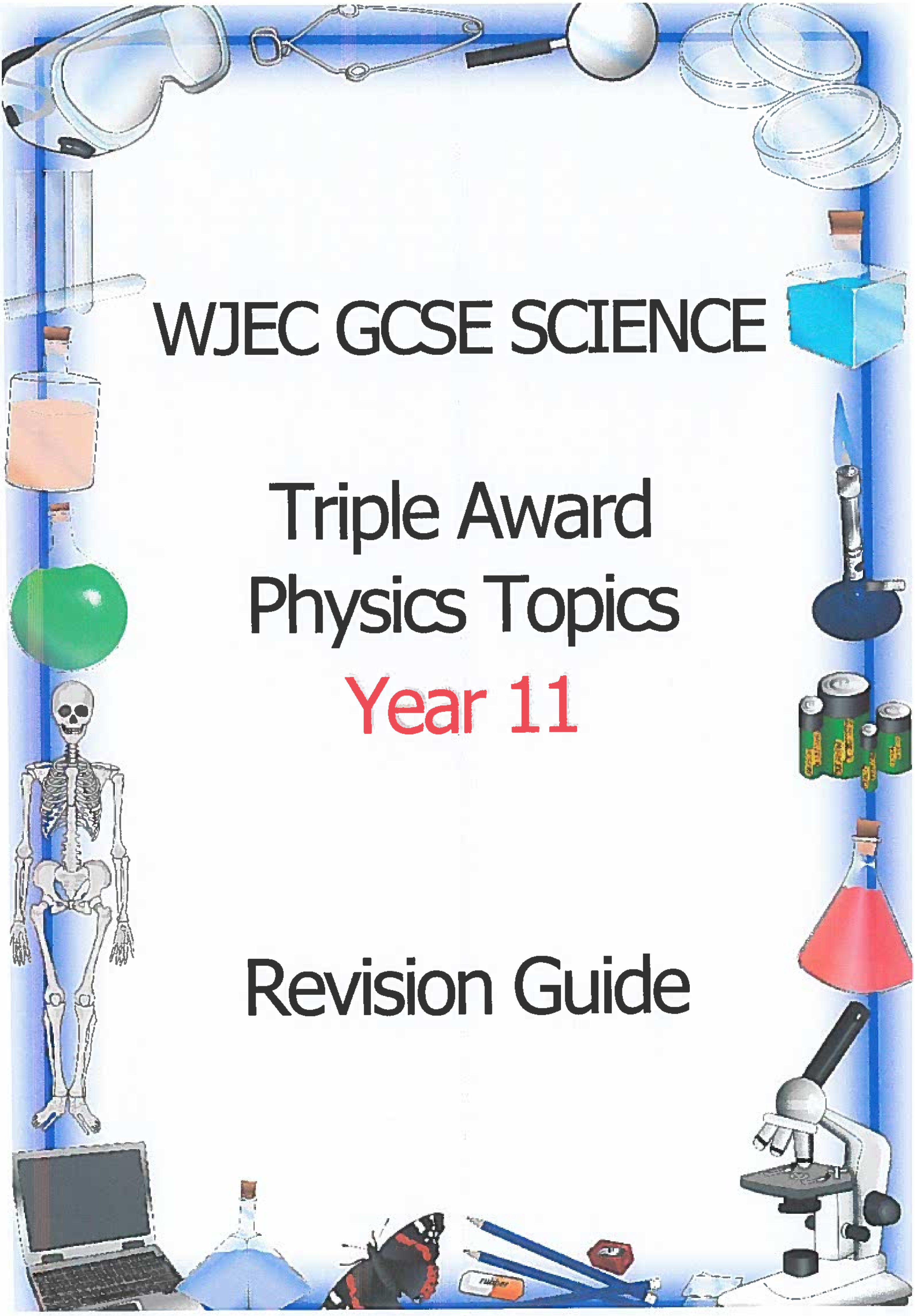

WJEC GCSE SCIENCE

Triple Award
Physics Topics
Year 11

Revision Guide

GCSE PHYSICS Unit 2 Foundation

Equations

$\text{speed} = \frac{\text{distance}}{\text{time}}$	
$\text{acceleration [or deceleration]} = \frac{\text{change in velocity}}{\text{time}}$	$a = \frac{\Delta v}{t}$
acceleration = gradient of a velocity-time graph	
resultant force = mass × acceleration	$F = ma$
weight = mass × gravitational field strength	$W = mg$
work = force × distance	$W = Fd$
force = spring constant × extension	$F = kx$
momentum = mass × velocity	$p = mv$
$\text{force} = \frac{\text{change in momentum}}{\text{time}}$	$F = \frac{\Delta p}{t}$
u = initial velocity v = final velocity t = time a = acceleration x = displacement	$v = u + at$ $x = \frac{u + v}{2} t$
moment = force × distance	$M = Fd$

SI multipliers

Prefix	Multiplier
m	1×10^{-3}
k	1×10^{3}
M	1×10^{6}

GCSE PHYSICS Unit 2 Higher

Equations

$\text{speed} = \frac{\text{distance}}{\text{time}}$	
$\text{acceleration [or deceleration]} = \frac{\text{change in velocity}}{\text{time}}$	$a = \frac{\Delta v}{t}$
acceleration = gradient of a velocity-time graph	
distance travelled = area under a velocity-time graph	
resultant force = mass × acceleration	$F = ma$
weight = mass × gravitational field strength	$W = mg$
work = force × distance	$W = Fd$
$\text{kinetic energy} = \frac{\text{mass x velocity}^2}{2}$	$\text{KE} = \frac{1}{2}mv^2$
change in potential energy = mass × gravitational field strength × change in height	$\text{PE} = mgh$
force = spring constant × extension	$F = kx$
work done in stretching = area under a force-extension graph	$W = \frac{1}{2}Fx$
momentum = mass × velocity	$p = mv$
$\text{force} = \frac{\text{change in momentum}}{\text{time}}$	$F = \frac{\Delta p}{t}$
u = initial velocity v = final velocity t = time a = acceleration x = displacement	$v = u + at$ $x = \frac{u+v}{2}t$ $x = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2ax$
moment = force × distance	$M = Fd$

SI multipliers

Prefix	Multiplier
p	1×10^{-12}
n	1×10^{-9}
µ	1×10^{-6}
m	1×10^{-3}

Prefix	Multiplier
k	1×10^{3}
M	1×10^{6}
G	1×10^{9}
T	1×10^{12}

Vector and Scalar Quantities (Yr11 Triple)

A *Quantity* is just something that can be measured.

The table below gives a list of the quantities you will use in the GCSE Physics course. It's up to you to fill in the blanks, as we go through the course.

Some quantities may have different name, e.g. distance may also be called length and vertical distance is height!

Vector or Scalar?

With ***scalar quantities***, we only need to know their size ***(magnitude)***.
But, with ***vector quantities*** we also need to know which direction they act. A force of 100N pushing right has a completely different effect to a force of 100N pushing left!
Remember*, Up, down, left, right, North, South, etc, are directions.* ***But****, bigger, smaller, higher, lower, etc, are not.*

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Quantity	Symbol (H)	SI Unit	Other units	Vector or Scalar
Distance	**d**	metre (m)	light years (l.y.) astronomical unit (AU)	scalar
Displacement	**x**	metre (m)		vector
Time	**t**	second (s)	hour, day, year	scalar
Speed	**S**	m/s		
Velocity Final Initial	**v** **u**	m/s m/s		
Acceleration	**a**	m/s^2		
Mass	**m**	kg		
Force	**F**	N		
Weight	**W**	N		
Momentum	**p**	kgm/s		
Moment (turning force)	**M**	Nm		
Gravitational field strength	**g**	N/kg		
Energy Work Gravitational Potential Energy Kinetic Energy	**E** **W** **GPE** **KE**	Joules (J) J J J		
Spring constant	**k**	N/kg		
Nucleon number (atomic mass)	**A**	-		
Proton number (atomic number)	**Z**	-		
Count rate/Activity		Becquerel (Bq)		

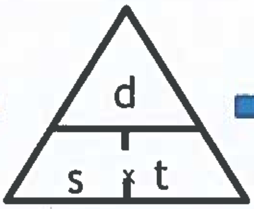
Unit 1 - Motion

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)

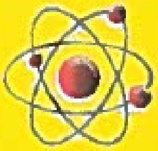
Example 1

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 ?

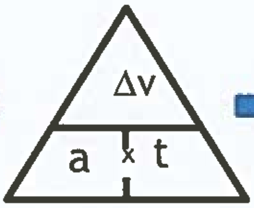
$d = s \times t = 2\,500\,000 \times 60 = 1.5 \times 10^8$ m (Almost 4 times around the Earth !)

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 (Δ) 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, $\Delta v = a \times t = 48.0 \times 0.45 = 21.6\ \text{m/s}$

So, final speed $= 12.4 + 21.6 = \mathbf{34.0\ m/s}$

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.

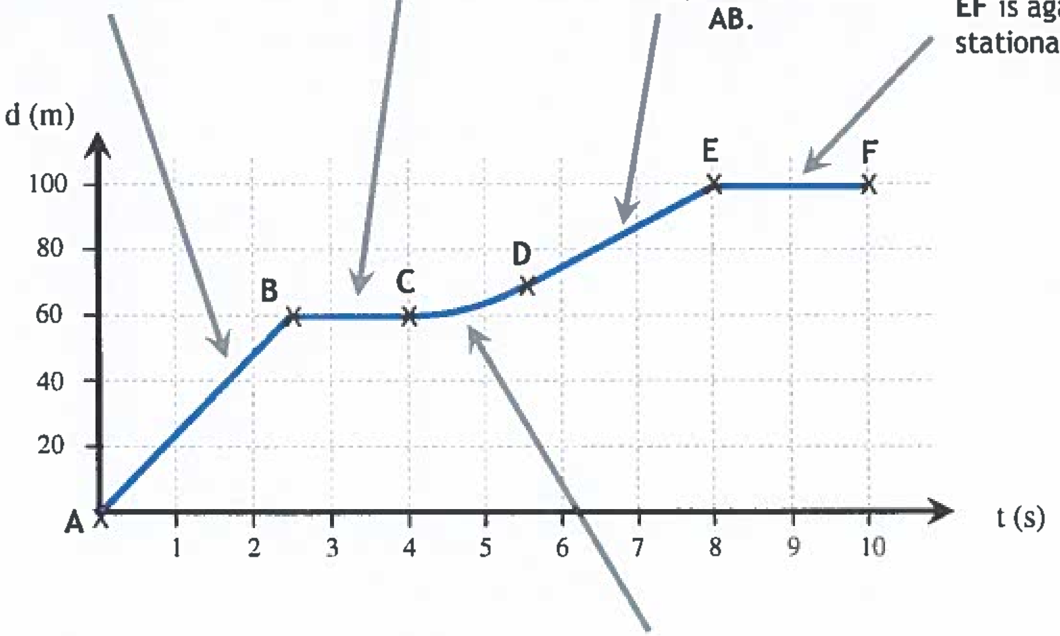
So,
a STEEP line ➔ a high speed
a less steep line ➔ a lower speed
a flat/horizontal line ➔ not moving

In the 1st section, the object is moving an equal distance each second. Hence, the object is moving at a 'constant speed'.

From **B** to **C**, the object is staying at a distance of 60m, so is not moving at all, i.e. **stationary**

This is a straight, diagonal line like section **AB**, and so is moving at a 'constant speed'. However, this is not as steep, so is moving **slower** than **AB.**

EF is again stationary.



This section is more difficult - since the slope is increasing, the speed is increasing, i.e. the object is **accelerating** !

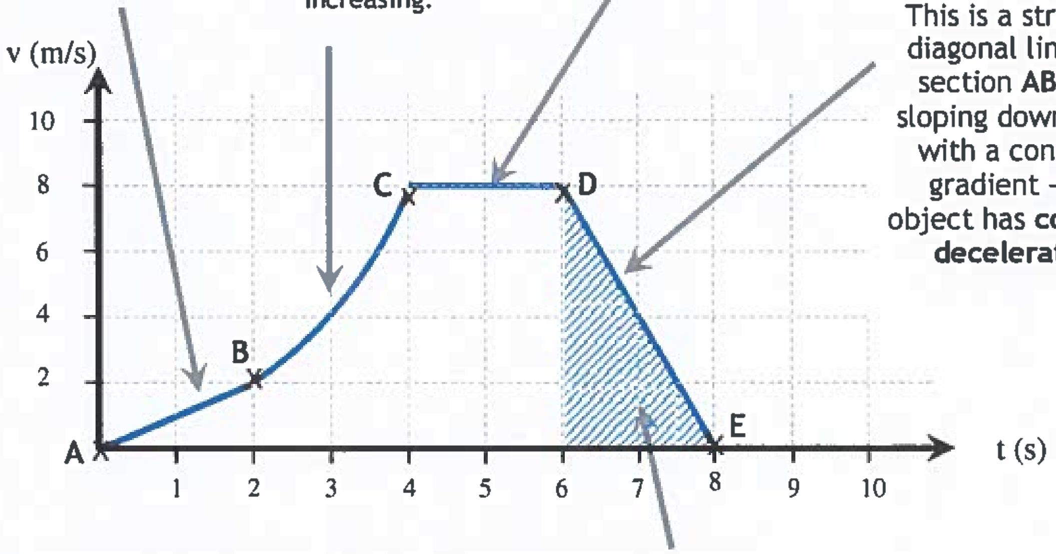
Motion graphs

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.**



In the 1st section, the object is speeding up steadily since the gradient is constant (straight line), i.e. it has **constant acceleration**

Curved line shows non-constant acceleration. Gradient/steepness increasing, so acceleration is increasing.

From **C** to **D**, the gradient is zero, and so, from rule 1 above, the acceleration is zero. This means the object is staying at the same speed (8 m/s), i.e. **constant velocity**

This is a straight, diagonal line like section **AB**, but sloping downwards with a constant gradient - the object has **constant deceleration**

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 :

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

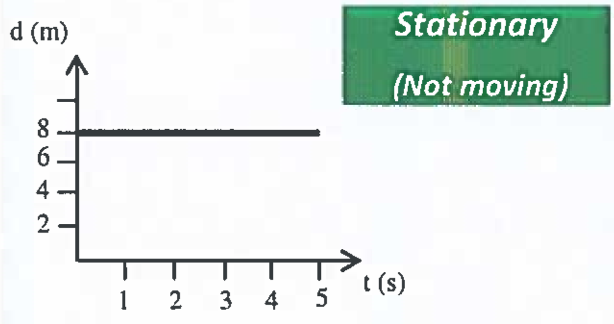
NOTE : Calculating the average speed in a sloping section is easy !! Since only straight line sections are used for this, it's simply half way between the start and end speed for that section e.g. for section DE, the average speed is 4 m/s (half way between 8 m/s and 0 m/s)

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).

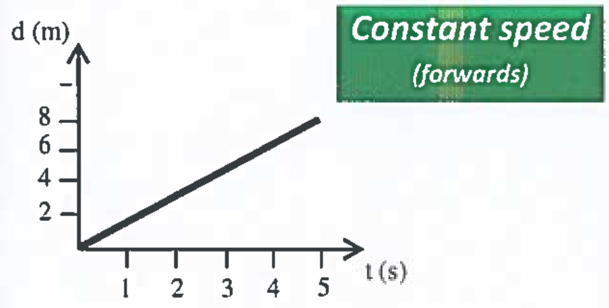
It's important that you learn what the shape of each type of graph tells you about the object's motion :

Distance - time graphs



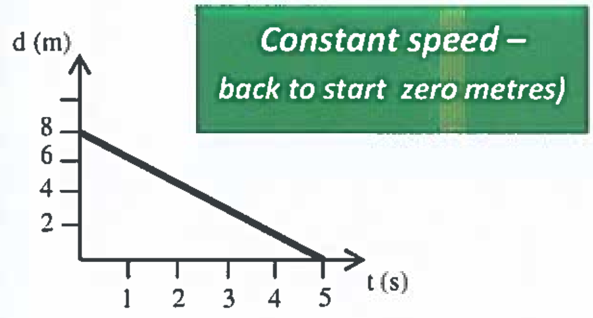
Stationary

(Not moving)



Constant speed

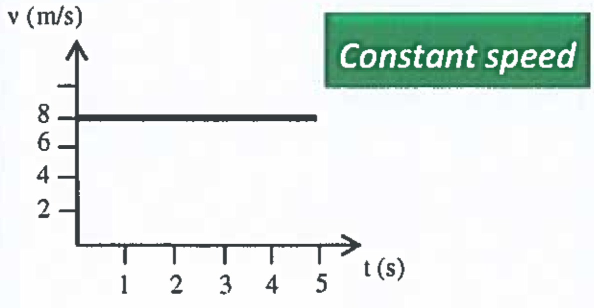
(forwards)



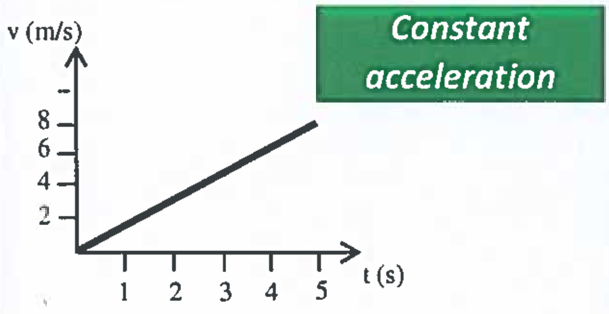
Constant speed –

back to start zero metres)

Velocity - time graphs

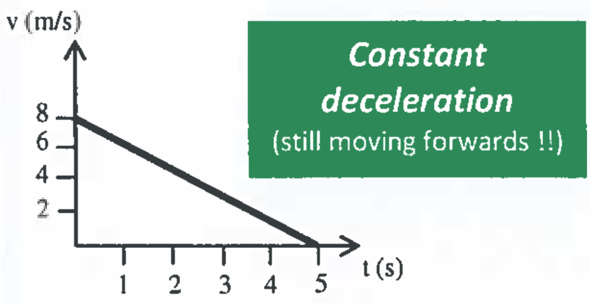


Constant speed



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 ($d = s \times t$)

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

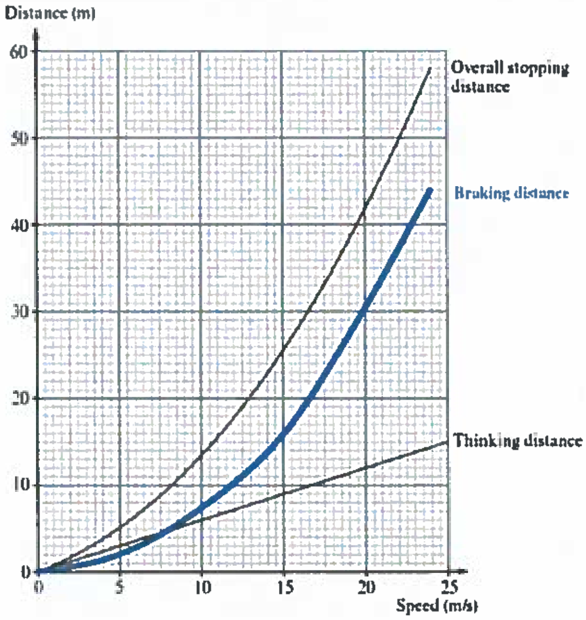
@ 40 m/s Thinking distance = 40 x 0.4 = 16m

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 ➔).

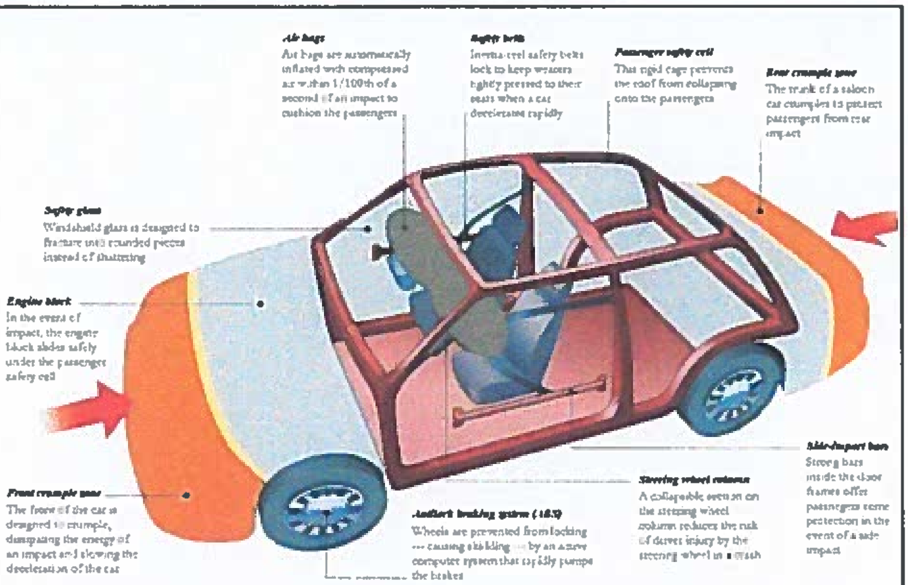
(In fact, doubling the vehicle's speed quadruples the braking distance, since the speed is squared in the KE equation).

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



Stopping distance & Car Safety

There are many safety fe
in modern cars/vehicles -
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.

Force = mass x acceleration

Since your mass is fairly constant, the only way to reduce the force is to reduce the **acceleration (or deceleration).** There are two ways of reducing the deceleration :

1. If the vehicle's speed is less, then less deceleration is needed to stop it!
2. The deceleration is less if the change in speed happens over more time.

The safety devices mentioned work by ensuring that you take **more time** to slow down. Remember the following reasoning :

Change the speed over more time. → Less deceleration → Less force

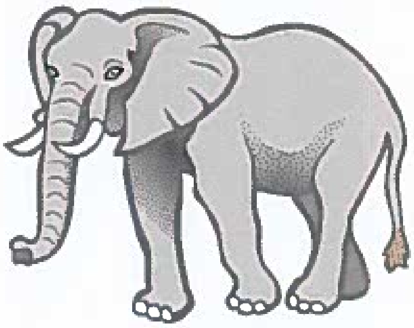
P6.2 (a) ~ Inertia:

Inertia: An object's resistance to any change in its motion.

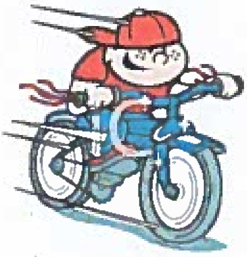
This just means that the heavier something is (***more massive)*** the more effort is needed to speed it up, slow it down or change its direction.

A. mouse

B. Jupiter



D. elephant.



B. bicyle and rider

Put these 4 objects in order of their ***inertia*** (least inertia first). *The pictures are **not** to scale.*

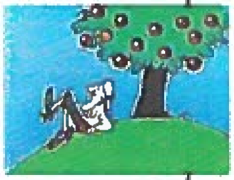
Unit 2 - Forces

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.**

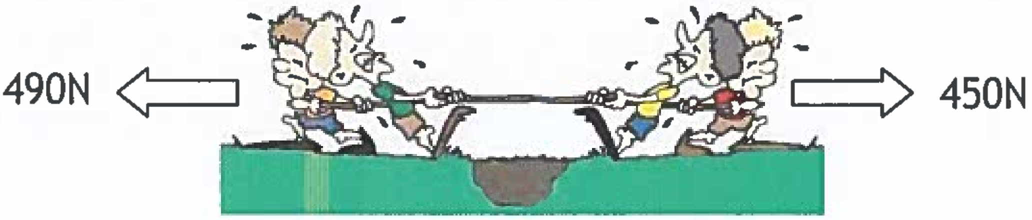
Sir Isaac Newton came up with three laws of motion, all of which describe the effect that forces have on things.

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



Resultant force

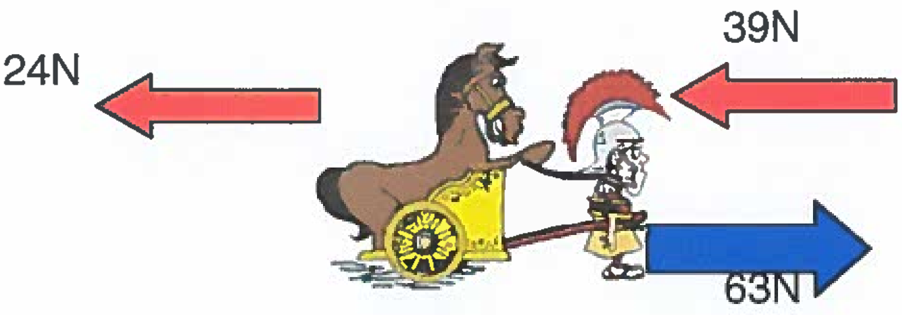
Usually, more than one force is acting on an object, like in the 'tug-of-war' below. In order to work out the effect of these forces on the object, we need to calculate what's known as '**resultant force**'.



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 laws

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').

Momentum

Newton's 2nd law (see the next page) is defined using a quantity called "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 like 'speed'). This is the equation for calculating momentum :

momentum = mass x velocity $p = m \times v$

$p = m \times v = 3\,000 \times 10$

$= 30\,000$ kgm/s

$p = m \times v = 70 \times 5$

$= 350$ kgm/s

Docked !

$p = m \times v = 50\,000\,000 \times 0$

$= 0$ (zero !) kgm/s

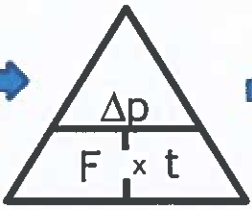
Newton's 2nd law

The rate of change of momentum is proportional to the (resultant) force applied, and takes place in the direction of the (resultant) force.

It is the **resultant** force on an object that causes a change in the speed or direction of the object. This is how it is written in equation form :

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

$$F = \frac{\Delta p}{t}$$



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

$$t = \frac{\Delta p}{F}$$

$$\Delta p = F \times t$$

Force is measured in newtons, N,
time in seconds, s,
'Δp' (change in momentum) is measured in kg m/s (or Ns)

In an examination, you will typically be asked to calculate the change in momentum before using the value in the above equation. There's a worked example below .

A small rocket is launched. At a certain point in the flight, the rocket's mass is 82kg, and is travelling at a velocity of 30m/s. 10 seconds later, the mass of the rocket has reduced to 72kg, and its velocity has increased to 65 m/s. Calculate the (average) resultant force on the rocket during this 10 seconds.

Step 1 : Calculate the change in momentum, **Δp.**

Momentum at the start of the 10 s, $p_s = m \times v = 82 \times 30 = 2460$ kg m/s

Momentum at the end, $p_e = m \times v = 72 \times 65 = 4680$ kg m/s

So, change in momentum , $\Delta p = p_e - p_s = 2220$ kg m/s

Step 2 : Use Newton's 2nd law to find 'F'.

$$F = \frac{\Delta p}{t} = \frac{2220}{10} = 222 \text{ N}$$

Newton's laws

Newton's 2nd law

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

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

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 !!

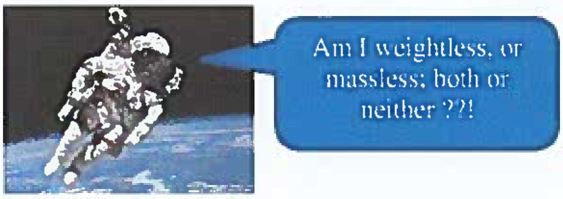
Mass does NOT depend on the location of the object, i.e. consider a 1 litre bottle of water – it has a mass of 1kg. If this bottle were taken to the surface of Mars, its **mass** would still be 1kg (as long as no water is taken out of the bottle !).

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 !

$$\boxed{W = m \times 10}$$

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

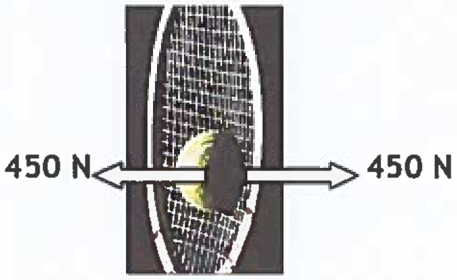
So, resultant force on the rocket = 75 – 25 = 50N (↑)

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

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 !

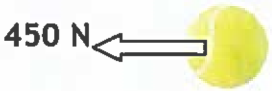


The racquet pushes the ball **forwards** with a force of 450N. Therefore, by Newton's 3rd law, the ball pushes the racquet **backwards** with an equal force.

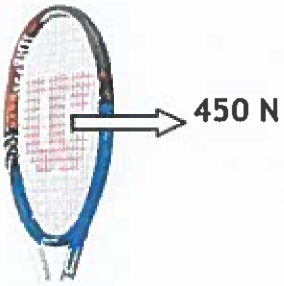
Note : one force is on the racquet, the other on the ball, so they don't 'cancel'.

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 :

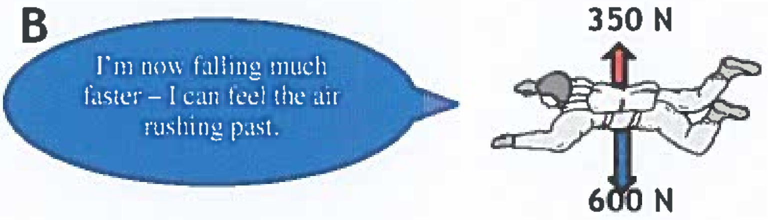


Note : Other forces like gravity and air-resistance have not been shown on these diagrams !

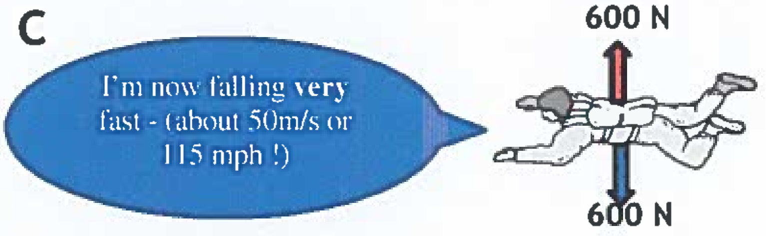
Applying Newton's laws

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.

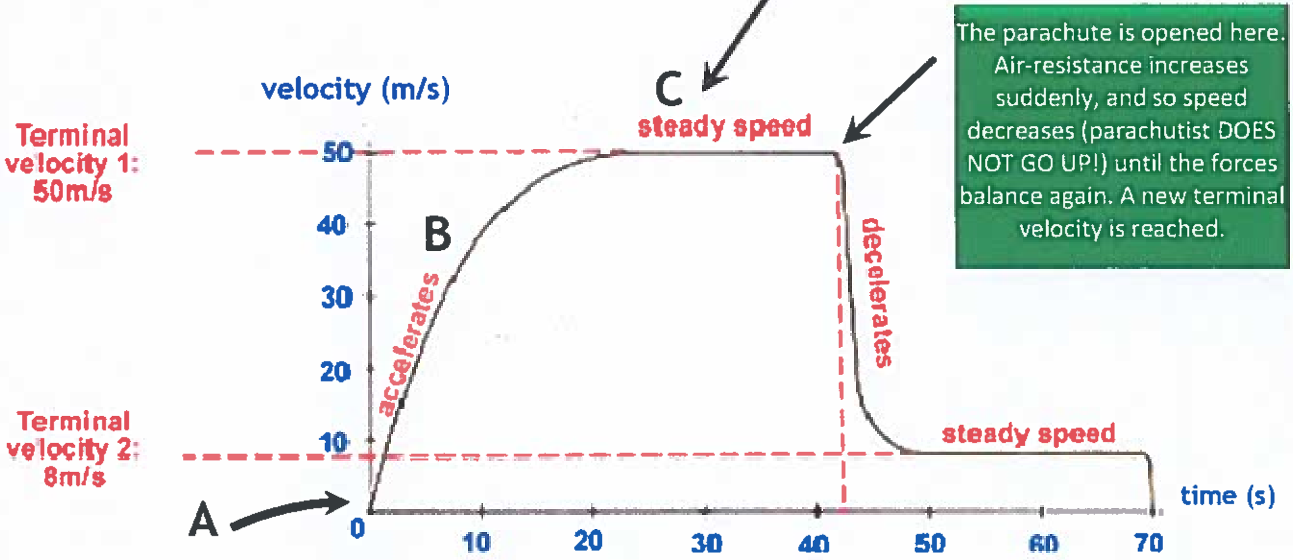


As the speed increases, so does the air-resistance. (The weight remains constant).Newton's 2nd law states that the skydiver will still **accelerate**, but not as much as before.



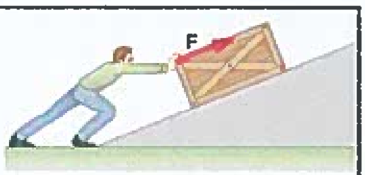
Eventually, the skydiver's speed is high enough such that the air-resistance is equal to the weight. Resultant force is zero, so zero acceleration. (Newton's 1st law) - **terminal velocity**

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 3 - Work done & Energy

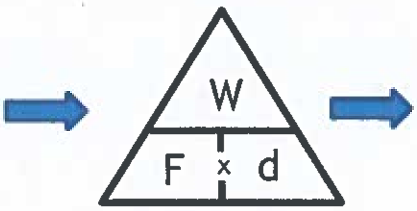
Work Done



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

$$\boxed{W = F \times d}$$



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

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

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

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

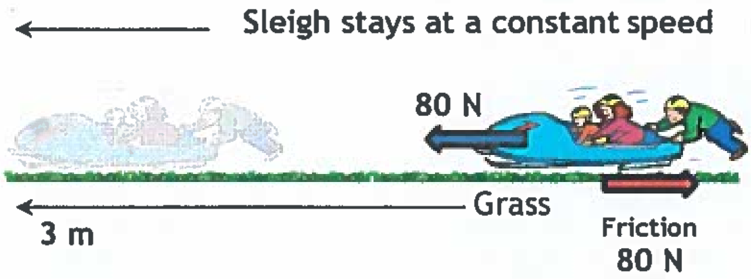
It's very important to remember the following fact :

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).



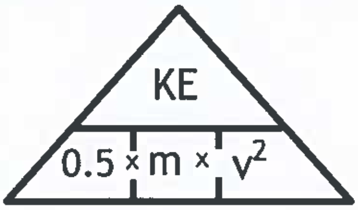
Work Done & Energy transfers

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 :

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



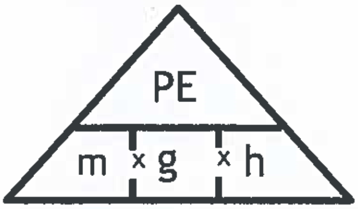
In order to find the speed of an object of known mass and KE, the above equation is re-arranged like this :

$$v = \sqrt{\frac{2\ KE}{m}} \quad \text{or} \quad v = \underbrace{\sqrt{\frac{KE}{0.5\ m}}}_{\text{Using the triangle}}$$

(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 :

$$\text{Change in potential energy} = \text{mass} \times \text{gravitational field strength} \times \text{change in height} \qquad PE = mgh$$



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

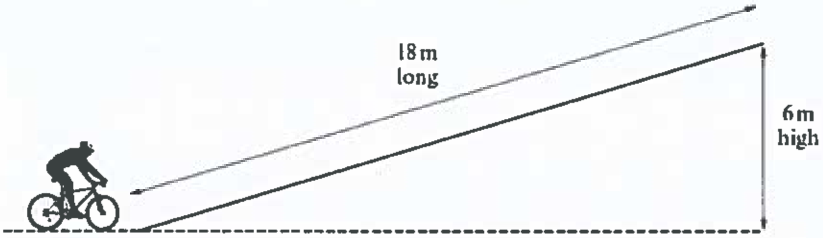
$$W = F \times d$$

Work Done & Energy transfers

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

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

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

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

(b) **Alternative method**

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

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

$\text{Friction} = W_{friction} / \text{distance} = 60$ 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 = $0.013\ m/s^2$

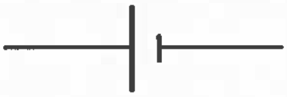
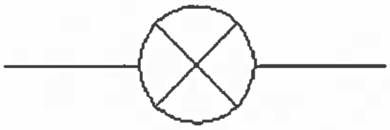
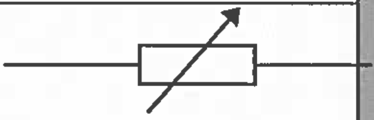
(b) (i) $W_{engine} = 3.84 \times 10^9$ J

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

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

Unit 4 - Electricity

Simple electrical circuits.

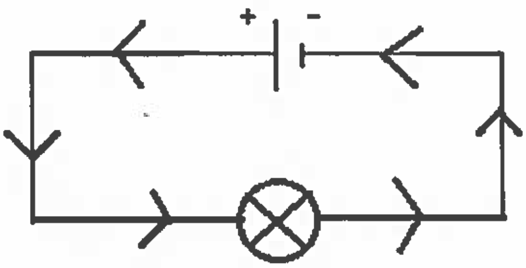
Device	Symbol	Device	Symbol
Wire		Cell / Battery	
Power Supply		Bulb	
Open switch (Off)		Closed switch (On)	
Diode		Resistor	
Variable resistor		Motor	

Electrical current (I)

Current is the flow of free electrons (negatively charged). As a comparison, think of measuring the amount of water flowing through a pipe.

- Current is described as a measure of the charge that flows past a point every second.

  It flows from + to − .



- Current is measured in **Amperes, A.**
- It is measured using an **Ammeter connected in series.**

Voltage (V)

Voltage is a measure of how much electrical energy a certain amount of electrons can transfer as they flow around a circuit. The higher the voltage, the more electrical energy is supplied to the circuit.

- Voltage is measured in **Volts, V**.
- It is measured using a **Voltmeter connected in parallel**.

Resistance (R)

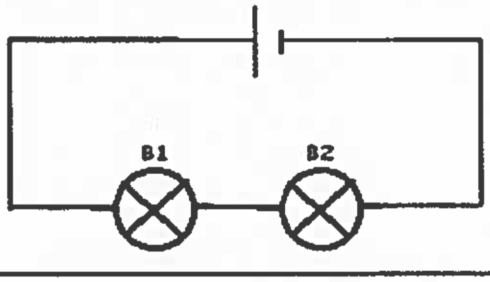
Resistance is a measure of how difficult it is for current to flow through a wire or device. More resistance means less current because it is more difficult for it to flow. Resistance is caused due to the collisions between the free electrons and the atoms/ions in the metal.

- Resistance is measured in **Ohms** - **Ω.**
- A thin wire has more resistance than a thick wire.

Name	Unit	Measured using	Symbol	Connected in...
Current	***Amps – A***	***Ammeter***		***Series***
Voltage	***Volts – V***	***Voltmeter***		***Parallel***
Resistance	***Ohms – Ω***			

Series and Parallel circuits.

Series circuit: in a series circuit there is only path and the bulbs (B1 and B2) in the diagram below are one after the other. If bulb B1 breaks then B2 will not work/go off.



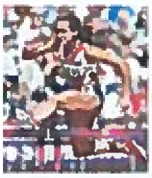
Momentum

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 $\quad$ p = m x v

$p = m \times v = 3\,000 \times 10$

$= 30\,000$ kgm/s



$p = m \times v = 70 \times 5$

$= 350$ kgm/s

Docked !!

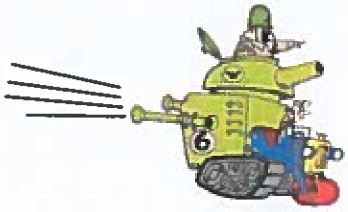
$p = m \times v = 50\,000\,000 \times 0$

$= 0$ (zero !) kgm/s

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 !

$$F = \frac{\Delta p}{t}$$ where Δp = change in momentum

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

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.

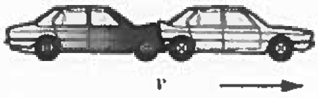
Before collision

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.

After collision



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 16000 N to the right on car **B**. What force does car **B** exert on car **A** during the collision? [2]

....

(b) 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

(a) (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)

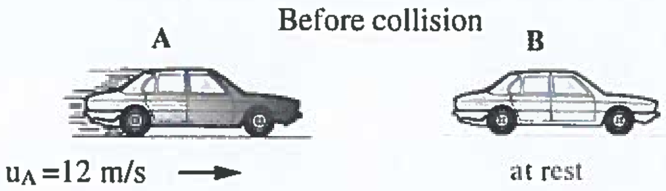
(b) (i) v = zero !!

(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,

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

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**

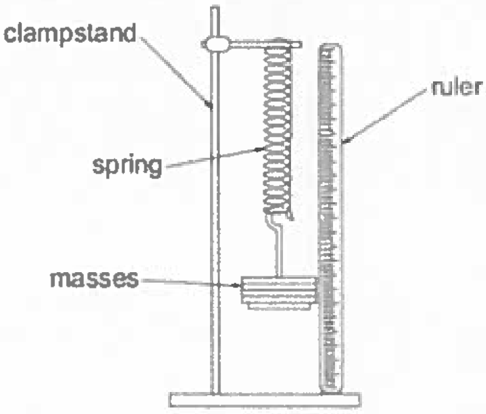
This shows that some KE is lost during the collision. Notice we do not take direction into consideration here since kinetic energy is NOT a vector.

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

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

Stretching Things: Hooke's Law

1. Stretching Springs:



Task A: The table below gives results from an experiment to find out how much a spring extends by, when different forces are applied to it.

Force/N	Total Length of Spring/cm				Mean Extension/cm
	Test 1	Test 2	Test 3	Mean	
0	4.0	4.1	3.9		
1	6.5	66.0	6.5		
2	9.2	9.0	9.2		
3	11.4	11.2	11.5		
4	14.0	13.8	11.2		
5	16.2	16.5	16.6		

1. Look for any anomalous results. Circle them and leave them out of any calculations.
2. Work out the mean total length of the spring for each force.
3. Complete the column for mean extension. (The extension is how much it has stretched by from its original length.)
4. Draw a graph to show these results. Extension goes on the x-axis, force on the y-axis. (This is back to front from what you should expect, don't worry, it's for this graph only!)

Task B: The next two tables show results from another two experiments. Two springs are used in each experiment. The way they are arranged is shown next to each table.

Two springs in series

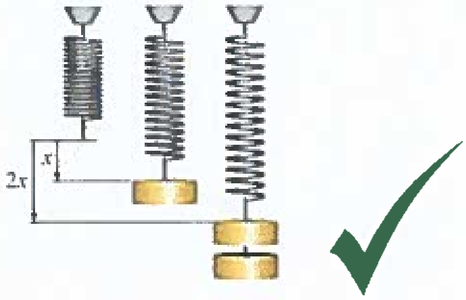
Force/N	Extension/cm
0	4.0
1	9.1
2	13.9
3	19.0
4	24.2
5	29.3

Two springs in parallel

Force/N	Extension/cm
0	4.0
1	5.2
2	6.5
3	7.8
4	9.0
5	10.3

5. Draw *one* graph to show *both* sets of results.
6. Write a conclusion to compare how much springs in series stretch compared to springs in parallel.

The Spring Constant.



The ***spring constant*** has got nothing to do with lambs gambolling!

It tells us how much a spring of a particular type will extend by for every 1N of force that's applied to it.
Every spring of the same type will have the same ***spring constant***.
But springs of a different type have different ***spring constant.***
The ***spring constant*** depends on the material the spring is made from, the thickness of the metal, etc.

The *spring constant* is often just written as *k*.

('Cause it's an awful lot easier!)

Using the spring constant (*k*):

Force* = *spring constant* x *extension

Newtons (N)

Newtons per metre (N/m)

metres (m)

$$F = kx$$

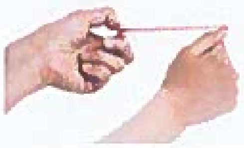
Tasks:

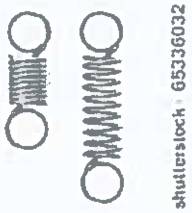
1. A spring has a spring constant of 5N/m. What force is needed to stretch it by 0.02m?

2. An ***open wound*** spring can be compressed or stretched.
a). ***Calculate*** it's extension when a force of 120N is applied, if it has a spring constant of 480N/m.
b). ***Describe*** what would happen if the direction of the force was reversed. *(you must give a magnitude as part of your answer).* No calculations are necessary.

3. During an experiment a large spring is found to extend 7.5cm when a force of 30kN is applied.
a). ***Calculate*** the spring constant for this particular type of spring.
b). How much would the spring extend by is a force of 90 000N was applied? Justify your answer.

Elastic Energy





When a force is applied to any ***elastic object*** (e.g. a spring, or a rubber band), the object ***deforms*** (stretches or changes shape). When the force is removed, the object goes back to its original size and shape.

When we use a force to stretch an ***elastic object***, ***elastic energy*** is stored.

How much elastic energy?

1. **Calculation:** This is based on the fact that work is done when something is stretched. (Don't worry about the ½, it's ***got*** to be there in this calculation, but you don't need to explain why).

Work = ½ x Force applied x extension

Joules (J) *Newtons (N)* *metres (m)*

$$W = Fx.$$

a). A spring is stretched from 6.0 cm to 15.0 cm. A maximum force of 25N is needed.
(i) ***Calculate*** the work done in stretching the spring (remember to calculate *extension* first, and change cm to m). [4]

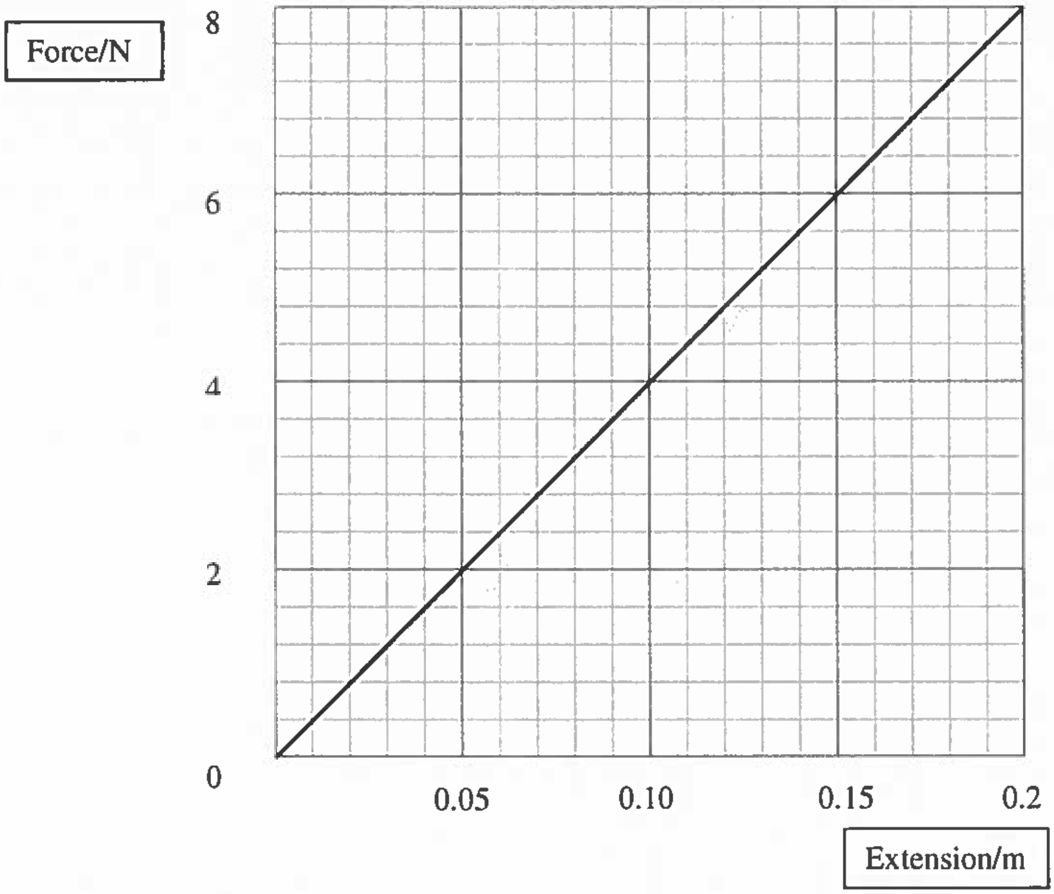
(ii) ***State*** the elastic energy that is now stored in the spring. [1]

b). A rubber ball is compressed 1.5cm when a 7N force is applied.

(i) ***Calculate*** the work done compressing the ball.

(ii) ***State*** the elastic energy that will be released by the ball when it goes back to its original shape.

2. **Graphs:** The elastic energy stored when an object is deformed (and, therefore, the ***work done*** in deforming it) can be worked out from the ***area under the force/extension (F/x) graph***).



a). The graph above is a Force/extension (F/*x*) graph for a metal spring.

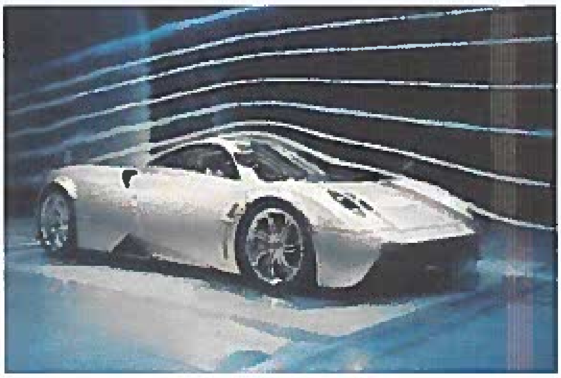
(i). Find the area under the graph for an extension of 15cm. You ***must*** show how you do this on the graph.
(ii). ***State*** the elastic energy stored in the spring.
(iii). ***State*** the work done stretching the spring by 15cm.
(iv). Use W = ½F*x* to check your answer.

Energy Efficiency ~ Vehicle Design (1)

Tyre pressure: Road bikes, including those used by Chris Froome in the Tour de France, have really high tyre pressures so the tyres are really, really hard and don't deform much as they are being ridden. Tyre pressures are often measured in ***Bars***. A road bike tyre may be blown up to nearly 9.0 bar. A car tyre, however, may only be inflated to less than 3.0 bar. This means that the car tyre deforms much more. The friction between the rubber molecules in the tyre wastes lots of heat energy. Try touching the tyres of a car after it's been on a long journey *(wait till it's stopped first).*

Inertial Energy losses: The greater any objects inertia is, the more force (and energy) that's needed to change its motion (speed up, slow down, change direction). The more mass any object has, the greater its inertia. That's why it's harder to push a bus out of the way than a tennis ball! Racing cars are designed to be as light as possible (low mass) so that their inertia is as low as possible.

All sorts of cutting edge technology is used to achieve this. Body panels are made from very low density composite materials. Engines are made from expensive metal alloys that are strong, resistant to high temperatures, but very light.



Streamlining: Vehicles that are designed to travel fast are ***streamlined.*** This is also known as being ***aerodynamic.*** Aerodynamic vehicles have a very low ***air resistance***. This means less of the engine's ***thrust force*** is used overcoming ***drag/air resistance***. This picture shows how air particles pass easily over an aerodynamic shape. Very few particles strike the car. Since less force is needed to overcome drag, less energy is wasted.

Stop – start systems: When an electric car stops at traffic lights, or in a traffic jam, the electric motor doesn't turn and so it doesn't use up any energy. Petrol, diesel and gas powered cars are not like this. If the engine is running, it's using energy. To help avoid this, some modern cars are fitted with automated ***start-stop systems.*** These use sensors to detect when the car has stopped moving and the car's on-board computer switches off the engine. When the driver is ready to move off, all the need to do is press the accelerator – the car does the rest. A running engine ***transfers*** the ***chemical energy*** stored in its fuel into ***thermal*** and ***sound energy***, as well as the ***kinetic energy*** we really want.

Energy Efficiency ~ Vehicle Design (2)

TASK: Each of the three examples shown below have at least one design feature that will either save energy, or waste it.
For each vehicle say; **a)** what the feature is,
b) use sheet 1 to help you ***explain*** how energy is saved, or wasted.

1. An Argocat is designed to cross very difficult, very soft ground. To achieve this it has very, very soft tyres. Each of its eight tyres are blown up to only 0.2 Bar (At the very most). A normal car tyre will be inflated to about 2.8 Bar (14 times higher). If an argocat ran over your foot, you probably wouldn't notice it. A car doing the same would probably put you in hospital!

2. Modern lorries: The articulated lorry (artic) on the left is modern. The one shown on the right was common about 40 years ago.

3. Bicycle frames: Over the years, bicycle designers have made use of new materials which are lighter ***(lower density)*** and ***stronger*** than the steel from which older bikes were made. This means that a modern bike may be less than half the weight of a bike from the 1950's.

P2.4(d) ~ Equations of Motion

We can describe the motion of any object by considering 5 variables:

Variable	symbol	SI unit
displacement	x	m
initial velocity	u	m/s
final velocity	v	m/s
acceleration	a	m/s^2
time	t	s

*(displacement is sometimes given the symbol "s", so the equations below are often known as "**suvat**" equations).*

Foundation

$$v = u + at$$

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

Higher

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

$$v^2 = u^2 + 2ax$$

Example:

A ball is dropped vertically off a high cliff. It falls under gravity for 15s. Calculate it's final velocity.

Notes: ***(i) In any questions involving objects falling vertically, acceleration (a) will always be $\underline{10\ m/s^2}$***
(ii) We will always ignore the effect of air resistance, friction, etc.

Step 1: **Data list**

x = ?
u = 0 m/s (the ball is not moving vertically at the start)
v = ? (this is what we are asked to find)
$a = 10\ m/s^2$
t = 15s

Step 2: **Choose the best equation to use.** Match up the data we have with the equations. We want to be able to fill in values for all the variables except the one we're calculating.
For this problem, we know *u, a and t and need to calculate v.*

$$v = u + at$$

Step 3: **Substitution, solution and units:** From the information in our data list.

$$v = 0\ m/s + 10\ m/s^2 \times 15s$$

$$\underline{= 150\ m/s}$$

P2.4(d) ~ Equations of Motion: Tasks (F)

$F = ma$ $\qquad v = u + at$ $\qquad x = ut + ½at^2$

$$x = \frac{u + v}{2} t \qquad v^2 = u^2 + 2ax$$

Use the equations above to answer the following questions:

1. A train of total mass 15 000 kg decelerates from a maximum speed of 12 m/s to 2 m/s, in a time of 80 s.

a) How far does the train travel while it is slowing down?

b) The driver said that the train decelerated at a rate of 0.125 m/s^2. Are they correct? Put this value into one of the equations above to see if the driver has worked out acceleration correctly. (*Remember, deceleration has a negative value).* Show all your working.

2. A ball is thrown vertically upwards at a speed of 20 m/s. For an instant, it will be stationary at the highest point it reaches before it comes back down.

a) What will the balls maximum height be if it takes 2 s to reach its highest point?

b) Now think about the ball falling back to the ground. Calculate the balls maximum speed just before it hits the ground. *Remember, it is stationary at the top and it will take exactly the same time to come back down as it took to go up.*

3. A skateboarder speeds up as they come down a long slope. They are moving at 2 m/s just before they hit the slope.

a) How fast will they be moving at the bottom if it takes 3 s to get there and they accelerate at 0.5 m/s^2 for the whole time?

b) Calculate the length of the slope.

4. To take off from the deck of an aircraft carrier, a jet aircraft accelerates from rest along the deck at 32 m/s^2 for 2.5 s to attain its take-off speed. **Calculate;**

a) The take-off speed, *v*

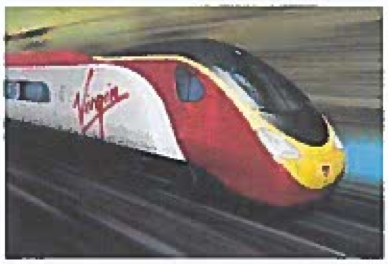
b) the length of the deck, *x*, required for the jet to take off.

P2.4(d) ~ Equations of Motion: Tasks (H)

$F = ma$ $v = u + at$ $x = ut + \frac{1}{2}at^2$

$$x = \frac{u + v}{2}t \qquad v^2 = u^2 + 2ax$$

1. A train is travelling at 50 m/s when the driver applies the brakes and gives the train a constant acceleration of -0.5 m/s^2 for 100 s. Describe what happens to the train and find out how far it travels in the 100 s.



2.

A motorway designer can assume that cars approaching a motorway enter a slip road with a velocity of 10 m/s and need to reach a velocity of 30 m/s before joining the motorway. If an acceleration of 4 m/s^2 is assumed, how long should the slip road be?

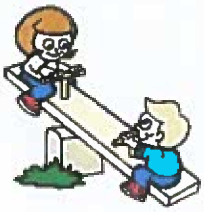
3. During the NASA (American) moon missions, a *lunar module* was used to transport astronauts to the moon's surface. During the descent *retrorockets* were used to keep the modules speed to 1.5 m/s. Three seconds before landing, the *retrorockets* were switched off and the lunar module fell to the surface with an acceleration of 1.6 m/s^2. (Gravitational field strength is much lower on the moon, so acceleration due to gravity is also much less).

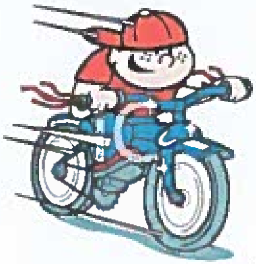
a) Select a suitable equation and use it to show that the lunar module was 11.7 m above the moon's surface when the retrorockets were switched off. [3]

3 **b)** Copy and complete the table and draw a graph to show how the height of the lunar module changes in the last 3 seconds of its motion. [4]

Time after rockets switched off/s	0.0	1.0	2.0	3.0
Distance moved by lunar module towards moon's surface/m	0.0			11.7
Height above the surface/m	11.7			0.0

Moments (Turning Forces)





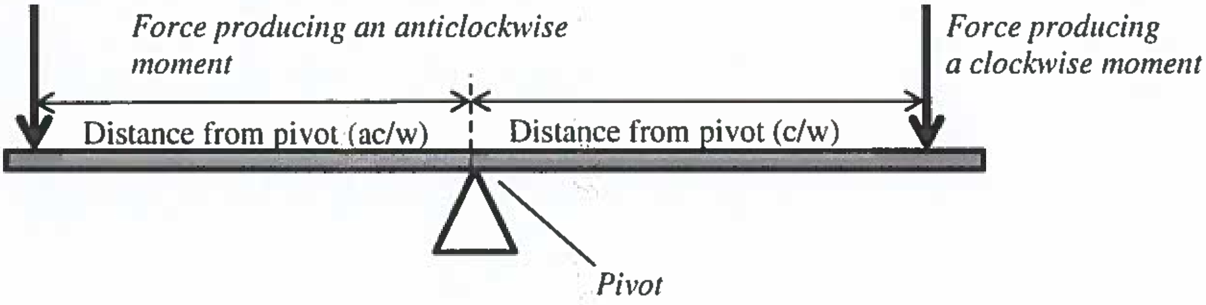
*A **moment** is a "turning force", (i.e. a force that makes something rotate). There are examples everywhere we look.*

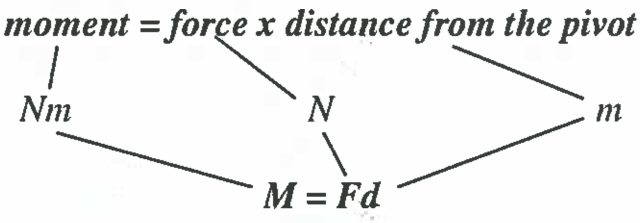
*The size (magnitude) of a **moment** depends on the size of the force and the distance of the force from the **pivot** (or fulcrum)*

***Moments** can be **clockwise (c/w)** or **anticlockwise (ac/w)** in direction.*

*The **effort force** is the force we apply.*

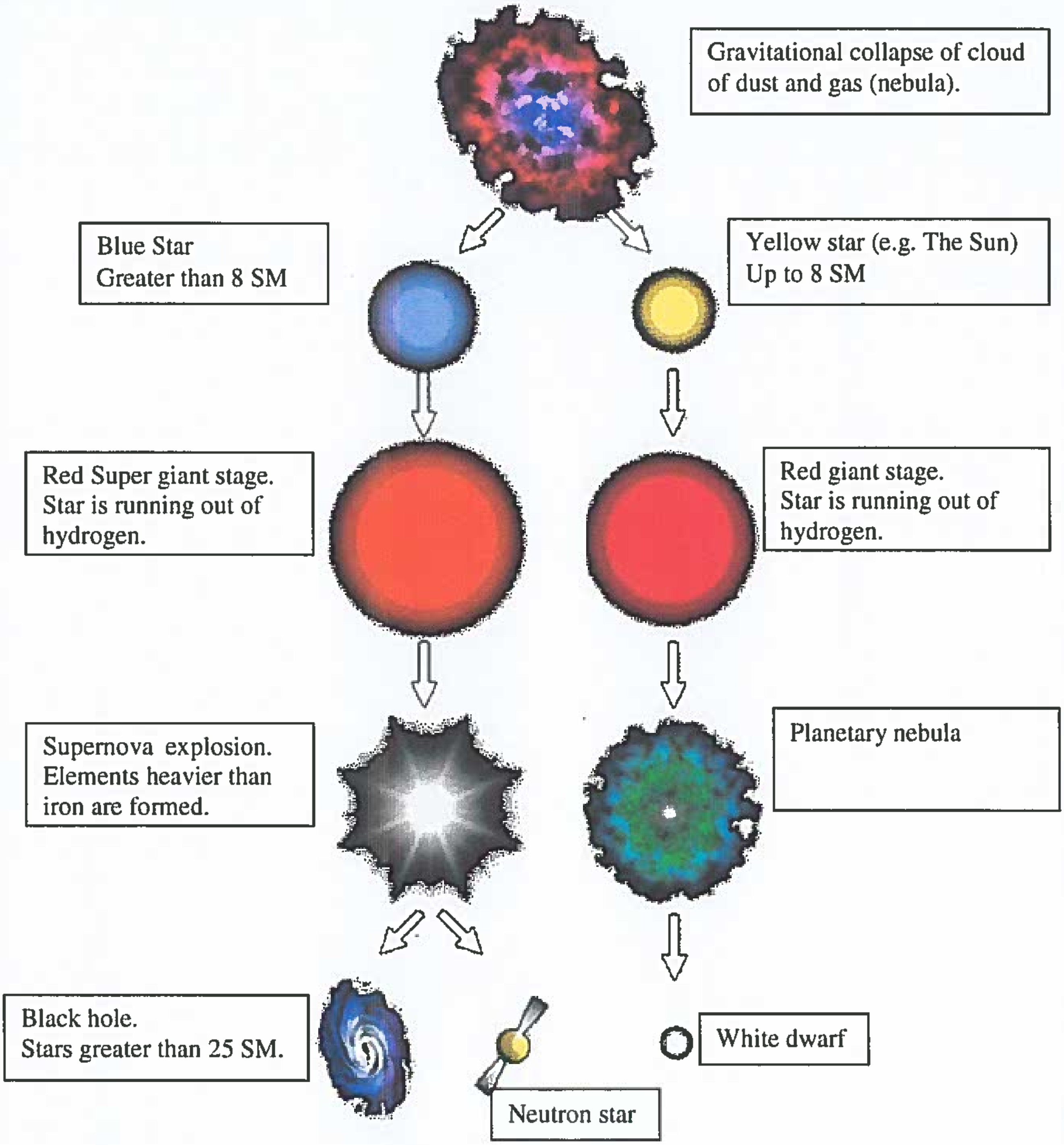
*The **load** is the effect of the thing we're trying to make turn.*





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 long lifetimes. They are main sequence stars.

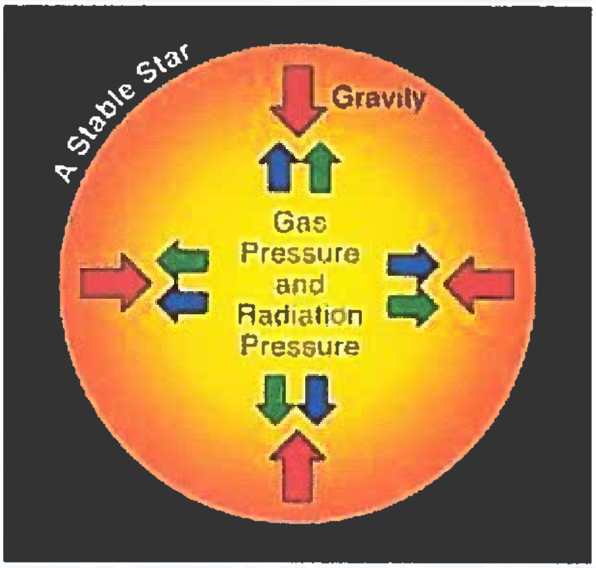
There are 2 forces at acting inside a star.

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.

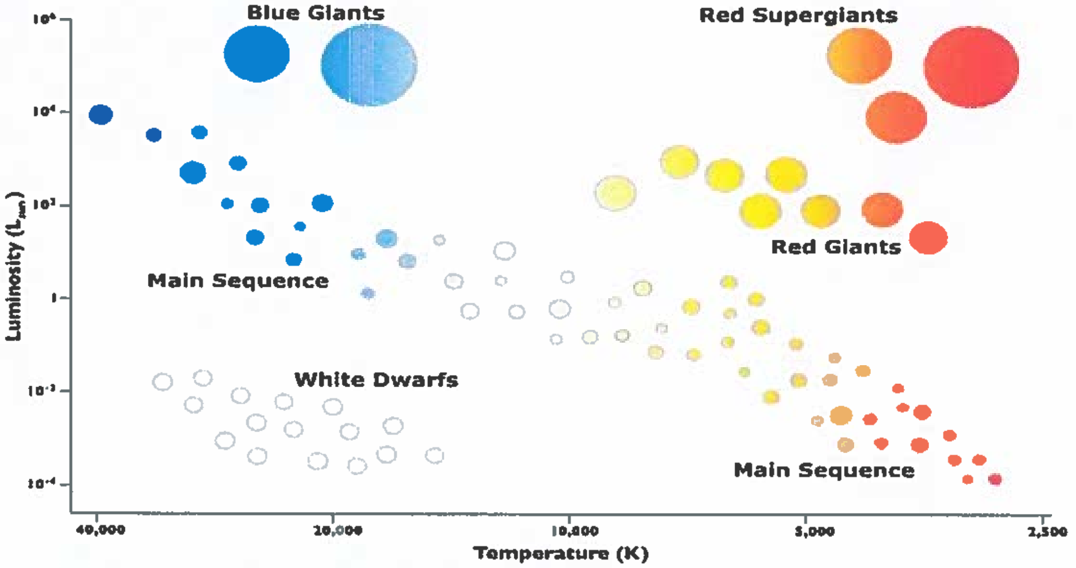


For most of the life of a star it is in a stable state in which the inward force of gravity on any part of the star is balanced (equal) by a force due to the increasing pressure towards the centre.

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 star smaller. If the pressure increases, the star will ***expand***.

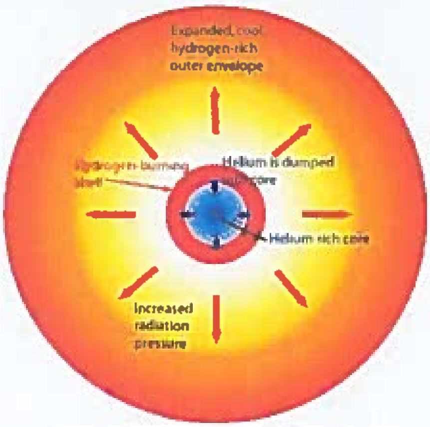
Main sequence stars.

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.



End of main sequence stage.

Once a star has exhausted (run out) of its supply of hydrogen it will swell up into a red giant. The temperature of the star 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 has begun and the temperature increases once again resulting in an increase in gas and radiation pressure.



Hydrogen Shell Burning on the Red Giant Branch

In 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/starlife_main.html

Nuclear fusion

All **main sequence stars** generate their energy by the fusion of hydrogen to helium, according to the equation (remember):

$$\underset{\text{Hydrogen}}{4\ {}_{1}} \longrightarrow \underset{\text{Helium}}{{}^{4}_{2}He} + \underset{\text{Positron}}{2\ {}^{0}_{1}e}$$

A and Z numbers on left and right hand side are balanced.

Left: total A = 4 x 1 = 4 | Right: total A= 4 + (2 x 0) = 4

total Z = 4 x 1 = 4 | total Z = 2 + (2 x 1) = 4

A positron is the antiparticle of an electron. When a particle and its corresponding particle meet they annihilate one another releasing a large amount of energy. Therefore when a positron is created during fusion it meets an electron and is annihilated.

Nuclear fusion

Other fusion reactions occur in stars.

$${}^{3}_{2}He \qquad {}^{3}_{2}He \longrightarrow {}^{4}_{2}He + 2\,{}^{A}_{Z}X$$

A=1 Z=1

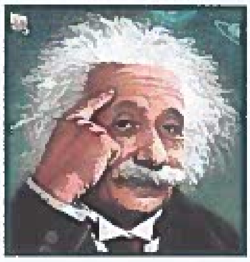
+

Determine the value of A and Z.

$${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{A}_{Z}X + \gamma \text{ (gamma ray)}$$

A=3 Z=2

Determine the value of A and Z.

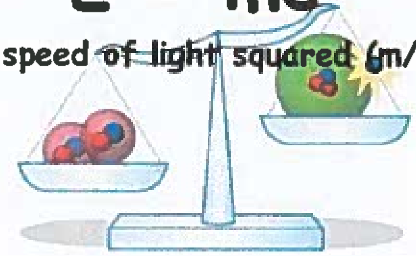


Why is energy released during fusion?

Look at the last equation showing the fusion of hydrogen and deuterium. The total mass of the helium formed is less than the mass of the 2 hydrogen isotopes and **that mass is converted into energy**. A famous scientist (Albert Einstein) predicted this to be true and gave one of the most famous of equations:

$$\mathbf{E = mc^2}$$

Energy (J) = mass (kg) x speed of light squared (m/s) (300,000,000 m/s or 3x10^8)



Question 1. When 1kg of coal is burnt 3x10^{7}J of energy is released. Calculate the mass lost.

$$E = mc^2 \qquad \text{rearrange formula} \quad m = \frac{E}{c^2} \qquad m = \frac{3 \times 10^7}{(3\text{x}10^8)^2} = 3.33\text{x}10^{-10}\text{ kg}$$

As you can see this is a very small mass so it is ***negligible/insignificant***.

Question 2. Calculate the mass loss per second from the Sun given that its energy output is 4×10^{26} W and the speed of light is 3x10^8 m/s.

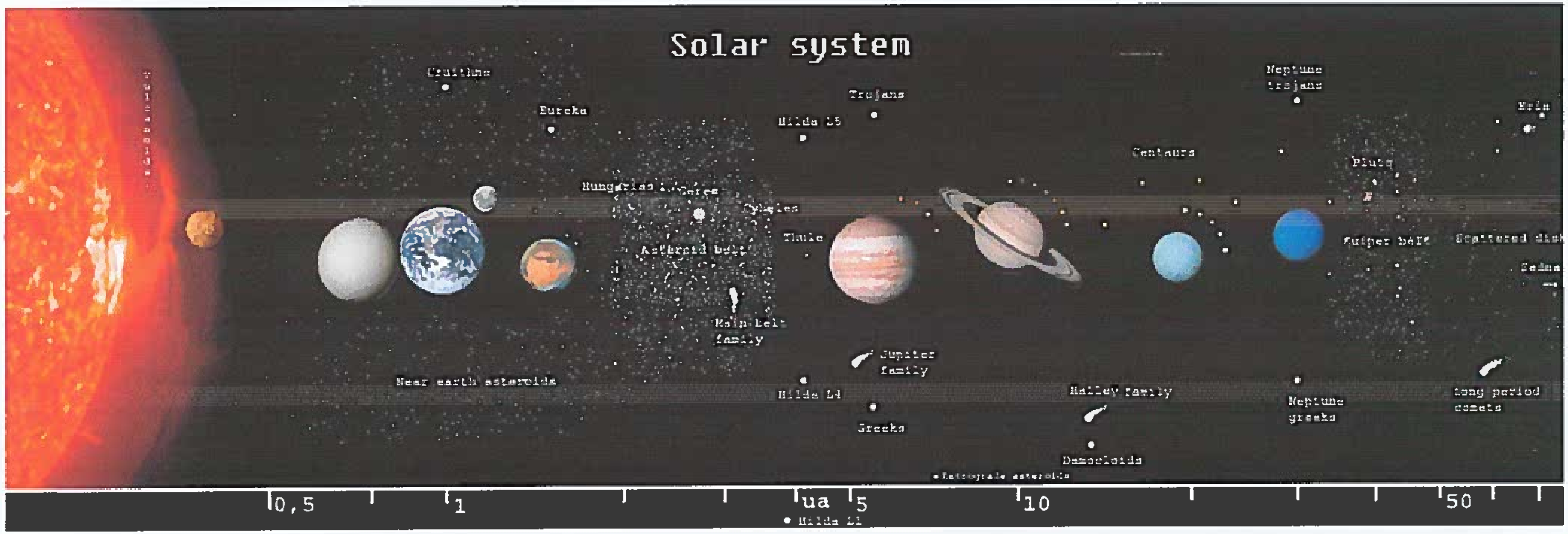
The first step is to realise that power is energy transferred per second. So the energy transferred from mass into energy per second is 4 ×10^{26} J. Now we must calculate how much mass this is equivalent to.

$$E = mc^2 \qquad \text{rearrange formula} \quad m = \frac{E}{c^2} \qquad m = \frac{4 \times 10^{26}}{(3\text{x}10^8)^2} = 4.44\text{x}10^9\text{ kg}$$

Nuclear fusion

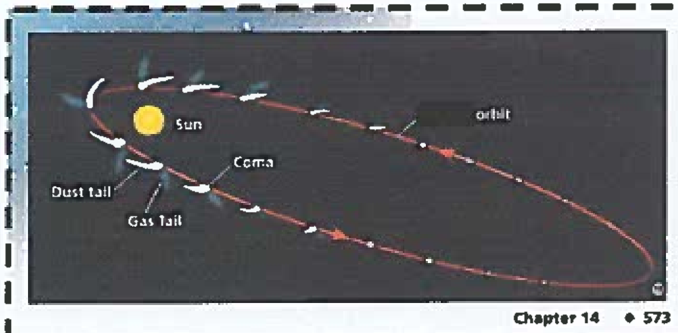
This means that the sun is losing ***4.4 million tonnes a second***!!!!!!!!!!!

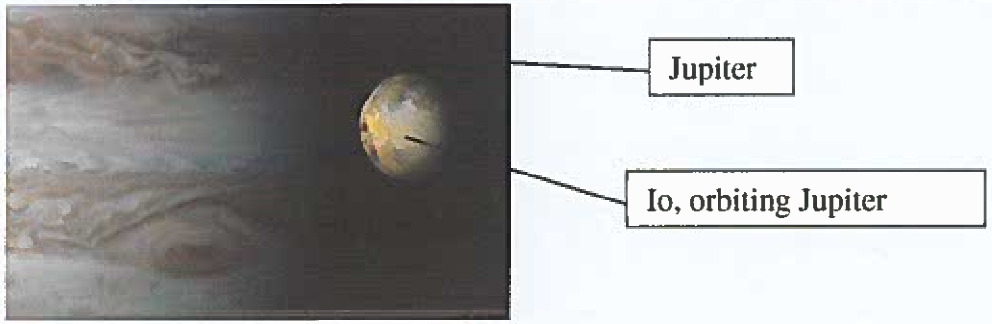
P6.4 (a) ~ Our Solar System:

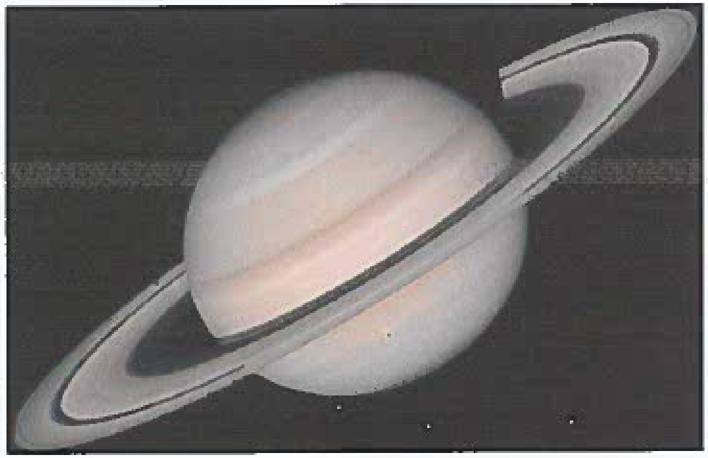


- Our solar system is made up of ***a star*** (the Sun) and many, many much smaller objects which ***orbit*** it.
- The ***inner planets,*** Mercury, Venus, Earth and Mars have solid, rocky surfaces. They are called ***terrestrial planets.***
- The ***outer planets,*** Jupiter, Saturn, Neptune and Uranus are ***Gas Giants.***
- Pluto is no longer classed as a planet. It is now grouped with lots of other smaller ***dwarf planets.***
- Some planets, like the Earth and Jupiter have ***moons***, much smaller, rocky spheres, which orbit them. ***Moons orbit a planet,*** They don't orbit the Sun.
- Between Mars and Jupiter lies the ***asteroid belt***, a ring of rocky fragments from dust sized right up to hundreds of kilometres across. These are thought to be the remains of two planets which collided when the Solar System was first being formed.
- ***Comets*** balls of rock and ice with *fiery tails,* which also orbit the Sun. The have a very ***elliptical*** (squashed) orbit. They fly in very close to the Sun before disappearing off out into the furthest reaches of the Solar System. Their orbits can take hundreds of years.

P6.4 (a) ~ Our Solar System (b):







Cut out each of the pictures and labels.

Match them up and stick them in your book.

Under each one, write at least one fact about it.

A moon

A terrestrial planet

A comet

A Gas Giant

An asteroid

A dwarf planet

P2.6.4(b) ~ Distances in Space

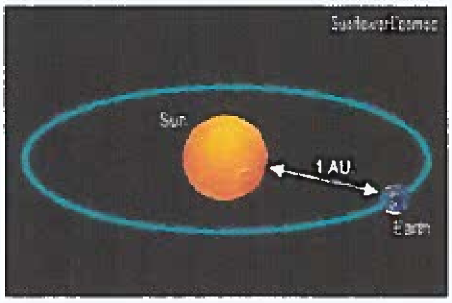
We measure distances on Earth using metres (m) and kilometres (km).

But space is ***Huge!*** Metres and kilometres are just too small to be useful.

You need to know about different units we use to measure distances in space.

Astronomical Units (A.U.).

The astronomical unit (A.U.) is dead simple, **1 A.U. is the *mean* distance from the Earth to the Sun.**

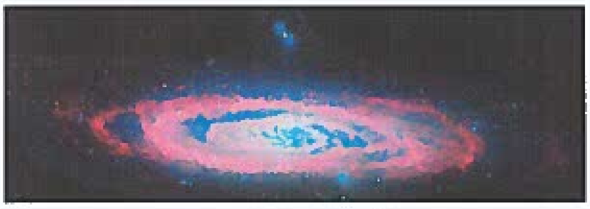


So 10 A.U. is just 10 times the distance from the Earth to the Sun.

But the Earth isn't always the same distance from the Sun – that's why we use the ***mean*** (average) distance.

1 A.U. is about 1.5 x 10^{11}m. So It's pretty big. *(You don't need to remember this).*

Light Years (l.y.).



The light year is also simple. **1 light year is the distance light can travel in one year.**

Light travels at 300 000 000 m/s (3.0 x 10^8 m/s), so a light year is ***really*** big! The Milky Way galaxy is so big it takes 100 000 years for light to cross it.

We can also use ***light minutes*** or ***light seconds***. The Sun is 8.3 light minutes from the Earth.

Task:

1. What is an Astronomical Unit?

2. What is a light year?

3. What are **(a)** light minutes and **(b)** light seconds?

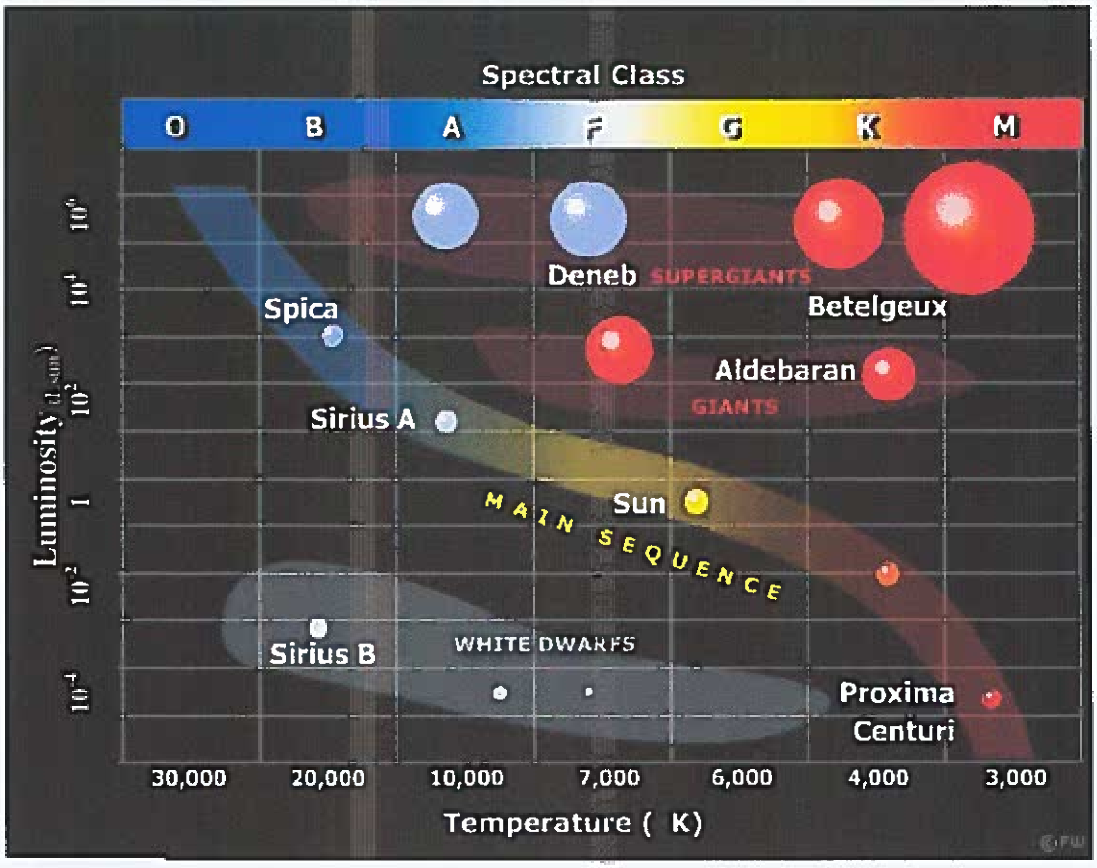
4. How many light minutes is 1 A.U. ? You don't have to do any calculations, the answers in the information above.

5. How many metres are in **(a)** 1 light second, **(b)** 1 light minute and **(c)** 1 light year?

(1 minute = 60s, 1hour = 60min, 1 day = 24h, 1 year = 365.25 days)

6. Using information from above, ***calculate*** **(a)** the distance across the Milky Way and **(b)** the size of 1 A.U. ***Give your answers in m.***

P2.6.4(g) Hertzprung-Russell Diagram (Higher)



***Don't** try to memorize this diagram!!!!*

This diagram looks fiendishly complicated, at first glance. But, with a bit of thought, it's dead easy!

Follow these simple steps:

1. Find the different ***classes of stars*** on the diagram (Red Super Giants, Blue Super Giants, Main Sequence, etc). You should find 5 on this diagram.

2. Look for names of specific stars (e.g., Sun, Sirius B). These are just there as examples.

3. Look at the scales on each axis. (Luminosity is another name for brightness). These are not ***linear scales,*** equal divisions are not worth the same. *N.B. the temperature scale on the x axis is going down as you look left to right.*

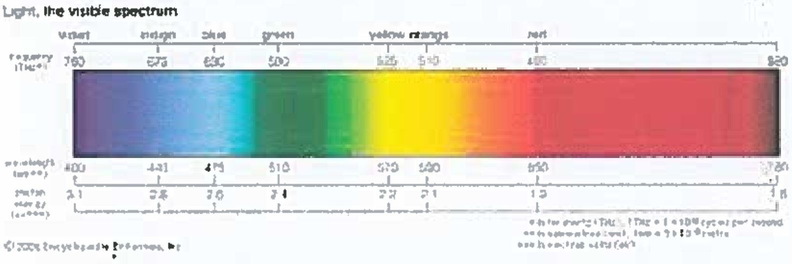
Now answer these questions:

a) *Name 2 main sequence stars that are (i) brighter and (ii) dimmer than the Sun*
b) *What other factor can be applied to the stars you names in **a**)?*
c) *Which star is given a luminosity value of 1?*
d) *How many times brighter than the Sun is Betelgeux (Beetle-juice)?*
e) *Which category of stars, in general, have a lower luminosity than main sequence stars?*
f) *Which main sequence star is an exception to this rule?*
g) *Are blue stars hotter or colder than red stars?*
h) *Where do you think yellow stars, like the Sun, go in this temperature sequence?*

P2.6(a -d) ~ “*Big Bang*” The Evidence

Emission and Absorption Spectra:

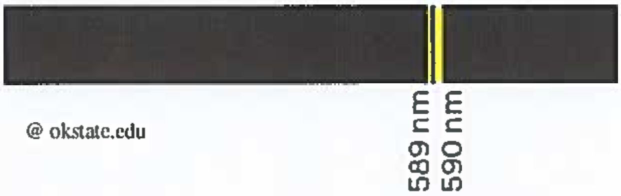
We are used to seeing the visible spectrum as a solid block of 9 colours, all merging into each other. These colours are produced when atoms of lots of different elements are heated up to high temperatures. But atoms of a specific element, e.g. hydrogen, only give out certain wavelengths (and, therefore, colours). These are called ***emission spectra*** *(emit, to give out).*



Emission Spectrum of hydrogen:

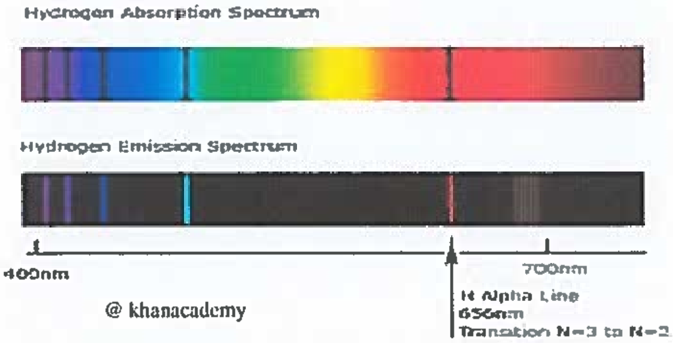
@ Quora.com

Emission Spectrum of sodium:



@ okstate.edu

But, when light from the whole of the visible spectrum (all the colours) is shone through vaporized atoms of the same elements, the ***absorb*** exactly the same wavelengths as the emit. This gives ***absorption spectra.*** These are unique to individual elements and can be used to tell which elements are present in the outer layers of a star.



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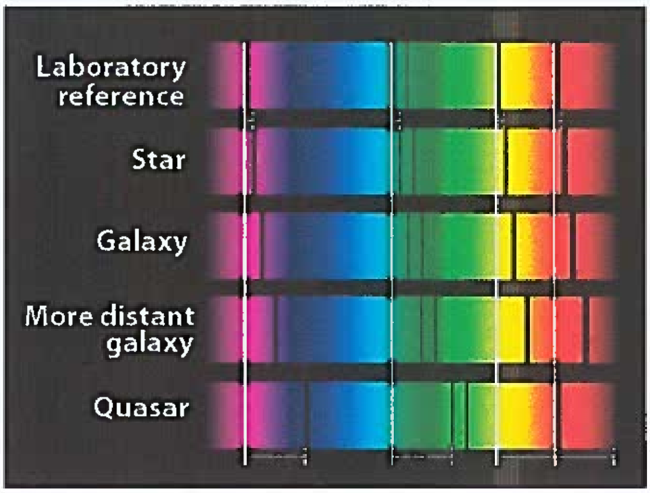
Hydrogen is by far the most common material in stars.

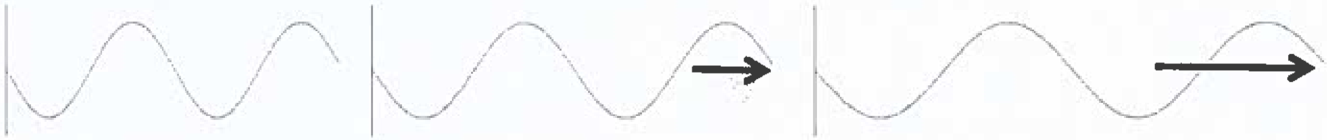
Cosmic Red Shift :

Galaxies are clusters of billions of stars, so they emit lots of light. Very distant individual stars cannot be seen, but the galaxies they belong to can. When astronomers compare light from galaxies close to us with light from a distant galaxy, the ***absorption spectra*** for specific elements is moved towards the red end of the spectrum. This is known as ***Cosmic Red Shift.*** This was originally observed by ***Edwin Hubble.***

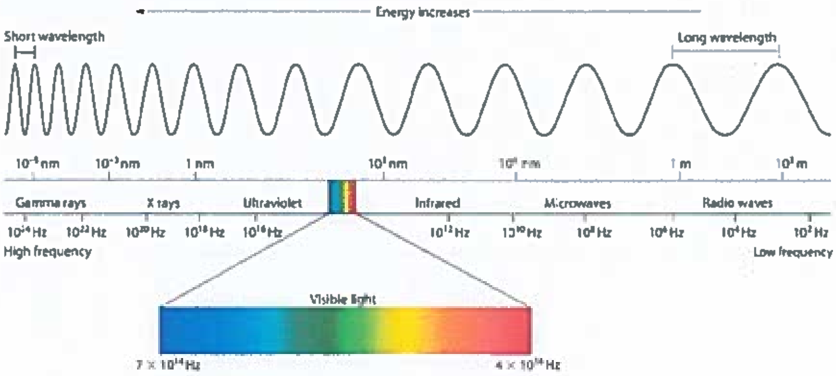


Cosmic Red Shift is very strong evidence that the Universe is expanding out from a central point, the site of the ***"Big Bang".*** Red shift is observed equally in all directions. The only thing that affects it is how far away the stars and galaxies are.

Light is Red Shifted because it is travelling through Space that is expanding (stretching). The light waves get stretched along with the Space



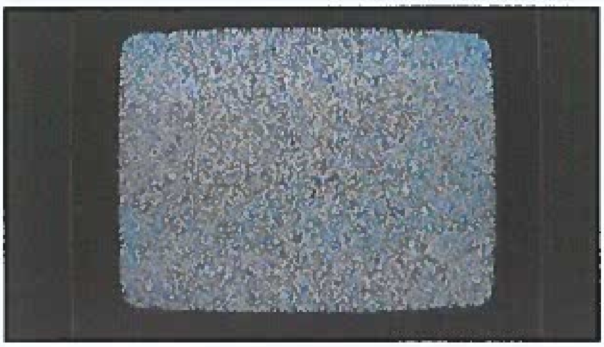
The electromagnetic spectrum:



The further the light waves have travelled through Space, the more they get stretched. This means their wavelength gets longer and longer. This works for all light, whether it's visible or not.

Gamma (γ) rays have very short wavelengths, but some γ rays have been travelling so long, they have been stretched to the point where they have the same wavelength as microwaves – right through the visible spectrum and out the other end!!

Cosmic Microwave Radiation (CMBR):

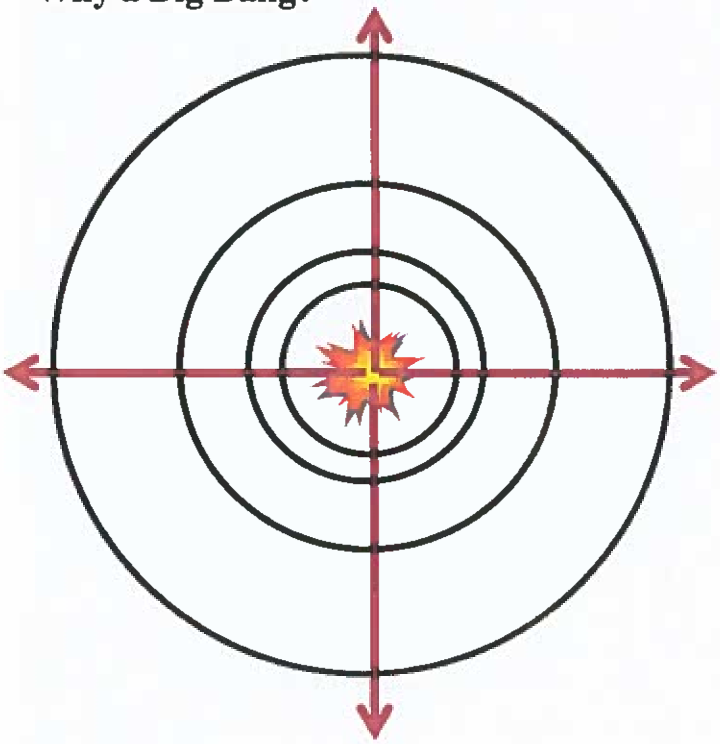


If you've ever tried to manually tune a t.v. or radio, you'll know all about the hissing noise coming out of the loudspeakers and the "snowstorm" on the screen. These are caused by a jumble of radio waves coming from all sorts of sources, including from space. It's been estimated that about 1% of these radiowaves are actually what's left of high energy γ rays released during the ***Big Bang***!

These waves have been travelling for so long through expanding space they have been stretched from the wavelength of γ rays to that of microwaves. *(Remember, microwaves are a type of radiowave).*

The fact that CMBR started off as γ rays is important, it's evidence that enormous amounts of energy was involved, supporting the ***<u>Hot</u> Big Bang theory.***

Why a Big Bang?



Remember, Red shift is seen equally in all directions and the further away a galaxy or star is, the faster it's travelling.(It has a greater ***recession velocity)***

CMBR is also constant in all directions, it doesn't come from one source that exists today. It comes from everywhere!

This is evidence for one enormous explosion that started started off the Universe. Ever since then, everything has been accelerating outwards, equally in all directions.

Exactly as you get after any explosion.

The *"Big Crunch"?*

Gravitational forces act on the Universe, just like on any object with a mass.

What do you think might happen if these forces overcome the forces causing the expansion of the Universe?

P2.6(a -d) ~ "*Big Bang*" Tasks

1. What is CMB Radiation?

2. The Universe is about 13.722 billion years old. (1.3772×10^{10} years). Why have the high energy γ rays produced by the big bang changed?

3. What does the fact that γ rays were released tell us about the Big Bang.

4. What is an absorption spectrum? What does it tell us about the gases in the atmosphere of a star.

5. **Decribe** and **explain** *Cosmic Red Shift*. Use diagrams to help.

6. What 2 things does Cosmic Red Shift tells us about stars and galaxies in the Universe. Use the expression ***recession velocity*** in your answer.

7. Suggest and describe one possible fate of the Universe, after reading **The Big Crunch.** Include *where* you think this will happen in your answer.

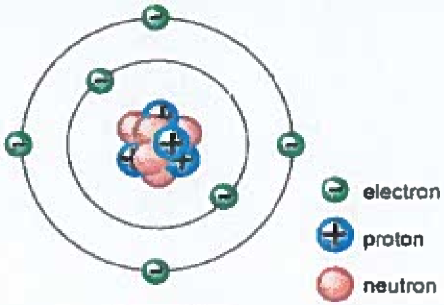
8. What evidence supports the theory that distant galaxies have the greatest recession velocity?

9. Which scientist's work on measuring the spectra of distant galaxies originally revealed the red shift?

Unit 5 - Nuclear Physics

Nuclear physics.

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



Carbon atom

The atom consists of:

6 protons

6 neutrons

6 electrons

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.

$$\boxed{N = A - Z}$$

Example: $^{7}_{3}Li$

Number of protons = 3

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

Try the following examples.

Element	Proton (Z) number	Nucleon (A) number	Number of protons	Number of neutrons, N
Hydrogen	1	1		
Iron	26	56		
Uranium	92	235		

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.

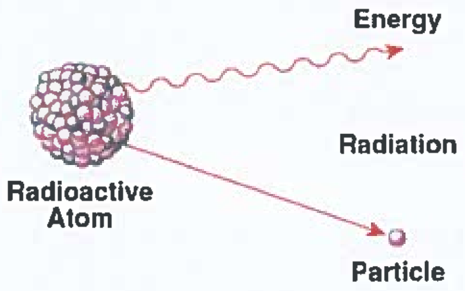
Example. Iodine-123 and iodine-131 are isotopes. Iodine-123 has 53 protons and 70 neutrons whereas iodine-131 has 53 protons and 78 neutrons.

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).

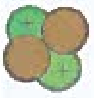


The nucleus tries to become stable by breaking up into stable fragments: **RADIOACTIVE DECAY**. Carbon has three common isotopes ^{12}C, ^{13}C a ^{14}C. Carbon-14 is radioactive because it has an ***imbalance of protons and neutrons.***

$\longrightarrow$ +

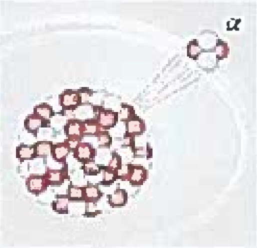
Carbon will **emit radiation** to try and make itself stable, a nitrogen nucleus is formed in the process. This process is called **RADIOACTIVE DECAY**.

There are 3 types of radiation emitted from the nucleus.

Information	**Alpha (α)**	**Beta (β)**	**Gamma (ɣ)**
Symbol			ɣ
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



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:

$$\boxed{\longrightarrow \qquad +}$$

$$\longrightarrow \qquad +$$

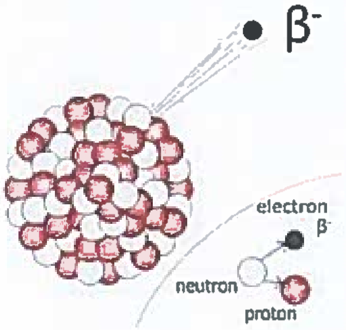
Balance the following nuclear equations by calculating the value of a, b, c and d.

1. $\longrightarrow \qquad +$

2. $\longrightarrow \qquad +$

a=237, b=93, c=232, d=82

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:

$$\boxed{\longrightarrow \qquad +}$$

$$\longrightarrow \qquad +$$

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

1. $\longrightarrow \qquad +$

2. $\longrightarrow \qquad +$

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

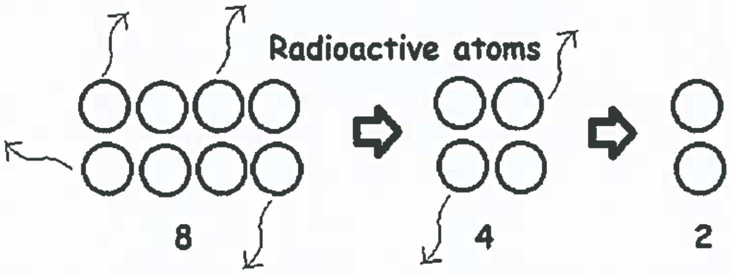
Half life.

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 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 bequerel 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?

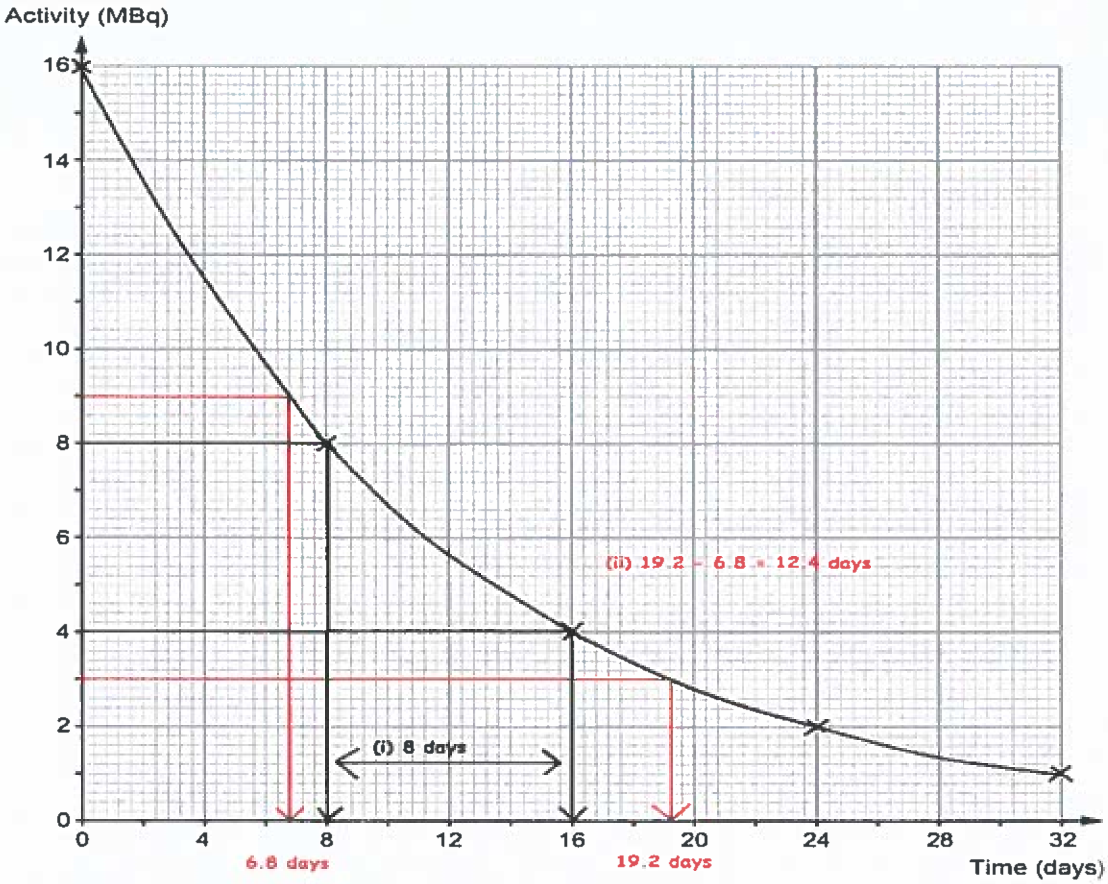
$$6400\text{Bq} \xrightarrow[\textbf{8 hours}]{1} 3200\text{Bq} \xrightarrow[\textbf{8 hours}]{2} 1600\text{ Bq} \xrightarrow[\textbf{8 hours}]{3} 800\text{ Bq} \xrightarrow[\textbf{8 hours}]{4} 400\text{ Bq}$$

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 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 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 in 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.

$$1 \text{ MBq} = 1{,}000{,}000 \text{ Bq} \xrightarrow[8 \text{ days}]{1} 500{,}000 \text{ Bq} \xrightarrow[8 \text{ days}]{2} 250{,}000 \text{ Bq}$$

Total time = 8 + 8 = 16 days

Uses of radioactive materials.

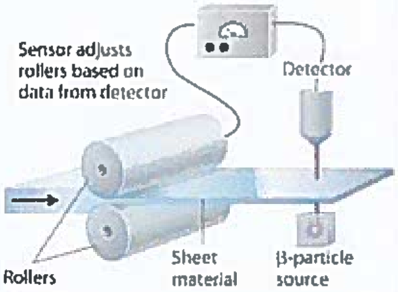
There are many uses of radioactive materials; carbon dating, sterilising medical equipment, killing cancer cells, smoke alarms and controlling the thickness of aluminium foil.

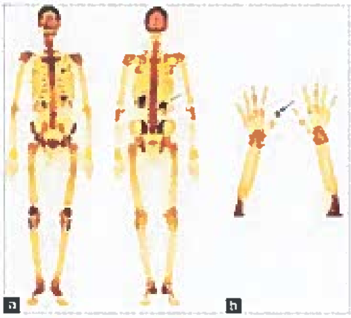
What is required is that you can select from a given list and explain which isotope is suitable for use in a specific case. Consider the ***type of radiation*** emitted and the ***half life.***

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**	**Alpha**
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)

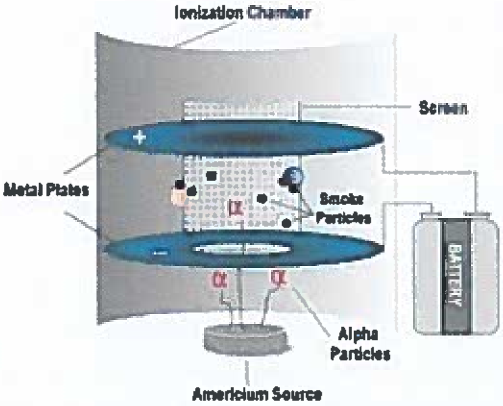
(a) Monitoring the thickness of aluminium sheet in a factory.
Isotope: Strontium – 90 (beta emitter).
Reason: because **fewer** beta particles will pass through when the thickness of aluminium increases. The half life is fairly long so the source will last a reasonable amount of time.



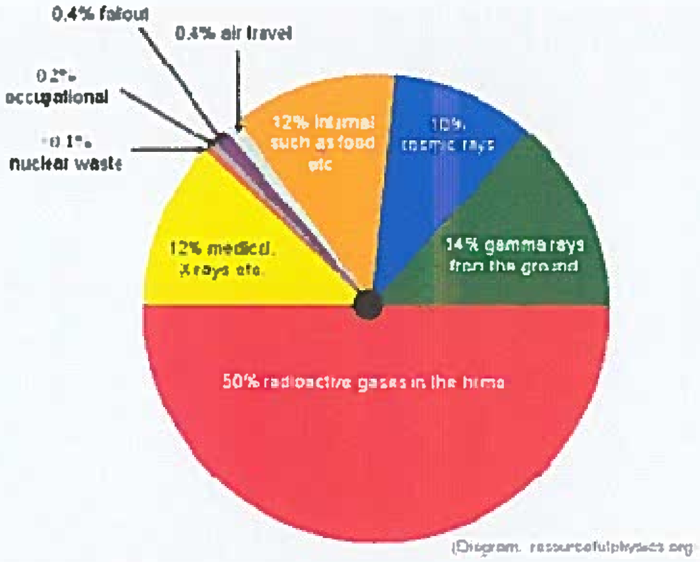


(b) Medical tracer in monitoring internal organs by using a camera outside the body.
Isotope: Technetium-99 (γ – emitter)
Reason: because it's a gamma emitter, it passes out of the body easily. The half life is short so it will not remain in the body for a long time.

(c) A smoke detector.
Isotope: 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



Background Radiation



(Diagram: resourcefulphysics.org

Background radiation is radiation that comes from, mainly. Natural sources. *Fallout (from nuclear bombs) Occupational (uses in industry), Nuclear Waste (from Power Stations) and Medical* are not natural.

Background radiation is perfectly normal and surrounds us all the time. Because ***radioactive decay*** is a ***random*** thing, background radiation changes all the time. Lots of different readings need to be taken to allow us to work out the ***mean value.***

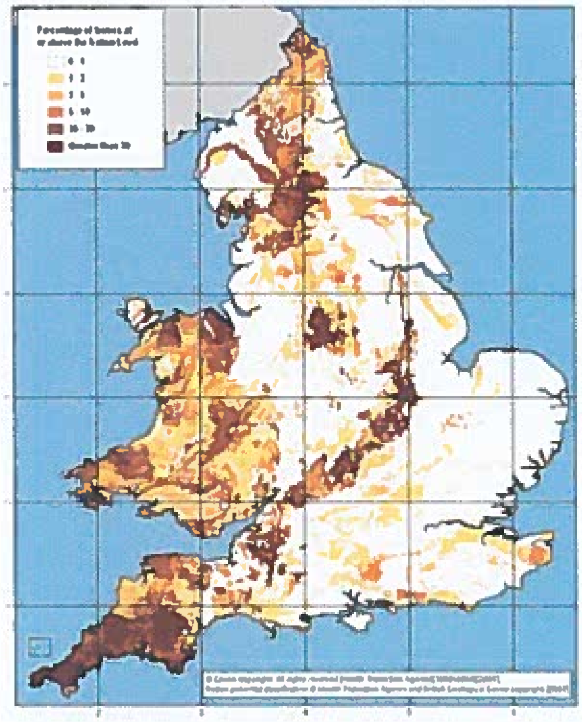
A ***Geiger-Muller (GM)*** counter can be used to measure background radiation.

Radon Gas:

The single main source of background radiation is ***Radon Gas.*** Radon is formed when ***unstable isotopes of uranium*** *decay in the Earth's crust.* This happens mainly in ***igneous rocks.*** So, Radon is far more common in some parts of the country than others.

The darker areas on this map are where most radon is found.

What do you thing will happen to background count rate in these places?



Nuclear Waste:

Some background radiation comes from ***Nuclear Waste.***

This waste can come from Nuclear Power Stations or from Hospitals.

Radiation from Nuclear Waste is only a tiny part of overall background radiation, but the safe storage of this waste is a major problem.

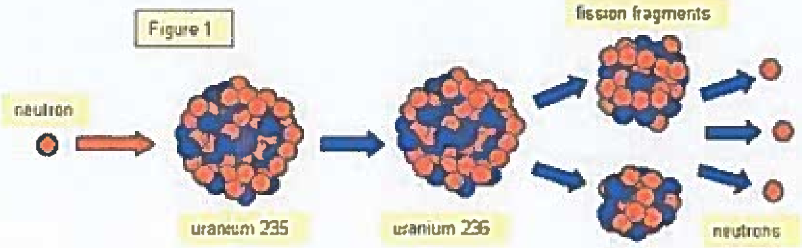
There are two reasons for this.

1. Some of the waste (***High Level Waste***) is very, very dangerous.
2. Some of the waste has a very long ***half life***. This means it will be dangerous for hundreds of thousands (100 000's) of years.

Nuclear Fission

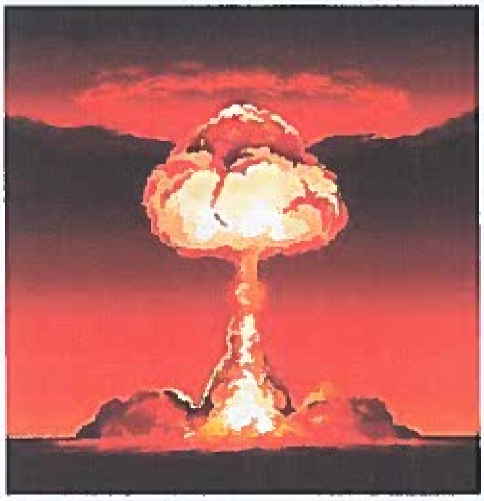
Nuclear fission. This is a decay process in which an unstable nucleus splits into two fragments of comparable mass or to put it another way it is the splitting of a heavy nucleus into two lighter nuclei.

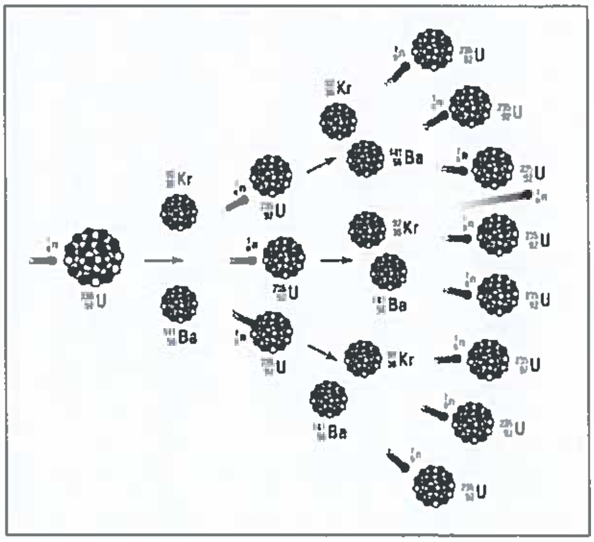
Figure 1



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 + → + + 4

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 + → + + 3

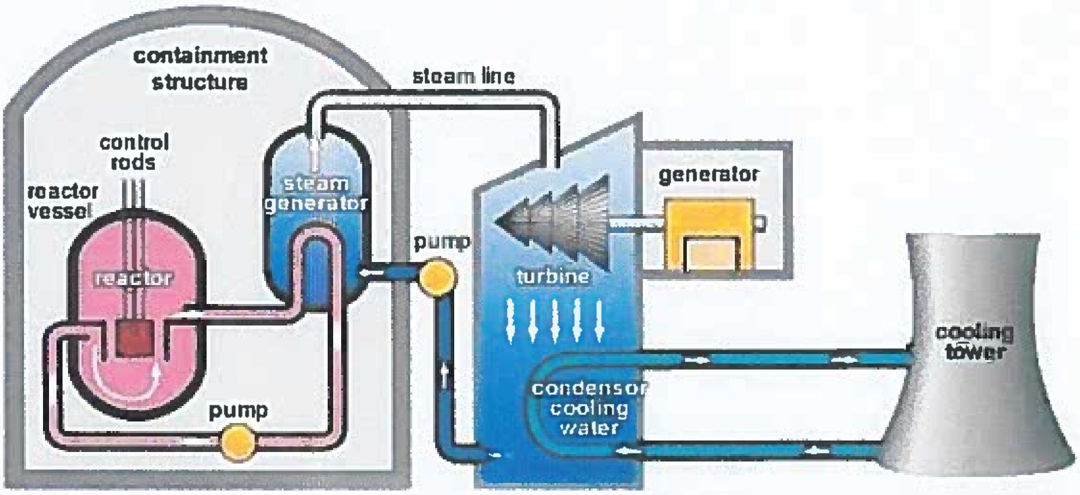
2. 1 + → + + d

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 U-235.

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**.

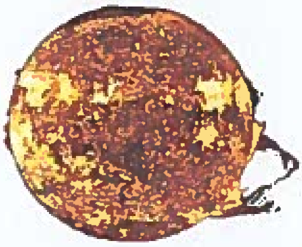
Control Rods.

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*** (1 proton, 1 neutron) and ***tritium*** (1 proton, 2 neutrons) can undergo fusion to form helium and a neutron.

This is a nuclear equation for the reaction.

$$+ \longrightarrow +$$

Total A = 2+3 = 5

Total Z = 1 + 1 = 2

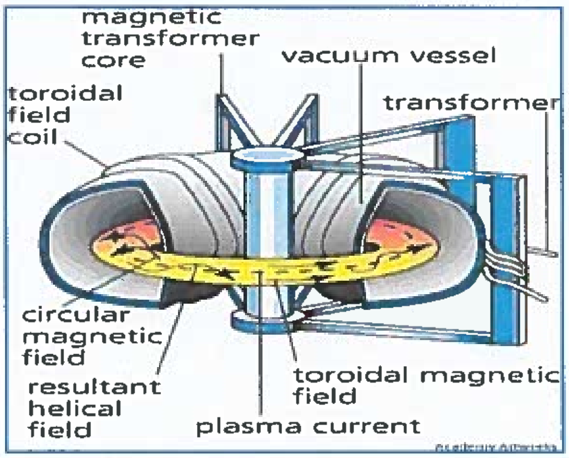
Total A = 4 + 1 = 5

Total Z = 2 + 0 = 2

Equation 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.

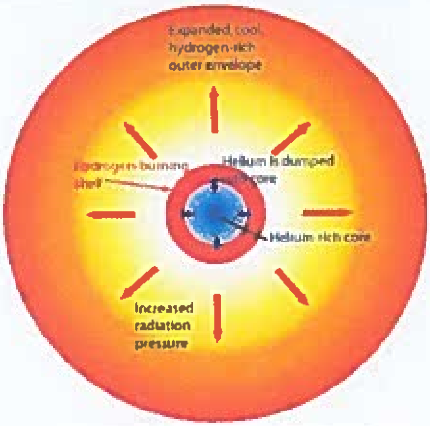
The **neutrons** that are generated can be captured by atoms in the reactor making them unstable and therefore **radioactive**. The reactor must therefore be **shielded** using concrete to prevent any radiation escaping and so protect the workers.

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.

End of main sequence stage.

Once a star has exhausted (run out) of its supply of hydrogen it will swell up into a red giant. The temperature of the star 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 has begun and the temperature increases once again resulting in an increase in gas and radiation pressure.



Hydrogen Shell Burning on the Red Giant Branch

In 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/starlife_main.html

Nuclear fusion

All **main sequence stars** generate their energy by the fusion of hydrogen to helium, according to the equation (remember):

$$4\ _{1} \longrightarrow {}^{4}_{2}He + 2\ {}^{0}_{1}e$$

Hydrogen Helium Positron

A and Z numbers on left and right hand side are balanced.

Left: total A = 4 x 1 = 4
total Z = 4 x 1 = 4

Right: total A= 4 + (2 x 0) = 4
total Z = 2 + (2 x 1) = 4

A positron is the antiparticle of an electron. When a particle and its corresponding particle meet they annihilate one another releasing a large amount of energy. Therefore when a positron is created during fusion it meets an electron and is annihilated.

Nuclear fusion

Other fusion reactions occur in stars.

$$^{3}_{2}He + {}^{3}_{2}He \longrightarrow {}^{4}_{2}He + 2\,{}^{A}_{Z}X$$

Determine the value of A and Z.

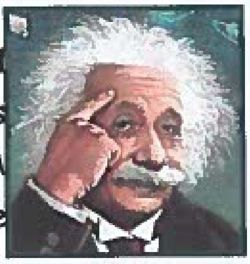
A=1 Z=1

$$^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{A}_{Z}X + \gamma \text{ (gamma ray)}$$

Determine the value of A and Z.

A=3 Z=2

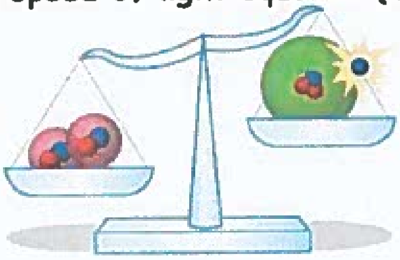
Why is energy released during fusion?



Look at the last equation showing the fusion of hydrogen and deuterium. The total mass of the helium formed is less than the mass of the 2 hydrogen isotopes and **that mass is converted into energy.** A famous scientist (Albert Einstein) predicted this to be true and gave one of the most famous of equations:

$$\mathbf{E = mc^2}$$

Energy (J) = mass (kg) x speed of light squared (m/s) (300,000,000 m/s or 3×10^{8})



Question 1. When 1kg of coal is burnt 3×10^{7}J of energy is released. Calculate the mass lost.

$$E = mc^2 \qquad \text{rearrange formula} \quad m = \frac{E}{c^2} \qquad m = \frac{3 \times 10^{7}}{(3 \times 10^{8})^2} = 3.33 \times 10^{-10}\,\text{kg}$$

As you can see this is a very small mass so it is ***negligible/insignificant***.

Question 2. Calculate the mass loss per second from the Sun given that its energy output is 4×10^{26} W and the speed of light is 3×10^{8} m/s.

The first step is to realise that power is energy transferred per second. So the energy transferred from mass into energy per second is 4×10^{26} J. Now we must calculate how much mass this is equivalent to.

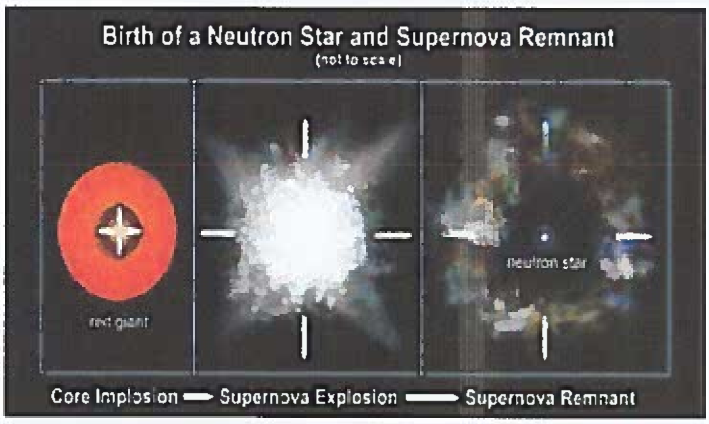
$$E = mc^2 \qquad \text{rearrange formula} \quad m = \frac{E}{c^2} \qquad m = \frac{4 \times 10^{26}}{(3 \times 10^{8})^2} = 4.44 \times 10^{9}\,\text{kg}$$

What happens to Stars which are heavier than our Sun?

It is much more difficult to fuse heavier elements because heavier nuclei ***repel each other*** more strongly than light nuclei and so require much higher temperatures and pressures to fuse. So the fusion of heavier nuclei only occurs in stars of greater mass than our Sun.

- The lifetime of these massive stars is much shorter as they use their fuel up much more quickly.
- Core temperature is much higher - 300,000,000°C.
- The production of increasingly heavier elements, up to iron-56, occurs in shells around the core of a star and the limit of this depends upon the mass/temperature of the star.

Useful video - http://www.bbc.co.uk/science/space/universe/sights/supernovae#p00fk7yv



When the nuclear power (fusion) source at the center or core of a star is exhausted, the core collapses. In less than a second the core collapses giving a supernova explosion and a neutron star (or a black hole if the star is extremely massive) is formed. If the **core** of the star is heavier than about **3.5 × the sun** it becomes a black hole.

The neutron star is very dense indeed. **One teaspoon has a mass of 6 billion tons.**

Fusion stops → Gravitational pull is too much → Core Collapse → Supernova explosion

During the supernova explosion two very important things happen.

1. **Much of the material (elements) from within the star is blasted out into space. The material spews off into interstellar space to form new stars.**

2. **As the shock encounters material in the star's outer layers, the material is heated to billions of degrees, fusing to form the heavier elements. All elements heavier than iron/nickel-56 (all the way up to Uranium) are formed in supernovae explosions.**