1.1 Motion

Speed

N4

Speed

Speed is the **distance** travelled by an object per **second** (usually expressed in metres per second, m/s or ms^{-1}).

Average Speed

The average speed of an object is the average for the whole journey
(total distance travelled divided by time taken).
e.g. Sports presenters on T.V. measure the average speed of a footballer's shot at goal

Instantaneous Speed

The instantaneous speed of an object is its speed at one particular point during the journey.
e.g. speed cameras measure the speed of a vehicle at a particular point in a journey to ensure that it is within the speed limit.

Speed during a journey

During a journey the instantaneous speed of a vehicle will change. For example at one point a car may be travelling along a street at 30 mph and when it is stopped at traffic lights its speed is 0 mph. These speeds can be very different from the average speed which may be something like 8 mph.

N4

Speed, Distance and Time Equation

From the definition: $\text{speed} = \frac{\text{distance}}{\text{time}}$

In symbol form: $\mathbf{v = \frac{d}{t}}$ $\mathbf{d = v\,t}$ $\mathbf{t = \frac{d}{v}}$

Quantity	**Symbol**	**SI Unit**
speed	v	m/s or ms^{-1}
distance	d	m
time	t	s

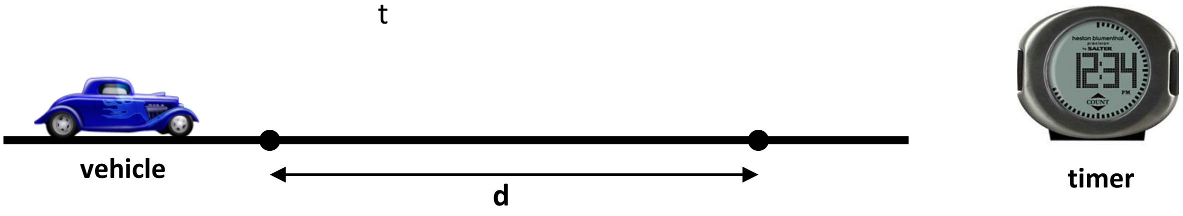
Example: Calculate the average speed of a car which takes 3 minutes to travel 1000m.

List	**Equation**	$d = v\,t$ (as written in data book)
d= 1000 m	**Substitute**	$1000 = v \times 180$
v = ?	**Answer & units**	$v = 5.56\ ms^{-1}$
t = 3 minutes = 180 s		

N4

Measuring Average Speed ($\bar{v}$)

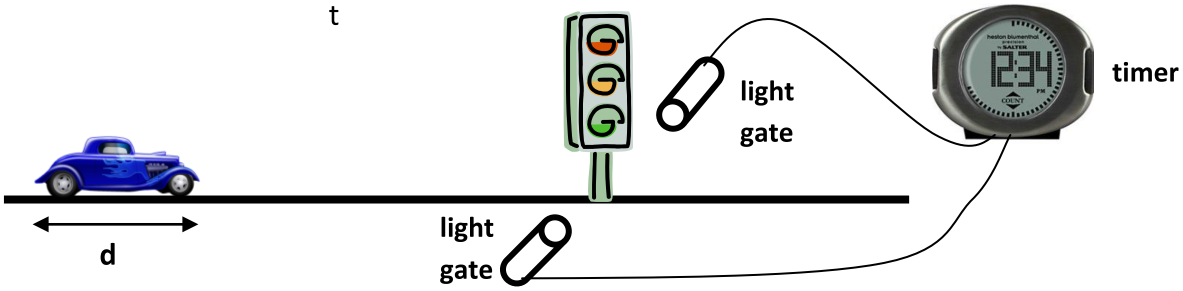
- Measure distance (**d**) travelled with a measuring tape.
- Measure time (**t**) taken for the vehicle to travel the distance (d) with a timer.
- Use the equation $\bar{v} = \frac{d}{t}$ to calculate the average speed ($\bar{\mathbf{v}}$).



N4

Measuring Instantaneous Speed (v)

- Measure the length of the vehicle (or card attached to the vehicle) (**d**) with a measuring tape.
- Measure time (**t**) taken for the vehicle to pass a point with a light gate connected to a timer.
- Use the equation $v = \frac{d}{t}$ to calculate the instantaneous speed (**v**).



Example: Calculate the speed of a car as it passes through the traffic lights. The car is 4m long and takes 0.75s to pass the traffic lights.

List	**Equation**	$d = v t$
d= 4m	**Substitute**	$4 = v \times 0.75$
v = ?	**Answer & units**	$v = 5.33ms^{-1}$
t = 0.75s		

Vectors and Scalars

N5

Classifying Vectors and Scalars

Physical quantities can be divided into two groups:

- a **scalar** quantity is completely described by stating its **magnitude** (size) only.
- a **vector** quantity is completely described by stating its **magnitude** and **direction**.

Which quantities are scalars and which are vectors?

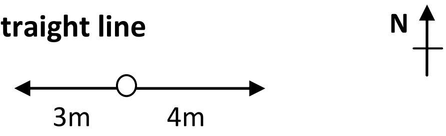
Scalars	Vectors
distance	displacement
speed	velocity
mass	force
time	acceleration
energy	

N5

Vector Diagrams

In order to carry out any calculations we need to know how to calculate the resultant of two vector quantities. This is illustrated in the examples below.

In a straight line

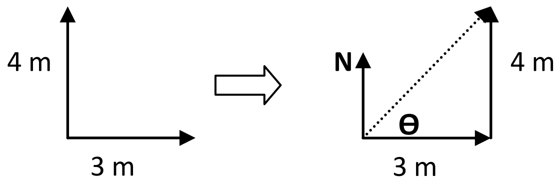


The resultant vector
= 4 – 3 = 1 m (090) or 1 m (due East)

At right angles

Hints

- **Ensure all vectors are drawn tip to tail**
- **Draw a North line at the start point**
- **Draw the resultant vector from the start to the end point**
- **All bearings are measured clockwise from the North line to the resultant vector.**



Use Pythagoras to calculate the magnitude of the vector

$x^2 = 3^2 + 4^2$

x = 5m

Use Tan Θ = opp / adj to find angle Θ

Tan Θ = 4 / 3

$\Theta = 53.1^o$ bearing = 90 – 53.1 = 36.9

Resultant vector = 5 m (036.9)

N5

Vector Diagrams and Calculations (ctd)

Distance and Displacement

Distance is the total distance travelled regardless of the direction.
Displacement is the length measured from the start point to the end point in a straight line. Its direction must be stated.

Speed and Velocity

As stated previously, speed is defined as the distance travelled per second.
Velocity can be defined as the displacement (s) of an object per second (t) measured in ms^{-1}.

Speed and velocity are described by the equations below:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \qquad \text{velocity} = \frac{\text{displacement}}{\text{time}}$$

In symbol form the velocity equation is:

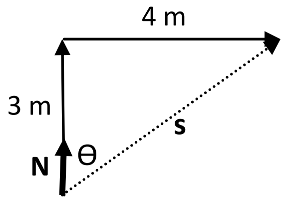
$$\mathbf{v = \frac{s}{t}} \qquad \mathbf{s = v\,t} \qquad \mathbf{t = \frac{s}{v}}$$

Quantity	**Symbol**	**SI Unit**
velocity	v	m/s or ms^{-1}
displacement	s	m
time	t	s

Velocity is a vector quantity and speed is scalar.
The direction of the velocity will be the same as the direction of the displacement.

Example: A woman walks 3 m due North and then 4 m due East. She takes 10 seconds.
a) Find the (i) distance she has walked and (ii) her displacement.
b) Calculate her (i) average speed and (ii) velocity.

Solution
We will represent her walk by drawing a vector diagram.



a) (i) The distance she has travelled is 3 + 4 = 7 m
(ii) Her displacement can be calculated using Pythagoras:

$$s^2 = 3^2 + 4^2$$
$$s = 5 \text{ m}$$

The angle Ɵ is calculated using

$$\text{Tan}\ \theta = 4 / 3$$
$$\theta = 53^{o}$$

s = 5 m (053)

b) (i) d = 7 m　　d= v t
v = ?　　7 = v x 10
t = 10 s　　$v = 0.7\ ms^{-1}$

(ii) s = 5 m　　s = vt
v = ?　　5 = v x 10
t = 10 s　　$v = 0.5\ ms^{-1}$ (053) **Remember that velocity is a vector and requires a bearing = bearing of the displacement.**

Acceleration

N4 N5

Acceleration

Acceleration is the **change in speed (or velocity)** every **second** and is measured in metres per second per second (ms^{-2}).

It can be calculated using the formula:

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time}}$$

In symbol form: $$a = \frac{v - u}{t}$$

Quantity	Symbol	SI Unit
acceleration	a	m/s/s or ms^{-2}
final velocity	v	ms^{-1}
Initial velocity	u	ms^{-1}
time	t	s

A common form of the equation worth remembering is **$v = u + at$**

Example:

1. Calculate the acceleration of a vehicle travelling from rest to 12 ms^{-1} in 5 s.

a = ?

$v = 12\ ms^{-1}$

u = 0 (at rest)

t = 5 s

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

$$a = \frac{12 - 0}{5}$$

$$a = 2.4\ ms^{-2}$$

2. A car accelerates at 4 ms^{-2} for 10 s from rest. Calculate the sped of the car after 10 s. N5

$a = 4\ ms^{-2}$

v = ?

u = 0 (at rest)

t = 10 s

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

$v = u + at$

$v = 0 + (4 \times 10)$

$v = 40\ ms^{-1}$

3. Calculate the deceleration of a train which travels from 30 ms^{-1} to 16 ms^{-1} in a time of 1 minute. N5

a = ?

$v = 16\ ms^{-1}$

$u = 30\ ms^{-1}$

t = 1 minute = 60 s

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

$$a = \frac{16 - 30}{60}$$

$a = -0.47\ ms^{-2}$ deceleration = $0.47\ ms^{-2}$

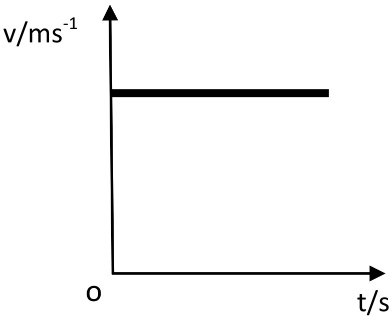
Graphs

N4

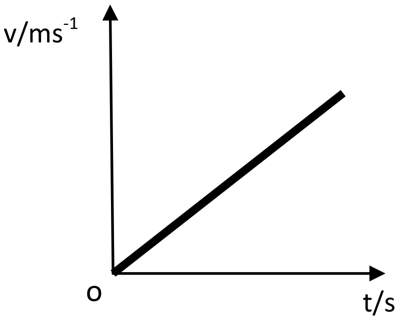
Speed – Time Graphs

A speed-time graph is a useful way of describing the motion of an object.
Since speed is a scalar quantity, a speed-time graph considers motion in one direction only.

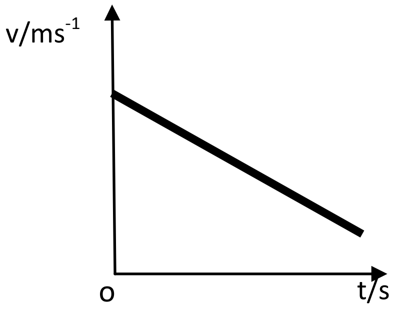
The graphs below illustrate the 3 types of motion you will study.



constant speed



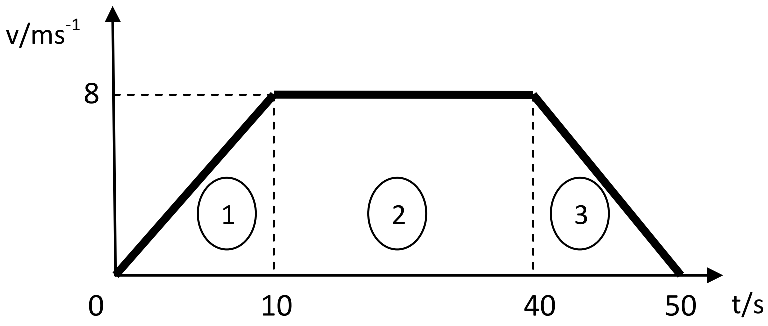
increasing speed
(constant acceleration)



decreasing speed
(constant deceleration)

The steeper the line (larger gradient) the greater the acceleration

Example: The motion of a car over 50 s is described in the speed-time graph below.



a) Calculate the acceleration of the car during the first 10 s.
b) Calculate the distance travelled by the car for the entire 50 s.

Solution

a) a = ?
$v = 8\ ms^{-1}$
u = 0 (at rest)
t = 10 s

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

$$a = \frac{8 - 0}{10}$$

$$a = 0.8\ ms^{-2}$$

b) **To calculate the distance travelled we cannot use d = vt as the speed is not constant throughout the journey.**

The distance travelled = area under the speed-time graph

Area 1 = ½ (10 x 8) = 40 (area of right angled triangle)
Area 2 = 30 x 8 = 240 (area of rectangle)
Area 3 = ½ (10 x 8) = 40 (area of right angled triangle)

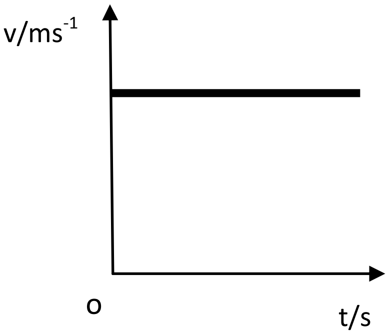
Total area = 40 + 240 + 40 = 320 so distance travelled = 320m

N5

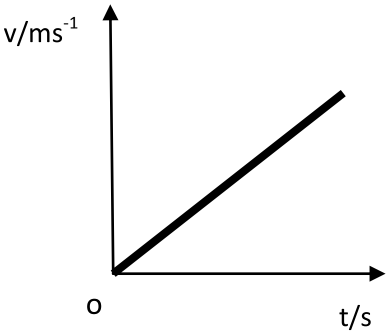
Velocity – Time Graphs

A velocity-time graph is a useful way of describing the motion of an object.
Since velocity is a vector quantity, a velocity-time graph can consider motion in two directions.

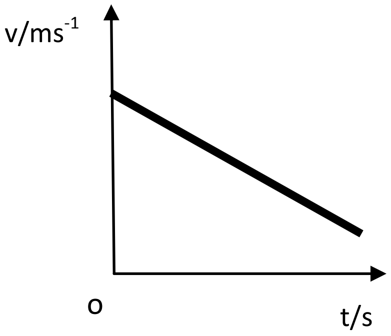
The graphs below illustrate the 3 types of motion you will study.



constant velocity



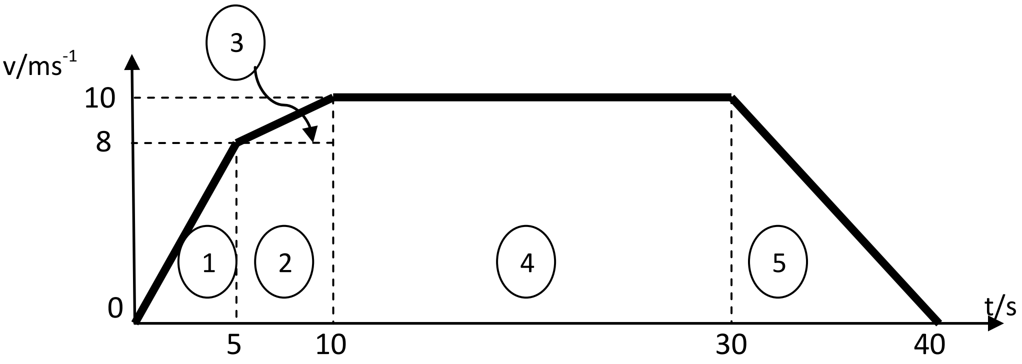
increasing velocity (constant acceleration)



decreasing velocity (constant deceleration)

The steeper the line (larger gradient) the greater the acceleration

Example: The motion of a car over 40 s is described in the velocity-time graph below.



a) **During which stage of the journey is the acceleration of the car the greatest?**
b) **Calculate the deceleration of the car between 30 and 40 s.**
c) **Calculate the displacement of the car for the entire 40 s.**

Solution

a) Between 0 and 5 s. **(the gradient of the line is greater than 5 s to 10 s)**

b) a = ?
v = 0
$u = 10ms^{-1}$
t = 10s

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

$$a = \frac{0- 10}{5}$$

$a = -2\ ms^{-2}$ deceleration = $2ms^{-2}$

c) Displacement = area under the velocity-time graph

Area 1 = ½ (5 x 8) = 20
Area 2 = 5 x 8 = 40
Area 3 = ½ (5 x 2) = 5
Area 4 = 20 x 10 = 200
Area 5 = ½ (10 x 10) = 50

Total area = 20 + 40 + 5 + 200 + 50 = 315 so the displacement = 315 m

Motion Equations

National 4

$d = v\,t$

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

distance travelled = area under v-t graph

National 5

$s = v\,t$

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

displacement = area under v-t graph

Prefixes

(National 5 only)

Prefix	**Symbol**	**Factor**
giga	G	1 000 000 000 = x10^{9}
mega	M	1 000 000 = x10^{6}
kilo	k	1 000 = x10^{3}
milli	m	0.001 = x10^{-3}
micro	µ	0.000 001 = x10^{-6}
nano	n	0.000 000 001 = x10^{-9}

1.2 Forces

N4

Effects of Forces

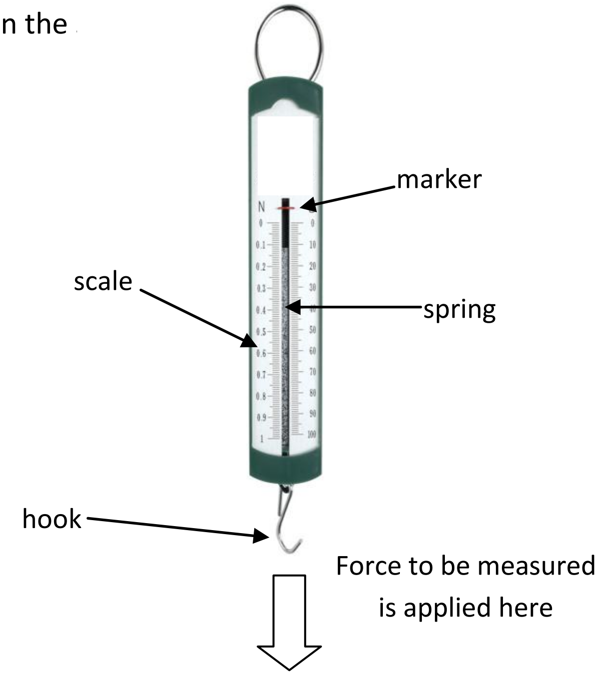
Forces can only be detected by their effects.
They can **change**:

- the **shape** of an object e.g. squeezing plasticine
- the **speed** of an object e.g. kicking a football from rest
- the **direction of movement** of an object e.g. hitting a tennis ball with a racquet.

N4 **N5**

Measurement of Forces

Forces are measured in units called **newtons** (N). Force is a **Vector** quantity.
Forces can be measured with a newton balance. This instrument depends on the effect of a force on the



- The force to be measured is applied to the hook which is attached to the spring.
- The force causes the spring to stretch.
- The greater the force, the greater the stretch of the spring and the further the marker moves across the scale.

Friction

N4

Introduction to Friction

Friction is a **resistive** force, which **opposes** the direction of motion of an object. This means that it acts in the **opposite** direction to motion.

Friction acts between any two surfaces in contact.
When one surface moves over another, the force of friction acts between the surfaces and the size of the force depends on the surfaces, e.g. a rough surface will give a lot of friction.

Air friction is usually called **air resistance** or **drag**. It depends mainly on two factors:

- the shape and size of the object
- the speed of the moving object.

Air resistance **increases** as the speed of movement **increases** (as the object accelerates).

N4

Increasing Friction

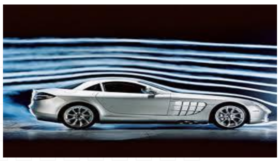
Where friction is used to **slow** an object down, it should be **increased**.
This can be achieved by:

- choosing surfaces which cause high friction e.g. sections of road before traffic lights have higher friction than normal roads
- increasing the surface area and choosing a shape to increase air friction, e.g. parachute.

Decreasing Friction

Where friction is making movement difficult, friction should be reduced.
This can be achieved by:

- lubricating the surfaces with oil or grease
- separating the surfaces with air, e.g. a hovercraft
- making the surfaces roll instead of slide, e.g. use ball bearings
- streamlining the shape of the object to reduce air friction (aerodynamic teardrop shape).



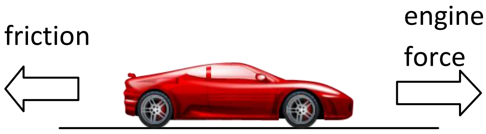
Newton's Laws of Motion (1 and 2)

N4

Balanced Forces

A force is a vector quantity because to describe it properly requires a direction as well as size.

Two forces which are **equal in size** which act in **opposite directions** are called **balanced forces.**



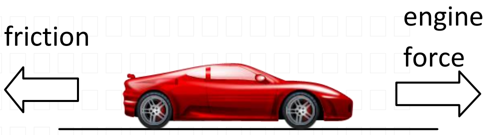
When the engine force = friction on the car the forces are balanced.

Balanced forces have the same effect as having **no** forces acting at all.

N4 N5

Newton's 1st Law of Motion

An object will remain at rest or travel in a straight line at a constant velocity (or speed) if the forces are balanced.



- If we consider the car moving in a straight line. If the engine force = friction, it will continue to move at a constant velocity (or speed) in the same direction.
- If the same car is stationary (not moving) and all forces acting on it are balanced (same as no force at all) the car will not move.

N4

Free Body Diagrams

We can use free body diagrams to analyse the forces on an object. This allows us to determine the motion of the object.

Example: If the bus is travelling with an engine thrust of 12kN and all forces acting on the bus are balanced

a) calculate the size of the frictional force acting

b) determine the motion of the bus.

Solution a) Draw the free body diagram

Since the forces are balanced

friction = 12kN

b) constant velocity (or speed) since the forces are balanced.

N4 **N5**

Newton's 2nd Law of Motion

This law deals with situations when there is an unbalanced force acting on the object. The velocity cannot remain constant and the acceleration produced will depend on:

- the mass (**m**) of the object **($a \propto 1/m$) - if m increases a decreases and vice versa**
- the unbalanced force **(F)** **($a \propto F$) - if F increases a increases and vice versa**

This law can be summarised by the equation F = ma

N4 **N5**

Force, Mass and Acceleration Equation

A newton is defined as the force which makes a 1 kg mass accelerate at $1 ms^{-2}$

From the definition: $\text{acceleration} = \frac{\text{unbalanced force}}{\text{mass}}$

In symbol form: $\mathbf{a = \frac{F}{m}}$ $\mathbf{F = ma}$ $\mathbf{m = \frac{F}{a}}$

Quantity	Symbol	SI Unit
unbalanced force	F	N
mass	m	kg
acceleration	a	ms^{-2}

Example: Calculate the unbalanced force acting on a 10000 kg bus accelerating at 3.5 ms^{-2}.

F = ?

m = 10000 kg

a = $3.5ms^{-2}$

F = ma

F = 10000 x 3.5

F = 35000 N

N5

Resultant Forces (1)

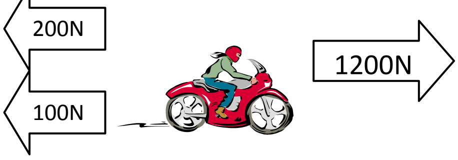
When several forces act on one object, they can be replaced by one force which has the same effect. This single force is called the **resultant** or **unbalanced** force.

Example: Horizontal

A motorcycle and rider of combined mass 650 kg provide an engine force of 1200 N. The friction between the road and motorcycle is 100N and the drag value = 200N.

Calculate:

a) **the unbalanced force acting on the motorcycle**
b) **the acceleration of the motorcycle**



Solution

a) Draw a free body diagram

F = 1200 - (200 + 100)

F = 900 N This 900 N force is the resultant of the 3 forces

b) F = 900 N

a = ?

m = 650 kg

F = ma

900 = 650 x a

a = 1.38 ms^{-2}

Resultant Forces (2) in the vertical direction will be considered in the Space Exploration section

N5

Motion During Free Fall and Terminal Velocity

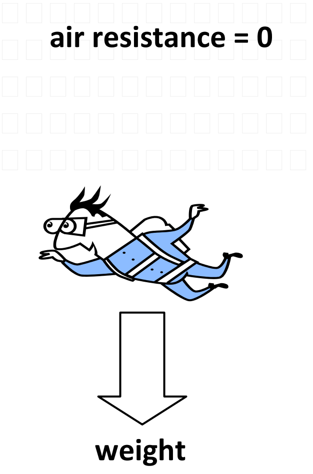
Free fall is the term used when an object is being acted upon only by the force of gravity (weight).

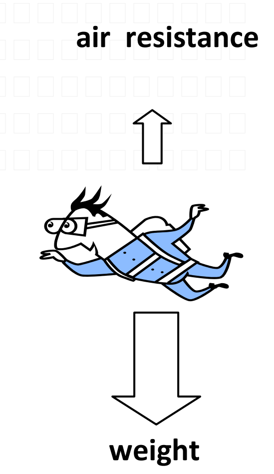
However, free fall will cause the object to accelerate and from the section Introduction to Friction, it states that:

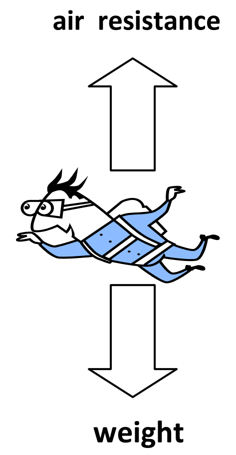
air resistance will increase as an object accelerates

so we have to look at air resistance as well as weight to study motion during free fall.

Example: If we consider a sky diver jumping out of an aeroplane







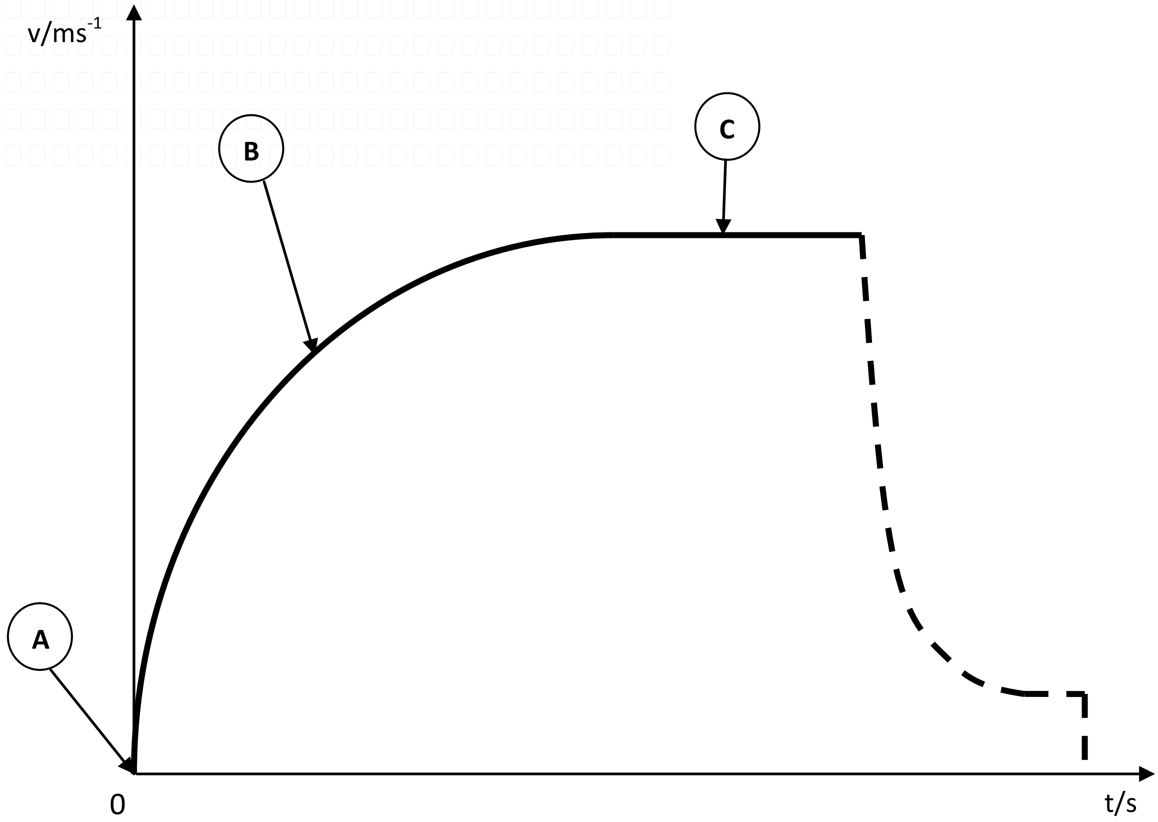
Ⓐ **As he jumps**	Ⓑ **During Free Fall**	Ⓒ **Terminal Velocity**
one force acting down	**weight > air resistance**	**weight = air resistance**
Unbalanced Force downwards (Newton's 2nd law)	**Unbalanced Force downwards (Newton's 2nd law)**	**Balanced Forces (Newton's 1st Law)**
maximum acceleration	**decreasing acceleration**	**acceleration = o (constant velocity)**

As the skydiver accelerates downwards, air resistance increases upwards until the value of air resistance = the skydiver's weight. This results in the two forces having the same value acting in opposite directions. According to Newton's 1st Law of Motion the skydiver will now travel at a constant velocity. This velocity is known as **Terminal Velocity**.

N5

Motion During Free Fall and Terminal Velocity (ctd)

The motion of the skydiver in the example is best illustrated in a velocity – time graph. Refer to the previous page to fully understand what happens at points A, B and C.



What do you think has happened to cause the motion represented by the dotted lines?
(Hint: How does the sky diver land on the ground safely?)

Forces and Energy

N5

Energy

Energy cannot be destroyed, but it can be changed from one form into another. All forms of energy are measured in the same unit: the **joule** (J).

When a force causes movement, some energy is changed from one form to another (it is transformed) and we say that **work is done**.
For example, the force of friction causes kinetic energy to be transformed into heat.

N5

Work Done

The **work done** is a measure of the **energy transformed**. It is equal to the force multiplied by the displacement (or distance) the force moves. The force and displacement (or distance) must be measured in the same direction.

N5

Work, Force and Displacement Equation

From the definition:

Work done = force x displacement

In symbol form: $\mathbf{s = \frac{E_w}{F}}$ $\mathbf{E_w = Fs}$ $\mathbf{F = \frac{E_w}{s}}$

Quantity	**Symbol**	**SI Unit**
work	E_w	J
force	F	N
displacement	s	m

Example: A car of mass 700 kg brakes to a halt 15 m after the driver hits the brake. If the breaking force = 1000 N, calculate the energy transferred (work done) by the brakes.

Solution

$E_w = ?$ $E_w = F s$

$F = 1000$ N $E_w = 1000 \times 15$

$s = 15$ m $E_w = 15000$ J.

N4

Weight

Weight is a force caused by gravity acting on an object's mass. On Earth, it measures the pull of the Earth on the object. It is measured in **newtons (N)**.

Mass

N4 **N5**

Weight, Mass and Gravitational Field Strength Equation

Weight always acts vertically downwards. Its size does not just depend on the mass of the object, but on the strength of gravity at that place.
The strength of gravity in a particular place is called the **gravitational field strength (g)** and is defined as **the weight per unit mass**. It is measured in **Nkg^{-1}. On Earth, g = 9.8 Nkg^{-1}.**

From the definition:

$$\text{gravitational field strength} = \frac{\text{weight}}{\text{mass}}$$

In symbol form: $\mathbf{g = \frac{W}{m}}$ $\mathbf{W = mg}$ $\mathbf{m = \frac{W}{g}}$

Quantity	**Symbol**	**SI Unit**
weight	W	N
mass	m	kg
gravitational field strength	g	Nkg^{-1}

Example: A girl has a mass of 70 kg on Earth (g = 9.8 Nkg^{-1})

a) Calculate her weight on i) Earth and ii) the moon where g = 1.6 Nkg^{-1}.

b) What is her mass on the moon?

Solution

a) i) W = ? W = mg ii) W = ? W = mg
m = 70 kg W = 70 x 9.8 m = 70 kg W = 70 x 1.6
g = 9.8 Nkg^{-1} W = 686 N g = 1.6 Nkg^{-1} W =
112 N

N5

W = m g Calculations - During Interplanetary Flight

The value for g is not always constant. It changes as you travel:

- further away from the centre of the earth;
- to a different planet, moon or star.

Every planet, moon and star has their own gravitational field strength.

Planet, Moon or Star	**Value for g / Nkg^{-1}**
Mercury	4
Venus	9
Earth	9.8
Earth's Moon	1.6
Mars	4
Jupiter	26
Saturn	11
Uranus	11
Neptune	12
Sun	270

Example: An un-manned space rocket of mass 20000 kg travels from Earth to Mars, Jupiter, Saturn and Uranus.

a) Calculate the rocket's weight on Mars.
b) What is the mass of the rocket on Jupiter?
c) Of the 4 planets (including Earth) visited by the rockets, on which planets would the weight of the rocket be the same? Explain your answer.

Solution

a)) W = ?	W = mg
m = 20000 kg	W = 20000 x 4
g = 4 Nkg^{-1}	W = 80000 N

b) m = 20000 kg

c) Saturn and Uranus. The values for g on both planets are the same with the mass of the rocket remaining constant.

During interplanetary flight there is no need for the engines to be kept on. Since space is a vacuum there is no friction acting on the space vehicle. With no unbalanced forces acting on the vehicle it will continue to move at a steady velocity (Newton's First Law of Motion).

Newton’s Laws of Motion (3)

N5

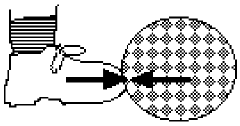
Newton’s 3rd law of Motion

Newton noticed that forces occur in pairs. He called one force the **action** and the other the **reaction**. These two forces are always equal in size, but opposite in direction. They do not both act on the same object (do not confuse this with balanced forces).

Newton’s Third Law can be stated as:
If an object A exerts a force (the action) on object B, then object B will exert an equal, but opposite force (the reaction) on object A.

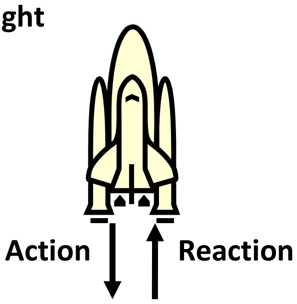
For example:

a) Kicking a ball



Action: **The foot exerts a force on the ball to the right**
Reaction: **The ball exerts an equal force on the left to the foot**

b) Rocket flight



Action: **The rocket pushes gases out the back**
Reaction: **The gases push the rocket in the opposite direction.**

1.3 Satellites and Projectiles

Satellites

N4

Satellites - Introduction

A **satellite** is an object which **orbits another object**.
The Moon is a natural satellite which orbits earth and Sputnik is a man made satellite as it was put into an orbit of the earth.

The **period** of a satellite is the **time** taken for the satellite to **complete one** orbit.

The **period** of a satellite depends on the **height of the satellite above the object** it is orbiting. The **higher** the orbit of the satellite the **greater** the period and vice versa.

N4

Geostationary Satellite

A **geostationary satellite** is a satellite which:

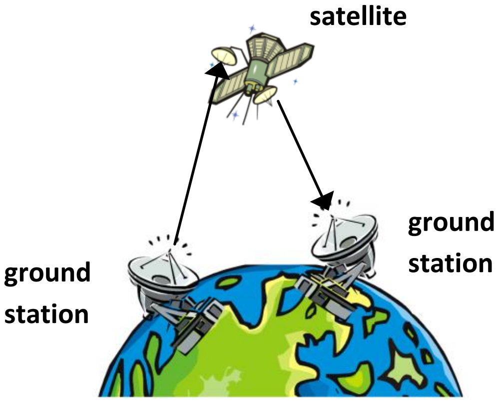
- has a period of 24 hours
- orbits at roughly 36000 km above the earth's surface which is much higher than other satellites
- stays above the same point on the earth's surface at all times.

N4

Satellite Communication

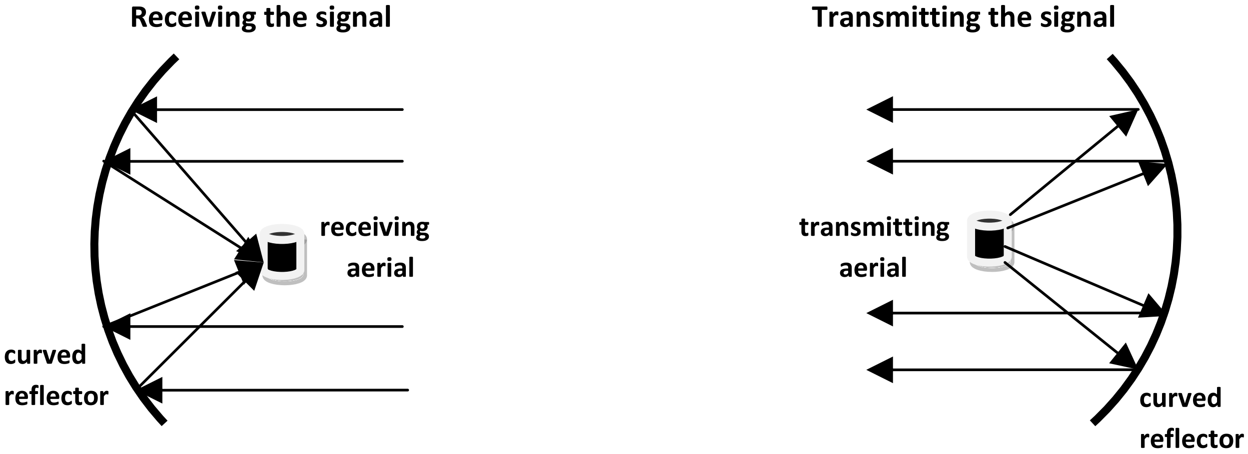
Ground stations send microwave signals to the satellite using a curved dish transmitter to transmit a strong signal. At the satellite the signal is **collected** by a curved dish receiver, then **amplified** and finally **retransmitted** (at a different frequency) back to the ground using another curved dish transmitter. The transmitting and receiving aerials are placed at the **focal point of the curved reflector.**

The signal is sent at a speed of 300 000 000 ms^{-1}. This allows the equation d = vt to be used with satellite communication.



N4

Satellite Communication – Parabolic (Curved) Reflectors



Curved reflectors are used to increase the strength of a received signal from a satellite or other source. The curved shape of the reflector collects the signal over a large area and brings it to a **focus**. The receiving aerial is placed at the focus so that it receives a strong signal.

Curved reflectors are also used on certain transmitters to transmit a strong, parallel signal beam. In a dish transmitter the transmitting aerial is placed at the focus and the curved shape of the reflector produces a parallel signal beam.

N4

Applications of Satellites

Satellites are being used by many countries in different ways. For example:

- **Sending a television or radio signal across the country or to another country**
  The Olympic Games can be beamed around the world using satellite communication. Three geostationary satellites, placed in orbit above the equator permits worldwide communication with satellites communicating with ground stations in different continents.
- **Navigation**
  There are many Global Positioning Satellite (G.P.S) systems available to put in a car so that you don't get lost. This uses the basic equation d = vt to establish your position.
- **Weather monitoring**
  The **weather satellite** is a type of satellite that is primarily used to monitor the weather and climate of the Earth.

N4 **N5**

Using Satellites to Monitor Global Change

Global environmental change is one of the most pressing international concerns of the 21st century. For many years, various types of satellites have been used to detect and monitor worldwide changes including:

- the effects of global warming
- depletion in the ozone layer and
- large scale changes in land cover.

These changes have been down to both:

- natural occurrences and
- as a consequence of the impact of our actions.

Satellites which are used to monitor such events orbit at heights much smaller than 36000 km and do not stay above the same point on the Earth’s surface. This allows continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps.

For example, the 2002 oil spill off the northwest coast of Spain was watched carefully by the European ENVISAT satellite, which, though not a weather satellite, flies an instrument (ASAR) which can see changes in the sea surface. It orbits at a height of approximately 800 km. With this information collected by the satellite, rescue teams and environmental agencies can attend the scene quickly and minimise the damage caused.

Other disasters, both natural and otherwise can be detected and monitored in a similar way.

Projectiles

N5

Projectile Motion

A **projectile** is an object which has been given a **forward** motion through the air, but which is also pulled **downward** by the force of gravity.
This results in the trajectory (path) of the projectile being curved.
For example, a cannon firing a cannonball will result in the cannonball following a curved trajectory as shown below.

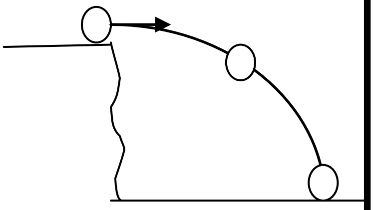
A projectile has two **separate** motions at right angles to each other - **horizontal and vertical**.
Each motion is **independent** of the other.

Points to note:

- The **horizontal** motion is at a **constant velocity** since there are no forces acting horizontally if air resistance can be ignored (Newton's first law of motion).
  Horizontal displacement = horizontal velocity x time in the air (**s = v t**)
- The **vertical** motion is one of **constant acceleration**, equal to the value of **g**.
  For projectiles which are projected horizontally, the initial vertical velocity is zero.
  For vertical calculations, use **v = u + at**, where **u = 0 and a = g (= 9.8ms^{-2} on Earth).**

Example: Using formulae
A ball is kicked horizontally at 5 ms^{-1} from a cliff top as shown below. It takes 2 seconds to reach the ground.

a) How far does the ball travel horizontally in 2 seconds?
b) What was its vertical velocity just before it hit the ground?



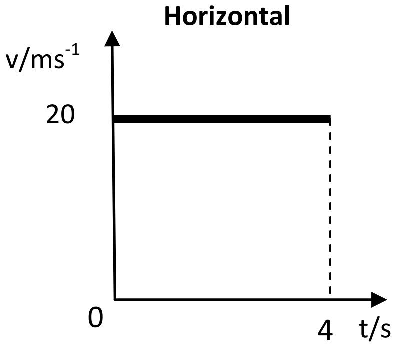
Solution

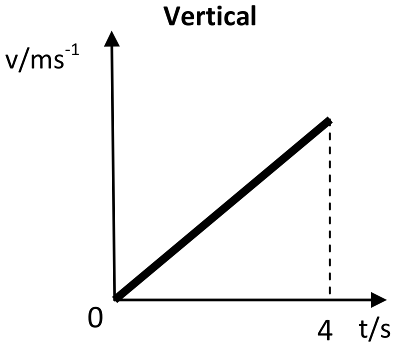
a) Horizontal	b) Vertical
s =?	v = ?
v = 5ms^{-1}	u = 0
t = 2 s	a = 9.8 ms^{-2} (= g on Earth)
	t = 2s (time is the same for vertical and horizontal motion)
s = v t	v = u + at
s = 5 x 2	v = 0 + (9.8x 2)
s = 10 m	v = 19.6 ms^{-1}

N5

Projectile Motion (ctd)

Example: Using Graphs
A bird flying horizontally at a constant velocity drops a fish it is carrying into a lake.
The velocity - time graphs for both the horizontal and vertical motion of the fish from when it is dropped until it hits the water are shown below.





Calculate

a) **The horizontal velocity when it hits the water.**
b) **The vertical velocity when it hits the water.**
c) **The horizontal displacement of the fish travelled after it was dropped.**
d) **The height the osprey was flying when it dropped the fish.**

Solution

a) Horizontal velocity = 20 ms^{-1} (horizontal velocity remains constant throughout).

b) Vertical

$v = ?$	$v = u + at$
$u = 0$	$v = 0 + (9.8 \times 4)$
$a = 9.8\ ms^{-2}$	$v = 39.2\ ms^{-1}$
$t = 3\ s$	

c) Horizontal displacement = area under the horizontal velocity - time graph
= area of rectangle
= 20 x 4
= 80 m.

d) Height = area under the vertical velocity - time graph
= area of triangle
= ½ x 40 x 4
= 80 m.

N5

Satellites – An Application of Projectile Motion

Satellite motion is an application of projectile motion. A satellite is continually accelerating vertically towards the ground just like any other projectile. However, the satellite is moving so fast horizontally that the Earth curves away from it as quickly as it falls. This means that the satellite never reaches the earth but continues to move in orbit.

1.4 Cosmology

The Universe

N4

Cosmic Definitions

There are many different bodies moving around in the universe. Below is a list of some of them with a definition of what they are:

Star	A hot ball of matter which is undergoing nuclear fusion emitting light. The sun is an example of a star.
Planet	A spherical ball of rock and / or gas which orbits a star. Earth is an example of a planet.
Moon	A lump of matter which orbits a planet. Our moon orbits Earth. Deimos which orbits Mars is another example of a moon.
Solar System	A solar system consists of a star and all the objects orbiting it as well as all the material in that system. Our Solar System includes the Sun together with the eight planets and their moons as well as all other celestial bodies that orbit the sun.
Galaxy	A large cluster of stars, some of which have planets orbiting them. The Milky Way is an example of a galaxy.
Exo Planet (or Extrasolar Planet)	A planet outside our Solar System. In 2009, there were between 220 and 350 reported exo planets depending on the criteria used by the counting organisation.
The Universe	Consists of many Galaxies separated by empty space.

N4

Life on an Exo Planet?

If you consider the growing population and dwindling resources of our home planet, some scientists believe that finding exo planets capable of sustaining life should be a top priority. Scientists need to consider the basic needs of life and if these needs can be delivered by an exo plant.
The basic needs for human life are:

- Oxygen
- Water
- Food
- Shelter
- Warmth.

In our search for a new home scientists need to identify an exo planet which has:

- A similar atmosphere to ours
- The potential to build shelter
- The potential to grow and nurture a sustainable food source.

The next problem once the exo planet has been identified is how to get there!

N4 **N5**

Light Year

Contrary to the name, a light year is a measure of **distance** and **not** time.

1 light year is the distance light travels in 1 year.

Light is an electromagnetic wave which travels at a speed of 300 000 000 ms^{-1}.

Question
How far does light travel in one year?

d = ?
v = 300 000 000 ms^{-1}
t = 1 x 365 x 24 x 60 x 60 = 31 536 000 s

d = v t
d = 300 000000 x 31 536 000
d = 9 460 800 000 000 000 m

one light year = 9 460 800 000 000 000 m

As the distances in the universe are very large we need to use the term light year instead of metres or even miles. Below are distances you will be required to know.

Approximate distance from **Earth** to:

- **The Sun** – 0.000016 light years (or 8.3 light minutes)
- **Proxima Centauri** (nearest star outside the solar system) – 4.2 light years
- **Canis Major Dwarf** (nearest galaxy to the Milky Way) – 25000 light years
- The **edge of the known Universe** – 46 billion light years.

Cosmogony

N5

The Big Bang Theory (The Theory of the Origin of the Universe)

Most astronomers believe the Universe began in a Big Bang about 14 billion years ago. At that time, the entire Universe was inside a bubble that was thousands of times smaller than a pinhead. It was hotter and denser than anything we can imagine.

Contrary to the name, astronomers believe that there was no explosion. The ‘bubble’ began to expand and the Universe that we know was born. Time, space and matter all began with the Big Bang. In a fraction of a second, the Universe grew from smaller than a single atom to bigger than a galaxy and it kept on growing at a fantastic rate. It is still expanding today.

As the Universe expanded and cooled, energy changed into particles of matter and antimatter. These two opposite types of particles largely destroyed each other. But some matter survived. More stable particles called protons and neutrons started to form when the Universe was one second old.

Over the next three minutes, the temperature dropped below 1 billion degrees Celsius. It was now cool enough for the protons and neutrons to come together, forming hydrogen and helium nuclei.

After 300 000 years, the Universe had cooled to about 3000 degrees. Atomic nuclei could finally capture electrons to form atoms. The Universe filled with clouds of hydrogen and helium gas. From these clouds, galaxies and solar systems formed.

N5

Evidence to Support the Big Bang Theory

Scientists are reasonably certain that the universe had a beginning. This is the basis of the Big Bang Theory. To support this argument scientists have discovered that:

- Galaxies appear to be moving away from us at speeds proportional to their distance. 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 small remains of this heat. In 1965, Radio astronomers discovered Cosmic Microwave Background radiation (CMB) which spread throughout parts of the observable universe. This is thought to be the small remains which scientists were looking for.
- Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.

As mentioned above, the Big Bang occurred about 14 billion years ago. Scientists estimate this by:

- Looking for the oldest stars
- Measuring the expansion of the universe.

The Electromagnetic Spectrum

N5

Electromagnetic Radiations

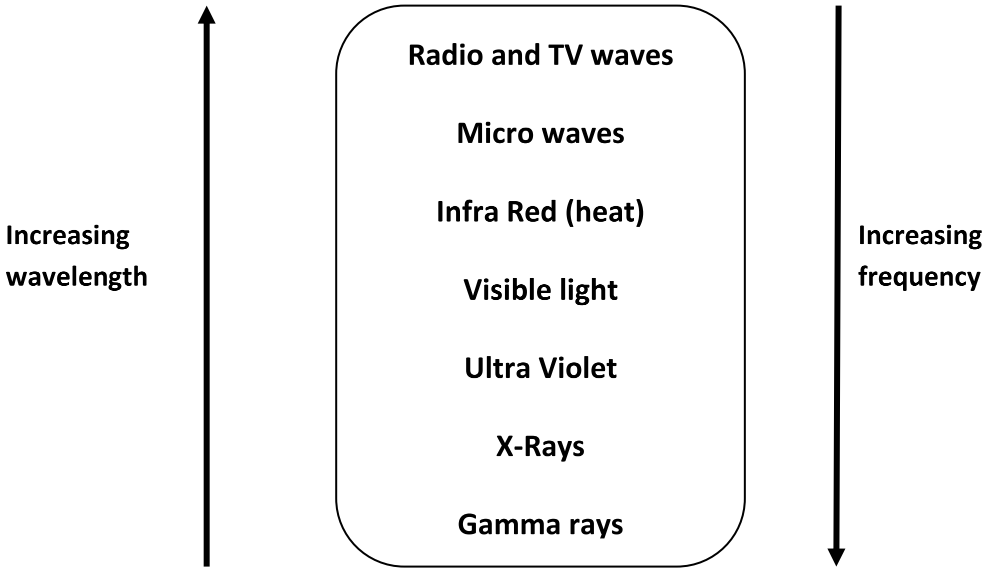
There is a group of radiations which have given astronomers a vast amount of information on the Universe. These radiations make up **The Electromagnetic Spectrum**.

Like all the notes on a piano, they are grouped in an order according to their frequency.

In unit 3 you will learn what frequency and wavelength means in Physics but all you have to know in unit 1 is the order in which these radiations fall in terms of their frequency and wavelength.

All these radiations travel at the speed of light = 300 000 000 ms^{-1}.

The 7 radiations are listed below:



How do I remember this?

Rabbits **M**ate **I**n **V**ery **U**nusual e**X**pensive **G**ardens

Can you think of your own pneumonic to remember The Electromagnetic Spectrum?

N5

Detectors of Electromagnetic Radiations

Humans can detect some of the electromagnetic radiations e.g. the eyes can detect visible light, infra red can be detected by skin and sun burn is a consequence of the skin being over exposed to ultra violet radiation from the sun.

However, energy is given out by objects in space (e.g. stars or galaxies) over the whole range of the electro-magnetic spectrum so to fully understand the universe we must collect information at all these wavelengths. Different kinds of telescope are therefore required to detect different wavelengths of radiation as one as alone cannot detect them all.

Below is a list of detectors for each radiation in the spectrum.

Radiation	**Detector**	**Use**
Radio and T.V	Aerial	Gives information on different planets e.g. distance from the Earth
Micro waves	Diode probe	The detection of Cosmic Microwave Background consolidated the belief the Big Bang occurred
Infra Red	Blackened thermometer	Infra red is used to detect objects just outside the visible spectrum
Visible Light	Photographic film	Gives information on planets and stars including temperature and size
Ultra Violet	Fluorescent paint	Used to study star formation – most “young” stars emit ultra violet radiation
X-Rays	Photographic film	Used to detect the presence of black holes
Gamma rays	Geiger-Muller tube	Used to detect the presence of black holes and supernova

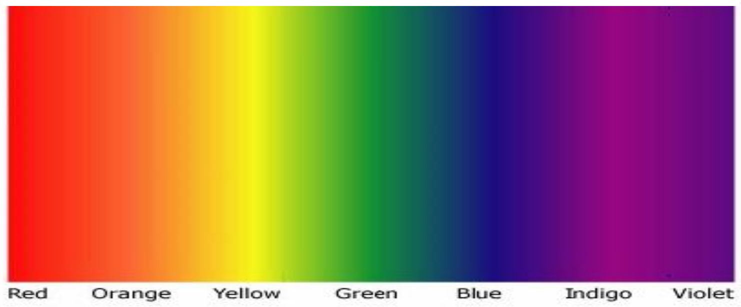
Spectroscopy

N5

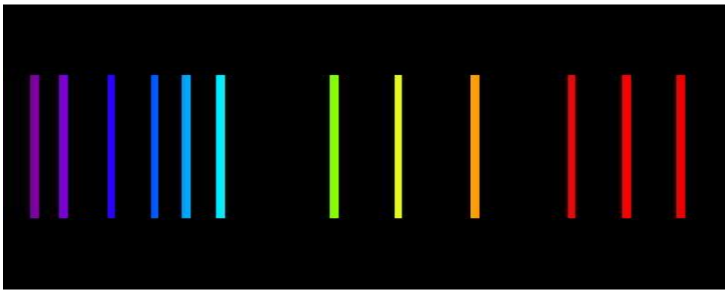
Continuous and Line Spectra

Astronomers can find out information about stars from the light the star emits using an instrument called a **spectroscope**.
The spectroscope splits up the light to produce a spectrum.
There are two types of spectra:

- **Continuous** – produced by light from solids, liquids and gases at high pressure and at high temperature. Each colour in the spectrum has a different frequency and wavelength



- **Line** – produced by hot gases at low pressure and gases which have an electric current passed through them. Each line in the spectrum corresponds to a particular frequency and wavelength.



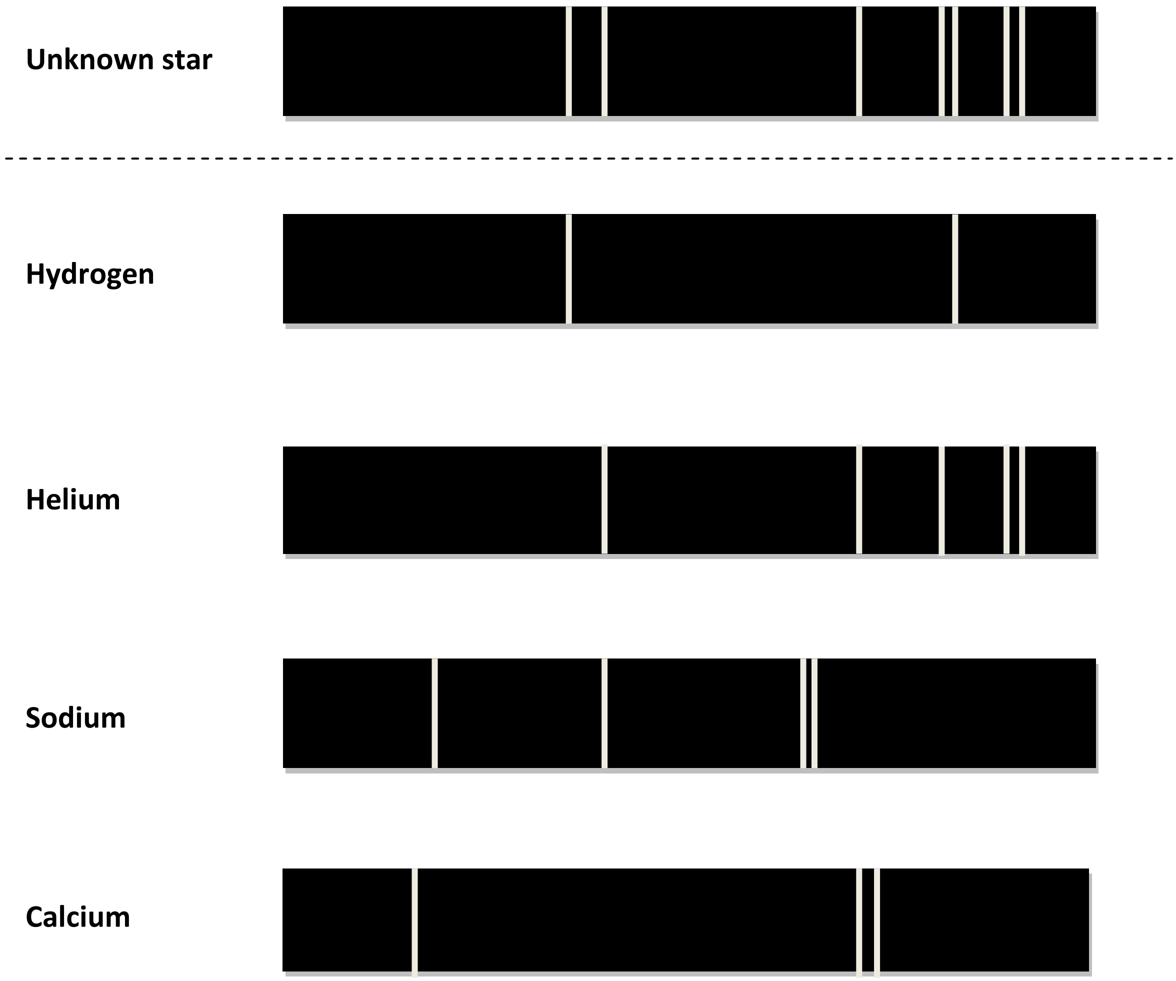
Line spectra are extremely useful for astronomers because every chemical element has its own unique spectrum (like D.N.A or fingerprints). This allows astronomers to identify elements present in distant stars.

You may find this easier to understand after looking at the example on the next page.

N5

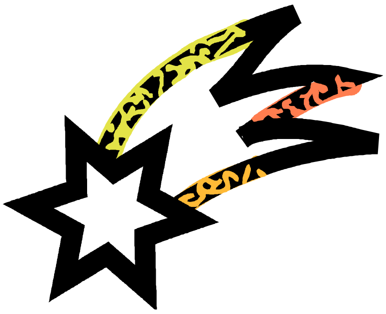
Stellar Detectives

Example: Identify the elements that make up the unknown star from the line spectra below. The line spectra for hydrogen, helium, sodium and calcium are given below to help you.



Answer : Hydrogen and Helium.

All spectral lines present in Hydrogen and Helium are present in the unknown star.



1.5 Space Exploration

Heading into Space

N4 N5

What We Have Learned by Heading into Space?

Read any debate about space exploration, and this question will invariably come up.

"Why should we be spending money exploring space when there are so many problems here on Earth that we need to solve first?"
It's a tricky one.

One answer is that reaching for new heights often creates new solutions, new opportunities and elevates hope back on the ground.

We have learned so much about our own planet and the expanding universe by exploring space. If mankind had not explored space and used telescopes then we would not have found out the following about:

The Earth

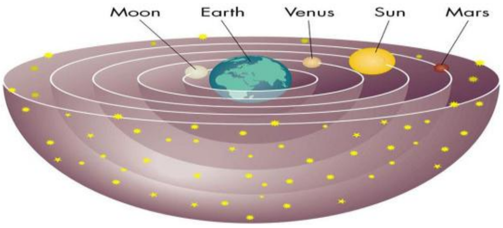
- A greater understanding about the rotation of the Earth, the orbit of the Earth around the Sun and how this affects time on earth. e.g. one rotation of the Earth is one day, one orbit of the Sun by the Earth is one year etc.
- It has allowed meteorologists to predict and monitor of the weather. Satellites have been put into orbit to monitor the Earth's weather systems and allows us to predict natural disasters e.g. tsunamis and hurricanes
- Allowed the monitoring of the polar ice caps and enabled a plan to be put in place to minimise their erosion and prepare for the consequences of the erosion i.e. rising water levels and the destruction of natural habitats for polar animals.

The Universe

- Greater understanding of the origin of the Universe
- The Universe is still expanding
- Estimate the age of the universe

Through exploration our understanding of the Universe has changed. There were a few misconceptions before our understanding shaped our belief of the expanding universe and the model of it we have today. Scientists at certain times thought:

- The Earth was thought to be flat - it's round.
- The Earth was thought to be the centre of the Universe (see diagram below) - it's not.
- The Sun was thought to be the centre of the Universe - it's not.
- The Milky Way was thought to be the centre of the Universe - It's not.
- The centre of the Universe was thought to have a definite location - it doesn't.



N5

Evidence to Support our Understanding of the Universe

From an earlier section titled ‘The Big Bang Theory’, it is stated that Physicists thought that at one second old, stable particles called protons and neutrons started to form. These particles form our model of the nucleus of the atom. However, something was missing from that model called the Higgs Boson. Professor Higgs, a British physicist wrote in 1969 that the Higgs Boson's role is to give the particles that make up atoms their mass. Without this mass, they would zip around the cosmos, unable to bind together to form the atoms that make stars and planets – and people.

On 4th July 2012, Physicists working at CERN at the world’s largest particle accelerator – The Large Hadron Collider – announced the discovery of the Higgs Boson – further evidence to support our understanding of the universe.

Some Physicists relate this finding to other landmarks in Scientific history e.g. Neil Armstrong walking on the moon.

The Space Rocket

N5

Resultant Forces (2)

Resultant forces in the horizontal direction was studied in the Forces section (1.2).
In this section we will consider resultant forces in the **vertical** direction in the context of a space rocket **launching.** In this section we will also consider the forces acting on the rocket **during flight and when landing**. This involves Newton's 1st, 2nd and 3rd laws of motion and the weight of the rocket (W = mg).

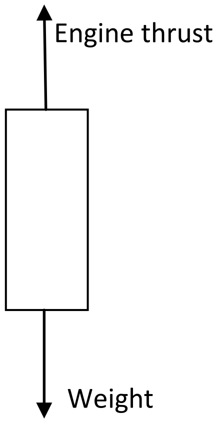
Example 1 - Launching

At launch, a rocket of mass 20 000 kg accelerates off the ground at 12 ms^{-2} (ignore air resistance)

- **a) Use Newton's 3rd law of motion to explain how the rocket gets off the ground.**
- **b) Draw a free body diagram to show all the vertical forces acting on the rocket as it accelerates upwards.**
- **c) Calculate the engine thrust of the rocket which causes the acceleration of 12ms^{-2}.**

Solutions

- a) The rocket pushes the gas out the back downwards (action) and the gas pushes the rocket upwards (reaction).
- b)

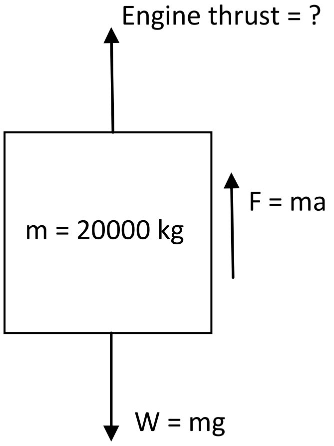


- c) Calculate F and W

F = m a
F = 20 000 x 12
F = 240 000 N

W = m g
W = 20 000 x 9.8
W = 196 000 N

F = upward force (thrust) – downwards force (Weight)
240 000 = thrust – 196 000
thrust = 44 000 N



N5

Resultant Forces (2) (ctd)

Example 2 – During Flight

The same rocket reaches a speed of 10 000 ms^{-1} as it accelerates away from earth.

a) Can you suggest 3 reasons why the acceleration of the rocket will increase? (Hint: this time take into consideration air resistance)

b) When the rocket is in space there is negligible gravity acting on it. Use all of Newton's laws of motion to explain how the rocket moves in space.

Solution

a)

- Decrease in mass due to fuel being used up
- Decrease in air resistance as there is less air particles the further away from the surface of the Earth
- Decrease in the value of g the further away from the centre of the Earth

b) Travelling at a constant speed – all thrusters are switched off and forces or both forward and backward thrusters are on applying the same force. In both situations the forces are balanced **(1st Law)**
Accelerating – forward thrusters on and the forces are unbalanced in the forward direction **(2nd law)**
Decelerating – backward thrusters on and the forces are unbalanced in the backward direction **(2nd law)**
When the thrusters are on they propel the gases out (action) which applies a force to the rocket in the opposite direction (reaction) **(3rd law)**

Example 3 – Landing

On returning from space the rocket has to overcome two major hurdles:

- **Re-enter the Earth's atmosphere**
- **Land safely on the ground**

a) As the rocket enters the earth's atmosphere what happens to it's velocity?
b) Explain your answer to part a)
c) What is the main energy change during re-entry (think back to S1 Heat topic)?
d) When the rocket touches down on the ground, explain in terms of forces why a parachute is activated out the back of the rocket to bring it to a safe stop.

Solution

a) It decreases
b) The rocket is travelling so fast (at around 8000 ms^{-1}) as it passes into the atmosphere air so a large frictional force will act against it.
c) Kinetic to heat
d) When the parachute opens, the force due to air resistance (drag) drastically increases and causes an unbalanced force acting backwards against motion. This will result in the rocket decelerating and eventually coming to a safe stop.

Space Technology

N5

Made in Space for Us – The Benefits of Space Exploration

Space technology is not limited to be used in space. There are many items that benefit us in our day to day lives which have evolved from equipment used and created for use in space exploration.

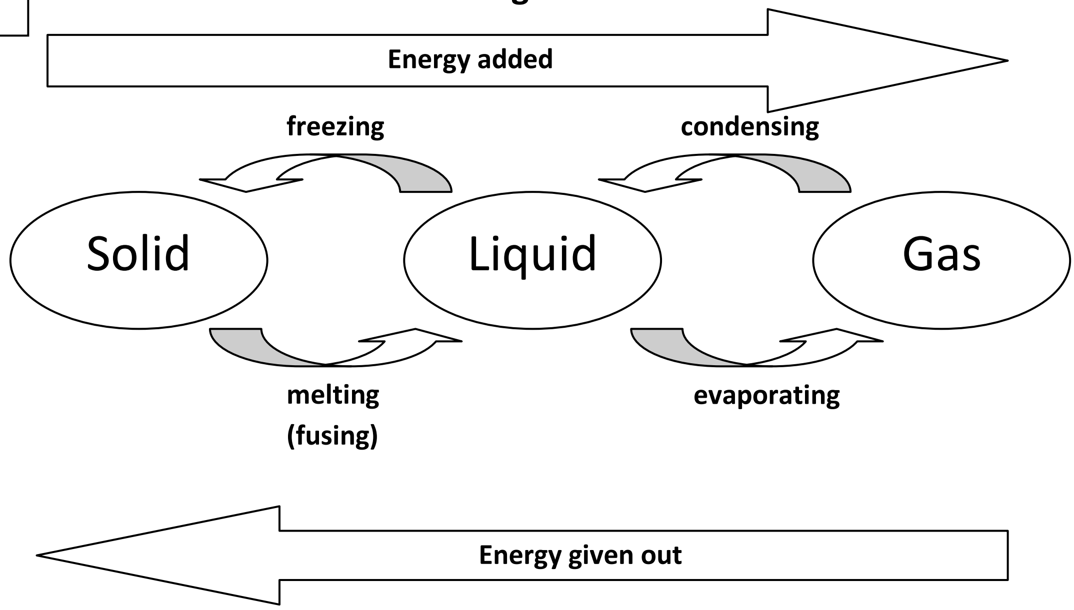
The following pieces of equipment have been developed and improved upon as a result of space exploration:

- **Artificial limbs** - Innovations in robotics and shock-absorption/comfort materials are inspiring and enable the private sector to create new and better solutions for animal and human artificial limbs.
- **Ear thermometers** - A thermometer which weighs only 8 ounces was developed which uses infrared astronomy technology to measure the amount of heat energy emitted by the eardrum, the same way the temperature of stars and planets is measured.
- **Water purification** - This system, makes use of available resources by turning wastewater from respiration, sweat, and urine into drinkable water. Commercially, this system is benefiting people all over the world who need affordable, clean water.
- **Heat resistant paints** - The spacecraft Apollo's heat shield was coated with a material whose purpose was to burn and thus dissipate energy during re-entry while charring, to form a protective coating to block heat penetration. This led to the development of other applications of the heat shield, such as fire-retardant paints and foams for aircraft.

Re-entry

N5

Changes of State



- During a change of state, energy is either added or given out as shown in the diagram above
- During a change of state, there is no change in temperature until the change of state of state is complete.

N5

Specific Heat Capacity

The specific heat capacity of a material is defined as the amount of energy required or given out when 1 kg of a substance changes in temperature by 1^{o}C without changing the state of the substance.

Specific Latent Heat of Vapourisation

The specific latent heat of vapourisation is defined as the amount of energy required or given out when 1 kg of a substance changes state from a liquid to a gas or a gas to a liquid without changing the temperature of the substance.

Specific Latent Heat of Fusion

The specific latent heat of fusion is defined as the amount of energy required or given out when 1 kg of a substance changes state from a solid to a liquid or a liquid to a solid without changing the temperature of the substance.

Latent heat will be studied in more detail in the Electricity and Energy unit.

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Specific Heat Capacity, Energy, Mass and Change in Temperature Equation

From the definition specific heat capacity = $\frac{\text{heat energy}}{\text{mass x change in temperature}}$

In symbol form : $c = \frac{E_H}{m \Delta T}$ $E_H = c\,m\,\Delta T$ $m = \frac{E_H}{c \Delta T}$ $\Delta T = \frac{E_H}{c\,m}$

Quantity	Symbol	SI Unit
Heat Energy	E_H	J
Specific Heat Capacity	c	$J\,kg^{-1}\,{}^oC^{-1}$
mass	m	kg
Change in temperature	ΔT	^oC

Example: How much heat is required to increase the temperature of 1.5 kg of concrete from 30 ^oC to 50 ^oC? ($c_{concrete}$ = 800 $Jkg^{-1}\,{}^oC^{-1}$)

Solution:

E_H = ?

c = = 800 $Jkg^{-1}\,{}^oC^{-1}$

m = 1.5 kg

$\Delta T = 50 – 30 = 20\,{}^oC$

$E_H = c\,m\,\Delta T$

E_H = 800 x 1.5 x 20

E_H = 24 000 J

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Challenges During Re-entry

When a space craft returns from space it re-enters the Earth's atmosphere.
There are many challenges associated with re-entry and two are listed below:

- **Rise in temperature due to friction**
  The craft is travelling at around 8000ms^{-1} so a large frictional force acts on it due to the air in the atmosphere. This results in the space craft slowing down. The frictional force causes a rise in temperature which is a problem for the craft. The space craft uses special silica tiles to protect it and the bottom and leading edge are covered with black reinforced carbon. These materials which make up the **Thermal Protection System** are designed to absorb large quantities of heat without increasing their temperature very much. **In other words, they have a high specific heat capacity.** The peak skin temperature, on the underside of the wings close to the leading edges, is around 1600°C - hot enough to melt steel.

- **The angle of re-entry**
  If the angle of approach is too steep, frictional heating will be too fast and burn the spacecraft up. If the angle of approach is too shallow the spacecraft will skip off the atmosphere into a highly elliptical orbit which will take it far from the Earth (think about skipping a stone across a pond). There is thus an optimum angle for re-entry.

Risks Associated with Space Exploration

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Risks

Human spaceflight is both risky and expensive. From the crash landing of the first manned Soyuz spacecraft in 1967 to the explosion of the shuttle orbiter *Columbia* in 2003, 18 people died during spaceflights. Providing the systems to support people while in orbit adds significant additional costs to a space mission, and ensuring that the launch, flight, and re-entry are carried out as safely as possible also requires highly reliable and thus costly equipment, including both spacecraft and launchers.