National 5 Physics

Dynamics and Space

Velocity & Vectors

Vector and Scalar Quantities

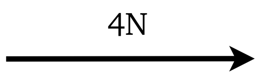
Physical quantities can be divided into two groups:

- Scalar quantities are completely described by stating their magnitude.
- Vector quantities are completely described by stating their magnitude and direction.

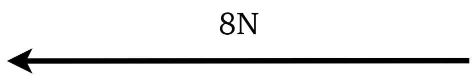
For example — speed is a scalar (i.e. the man was walking at 4 ms^{-1}), but force is a vector (i.e. the block was pushed with a force of 4N to the right).

Vectors are represented in diagrams by drawing arrows. The length of the arrow gives the magnitude of the vector and the direction of the arrow gives the direction of the vector.

A force of 4N to the right can be represented like this:



A force of 8N to the left can be represented like this:

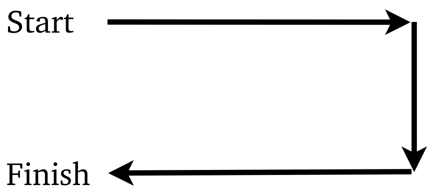


Distance and Displacement

Distance is the total distance travelled. It is a scalar quantity.

Displacement is the length measured from the starting point of a journey to the finishing point in a straight line. Its direction must be stated because it is a vector quantity. The direction can be given as left or right, up or down, as one of the compass points, as an angle or as a three figure bearing.

Example: A man travels 4 km East to A, then 2 km South to B and then 4 km West as shown below.



The total distance travelled by the man is:

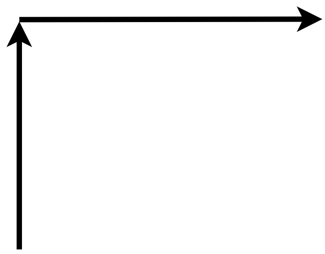
$$4 + 2 + 4 = 10 \text{ km}$$

The displacement of the man from the start is:

2 km South

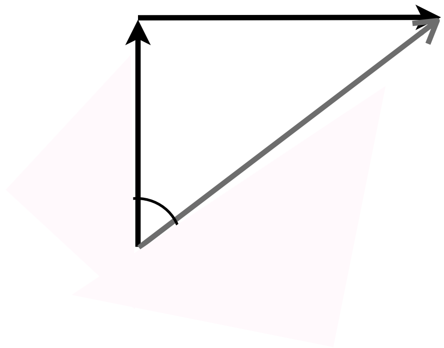
Scale diagram

Displacement can be found by drawing a scale diagram of the problem. For instance If a ship sails 3km north and then sails 4km east you could represent that motion like this…



Here a scale of 1cm = 1km was used.

The displacement is found by drawing on a new vector joining the start to the finish, like this:



To find the displacement you simply measure the length of the new vector using a ruler, and measure the angle using a protractor. In the diagram above you should find the length of the displacement vector to be 5cm and the angle from North to be 53°. Therefore the displacement of the ship is 5km on a bearing of 053°.

Trigonometry

Another way to find displacement is to use the rules and laws you have learnt in maths. Sometimes you can use simple Pythagorean rules but you might need to use the cosine rule:

$$a^2 = b^2 + c^2 - 2bc\cos A$$

This does **not** appear on the formula sheet. At National 5 it is going to be easier to use a **scale diagram**.

Practice Questions

1. What is the difference between a vector and a scalar?

2. What is the difference between distance and displacement?

3. A car travels 40 km north, then turns back south for 10 km. The journey takes 1 hour. Calculate

    a) The displacement of the car

    b) The distance the car has travelled

    c) The average speed of the car (in km/h)

4. One complete lap of a running track is 400m. An athlete completes one lap in 48s in the 400m race. Calculate the athlete's:

    a) Total distance travelled

    b) Displacement

    c) Average speed

5. An aircraft flies 100km due west. There is a crosswind blowing which has moved the plane 5km due north. What is the displacement of the aircraft?

Speed

When we measure the speed of something we are measuring the distance travelled each second (or hour).

Speed is found by measuring the distance travelled in a certain time interval. The speed is then calculated by dividing the distance by the time.

Speed, Distance and Time Formula

Speed is equal to the distance travelled divided by the time taken to travel that distance. In the formula book the equation is written like this:

$$d = v\,t$$

Distance measured in meters (m)

Speed measured in meters per second (ms^{-1})

Time measured in seconds (s)

Average Speed

Sometimes an object's speed varies. For instance a car travelling along a road will speed up and slow down due to traffic. In these situations we calculate the average speed.

Average speed = Total distance travelled ÷ Total time taken

Units of speed

In Britain we measure road speeds in miles per hour (mph).

In Europe they measure road speeds in kilometres per hour (km/h).

In Physics we usually measure speed in metres per second (ms^{-1}).

In towns the speed limit is 30 mph, this is 48 km/h or 13.4 ms^{-1}.

On motorways the speed limit is 70 mph, this is 113 km/h or 31.3 ms^{-1}.

Practice Questions

1. A car travels 600km in 5 hours. Calculate its average speed in km/h.
2. A train travels 150 miles in 3 hours, what is its average speed in miles per hour?
3. What is the average speed of a man who walks 50 metres in 25 seconds?
4. How long will it take a car travelling at an average speed of $25ms^{-1}$ to travel 2km?
5. How far will an aeroplane travel in 6 hours if it travels at a constant speed of 2160 km/h? Give your answer in km.
6. A London to Glasgow flight takes 50 minutes to travel a distance of 850km. What is its average speed in ms^{-1}?

Instantaneous speed

Instantaneous speed is the speed of an object at any given moment. In a car this is shown by the speedometer. The police can measure the instantaneous speed of a car using a RADAR gun or speed camera. In Physics experiments we use a piece of equipment called a light gate connected to an electronic timer.

Measuring average and instantaneous speeds

Average speeds are measured over long time intervals. Instantaneous speeds are measured over very short time intervals. The instantaneous speed can be found by measuring the average speed over a very short time interval, usually less than 1 second. Short distances can be measured with a ruler, metre stick or tape measure. Long distances can be measured with a trundle wheel. Long time intervals can be measured with a stop watch. Short time intervals can be measured using a computer connected to light gates.

Measuring average speed — experiment

Aim: To measure the average speed of a student for one lap of the lab.

Write up an experimental report for this aim. Your report should include:

- What equipment you used, including a labelled diagram
- What measurements you made.
- Which was the independent and which was the dependant variable.
- How you made these measurements (a method).
- How you calculated the average speed.
- An evaluation of your experiment.

Measuring instantaneous speed — experiment

Aim: Measure the instantaneous speed of a car (you will be using either the air track or mechanics trollies).

Write up an experimental report for this aim. Your report should include:

- What equipment you used, including a labelled diagram
- What measurements you made.
- Which was the independent and which was the dependant variable.
- How you made these measurements (a method).
- How you calculated the instantaneous speed.
- An evaluation of your experiment.

Practice Questions

1. A car has an average speed of 40 mph on the road from Laurencekirk to Aberdeen. Behind a tractor its speed is 20 mph but on a straight the car's speed is 55 mph. From this information, identify the average and instantaneous speeds (stating them) and explain the difference between average speed and instantaneous speed.

2. In the laboratory, a vehicle travels down a ramp. The vehicle is 10cm long and takes 0.2s to travel through a light gate. What is the instantaneous speed of the vehicle?

3. Given the following information from an experiment, calculate the instantaneous speed of a vehicle. Mass of vehicle, 0.5 kg; Length of card on vehicle, 2cm; Time taken to pass through light gate, 0.05s.

4. Two light gates are set up on a ramp. One light gate is 20cm down the ramp. The other is 60cm down the ramp. A vehicle with a 2cm wide card on it rolls down the ramp. Times for the first and second gate are listed below:

First gate	0.018 s
Second gate	0.012s

Calculate:

a) The first instantaneous speed.

b) The second instantaneous speed.

c) The change in speed.

d) Describe the motion of the vehicle.

Velocity

The main difference between speed and velocity is that:

- Speed is a *scalar* quantity and requires only a magnitude.
- Velocity is a *vector* quantity and requires a magnitude **and direction**.

Velocity equation

Velocity is equal to the displacement divided by the time. In the formula book the equation is written like this:

$$s = v\,t$$

Displacement measured in meters (m)

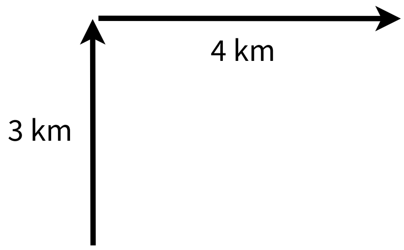
Velocity measured in meters per second (ms^{-1})

Time measured in seconds (s)

NB: The velocity will be in the **same direction as the displacement**.

Example: A person on a train is travelling at $100ms^{-1}$. They walk to the front of the train at $2ms^{-1}$. The person's resultant velocity is 102 ms^{-1} in the direction of the train. They then walk back to their seat at 3 ms^{-1}. The person's new resultant velocity is 97 ms^{-1}, still in the direction of the train.

Example: A woman walks 3 km due North and then 4 km due East. She takes two hours.



a) Find the distance she has walked and her displacement.

b) Calculate her average speed and velocity.

The easiest way to solve this type of problem is by drawing a scale diagram, in this case 1 cm = 1 km (the diagram above is already to scale).

a) The distance she has travelled is:

3 km + 4 km = 7 km

Her displacement is from A to C. This can be measured on the diagram as 5 cm. Using the scale this is converted to 5 km.

The angle BAC is measured using a protractor to find the direction of her final displacement. BAC is 53°. Therefore the woman's displacement is:

5 km at on a bearing of 053°

b) Her average speed and velocity are:

speed = distance ÷ time = 7 ÷ 2 = 3.5 km/h

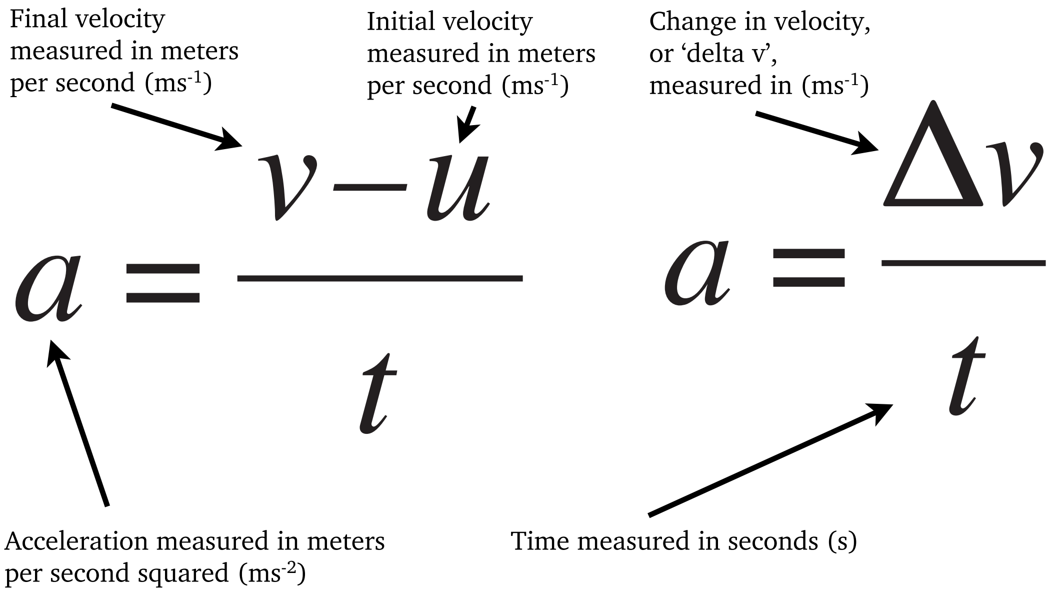
velocity = displacement ÷ time = 5 ÷ 2 = 2.5 km/h on a bearing of 053°

ACCELERATION

The rate at which an object changes its velocity is called its acceleration. Acceleration is a vector quantity as it has a direction. Deceleration is simply acceleration in the opposite direction to the velocity of an object, i.e. it is slowing down. Deceleration is sometimes called a negative acceleration. An object travelling at a constant velocity has an acceleration of zero.

Acceleration formula

The acceleration of an object is given by the change in velocity divided by the time taken. There are two versions in the formula book:



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

Practice questions

1. Calculate the acceleration of a car that changes its speed by $20ms^{-1}$ in 5 seconds.

2. What is the acceleration of an object that has a changes its speed by $50ms^{-1}$ in 10 seconds?

3. What is the acceleration of a vehicle as it brakes from $30ms^{-1}$ to rest in 1.5s?

4. An object accelerates at 4 ms^{-2}, how long will it take to change its speed by 500 ms^{-1}?

5. A car accelerates from rest at 2 ms^{-2} for 15 seconds. What is the car's final speed?

6. A car accelerates from $30ms^{-1}$ to $43ms^{-1}$ in 0.5 seconds. What is the car's acceleration?

7. The space shuttle takes 45 seconds from launch to reach a speed of $1000ms^{-1}$. Calculate its acceleration.

8. An intercity train increases its speed from 0 to $55ms^{-1}$ in 10 minutes. Calculate its acceleration.

9. A lorry travelling at a constant speed begins to accelerate at $1.5ms^{-2}$ for 6 seconds to $20ms^{-1}$. What was the original speed of the lorry?

Velocity / Time Graphs

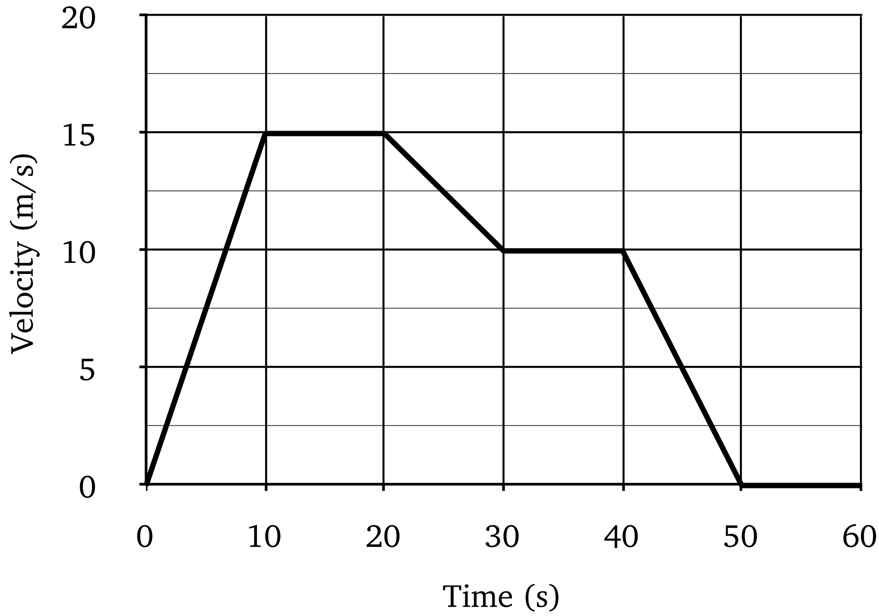
One of the best ways to get a 'picture' of how something is moving is to draw a graph of velocity against time. The graph will display the instantaneous speed at any time on the journey. The graph will clearly show when an object is accelerating, decelerating or moving with constant speed.

Acceleration	the line slopes up
Deceleration	the line slopes down
Constant speed	the line is horizontal

The **gradient** of the line is equal to the acceleration.

The **area** underneath the line is equal to the displacement of the object.

Example



This velocity time graph shows the motion of an object over one minute. Simply by looking at the graph we can describe the motion of the object.

- From 0 to 10 seconds the object is accelerating from $0ms^{-1}$ to $15ms^{-1}$.
- From 10 to 20 seconds the object is at a constant velocity of $15ms^{-1}$. It is not accelerating.
- From 20 to 30 seconds the object is decelerating from $15ms^{-1}$ to $10ms^{-1}$.
- From 30 to 40 seconds the object is at a constant velocity of $10ms^{-1}$. It is not accelerating.
- From 40 to 50 seconds the object is decelerating from $10ms^{-1}$ to $0ms^{-1}$.
- From 50 to 60 seconds the object is stationary. It is not accelerating.

You can now do some calculations to find:

a) The acceleration from 0 to 10 seconds

b) The deceleration from 20 to 30 seconds

c) The deceleration from 40 to 50 seconds

Practice questions

Plot a speed/time graph using the following data:

Time (s)	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
Speed (ms^{-1})	0	6	12	18	24	30	30	30	30	30	30	30	30	30	20	10	0

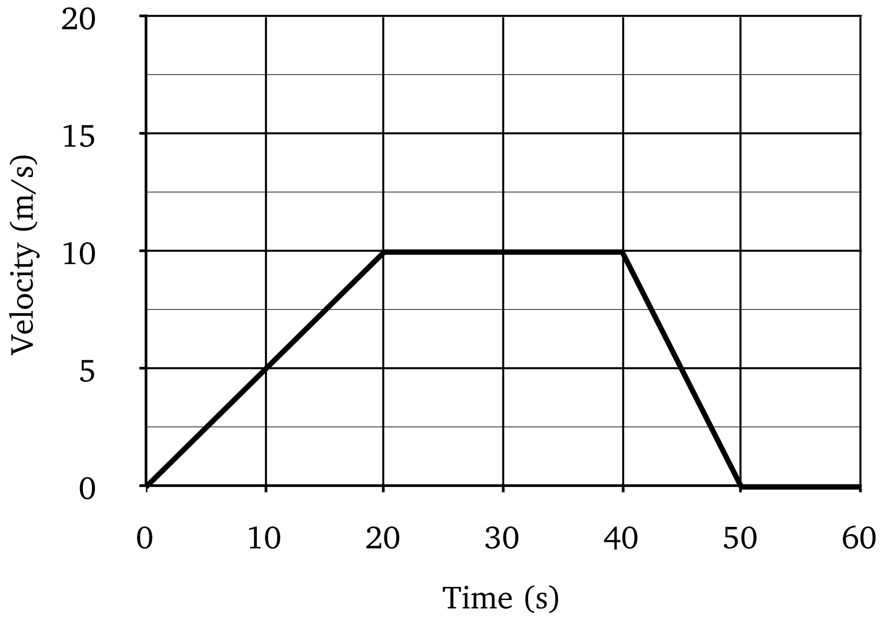
On your graph

1. Label the parts of the motion where the object is at a constant velocity.
2. Label the parts of the motion where the object is accelerating.
3. Label the parts of the motion where the object is decelerating.

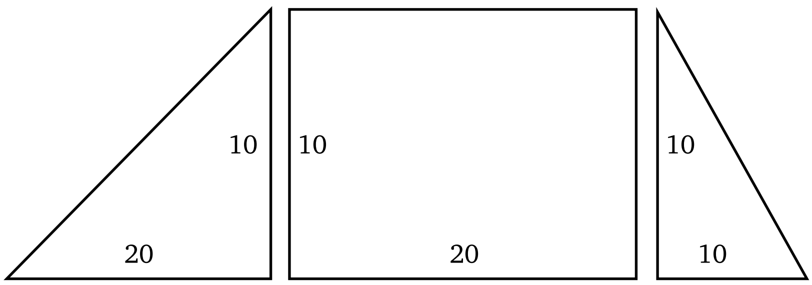
Using information on your graph calculate the acceleration and the deceleration of the object. Then write a description of the motion of the object.

Area underneath a line

The area underneath a speed time graph shows the distance travelled. However the shapes of the graphs you will see will not always be a rectangle or triangle. Often they will look similar to this…



To tackle this sort of problem you simply split the area into rectangles and triangles. In this case we have two triangles and a rectangle:



The area of the three shapes added together will give the distance travelled.

area of triangle 1 = $0.5 \times (10 \times 20) = 100$

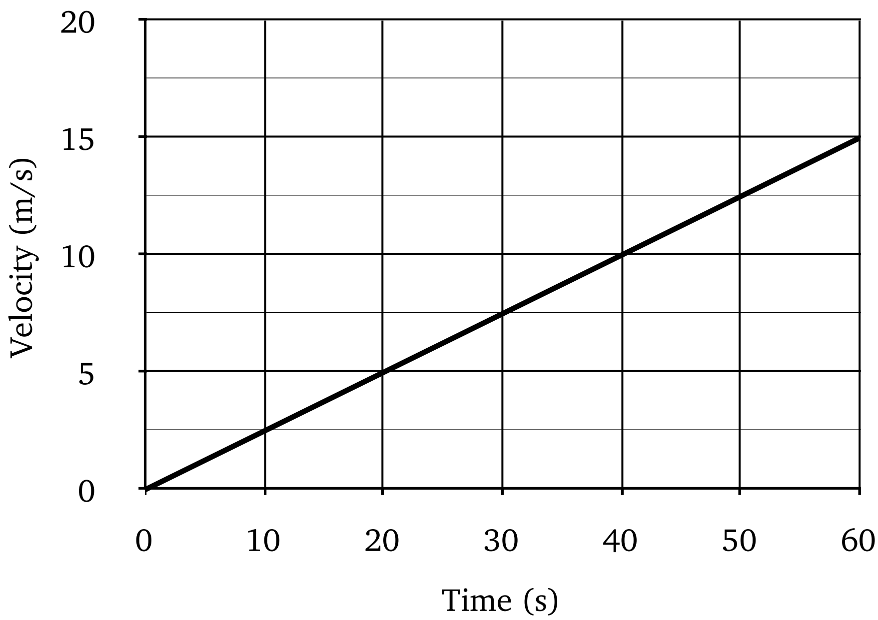
area of rectangle = $10 \times 20 = 200$

area of triangle 2 = $0.5 \times (10 \times 10) = 50$

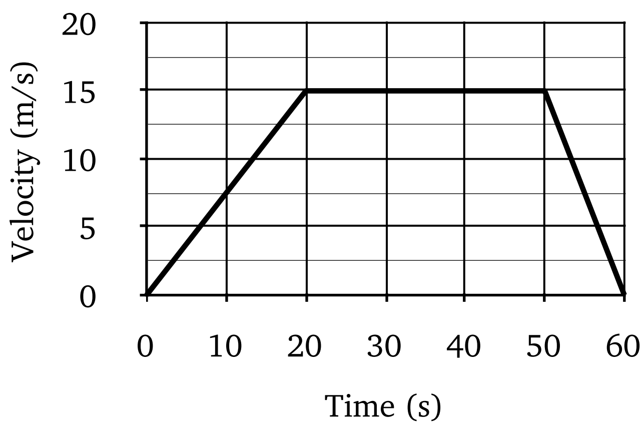
distance travelled = total area = $100 + 200 + 50 = 350$m

Practice Problems

1. The graph below shows how the velocity of a car changes as it accelerates from rest. What is the acceleration of the car?



2. A bus moves from a bus stop to a set of traffic lights. The velocity/time graph for the journey is shown below.



a) Calculate the initial acceleration.

b) Calculate the deceleration.

c) Find the distance travelled in the first 20 seconds.

d) Calculate the average speed for the journey.

Forces

In S1/2 you learnt that forces can do three things to an object

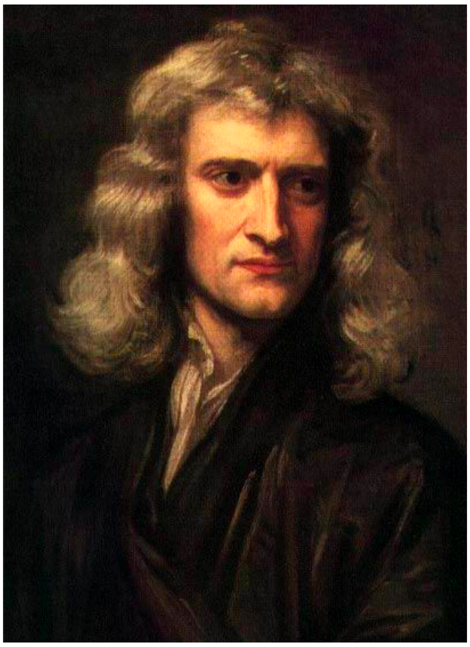
1. Push them.
2. Pull them.
3. Change their shape.

Measuring forces

Forces are a **vector**, they have both magnitude and direction. Forces can be measured using a Newton Balance. A Newton balance is simply a calibrated spring. A spring is used to measure forces because it increases its length when you apply a force to it (according to Hooke's Law). The change in length of the spring (or its *extension*) is proportional to the force applied to it. If you double the force on a spring its extension will double. When the force is removed the spring returns to its original length. If you apply too much force to a spring you can break this relationship and the spring will not return to its original length, so Newton meters have a maximum force that they can measure.

The unit used to measure force is the newton (N) — after Sir Isaac Newton.

Robert Hooke FRS (28 July 1635 – 3 March 1703)



Sir Isaac Newton PRS MP (25 December 1642 – 1727)

Gravity

All objects with mass attract each other; this force is called the force of gravity.

The force of gravity depends on:

- The magnitude of the two masses
- Their distance apart

The force of gravity is not very noticeable unless one of the masses is huge like the Earth or the Sun. The strength of the gravitational force between two masses gets weaker as they move further apart. In National 5 we are only going to look at how gravity affects objects close to the surface of a planet, which makes things much easier.

Gravitational Field Strength (g)

The gravitational field strength is a measure of how strong the gravity of an object is. The gravitational field strength on a planet or moon's surface depends on the mass of the planet or moon. On the surface of Earth the gravity pulls with a force of 9.8 Newtons on each kilogram of mass, usually written as $9.8Nkg^{-1}$. On the Moon the gravitation field strength is $1.6Nkg^{-1}$.

Measuring *g*

Design an experiment to measure the acceleration due to gravity on Earth.

You will need:

- Title
- Aim: What is it you want to investigate?
- Apparatus: What equipment will you need?
- Diagram: How will you set up your apparatus?
- Method: What measurements you will make and how will you gather the evidence?

Check your experiment with your teacher and carry out your experiment.

- Results: should you record results in a table?
- Analysis: What calculations do you have to carry out? Is a graph an appropriate way to display your results?
- Conclusion: What have you found out?

How does your value of acceleration compare with the actual value?

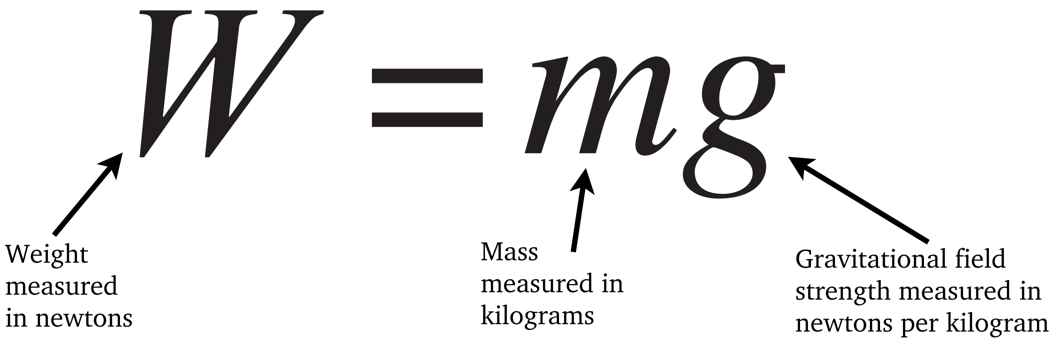
- Evaluation: Did the experiment go well? Was it easy to carry out? Did you find out what you expected to find out? Were the results reliable – could they be repeated? How could you improve the experiment? Was it so good you don't need to improve it? Any further experiments you could do to find you more about your aim?

Weight

The pull of gravity on an object is called its **weight**. Like all forces weight is measured in newtons (N).

Weight formula

The weight of an object is given by the object's mass multiplied by the gravitational field strength. It appears in the formula book and looks like this:



On Earth *g* is always equal to $9.8 Nkg^{-1}$ in National 5.

Weight and Mass

Mass is a measure of the amount of matter (stuff) contained in an object and is measured in kilograms (kg). Weight is the pull of gravity on an object and is measured in newtons (N). Do not confuse the two! If someone states that their weight is 70kg they are **incorrect**. They should have used the above formula to calculate their weight in newtons.

Weight problems

1. Complete the following table:

Mass	Weight
1 kg	
	10 N
5kg	
	7 N
500g	
	2.5 N

2. A pupil says that his weight is 60 kg. Is he correct? What is his weight?

3. A lift is designed to hold 5 adults. The mass of the lift is 500kg. The average mass of an adult is 80kg.

    a) Calculate the weight of the lift when it is fully loaded.

    b) Calculate the upward pull by the cable when the lift is stationary.

Leaving Earth

Weight is caused because a mass is in a gravitational field — what happens to weight when you leave the gravitational field? Below is a table of measurements indicating the relationship between distance and *g* the further you get from Earth.

Distance ($km \times 10^3$)	0	1.0	2.5	5.0	10	25	50	75	100
g (Nkg^{-1})	10	7.3	5.1	3.1	1.5	0.41	0.13	0.06	0.04

Plot a graph of the above data. Looking at your graph what do you think the relationship between the distance from a body and the gravitational field strength at that distance is?

___

___

___

___

The international space station and shuttle missions all occur in Low Earth Orbit (approximately 330km in altitude). Although all the objects and personnel appear weightless — are they truly weightless?

___

If you went to Mars, would you still have weight? Would you still have mass?

___

Mass is a measure of how much stuff (protons, neutrons, electrons etc.) there is in a object. Mass **does not change** unless a part of the object is removed or something added to it. Weight on the other hand is dependent on *g* and will be different on different planets and will also change as an object moves away from a planet. Below are the values of *g* at the 'surface' of some celestial bodies in the Solar System.

Body	*g* (Nkg^{-1})	Body	*g* (Nkg^{-1})	Body	*g* (Nkg^{-1})
Mercury	3.7	Jupiter	23	The Sun	270
Venus	8.9	Saturn	9	Pluto	0.7
Earth	9.8	Uranus	8.7	Titan	1.4
Mars	3.7	Neptune	11	Eris	0.8

More weight problems

1. An astronaut is touring the solar system and visiting the Moon, Venus and Mercury. If the astronaut has a mass of 75kg, what is the astronaut's weight on each planet?

2. The same astronaut goes to another planet. On this planet their weight is 277.5N. Assuming they lost no mass, what planet are they on?

3. The Curiosity Mars Rover has a mass of 750kg. Calculate its weight on Earth and Mars.

4. As Curiosity travels from Earth to Mars does its mass change?

5. As Curiosity travels from Earth to Mars does its weight change?

6. What is the mass of an astronaut who has a weight of 660N on Neptune?

Friction

Friction is a force which opposes movement. For instance, brake pads produce a large frictional force when pushed against the disc on the wheel. This force is used to change the speed of the car. Friction decreases the speed (it causes deceleration).

Whenever an object moves or tries to move and is in contact with something else friction is present. Friction is always in the **opposite** direction to the motion. Drag and air resistance are also caused by friction.

Reducing friction

You can reduce friction by:

- Putting oil or other lubricants between the surfaces.
- Having air between the surfaces.
- Using rollers or ball bearings which reduce the area of contact and allow surfaces to slide past each other more easily.

Practice Problems

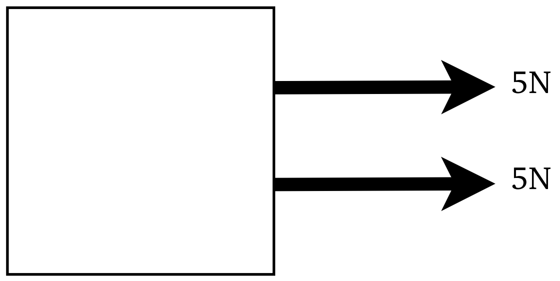
List as many ways as possible to **decrease** the force of friction — not just between two surfaces but in any situation. Compare these with your neighbour.

List as many ways as possible to **increase** the force of friction. Compare these with your neighbour.

Combining Forces

When two or more forces act together the effect will depend on the size and the direction of these forces. In Physics we combine multiple forces into a **resultant** force.

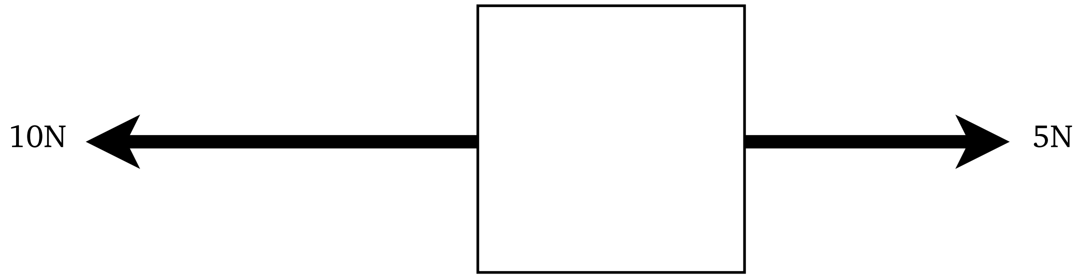
If forces are acting in the **same** direction you simply add the forces together.



The block above has two 5N forces acting on it. Both are acting from the left to the right. The resultant force will be:

$$F = 5 + 5 = 10\text{N to the right}$$

If forces are acting in **opposite** directions you subtract the forces.

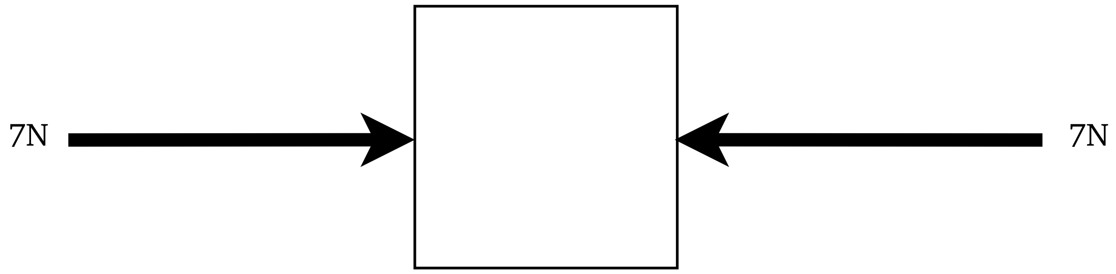


The block above has a 10N and a 5N force acting on it. The 10N is acting to the left and the 5N is acting to the right. The resultant force will be:

$$F = 10 - 5 = 5\text{N to the left}$$

Balanced Forces

If the forces are equal in size but opposite in direction the forces are said to be **balanced**. The combined effect is the same as no force. The resultant force is zero.



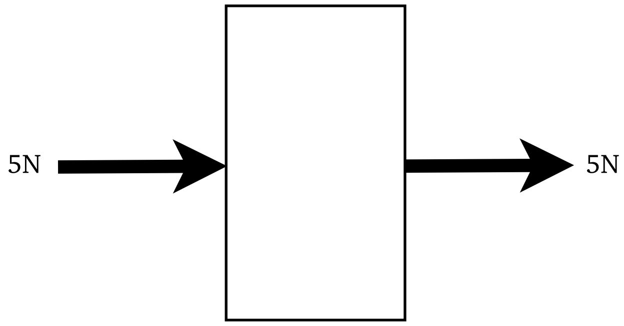
The block above has two forces of equal size acting in opposite directions. The resultant force will be:

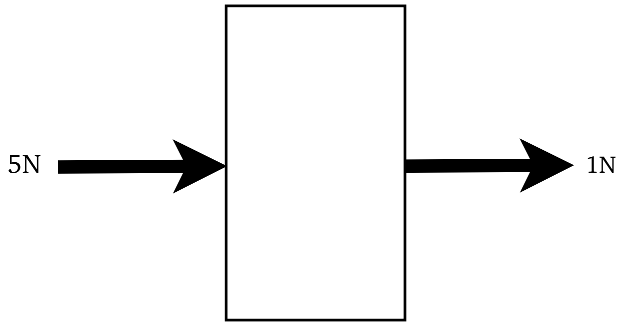
$$F = 7 - 7 = 0N$$

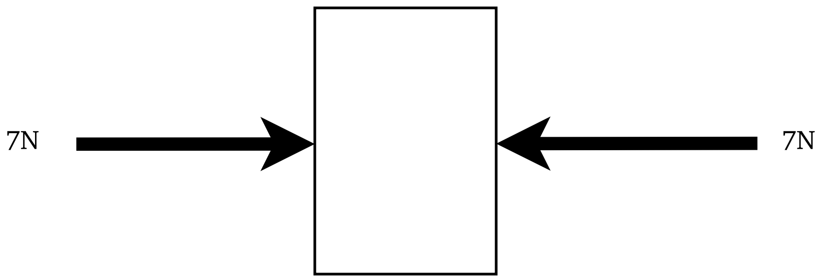
The forces are **balanced**.

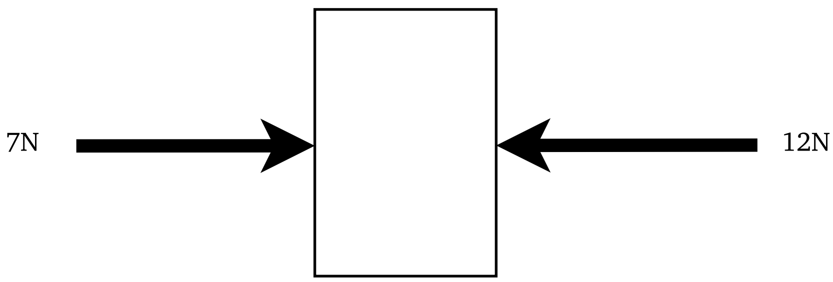
Practice problems

Calculate the resultant forces in the situations below:









Newton's First Law

> Every body persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed — Isaac Newton, *Philosophiæ Naturalis Principia Mathematica*, 1687.

Or, in today's language, an object will travel at the same speed, in a straight line, unless a force acts on the object. Newton's first law means that an object will never speed up, slow down or change direction unless there is an **unbalanced** force acting on it. This law is sometimes known as the *law of inertia*. It is a somewhat counter-intuitive law as we are used to friction acting on everything. So a car travelling along a road will slow to a stop if the engine was turned off. We tend to forget that there *is* an unbalanced force acting on the car, friction. In space, where there is no friction, Newton's first law is clearly evident — spacecraft need to use rockets or a planet to slow down. Newton's first law is also important when you consider going around a corner. To change direction, even if you have the same speed, need an unbalanced force.

Newton's Second Law

> The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed — Isaac Newton *Philosophiæ Naturalis Principia Mathematica*, 1687.

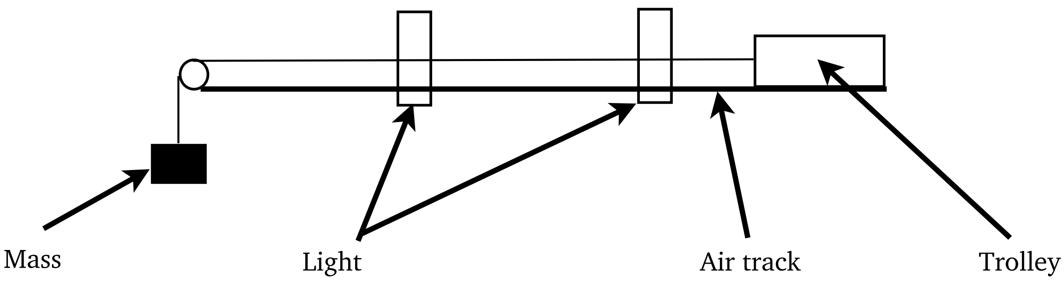
In more modern language what Newton stated in his second law is that an object will accelerate in the same direction as the unbalanced force acting on it. He also stated that the magnitude of the acceleration was proportional to the magnitude of the unbalanced force.

Investigating Newton's Second Law

Aim: To find out how the unbalanced force affects the acceleration of an object.

Hypothesis: Increasing the unbalanced force will increase the acceleration.

Diagram:



Method: Use the light gates to measure the acceleration of the trolley, they can do this automatically. Vary the size of the masses on the end of the string and record the (hopefully different) accelerations. You need to keep the total mass that is accelerating constant, so when you remove a mass from the end of the string make sure to add it to the trolley. Remember — we need to repeat and average.

Results:

Mass (kg)	Force = mass × 9.8 (N)	a_1 (ms^{-2})	a_2 (ms^{-2})	a_3 (ms^{-2})	Average Acceleration a (ms^{-2})

Analysis: Draw a graph of the force (on the x axis) vs average acceleration (on the y axis). If the hypothesis is correct, the line of best fit should be a straight line through the origin.

Conclusion: Was the hypothesis correct? Why might the hypothesis be incorrect (if it is)? Can you think of a way to improve the experiment? What other factor (that was kept constant in this experiment) could affect the acceleration?

Newton's Second Law — formula

The unbalanced force acting on an object is equal to the mass times the acceleration of the object. This is the mathematical way of representing Newton's Second Law. It appears in the formula book and looks like this:

$$F = ma$$

Unbalanced force measured in newtons (N)

Mass measured in kilograms (kg)

Acceleration measured in meters per second squared (ms^{-2})

Practice problems

1. Fill in the missing values.

Force	Mass	Acceleration
10N	2kg	
5N	500g	
20N		5 ms^{-2}
4N		0.5ms^{-2}
	6kg	20ms^{-2}
	0.2kg	5ms^{-2}

2. A 7kg bag of potatoes accelerates down a factory chute at 3ms^{-2}. Calculate the unbalanced force acting on potatoes.

3. A sprinter of mass 70kg accelerates at 10ms^{-2}. Calculate the unbalanced force driving him forward.

4. There is an unbalanced force acting on a car of 500 N and this causes it to accelerate at 2.5 ms^{-2}. Calculate the mass of the car.

5. An oil tanker of mass 10,000,000 kg is travelling at a steady speed. The tankers engines are switched off causing it to decelerate at 0.01 ms^{-2}. Calculate the size of the frictional forces causing the deceleration.

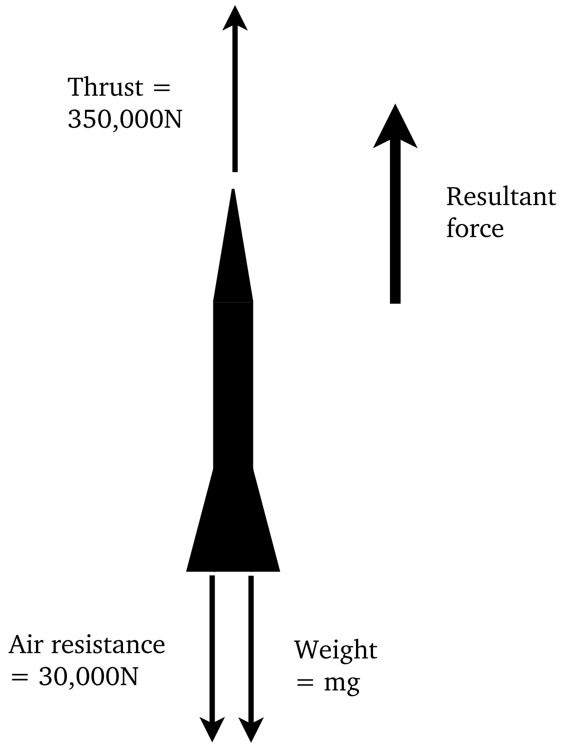
6. What was the size of the forward force exerted by the tanker's engines before they were switched off?

Rocket problems

Rockets are a common type of problem in National 5. When dealing with Newton's second law rocket problems are slightly more complex.

For example: A short time after take off, a rocket of mass 10,000 kg has a thrust of 350,000 N and experiences air resistance of 30,000 N. Find the acceleration.

How to solve —Draw a diagram and then find the resultant force acting on the object. Using the resultant force, find the acceleration of the rocket.



Resultant force (F) = 350000 − (30000 + mg)

F = 350000 − (30000 + (10000 × 9.8))

F = 350000 − (30000 + 98000)

F = 350000 − 128000

F = 222000N

F= ma

222000 = 10000a

a = 222000 ÷ 10000

a = 22.2ms^{-2}

Practice problems

1. A rocket of mass 1500kg is initially accelerated upwards by the thrust of rocket engines.

    a) What is the weight of the rocket?

    b) If the engine thrust is 20,000N, what is the unbalanced force on the rocket?

    c) Find the acceleration of the rocket.

2. A rocket of mass 100kg is accelerated upwards by a thrust of 3000N. What is the acceleration of the rocket?

3. If a rocket of thrust 20,000N accelerates and has a weight is 4000N, what is the acceleration of the rocket?

NEWTON'S THIRD LAW

To every action there is always an equal and opposite reaction — Isaac Newton
Philosophiæ Naturalis Principia Mathematica, 1687.

Newton's third law simply means that if you push something, the something pushes back with the same force. This is why you do not fall through your chair. But it also explains how rockets and jet engines generate thrust. Imagine sitting on a chair with wheels that is on a surface with very low friction. You have a bucket of tennis balls. When you throw a tennis ball you exert a force on the ball (to throw it). However the ball exerts the same size of force on **you**. This force will actually move you backwards. Rockets use the same principle but use a stream of extremely hot gasses instead of tennis balls.

Practice questions

1. A rugby ball has a mass of 400g. When kicked, the ball accelerates briefly at $500ms^{-2}$.

   a) What is the unbalanced force acting on the ball?

   b) What is the magnitude of the force acting on the kickers boot?

   c) What is the direction of the force on the kickers boot?

2. A girl steps out of a stationary rowing boat. She has a mass of 65kg and the boat has a mass of 25kg. She steps up and pushes herself away from the boat and onto the shore with a force of 375N

   a) What is the force acting on the boat?

   b) What is the acceleration of the boat?

   c) If the force acts for 0.16s, what is the final speed of the boat?

Work Done

Work is a type of **energy**. Any time a force acts over a distance it requires work.

Work formula

Work done is defined as being equal to the force times the distance over which the force acts. It appears in the formula book and looks like this:

$$E_w = Fd$$

Work done measured in joules

Force measured in newtons (N)

Distance measured in meters (m)

Practice problems

1. A car applies its brakes and comes to a halt in 30m. If the car's brakes provide an average breaking force of 3,000N, how much work did the brakes do?

2. If a block is pushed 2m and required 14,000J of work, how large was the force pushing the block?

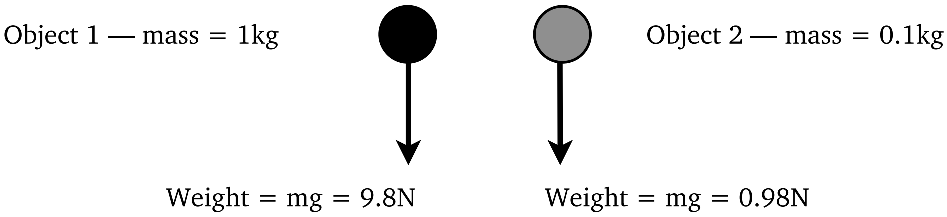
3. An engine produces a force of 5,000N and has done 8000J of work moving a car. How far has the car travelled?

Freefall

Galileo Galilei once conducted a (now famous) experiment. He went to the top of the Leaning Tower of Pisa and dropped two objects with different masses from the top. The Physics of Aristotle and the ancient Greeks said that the more massive object would hit the ground first. Galileo found that they both hit the ground at the (almost) same time. When the Apollo astronauts tried this type of experiment on the Moon they found that a hammer and a feather both hit the ground at the same time. Why? Consider two objects with different masses:

Galileo Galilei (15 February 1564 — 8 January 1642)

What forces are acting on the two objects if we ignore air resistance?



The weight of object 1 is 10 times as large as the weight of object 2. This is why Aristotle thought that object 1 would hit the ground first. However what happens when we calculate the accelerations of the two objects using Newton's second law?

$a_1 = F \div m_1$	$a_2 = F \div m_2$
$a_1 = 9.8 \div 1$	$a_2 = 0.98 \div 0.1$
$a_1 = 9.8\text{ms}^{-2}$	$a_2 = 9.8\text{ms}^{-2}$

The acceleration of the two objects is the **same** and equal to *g*. As both objects are dropped with the same initial speed (0ms^{-1}) and from the same height they must hit the ground at the same time.

This happens to projectiles as well. If you fire a gun horizontally and at the same time drop a bullet, both bullets will hit the ground at the same time.

Projectile Motion

A projectile is any object, which, once projected, continues its motion by its own inertia and is influenced only by the downward force of gravity. Projectiles have both *horizontal* and *vertical* components of motion. As there is only a single force, gravity, acting in a single direction, only one of the components is being acted upon by a force. The two components are not undergoing the same kind of motion and must be treated **separately**.

Projectiles fired horizontally

In National 5 you only have to worry about projectiles fired horizontally, which makes things much easier. Here is a classic horizontal projectile scenario, from the time of Newton. In projectile motion we **ignore air resistance**, or any force other than gravity. When we look at the horizontal and vertical components we find that…

Horizontally: There are no forces acting on the object and therefore the horizontal velocity is constant. You use the speed, distance, time formula in the horizontal direction.

Vertically: The force due to gravity is constant so the cannonball undergoes a constant acceleration equal to the gravitational field strength *g*. You use the acceleration formula in the vertical direction.

The combination of these two motions causes the curved path of a projectile.

Horizontal projectile formulae

You can solve projectile problems in National 5 using the speed, distance, time and acceleration formulae that you have already learnt in this unit. There is a 'shortcut' formula that you can use as well in the vertical direction. This is **not** on the formula sheet, you will need to remember it if you want to use it!

$$v = u + at$$

Final speed measured in meters per

Initial speed measured in meters per

Acceleration measured in meters per second squared

Time measured in seconds (s)

Example: A cannonball is fired horizontally from a cliff with a velocity of $100ms^{-1}$. The cliff is 20 m high and the cannonball takes 2s to hit the water.

Determine:

1. The vertical speed of the cannonball, just before it hits the water.

2. If the cannonball will hit a ship that is 200 m from the base of the cliff.

Solution 1:

$$v = u + at$$

$$v = 0 + (9.8 \times 2)$$

$$v = 19.6ms^{-1}$$

Solution 2:

$$s = vt$$

$$s = 100 \times 2$$

$$s = 200m$$

The cannonball will hit the ship (just).

Practice questions

1. A stone thrown horizontally from a cliff lands 24m out from the cliff after 3 s. Find:

    a) The horizontal speed of the stone.

    b) The vertical speed at impact

2. A ball is thrown horizontally from a high window at 6 ms^{-1} and reaches the ground after 2s. Calculate:

    a) The horizontal distance travelled

    b) The vertical speed at impact.

3. A ball is projected horizontally at 15 ms^{-1} from the top of a vertical cliff. It reaches the ground 5s later. For the period between projection until it hits the ground, draw graphs, with numerical values on the scales, of the ball's:

    a) Horizontal velocity against time

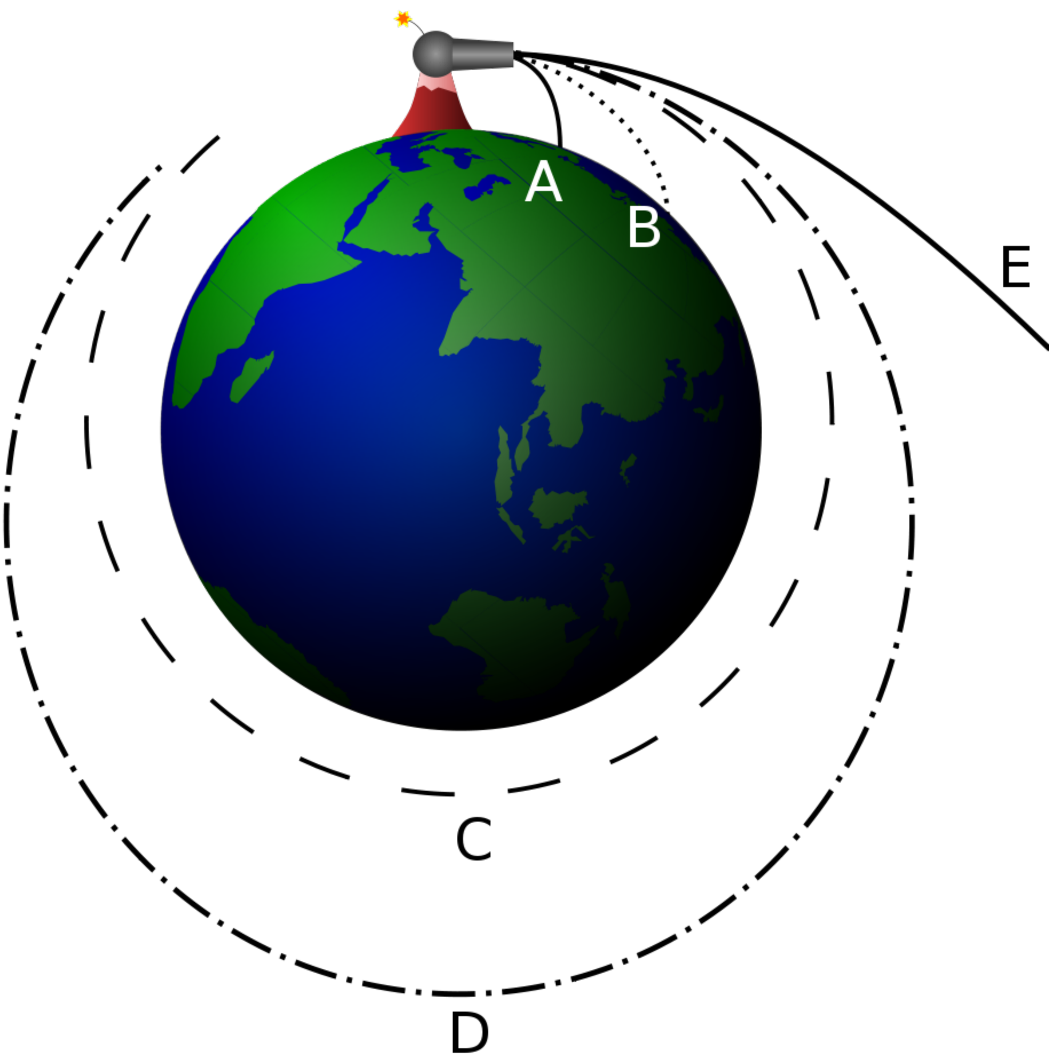
    b) Vertical velocity against time

    c) From the graphs, calculate the horizontal and vertical distances travelled.

Satellites

Newton conducted a thought experiment that is now dubbed “Newton’s Cannon”. He imagined placing a cannon on top of a mountain and firing a cannonball horizontally. He knew that the cannonball would fall towards the ground at a constant acceleration and also that Earth was a sphere. He reasoned that if the mountain were high enough, and the cannonball fired fast enough, the cannonball would ‘miss’ the earth and travel right around the planet.

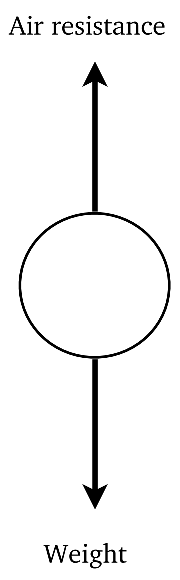
This is what we call a satellite. Though scientists knew in Newton’s time that the planets went around the sun in well defined orbits,Newton was the first to explain how the force of gravity could cause this type of motion.



Terminal Velocity

Under realistic conditions you know that a feather and a hammer do not hit the ground at the same time. This is because on Earth we have an atmosphere. This causes air resistance — which means that weight is **not** the only force acting on a falling object. Air resistance increases the faster you go. Eventually the force of air resistance will be the same as the weight of the object. Now the forces are **balanced** which means that the resultant force on the object is **zero**. This means it will stop accelerating and travel at a constant velocity.

We call this terminal velocity.



Re-Entry

Although the vast majority of satellites are in stable orbits, there are some very old satellites whose orbits have started to degrade. They will enter the Earths atmosphere at a high speed. Asteroids in space enter the Earths atmosphere and become meteors. Astronauts who went to the Moon or work on the International Space Station all need to re-enter the Earths atmosphere.

This is an extremely hazardous process.

While in orbit around the Earth, an object in space will be travelling extremely quickly (to the order of several miles per second). In the vacuum of space, where there is no air, there are no frictional forces acting on objects. However, as an object starts to fall towards the Earth, it begins to enter the atmosphere and when that happens, the object encounters frictional forces due to the air.

When moving at great speed in space, the object will have a large amount of kinetic energy. As the object enters the atmosphere, the frictional forces decrease the speed of the object. This causes a loss in kinetic energy which is changed into heat energy. Because energy must be conserved we know that:

Change (loss) in kinetic energy = Heat energy gained by the vehicle.

$$\Delta E_k = \frac{1}{2} mu^2 - \frac{1}{2} mv^2 = E_h$$

Where u is the initial velocity and v is the final velocity. Remember that from the Electricity and Energy unit we know that:

$$E_h = cm\Delta T$$

Therefore

$$\frac{1}{2} mu^2 - \frac{1}{2} mv^2 = cm\Delta T$$

This means that the temperature of the object will increase. The rise in temperature can be calculated if we know the specific heat capacity of the object.

On spacecraft that are re-entering the Earths atmosphere, ceramic tiles are used to protect the underbelly of the spacecraft. Ceramic tiles have an extremely high specific heat capacity.

The frictional forces can be calculated using the work done formula:

$$E_w = Fd$$

As through the conservation of energy

$$\Delta E_k = E_h = E_w$$

Practice questions

1. A meteor enters the Earth's atmosphere at 30,000ms^{-1}. It has a mass of 880kg and is made of a material with an specific heat capacity of 570Jkg^{-1}°C^{-1}. The material melts at 2200°C.

    a) Calculate the kinetic energy of the meteor.

    b) What happens to the speed of the meteor as it hits the atmosphere? Explain why this happens.

    c) If all the kinetic energy becomes heat energy, and is used to change the temperature of the meteor, calculate the change in temperature of the meteor.

    d) Does the meteor hit the Earth? If not, explain why not.

2. A space capsule with a mass of 1440kg re-enters the Earths atmosphere at 24,000ms^{-1}. The capsule has an average specific heat capacity of 970Jkg^{-1}°C^{-1}.

    a) Calculate the kinetic energy of the capsule on re-entry.

    b) If all the kinetic energy is transferred to heat energy of the capsule, calculate the predicted final temperature of the capsule if there is no change of state.

3. A spacecraft has a mass of 875 kg, decelerates from 10,000 ms^{-1} to 500 ms^{-1} as it enters the atmosphere.

    a) Calculate the original kinetic energy of the spacecraft.

    b) Calculate the final kinetic energy of the spacecraft.

    c) If the spacecraft travels $1x10^5$ km through the atmosphere as it comes into land, what is the average force due to air friction during this process?

Latent Heat

In reality space craft do not experience the temperature rise you would expect. This is because they are designed to radiate heat when re-entering the Earths atmosphere. A certain amount of heat energy still needs to be absorbed by the spacecraft and when the insulation gets too hot it begins to melt, boil and evaporate.

Heat shields are designed with coatings that deliberately vaporise. When a substance changes state the temperature of the substance remains constant whilst it is changing state. All of the heat energy that the heat shield is absorbing is going into melting or vaporising the coating, not into raising the temperature of the spacecraft. When a substance changes state from a solid to a liquid or liquid to a gas it **requires** energy. When a substance changes state from a gas to a liquid or liquid to a solid it **releases** energy. This effect is called **latent heat**.

Latent heat formula

The energy required to change the state of a substance is given by multiplying the mass of an object by its latent heat. There are two latent heats for every material. The *latent heat of fusion* is used when going between **solid** and **liquid**. The *latent heat of vaporisation* is used when going between **liquid** and **gas**. The formula appears in the formula book and looks like this:

$$E_h = ml$$

Heat energy measured in joules (J)

Mass measured in kilograms (kg)

Latent heat (of fusion or vaporisation) measured in joules per kilogram (Jkg^{-1})

Example:

How much heat energy is required to turn 5kg of water at 100°C to 5kg of steam at 100°C? (l_v water = $2.26x10^6$ Jkg^{-1})

Solution:

$E_h = m \times l_v$

$E_h = 5 \times 2.26x10^6$

$E_h = 1.13x10^7 J$

Note that if 5kg of steam condenses then it would *release* the same amount of energy. This is why a steam burn is much worse than a hot water burn.

Practice problems

1. Which of the following liquids has the larger latent heat of vaporisation? Vinegar which requires 195 kJ to vaporise 500g or benzene which requires 320kJ to vaporise 800g.

2. At 357°C Mercury boils into a vapour. If 20g of Mercury can be vaporised with 5880J of energy, what is the specific latent heat of vaporisation of Mercury?

Cosmology

There are some basic terms used in Cosmology that you need to be familiar with:

Celestial Body	Definition
Planet	An object, that is not undergoing fusion, orbiting a star and of sufficient size to be rounded by its own gravity.
Moon	A natural object orbiting a planet
Star	An object undergoing thermonuclear fusion
Solar System	A set of objects in orbit around a star (or star system)
Galaxy	A group of gravitationally bound stars, gas and dust clouds, and (we think) dark matter. The Milky Way galaxy is 100,000 light years across.
Universe	The totality of existence. The *observable universe* is everything we can see from Earth and is approximately 46 billion light years across.

The Light Year

Distances in space are so huge that using numbers in conventional units such as metres and kilometres would become clumsy and incomprehensible. For example, the distance from the Sun to the Earth is 140,000,000,000m ($1.4 \mathrm{x} 10^{11}$m). If we look outside of our solar system, the numbers get far too big. For example, the distance to our nearest neighbouring star, Proxima Centauri is 4,100,000,000,000,000m ($4.1 \mathrm{x} 10^{15}$m).

Instead we use the light-year (or ly for short). It is a unit of **distance** not time and is equal to the distance that light would travel in one year. So how far is that in meters?

$$1\text{ly} = d = vt$$

$$1\text{ly} = 3\times10^{8} \times (1 \times 365.25 \times 24 \times 60 \times 60)$$

$$1\text{ly} = 9.4607\times10^{15}\text{m}$$

The other units you may come across when reading about cosmology and astrophysics are:

- The astronomical unit (au) — equal to the distance between the Earth and the Sun (8 light minutes, 15 light seconds).
- The parsec (pc) — equal to 3.26ly.

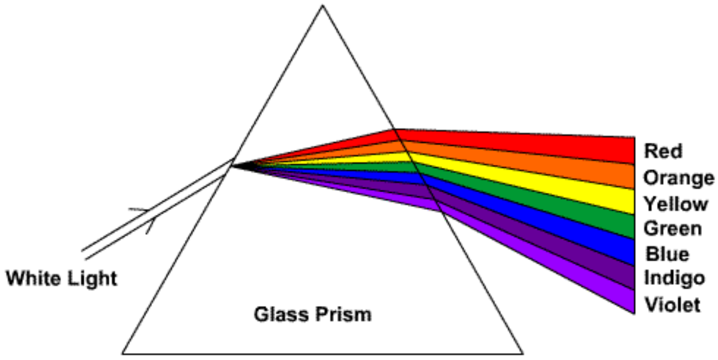
Exploring the Spectrum

By looking at the emissions (visible light and other parts of the electromagnetic spectrum) of a star, we can tell its temperature, mass, size and composition. Light can be gathered by telescopes and analysed by spectroscopes.

Visible light can be split into its component parts using 2 methods:

1. A Prism.

2. A diffraction grating.



Because white light is made up of seven other colours, we can show the separate colours using a prism. Each colour is refracted by a different angle depending on the wavelength of the light.

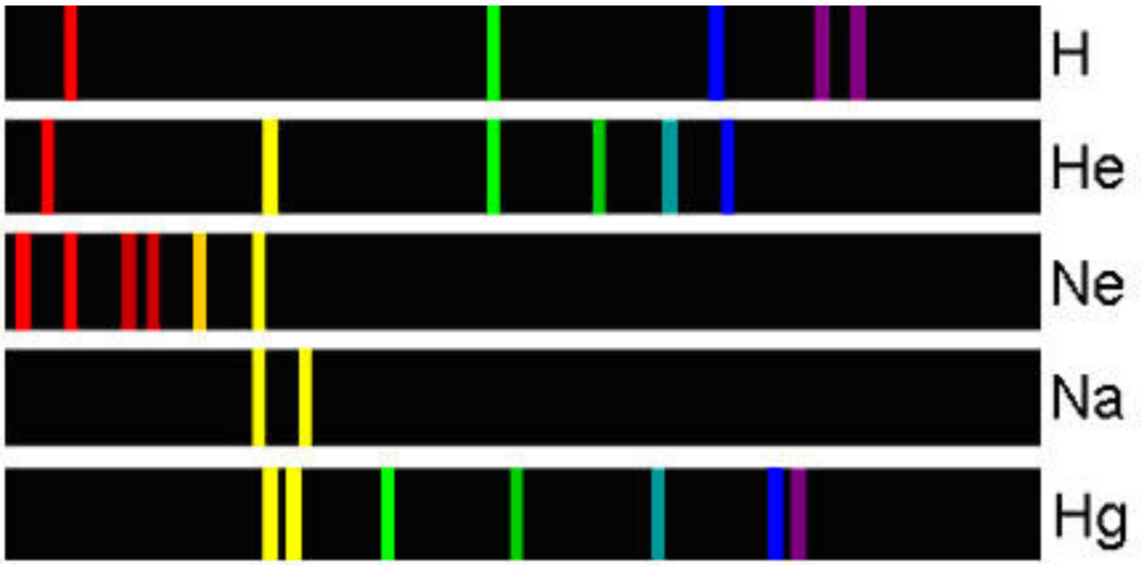
Looking at the single spectra produced, we can see that the white light is split into its component colours. Look carefully:

- Which colour is refracted the least? ________________________________
- Is this a long or short wavelength? ________________________________
- Which colour is refracted the most? ________________________________
- Is this a long or short wavelength? ________________________________

Line Spectra

When an electrical current is passed through a gas (or if it is extremely hot), energy is emitted from the gas in the form of light. The light produced has very specific frequencies for each element. This is called a line emission spectrum. This means that any gas can be identified by the light produced when burned, so we can identify the elements contained within a star just by looking at the starlight produced.

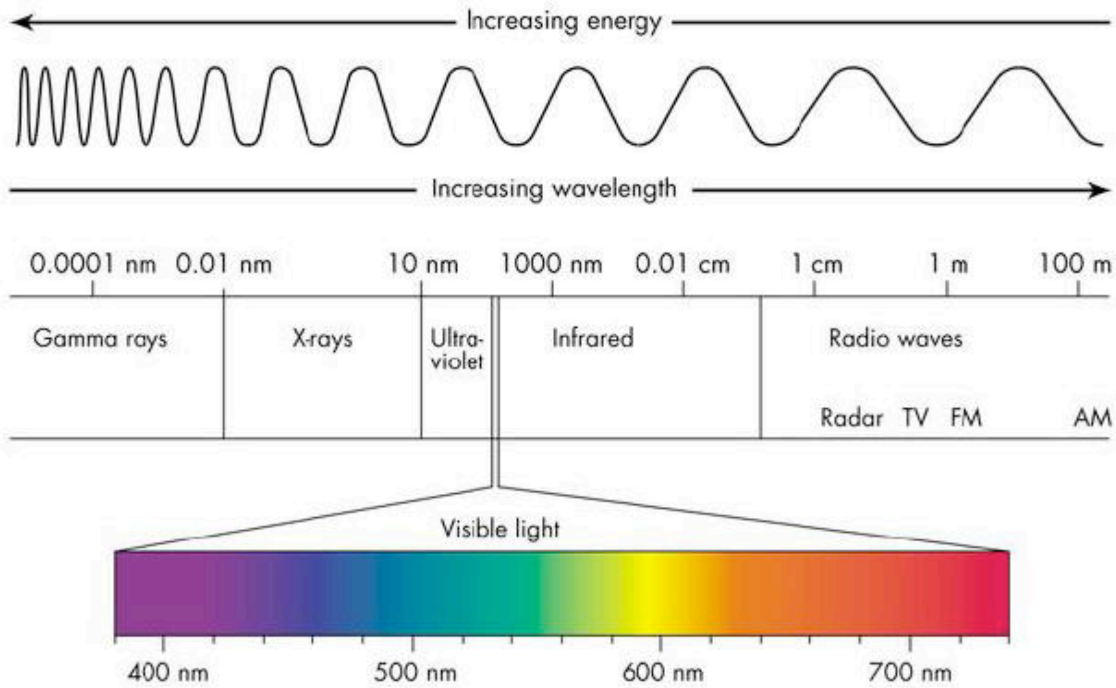
Below are some line spectra of various elements:



When light from a star is analysed in a spectrometer and compared to a database to find out what elements are contained in that star.

The Electromagnetic Spectrum

Remember that visible light is not the only part of the Electromagnetic Spectrum. There are many other wavelengths that we cannot see but we can detect.



Note that as wavelength decreases, the frequency of the wave increases and so the energy of the wave also increases.

All members of the spectrum travel at the same speed: the speed of light, $3 \times 10^8 ms^{-1}$.

Detecting Signals from Space

The stars in the night sky don't just give out the light that we see — they can also produce radio waves with very long wavelengths. The majority of the electromagnetic radiation hitting the Earth is absorbed by the Earth's atmosphere and its magnetic field. However, there is a "window" of wavelengths that allows radio waves to be travel through the atmosphere.

Radio waves from space can be detected by an aerial or receiver, the problem is that the radio waves are extremely weak. To combat this we can make curved reflectors that are either as large as possible or put together in an array. These receivers are called Radio Telescopes. They can be set to receive radio signals from a certain part of the sky, they do the same job that conventional telescopes do, but for radio waves.

Recently there has been an effort to look at other parts of the EM spectrum as well. This requires launching a telescope into orbit so that the Earth's atmosphere and magnetic field do not block the signals. Using satellites such as *Swift* and the planned *James Webb Space Telescope* we are able to look at the universe in every part of the EM spectrum.

In addition to light there are other things that we can detect from stars and galaxies:

Cosmic Rays — These are parts of atoms and other particles that are blasted across the universe by supernovae. The vast majority of these (99%) are Hydrogen and Helium nuclei. They travel at close to the speed of light and interact with magnetic fields making it very difficult for us to trace where they came from.

Neutrinos — A particle produced in massive numbers by the nuclear reactions in stars. They are very hard to detect because the vast majority of them pass completely through the Earth without interacting.

How old is the universe?

The universe is 13.8 billion years old. That's 13.8 $x10^9$ years old.

How do we know this?

In simple terms, we know that the universe is still expanding — the galaxies that we can observe are accelerating away from us. Galaxies move further away the light coming from them is redder than what is should be. It is the same principle as when a police car drives past with the siren on, as it moves away from you, the sound changes to a lower pitch. It is called the Doppler Effect.

If we know the rate at which galaxies are accelerating we can reverse the process and see how long it would take to come to a single point — the Big Bang.

The Big Bang

Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. Prior to that moment there was nothing. During and after that moment there was something — our universe.

Though science is still unsure how or why this happened we do know what happened next. From 10^{-43} seconds after the Big Bang (the Planck Epoch) we know that the universe had a massive density (close to infinity), was expanding rapidly and all the fundamental forces acted as one. We know relatively little about this early stage of the universe's life and virtually nothing about what the universe was like before this.

By the time that the universe was 10^{-12} seconds old the four fundamental forces (electromagnetism, gravity and the strong and weak nuclear forces) have separated. The universe is filled with an extremely hot and dense quark-gluon plasma. The universe doesn't get cool enough for protons and neutrons to form until 1 second after the Big Bang. It is thought that neutrinos came into existance around this time as well. After about 10 seconds electrons start to appear in the universe.

When the universe is about 3 minutes old it is cool enough for the protons and neutrons to form into nuclei. This nuclear fusion lasts for about 17 minutes, producing a universe consisting of about 75% Hydrogen, 25% Helium with traces of a few heavier elements such as Lithium and Beryllium. Atoms still cannot form however, thanks to the vast numbers of high energy photons.

Atoms start to appear after the universe is about 377,000 years old but it isn't until the universe is 150 million years old that the first stars start to form. 8 billion years after the Big Bang the Milky Way galaxy was formed and a billion years later (4.6 billion years ago). Our own Solar System collapsed, forming the Sun. The dust and gas around the Sun would eventually form the planets, including our own.

Evidence for The Big Bang

Galaxies appear to be moving away from us at speeds proportional to their distance. The light from galaxies appears to be more red than it should be due to the Doppler Effect. The decreased frequency of the light tells us that the galaxies are moving away from us. This is called "Hubble's Law", named after Edwin Hubble (1889 – 1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted.

If the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (–270.425°C) noise in their radiometer. After eliminating all other possibilities (including that pigeons had defecated inside the antenna) they realised they had found this remnant. The Cosmic Microwave Background radiation (CMB) pervades the observable universe and research continues into its properties. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.

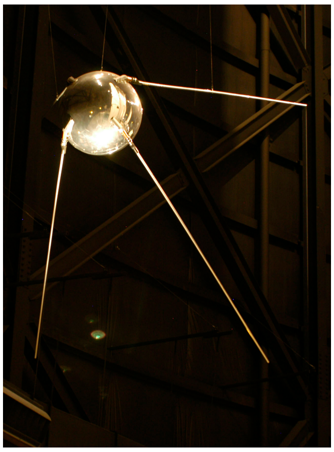
The models of the Big Bang predict that the universe will have a certain ratio of elements (specifically Hydrogen to Helium, Deuterium to Hydrogen, Helium-3 to Hydrogen and Lithium- 7 to Hydrogen). The measured ratios all fall well within the predicted values.

The Big Bang also influences how stars and galaxies form. Observations of the distribution of galaxies across the universe very closely match what would be expected from the Big Bang.

Stars produce heavy elements (such as Iron) in their cores and in supernovae explosions. When scientists discovered some gas clouds in 2011 they found that they contained nothing heavier than deuterium. This shows that there must have been a point in the universe when there were no stars or heavy elements.

Benefits of Space Exploration

There are many technologies today that we take for granted that have directly or indirectly resulted from the efforts of various countries' space programs. Since the first artificial satellite, the Soviet built *Sputnik 1*, launched in 1957 satellites have become so commonplace that nearly everyone uses one every day. Satellites can be built to do a wide variety of jobs:



- Communications (including the internet)
- Weather information capture
- Long term climate change monitoring
- Pollution monitoring (e.g. the Ozone layer)
- Navigation (GPS and GLONASS)
- Military observations — "spy satellites"
- Cartography (Google Earth and other similar satellite mapping tools)
- Entertainment — primarily satellite TV services (such as Sky or Freesat)
- Science — Hubble and James Webb space telescopes, the International Space Station and many others

Today there are over 3000 artificial satellites in orbit around Earth, but satellites are not the only beneficial technology to arise from the exploration of space. To support manned missions into space — such as the first manned flight into space by Yuri Gagarin aboard *Vostok 1* in 1961 — many other technologies were developed and now see various applications back on the Earth's surface. For instance:

- Infrared thermometers were made possible by research into infrared telescopes
- Water purification systems developed for long term space missions are now used to help treat kidney disease
- Advances in robotic arms used in the Space Shuttle program were adapted to improve the functionality of prosthetic limbs
- Scratch resistant lenses were originally developed to prevent the visors on space suits becoming scratched by lunar dust and microscopic space debris. Enhanced UV protection in sunglasses was also originally developed for use in space suit visors
- The 'space blanket' was developed by NASA for the Apollo missions

- After helping to make tyres for rovers sent to Mars Goodyear developed a new type of radial tyre with a vastly improved tread life
- Extensive research into heat shielding and fire resistant materials (for re–entry) have been adapted into building and aircraft designs
- NASA’s advanced fire fighting equipment is now standard issue
- Temper memory foam was developed as a crash protection material
- Enriched baby food is a result of fortifying astronaut’s food for long missions
- Portable cordless vacuums were designed for the Apollo missions to allow astronauts to collect dust from drilling Moon rock
- Freeze dried food was also developed for the Apollo missions
- Development of solar cells to provide power to satellites is now used for electricity generation
- The NASA Structural Analysis Program (NASTRAN) software package is used the world over to model the stress, vibration and acoustic properties of all sorts of structures and vehicles
- Remotely operated ovens developed for the International Space Station are now commercially available
- A powdered non liquid lubricant — PS300 is now seeing widespread usage and was originally designed for moving parts of spacecraft exposed to vacuum
- MRI scanning has benefitted from advances in imaging software and technology developed for imaging the Moon and other celestial bodies

Velcro is commonly thought to have been invented by NASA for the Apollo missions — however NASA’s use of the material merely popularised it — Velcro was in fact invented in 1948 and commercially available by the late 50’s.

Dynamics and Space

You need to know:

	✓ ? ✘
The difference between a scalar and a vector	
Weather a quantity is a vector or a scalar	
How to work out a resultant vector	
The difference between distance and displacement	
How to calculate displacement	
How to calculate velocity	
How to draw a velocity time graph	
How to describe the motion of an object from its speed time graph	
How to calculate displacement from a velocity time graph	
How to use the $a=(v-u)/t$ formula	
How to calculate acceleration from a velocity time graph	
Newton's First Law and its implications	
Newton's Second Law and how to use the $F=ma$ formula	
What Work Done is and how to use the $E_W=Fd$ formula	
The difference between mass and weight	
How to use the $W=mg$ formula and how it relates to $F=ma$	
Newton's Third Law and its implications	
What free fall and terminal velocity are	
How to explain projectile motion	
How to do calculations involving horizontally launched projectiles	
How to explain orbital motion (in terms of projectiles)	
What evidence there is for the Big Bang	

	✓ ? ✘
The impact of space exploration	
The benefits of space exploration	
What Latent Heat is	
How to use the $E_h=ml$ formula	
How to use the various energy formulae and the conservation of energy to do calculations regarding re–entry	
What a light year is	
How to calculate the number of meters in a light year	
The age of the Universe	
How the Universe formed (The Big Bang)	
How different parts of the EM spectrum can be used to give information on astronomical objects and phenomena	
How to identify continuous and line spectra	
How to identify individual elements in the spectra of a star	