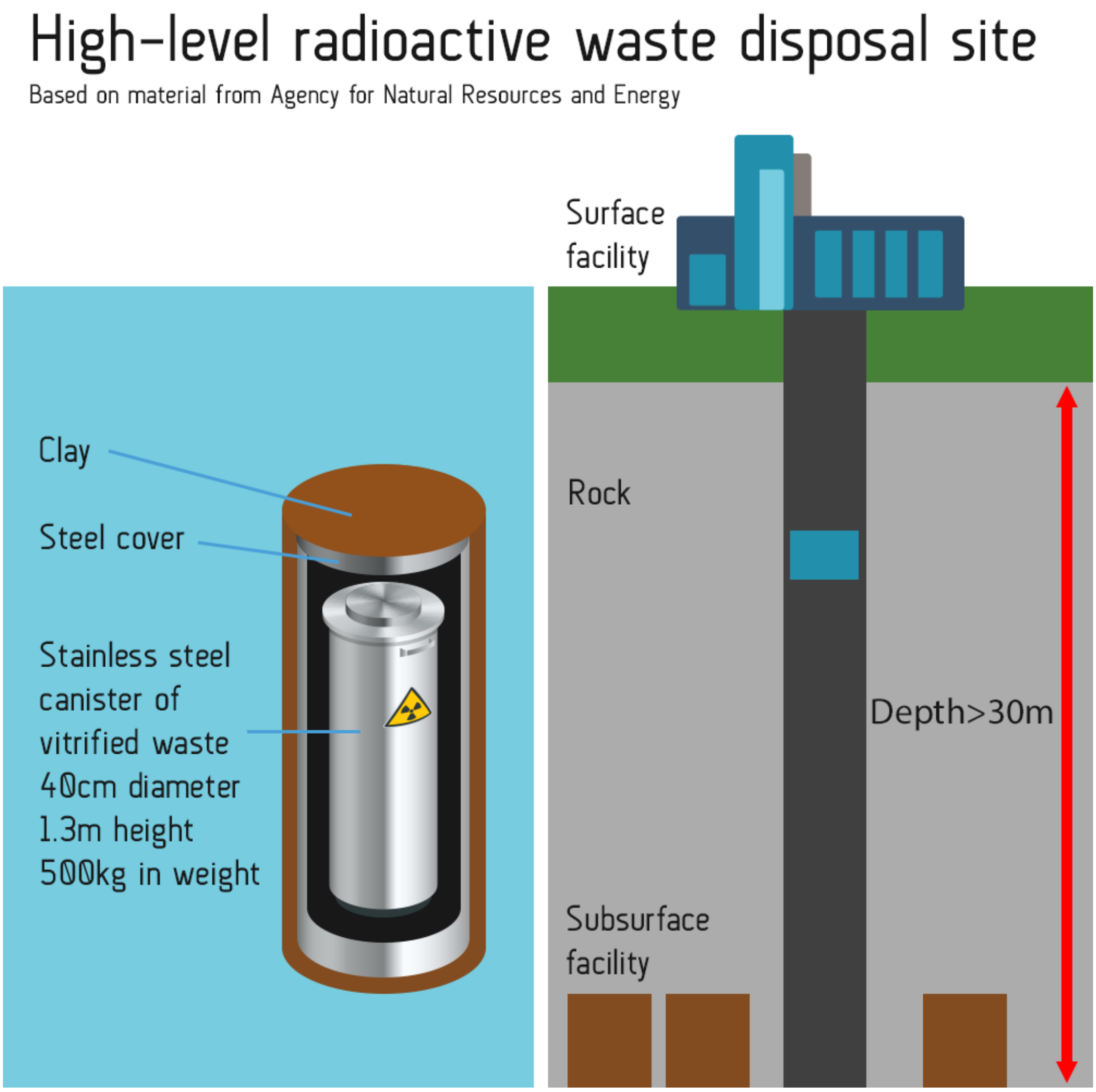
4. **Containment.** Highly radioactive materials are confined and kept out of the workplace and environment. Nuclear reactors operate within closed systems with multiple barriers which keep the radioactive materials contained.

Storing Nuclear Waste

Nuclear waste is produced by the nuclear industry in **nuclear power stations** and ***nuclear medicine***. Nuclear waste is very difficult to get rid of and make safe.

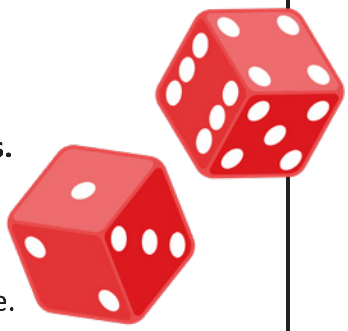
Only **time** can reduce the radiation emitted because they can remain radioactive for a long period of time (**thousands of years** with some materials). It is very ***costly*** to ***process***, ***store*** and ***guard*** the nuclear waste.

Nuclear power stations produce the vast majority of the nuclear waste. Due to the radiation emitted the waste is very hot and so must be cooled. It is then turned into a glass so that it cannot flow. The waste is placed inside steel drums and then sealed in concrete. **Deep underground** is one possible idea for storage. Care must be taken that the waste does not pollute the local water source if it were to leak.



Unit 6.6 : Half-life

There are billions upon billions of atoms in a small amount of a radioactive sample so the chance that one atom will undergo decay is high.

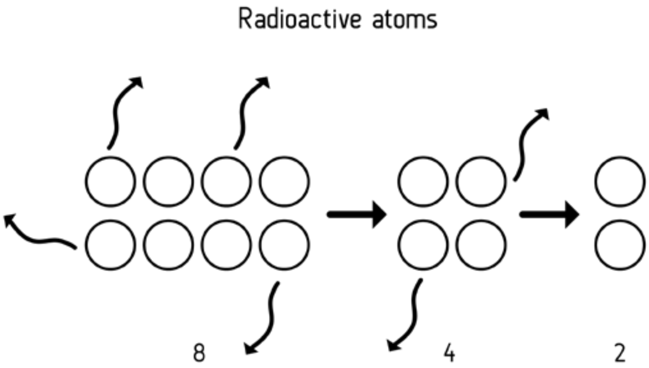


Is it possible to determine **which** radioactive nuclei/atom will decay next in the sample? No, because the process is **random.** Is it possible to determine when the next radioactive nuclei will decay? No, because the process is **spontaneous.** Since its random and spontaneous process we can get more accurate information/results by:

1. Repeating. . . . . 2. Measuring over a long time.

The half life.

Each half life the number of unstable atoms halves. The half life remains constant.



The half life is the time it takes for half the unstable atoms to decay.

The half life is the time it takes for the activity to halve from its original value.

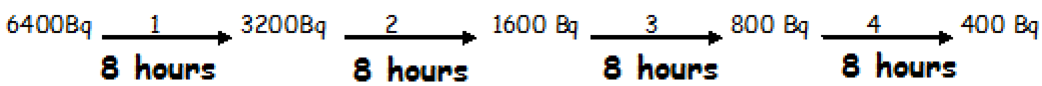
Actvity. The activity is a measure of number of radioactive decays per second. It is measured in **becquerel, Bq.** So an activity of 1 becquerel is equivalent to 1 radioactive decay per second. The activity of a sample of radioactive material will depend on 2 things:

1. The number of radioactive/unstable atoms present.

2. The half life of the atoms.

The more atoms present the greater the activity. The shorter the half life the greater the activity.

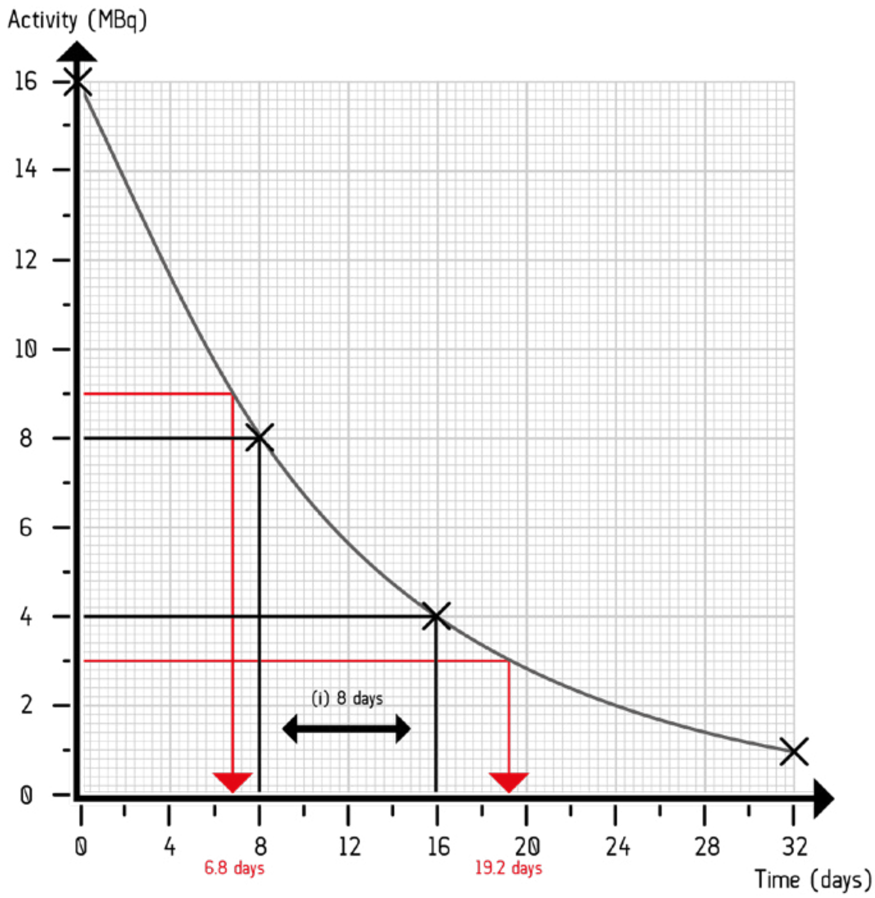
Example. A radioactive isotope has an activity of 6400Bq.The half life of the isotope is 8 hours. . . . .
What is its activity after 32 hours?



There have been 4 half lives totalling 32 hours (8 hours x 4).

Radioactive decay curves.

Whether you are plotting a graph of activity or the number of radioactive atoms the curve/line of the graph is the same. In this example the activity of the isotope iodine-131 has been plotted against time. The sample has a starting/initial activity of 16 MBq (16,000,000Bq).



(i) We can calculate the half life using the method shown above. You must choose one activity value and then halve it. In the example the activity has halved from 8MBq to 4MBq. This has taken 8 days so we can say that the **half life of iodine-131 is 8 days.**

(ii) We can also calculate how long it will take for the activity to fall a certain amount, e.g. from 9 MBq to 3 MBq. The activity was 9 MBq after 6.8 days and the activity was 3 MBq after 19.2 days. Therefore by calculating the time difference we can calculate how long this took.. . . . .
19.2 – 6.8 = **12.4 days.**

(iii) How long would it take for the activity to fall from 1 MBq to 250,000 Bq?

It is not possible to continue the graph so we must use the same method as on the previous page.

1 MBq = 1,000,000 Bq —1→ (8 days) 500,000 Bq —2→ (8 days) 250,000 Bq

Total time = 8 + 8 = **16 days**

Uses of radioactive materials

There are many uses of radioactive materials; carbon dating, sterilising medical equipment, killing cancer cells, smoke alarms and controlling the thickness of aluminium foil.

What is required is that you can select from a given list and explain which isotope is suitable for use in a specific case. Consider: 1. **Penetrating power. . . . . 2. Half life. 3. Biological effect.**

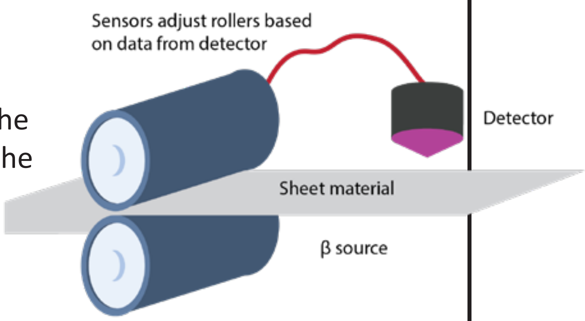
In this case we will choose one of the isotopes for a particular use and explain our reasoning.

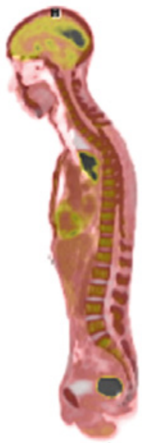
Example of radioactive isotope. The half life given in brackets ( )		
Gamma – γ	**Beta** $_{-1}^{0}e$	**Alpha** $_{2}^{4}He$
Technetium-99 (6.01hrs) Cobalt-60 (5.27 yrs)	Iridium-192 (74 days) Strontium-90 (28.5 yrs) Carbon-14 (5730yrs)	Polonium-210 (138days) Americium-241 (432 yrs) Plutonium-238 (87.7 yrs)

(a) Monitoring the thickness of aluminium sheet in a factory.

Isotope chosen : Strontium – 90 (beta emitter).

Reason: because **fewer** beta particles will pass through when the thickness of aluminium increases. The half life is fairly long so the source will last a reasonable amount of time.





(b) Medical tracer in monitoring internal organs by using a camera outside the body.

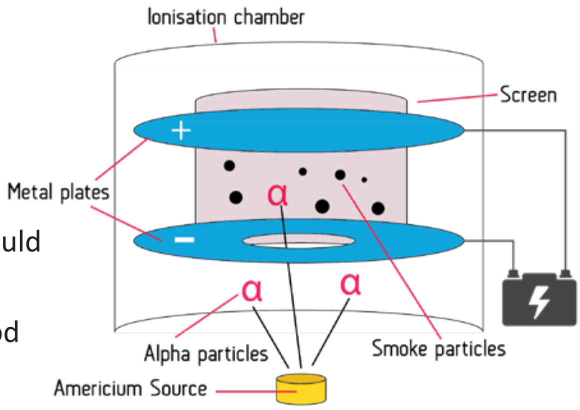
Isotope chosen: Technetium-99 (γ – emitter)

Reason: because it's a gamma emitter, it passes out of the body easily. The half life is short so it will not remain in the body for a long time.

(c) A smoke detector.

Isotope chosen: Americium-241 (alpha emitter)

Reason: Gamma more penetrating than alpha so it would not be blocked by smoke. It has a longer half life so detector stays active / keeps working for a longer period of time. (Polonium-210 has too short a half life so it would not last very long and therefore it's not suitable).



(Triple) Unit 2.4 - Further Motion

The equations

Speed is defined as the distance moved per unit time, and hence, the equation for speed is :

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

Distance is measured in **metres (m)**
Time is measured in **seconds (s)**
Speed is measured in **metres per seconds (m/s)**

If the speed is **not** constant this equation can still be used, but it gives a value for the **average speed.**

There are also equations for objects that are **accelerating,** e.g.

$$\text{acceleration} = \frac{\text{change in speed}}{\text{time}}$$

Re-arranging ➔

$$a = \frac{v - u}{t}$$

$$v = u + at$$

If the acceleration is **constant**, then there are 3 other equations that we can use. These are known as the 'equations of motion' or 'kinematic equations', and are **all given in the examination** :

$$v = u + at$$

$$x = \frac{(u + v)}{2} t$$

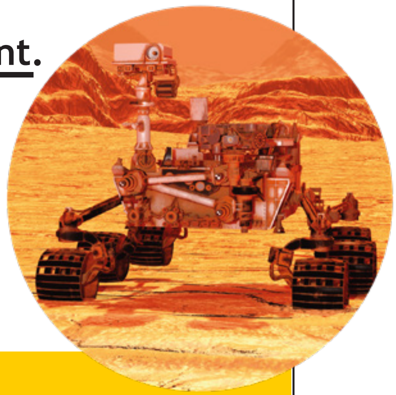
$$x = ut + \frac{1}{2} a t^2$$

$$v^2 = u^2 + 2a x$$

Symbol		Quantity	Unit
x	=	distance/displacement	m
u	=	initial velocity	m/s
v	=	final velocity	m/s
a	=	acceleration	m/s^2
t	=	time	s

All the above quantities, except for 'time', are **vectors**, meaning that they must have a **direction**. For example, displacement is simply the 'straight line' distance between the start and end point of your journey, **in a certain direction**.

Remember !!
These equations only work if the acceleration is constant.



This means that the equations work well for objects moving under the influence of gravity, but only if the friction and air-resistance are negligible. They work very well on the surface of the moon and Mars etc., since there's little or no air, so the acceleration due to gravity has a constant value near the surface. They also work fairly well on Earth, as long as air-resistance isn't too large !

Example 1

A child, initially sitting on the edge of a diving platform, lets himself drop into the swimming pool 4 m below. Assuming no air-resistance, and given that the acceleration due to gravity is 9.81 m/s^2, calculate,

(i) the child's speed as he hits the water

Start by inserting all known values :

x = 4 m
u = 0 m/s
v = ?
a = 9.81m/s^2
t = ?

Since 3 of the 5 quantities are known, we can use the equations of motion to calculate the other 2.
The only equation with 'x', 'u', 'v' and 'a' (i.e. not 't') is :

$$v^2 = u^2 + 2ax$$
$$v^2 = 0 + 2 \times 9.81 \times 4$$
$$v^2 = 78.48$$

... and so, the answer is **v = 8.9 m/s**

(ii) the time it takes the child to reach the water's surface

We now know 4 values :

x = 4 m
u = 0 m/s
v = **8.9 m/s**
a = 9.81m/s^2
t = ?

Since 4 of the 5 quantities are known, we can use **any** equation containing 't'. Here's the easiest one :

$$v = u + at$$

Re-arranging ➔ $t = \frac{v - u}{a} = \frac{8.9 - 0}{9.81} = \mathbf{0.91\ s}$

Since these equations only work if the acceleration is constant, we can only calculate the speed of the child just before making contact with the water's surface, as once contact is made, the acceleration changes. This is very important in cases where something falls to the ground – the final velocity,v, is **NOT ZERO** since we're calculating the velocity just before the object hits the ground.

The equations

Remember that displacement, velocity and acceleration are all 'vectors' - you must be aware of their directions.

In the last example this wasn't a problem since the direction of movement was in the same direction as gravity (downwards). However, you must be prepared for examination questions that involve using the correct direction, as shown in the next example :

Example 2

A ball is thrown vertically upwards with a speed of 7.2 m/s. Taking the acceleration as 9.81 m/s^2 , calculate,

(a) the time it takes to reach its maximum height

We start by deciding on a 'positive' direction. So, let's take **upwards as positive.**
Next, lets insert all given values :

x = ?
u = +7.2 m/s
v = ?
a = - 9.81 m/s^2
t = ?

At first glance it seems we're stuck as we need 3 values but only have 2 ! However, since the question asks for the time it takes to reach the greatest height, we know that, at this instant, the final velocity, v is zero !

Also notice that the acceleration is negative (since it's always downwards)

The only equation containing 'u', 'v', 'a' and 't' (i.e.not 'x') is :

$$v = u + at$$

Re-arranging ➔ $t = \frac{v - u}{a} = \frac{0 - 7.2}{-9.81} = +0.73$ **s**

(b) the maximum height reached by the ball

We now know 4 values :

x = ?
u = + 7.2 m/s
v = 0
a = - 9.81
t = 0.73 s

Since 4 of the 5 quantities are known, we can use **any** equation containing 'x':

$$x = ut + \tfrac{1}{2} a t^2$$

$$x = (7.2 \times 0.73) + (0.5 \times -9.81 \times 0.73^2)$$

$$x = 5.256 - 2.614$$

$$x = \mathbf{2.64\ m}$$

Notice that if we had NOT taken direction into account, the acceleration value would have been positive, and the answer would have been "5.256 **+** 2.614", which is incorrect !!

Momentum

Momentum is a difficult thing to explain – simply, it is how much 'motion' an object has. However, it is quite easy to calculate the momentum, **p**, of an object if you know the object's mass, **m**, and velocity, **v**, (velocity is the vector version of 'speed'). This is the equation for calculating momentum :

momentum = mass x velocity   p = m x v

p = m x v = 3 000 x 10
= 30 000 kgm/s

p = m x v = 70 x 5
= 350 kgm/s

Docked !!

p = m x v = 50 000 000 x 0
= 0 (zero !) kgm/s

Momentum & Newton's 2nd law

Here's the Law of Conservation of Momentum :

The total momentum of a system of interacting bodies is constant provided there are no external forces acting.

This law is perfectly consistent with Newton's 3rd Law ! Take a look at the imminent collision below :

Car A

Car B

As they collide, car A will create a force to the right (➔) on car B. Newton's 3rd Law states that car B will therefore produce an **equal** but opposite force on car A to the left (🡐).
We need Newton's 2nd Law too (original form)!

$$\text{Force} = \frac{\text{change in momentum}}{\text{time}} \qquad F = \frac{\Delta p}{t}$$

where Δ p = change in momentum

Re-arranging ➔ $F \times t = \Delta p$

Since the cars are in contact with each other for the same amount of time, **F x t** will have the same value for both cars, and hence, **Δ p** will have the same value for both cars – this is 'conservation of momentum' since any momentum lost by car A will be given to car B.

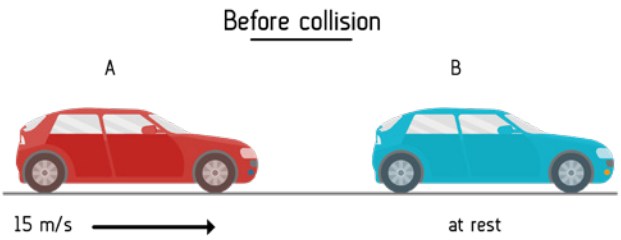
(Remember that momentum is a vector, and so 'positive momentum' (➔) from car A will seem to 'cancel out' some of car B's negative momentum !)

Momentum

Example

(a)

(i) Two cars of equal mass, 800 kg, collide. Before the collision, car **B** is at rest while car **A** has a constant velocity of 15 m/s. In the questions that follow, ignore the effects of friction.



Use an equation from page 2 to calculate the momentum of car **A** before the collision. [2]

Momentum = ... kg m/s

(ii) After the collision, the two cars are stuck together.

Use the equation:

$$\text{velocity} = \frac{\text{momentum}}{\text{mass}}$$

to calculate the velocity *v* of the cars after the collision. [3]

(iii) During the collision, car **A** exerts a force of 16 000 N to the right on car **B**. What force does car **B** exert on car **A** during the collision? [2]

....

Suppose both cars had been travelling towards each other at the same speed.

(i) What would their velocity be after a head-on collision if they stuck together on impact? [1]

....

(ii) Explain your answer. [2]

....

....

Answer

(c) (i) p = mv = 800 x 15 = 12000 kg m/s

(ii) v = p / m = 12000 / 1600 = 7.5 m/s (Notice the mass is the total mass of both cars)

(iii) F = 16 000 N to the **left** (equal but opposite)

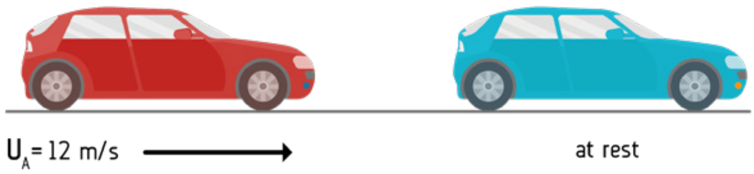
(d) (i) v = zero !!

(ii) Momentum is a vector. The total momentum before collision is therefore zero since they have equal momenta, but in opposite directions. Hence, the total momentum after collision must be zero.

Is kinetic energy conserved in collisions ?

Energy cannot be created or destroyed. However, energy can be transferred from the kinetic energy of a colliding object (e.g. a car) into heat and sound energy which escapes into the surroundings.

This means that it's quite normal (even expected) that KE is 'lost' from the colliding objects during a collision. Look at the situation below :



After colliding, the velocity of car A reduces to 2m/s (➔). If the mass of car A, m_A = 1400 kg, and car B, m_B = 1200 kg, then by conservation of momentum,

$$\text{momentum before} = \text{momentum after}$$
$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$
$$16\,800 + 0 = 2800 + 1200\, v_B$$
$$16\,800 - 2800 = 1200\, v_B$$
$$14\,000 = 1200\, v_B$$
$$v_B = 11.67 \text{ m/s (to the right)}$$

Note : Since the answer is a positive number, we therefore know that it is to the right.

We can now check to see what happens to the kinetic energy of the cars :

KE before = $KE_{car\ A}$ = $0.5\, m\, v^2$ = $0.5\, m_A u_A^2$ = $0.5 \times 1400 \times 12^2$ = **100 800 J**

KE after = $KE_{car\ A}$ + $KE_{car\ B}$ = 2800 + 81 667 = **84 467 J**

This shows that some KE is lost during the collision. Notice we do not take direction into consideration here since kinetic energy is NOT a vector.

Elastic collision : There is **no** loss in kinetic energy.

Inelastic collision : There **is** loss in kinetic energy.

Moments

"Moment" is the word used to describe the 'turning effect' of a force. It is calculated using the following equation :

Moment = Force x distance to the pivot	$M = F \times d$

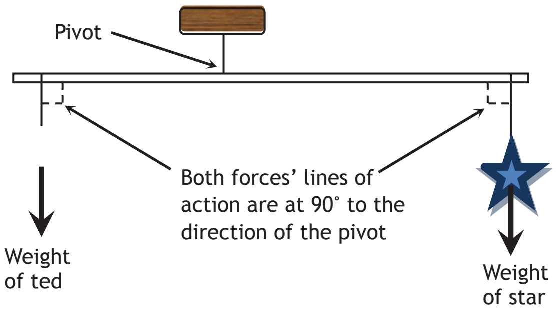
And so we can say that for a rotating system that is in equilibrium (balanced),

The sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about the same point.

This is known as the "Principle of Moments".

Examples

A) Is the system balanced?
Ted weighs 1.8N and is 32cm from the pivot.
The star weighs 1.2N and is 48cm from the pivot.

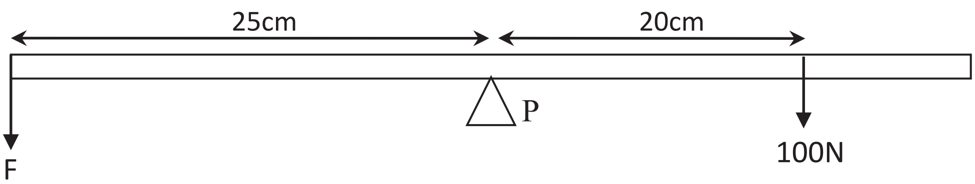


Clockwise moment, M = F x d = 1.2 x 48 = 57.6Ncm

Anti-clockwise moment, M = F x d = 1.8 x 32 = 57.6Ncm

Both moments are equal, and so the system is balanced.

B) The pivot is at the mid-point of an uniform beam. Find the weight, W, when the beam is in equilibrium.



Since the system is in equilibrium,

Clockwise M = Anticlockwise M

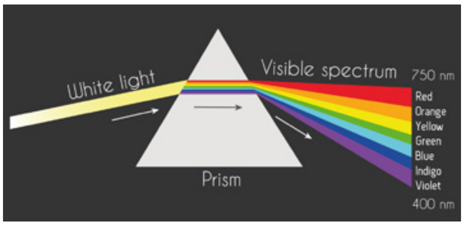
i.e. 100 x 0.2 = 0.25 x F

$$F = \frac{20}{0.25}$$

F = 80 N

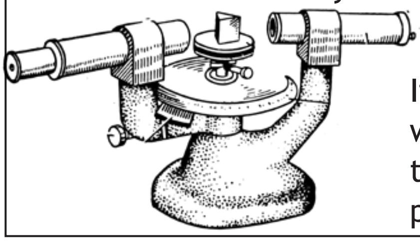
(Triple) Unit 2.6 - The Universe

Spectra



Sir Isaac Newton passed ‘white’ light through a small glass prism, and found that white light is actually a mixture of all the different colours or **wavelengths** in the visible spectrum :

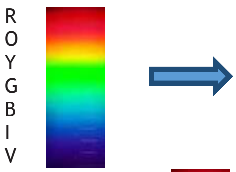
A better device to ‘split-up’ light is a ‘diffraction grating’. The surface of a CD or DVD acts like a diffraction grating – you may have noticed a rainbow effect when you look at them ?



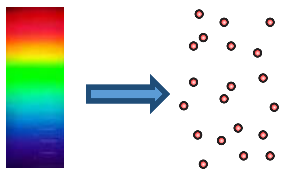
If you want to analyse light from stars or galaxies, you will need a **spectrometer.** This has a diffraction grating that splits all the different wavelengths up in a very precise way.

The picture below shows the Sun’s **spectrum** as you would see it through a spectrometer. If it were in colour, you would see that almost all the colours (or wavelengths) can be seen, but, there are quite a few wavelengths ‘missing (dark lines). Why ?

Red ➔ Green ➔ Blue ➔ Violet

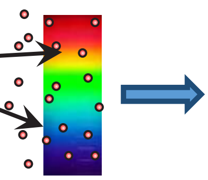


Light produced by *a star contains all the (visible) wavelengths.*

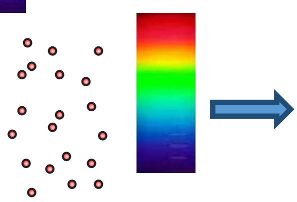


However, this light has to travel through the star’s atmosphere and then through space before it reaches our telescopes.

Dust and gas, either in a star’s atmosphere or in large clouds in space (nebulae).



This dust and gas absorbs some of the wavelengths/colours of the light from the star.



This means that if this light is then looked at through a spectrometer dark lines are seen where there are ‘missing’ wavelengths.

Spectra

These dark lines are known as **absorption lines.**

Each different element can only absorb a certain set of colours. This means that each element has a kind of 'unique fingerprint'. Check out this website :

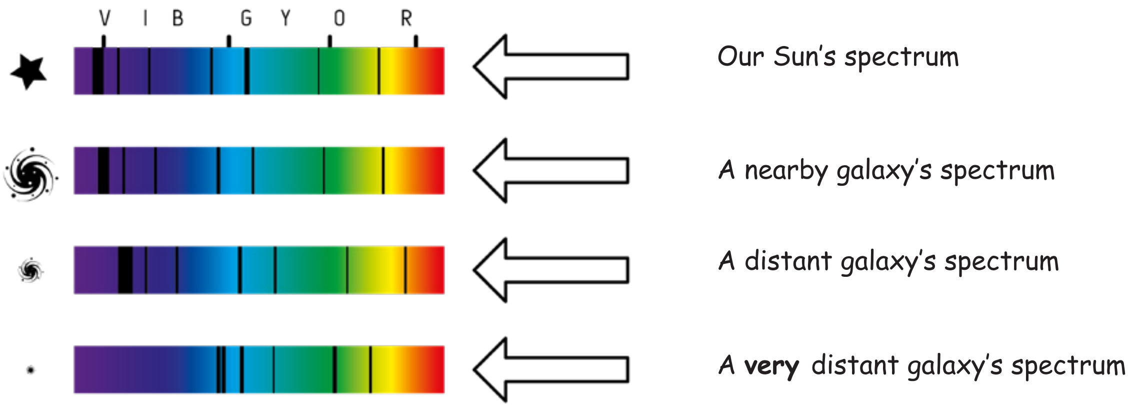
http://jersey.uoregon.edu/elements/Elements.html

Since every different element has its own 'unique fingerprint' of absorption lines, if the position of these lines in a star's spectrum is studied carefully, you can tell which chemicals/elements are present.
Scientists have been using this method since the 19th century to identify the elements in stars and gas clouds in space (nebulae).

When astronomers started looking at the light from stars **within our own galaxy,** they saw that the absorption lines were mainly those produced by **Hydrogen** and **Helium** (the 2 simplest atoms).

The Big Surprise !!

When astronomers analysed the light from **other galaxies** they found the same absorption lines as before (mainly Hydrogen and Helium), but they were all **shifted** towards the red end of the spectrum i.e. **red shifted !**



Edwin Hubble, an American astronomer, studied this curious effect at length.

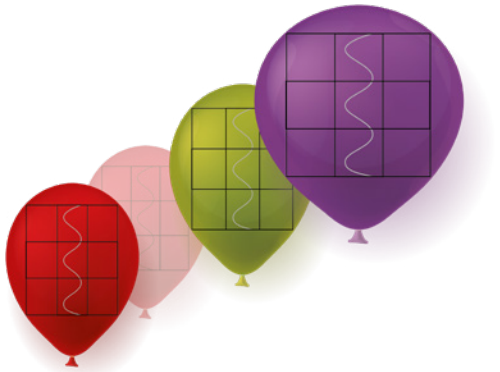
He realised that the further away a galaxy is, the more redshifted its light appears.

This led him to realise that the universe is expanding, as previously predicted, and that it was therefore much smaller in the distant past, and had a definite beginning - **the Big Bang !**

Edwin Hubble
(1889-1953)

The Big Bang !!

How does the 'cosmological red shift' seen by Hubble show that the Universe is expanding ?



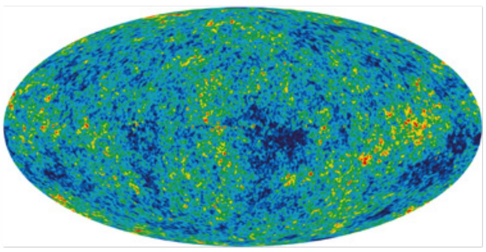
The idea is that if the Universe has been expanding since the Big Bang, then the light waves that have been travelling through it must also have been stretched. If light waves are stretched then their wavelengths will be greater i.e. they will appear red-shifted.

Big Bang Prediction

The Big Bang theory suggests that our Universe began with a massive explosion throwing energy (gamma rays) out in all directions. The Universe, therefore, began in a very hot and very dense state, but has been expanding and cooling since.

This idea of an expanding universe brought about an important prediction :

The enormous 'flash' of light at the beginning of the universe should still be visible today. However, because the universe has been expanding for billions of years, this light (originally gamma rays) should be severely red-shifted. It should now be microwave radiation and should be seen everywhere in all directions.

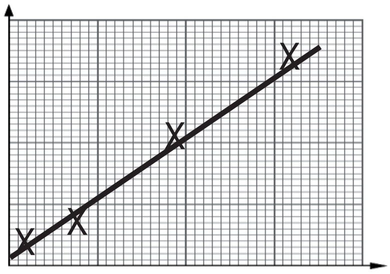


In 1964, 2 scientists, Penzias & Wilson found this background radiation, completely by accident. It's now known as the CMBR (Cosmic Microwave Background Radiation). They both received a Nobel prize in 1978 for their work, since this is very strong, independent evidence for the Big Bang !

The Big Bang !!

Summary

1st - The Big Bang theory was proposed.



2nd -Edwin Hubble's measurements showed that the further away a galaxy is the greater the redshift. This became known as **COSMOLOGICAL REDSHIFT**.
The graph seen ➔ was strong evidence that the Universe is expanding.

3rd – A prediction :– Cosmological Redshift means that the gamma waves from the big bang should have moved to the microwave region of the spectrum by today, and that scientists should be able to see this "background" radiation left over from the Big Bang in all directions.

4th - Penzias a Wilson found the Cosmic Microwave Background Radiation. (CMBR)

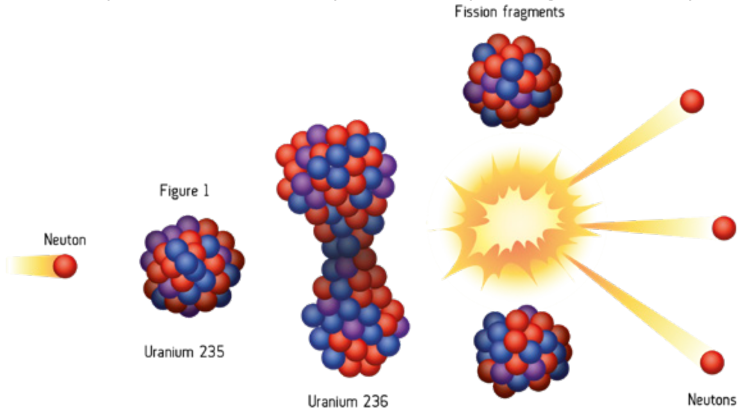
5th – The wavelength and temperature of the microwave radiation from the big bang was at the exact temperature that was expected/ predicted by the Big Bang.

Theory	Evidence
The universe is expanding	Cosmological redshift – more distant galaxies have greater redshifts
Large explosion (big bang) at the start.	CMB radiation is the red-shifted gamma rays produced by the Big Bang.

Unit 2.9 - Nuclear Decay & Nuclear Energy

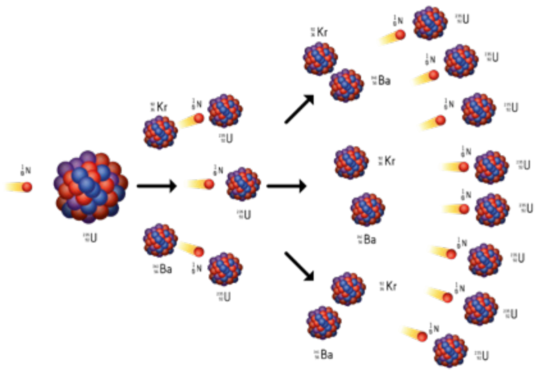
Nuclear Fission

Nuclear fission. This is a decay process in which an unstable nucleus splits into two fragments of comparable mass or to put it another way it is the splitting of a heavy nucleus into two lighter nuclei.



Most elements need to be stimulated to undergo fission; this is done by bombarding them with neutrons. The process is called ***induced fission.*** Fission of uranium-235 will occur when it absorbs a **slow moving neutron**, making the resulting nuclide ^{236}U, unstable. The ^{236}U is in a highly excited state and splits into two fragments almost instantaneously.

Uranium Isotopes. There are two main isotopes of uranium – uranium-238 and uranium-235. Uranium which is mined is 99.3% U-238 and only 0.7% U-235. This uranium must be enriched to make bombs, which means increasing the amount of U235 present. In nuclear reactors the uranium is only slightly enriched. Uranium-238 and uranium-235 are radioactive.



Chain reaction. During fission of uranium-235 neutrons are emitted as fission products. A large amount of **energy** is released.

Sustainable fission involves one of the neutrons causing further decay. Just because it's a chain reaction it does **not** mean that it will result in an explosion.

Balancing fission nuclear equations. When uranium-235 undergoes fission the same products/nuclei are **not** produced each time.

Example

$$1\,{}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{135}_{52}Te + {}^{97}_{40}Zr + 4\,{}^{1}_{0}n$$

Left: total A = 235 + 1 = 236

Total Z = 0 + 92 = 92

Right: total A= 135 + 97 + (4 x 1) = 236

Total Z = 52 + 40 + (4 x 0) = 92

The total A (nucleon) and Z (proton) numbers on both sides must be equal/the same.

Balance the following nuclear equations by calculating the missing numbers (letters a, b, c and d)

1. $1\,{}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{a}_{56}Ba + {}^{92}_{b}Kr + 3\,{}^{1}_{0}n$

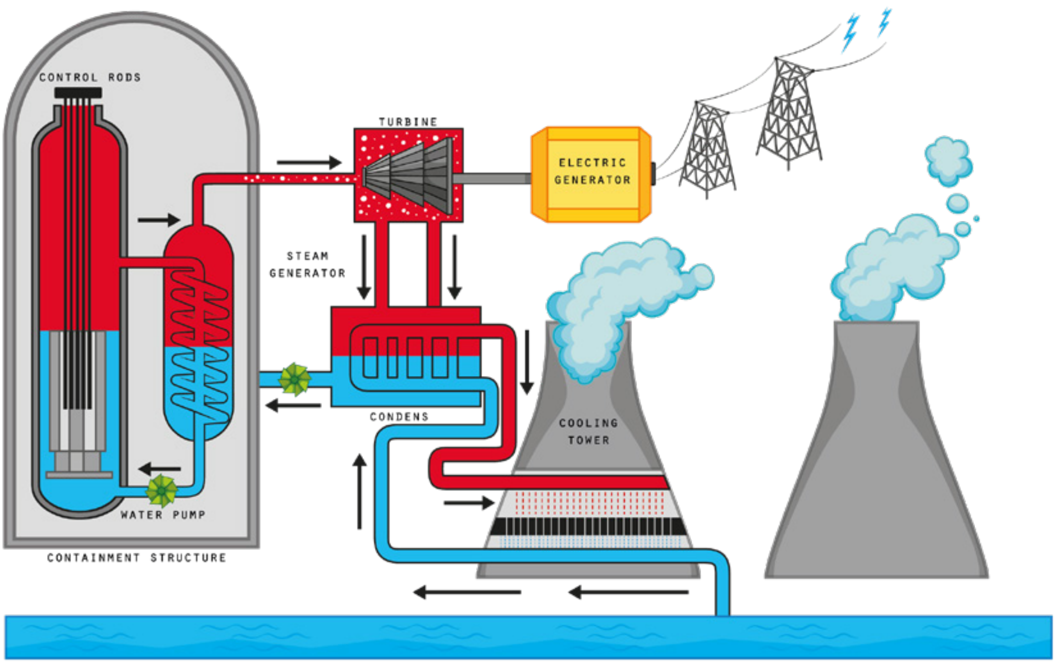
2. $1\,{}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{140}_{c}Xe + {}^{94}_{38}Sr + d\,{}^{1}_{0}n$

The fission fragments are themselves unstable.

a = 141, b = 36, c = 54, d = 2

Nuclear Reactor

In a thermal nuclear reactor the chain reaction is steady and controlled (hopefully) so that on ***average only one neutron, from each fission produces another fission.***



Control rods and the moderator.

Moderator

The moderator **slows down neutrons** to allow them cause further fission. The neutrons released in the fission of U-235 are not fast enough to cause fission in U-238 but fast enough to be captured. So in a thermal reactor, the neutrons must be slowed down so that they avoid capture by the U-238 and cause fission in U235.

The **moderator** surrounds the fuel rods and is used to slow down the neutrons. Most nuclear reactors use water as a moderator whilst some use **graphite rods**. The advantage of using **water** as a moderator is that is can also be used as the coolant to transfer the heat energy away from the reactor to generate electricity. However if the **coolant** is lost, (as happened in Fukushima in Japan tsunami March 2011) the neutrons will not be slowed down and so the nuclear chain reaction stops but this loss of coolant cause the reactor to **overheat.**

Control Rods.

They can use **control rods** to stops/control the number of thermal neutrons inside the fuel rods/reactor. This alters the rate (number of fission reactions per second) at which nuclear fission takes place. The control rods **absorb** the neutrons thus preventing them from causing further fission in U-235. Metals such **boron** and **cadmium** are used to make the control rods. If a fault occurs then the **control rods should drop into the reactor** automatically thus stopping the chain reaction. By moving the control rods down the chain reaction is slowed down (more thermal neutrons absorbed) and it can be speeded up by moving the control rods up (fewer neutrons absorbed).

Steel is used as a material for the pressurised **reactor vessel** which is then surrounded by thick walls of **concrete**. The steel vessel is pressurised to prevent the water from boiling but can be dangerous if overheating occurs, causing the vessel to explode. The water in the vessel is not the same water which is used to drive the turbine.

Unfortunately the **fission products** e.g. Barium, Krypton, Caesium and Iodine, which are contained within the fuel rods, are also radioactive and many have very **long half-lives**. They are radioactive because they have a too many neutrons and so usually undergo beta decay. Once the uranium-235 has been used up in the fuel rods they must be stored safely under water in **cooling ponds**. This allows them to cool down safely, without their radiation escaping from the building. The water also provides some **shielding** from the radiation. The used fuel rods spend many years in the cooling ponds after which they are sent to places like Sellafield in Cumbria to be reprocessed.

Nuclear Fusion

Fusion: When two smaller nuclei are joined together to form a larger one. A Large amount of **energy** is released in the process.

In the Sun fusing two hydrogen nuclei is possible because of the high pressure and they are moving at such high speeds due to the very high temperature at the core of 15,000,000˚C.

They are experimenting with fusing light elements together. Two isotopes of hydrogen – ***deuterium*** $^{2}_{1}H$ (1 proton, 1 neutron) and ***tritium*** $^{3}_{1}H$ (1 proton, 2 neutrons) can undergo fusion to form helium and a neutron.

This is a nuclear equation for the reaction.

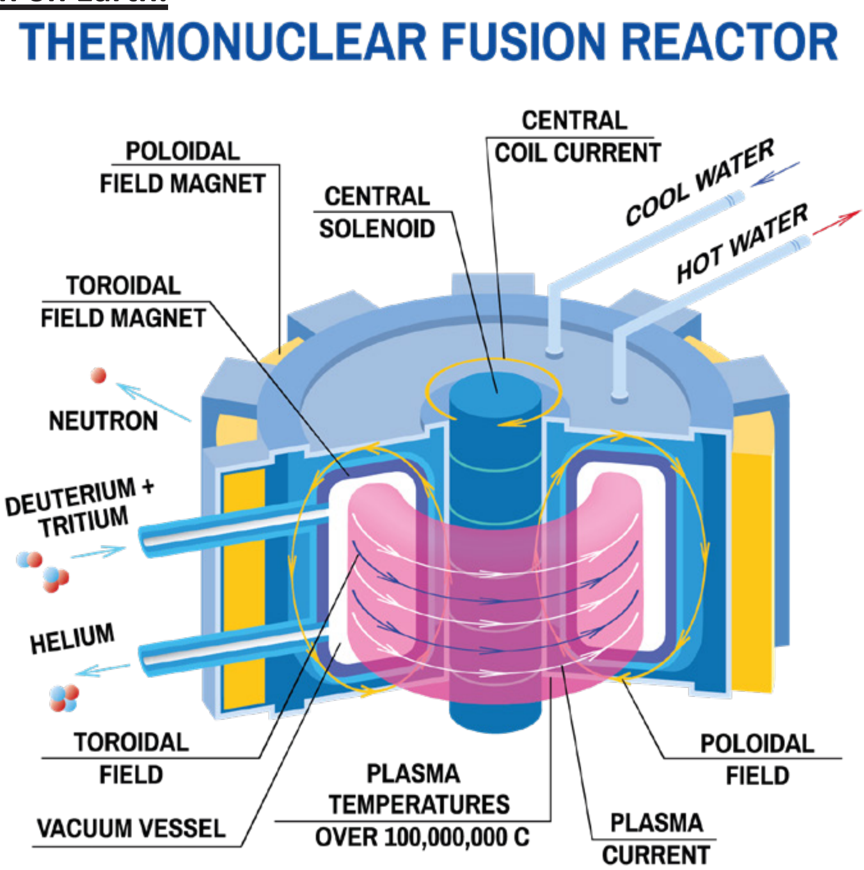
$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

Total A = 2+3 = 5	Total A = 4 + 1 = 5	Equation
Total Z = 1 + 1 = 2	Total Z = 2 + 0 = 2	Balanced

A good source for the hydrogen isotopes would be **sea water.**

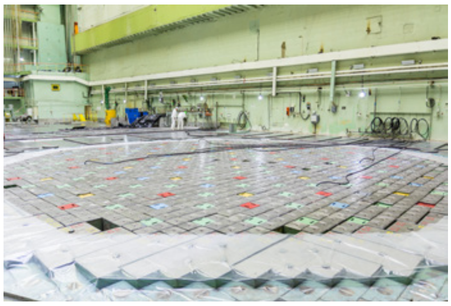
Achieving controlled fusion on Earth.

Containment is in a doughnut shaped reactor. Deuterium and tritium are heated to very high temperatures, using large currents to form a plasma (ionised gas). The strong magnetic field contains and accelerates the particles to very high speeds so that they can collide with enough energy to undergo nuclear fusion. The neutron that is produced has a large amount of kinetic energy which can be used to generate heat and then generate electricity.



The **neutrons** that are generated can be captured by atoms in the reactor making them unstable and therefore **radioactive.** The reactor must therefore be **shielded** using concrete to prevent any radiation escaping and so protect the workers.

Comparing fission and fusion.

Power source	Advantage	Disadvantage
Nuclear Fusion	• Abundant source of deuterium and tritium in sea water.  • Does not produce greenhouse gases. • No long lived radioactive materials produced.	• High temperature required. • Pressure containment of the plasma.  • Shielding of neutrons using concrete • High energy input required.
	Advantage	Disadvantage
Nuclear Fission	• Does not produce greenhouse gases. • Large amount of power produced. • Uses small amount of fuel.	•Radioactive material produced with long half life. •Risk of nuclear meltdown. • Cost of decommissioning the power station and storing of waste material.