National 4 &5 Physics

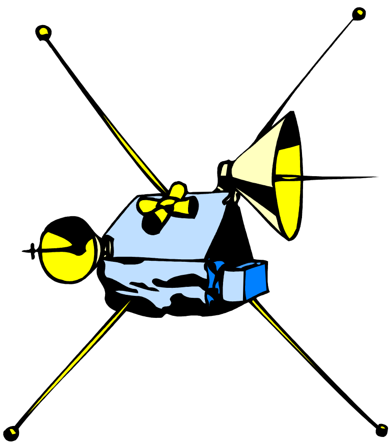
Barrhead High School

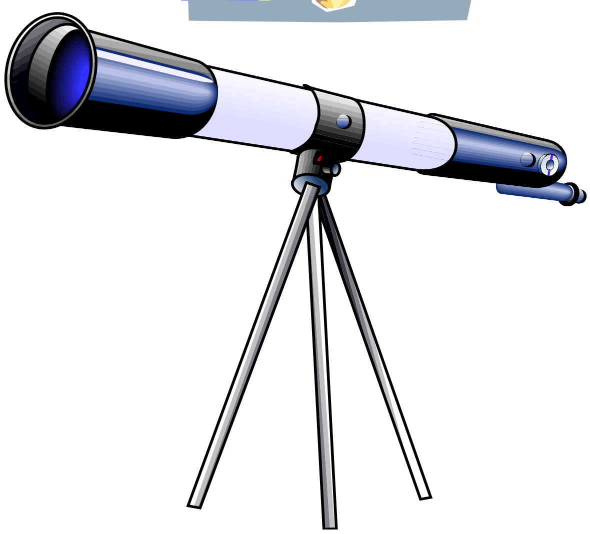
Physics Department

Dynamics and Space

National 4 &5

Summary Notes





Speed

Learning Outcomes

At National 4/5 you should be able to:

- ☐ Explain the meaning of the word speed.
- ☐ Describe how to measure an average speed
- ☐ Describe how to measure instantaneous speed.
- ☐ Carry out calculations involving distance, time and speed.
- ☐ Identify situations where average speed and instantaneous speed are different.

Summary Notes

N4/5

Definitions and Explanations

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.

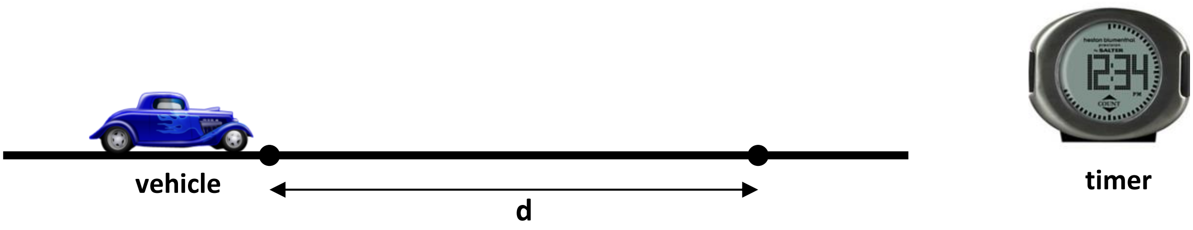
Speed during a journey

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.

N4/5

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

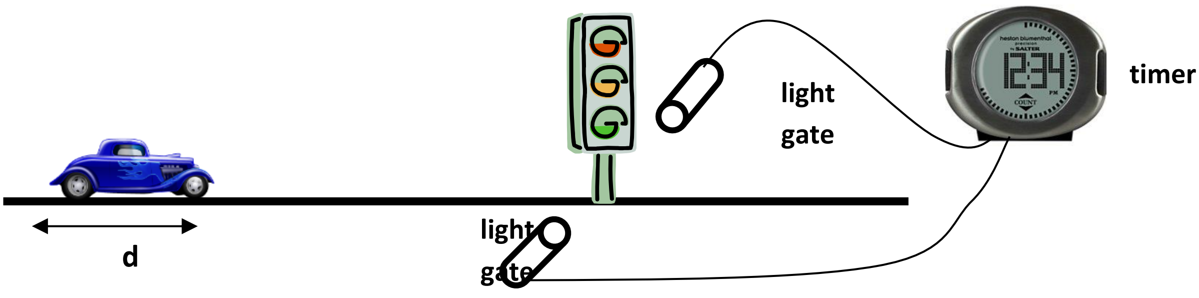
- Measure the distance (**d**) travelled with a measuring tape.
- Measure time (**t**) taken for the vehicle to travel the distance (d) with a timer.
- Use the equation $v = \frac{d}{t}$ to calculate the average speed (**v**).



N4/5

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 x 0.75
v = ?	**Answer & units**	<u>**v = 5.33ms^{-1}**</u>
t = 0.75s		

Vectors and Scalars

Learning Outcomes

At National 5 you should be able to:

- ○ Describe what is meant by vector and scalar quantities.
- ○ Identify a physical quantity as a vector or a scalar.
- ○ State the difference between distance and displacement.
- ○ State the difference between speed and velocity.
- ○ Find a distance or resultant displacement by calculation, or by using a scale diagram.
- ○ Calculate speed and velocity using vector diagrams.
- ○ Calculate the resultant of two vectors in one dimension or at right angles.

Summary Notes

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**.

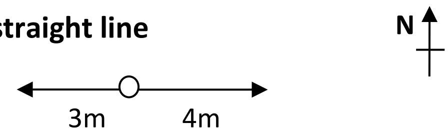
Sorting quantities into vector or scalar.

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

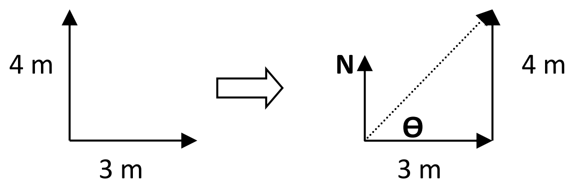


The resultant vector
= 4 – 3 = 1 m (090) or 1 m (due East)

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

Θ = 53.1° bearing = 90 – 53.1 = 36.9

Resultant vector = 5 m (036.9)

N5

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.

N5

Speed and Velocity

1. **Speed** (v) is defined as the distance (d) travelled per second.

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

$v = d/t$

$$d = v \times t$$

2. **Velocity** (v) is defined as the displacement (s) of an object per second.

$$\text{velocity} = \frac{\text{displacement}}{\text{time}}$$

$v = s/t$

$$s = v \times t$$

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

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

N5

Example Calculation

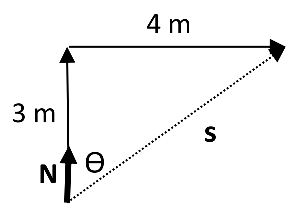
A woman walks 3 m due North and then 4 m due East. She takes 10 seconds.

a) Find (i) the distance she has walked
(ii) her displacement.

b) Calculate (i) her average speed
(ii) her velocity.

Solution

The walk is represented by the vector diagram below.



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 Θ is calculated using

$$\tan \Theta = 4 / 3$$

$$\Theta = 53^o$$

Displacement (s) = 5 m (053)

The diagram can also be drawn to scale and measurements taken from an accurately drawn diagram.

For this example a suitable scale would be:

1cm : 0.5m

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 and Graphs of Motion

Learning Outcomes

At National 4/5 you should be able to:

- ☐ State that the size of the acceleration, of an object travelling in a straight line, is the change in speed per second.
- ☐ Describe the motions represented by a speed-time graph.
- ☐ Calculate distance travelled from speed-time graphs.
- ☐ Carry out calculations involving the relationship between speed, time and acceleration.

National 5 you should also be able to:

- ○ State that acceleration is the **change in velocity per unit time**.
- ○ Carry out calculations involving the relationship between initial velocity, final velocity, time and uniform acceleration.
- ○ Describe the motions represented by a velocity-time graph, including changes in direction.
- ○ Calculate displacement from velocity-time graphs.
- ○ Draw velocity time graphs that show the motion of an object.

Acceleration

N4 | N5

Acceleration

Acceleration is the **change in velocity** per **second,** and is measured in metres per second per second (ms^{-2}). The size of the acceleration, of objects travelling in a straight line with no change in direction, is equal to the change in speed per second, also measured in (ms^{-2}).

It can be calculated using the formula:

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

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

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

A common form of the equation worth remembering is

$$v = u + at$$

Examples:

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.

a = 4 ms^{-2}

v = ?

u = 0 (at rest)

t = 10 s

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

v = u + at

v = 0 + (4 x 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.

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} or deceleration = 0.47 ms^{-2}

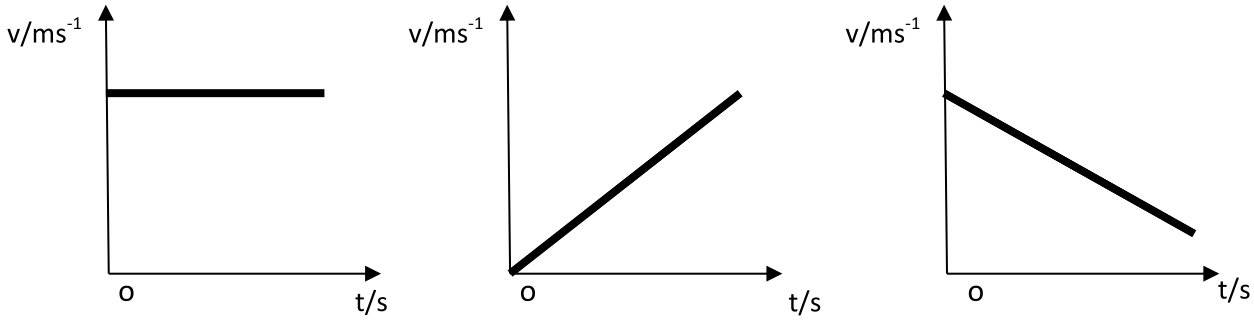
Graphs

N4/5

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.

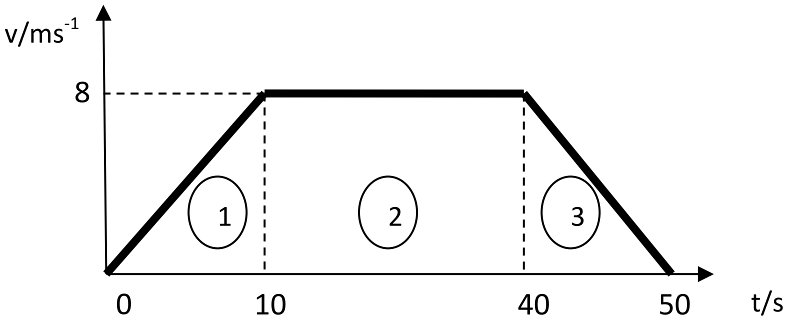
The graphs below illustrate the 3 types of motion you will study.



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.



Calculate the acceleration of the car during the first 10 s.

Solution

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

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

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

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

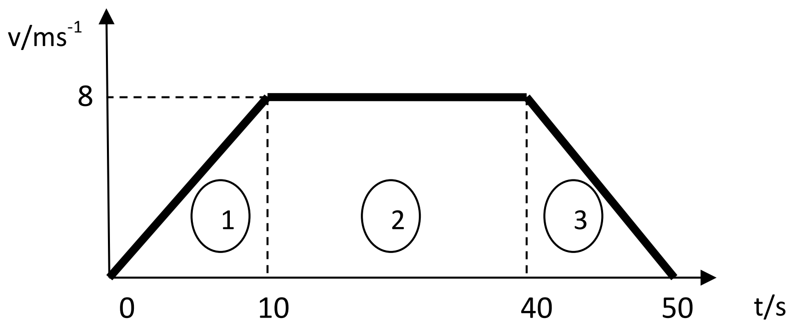
N4/5

Distances from speed time graphs

To calculate the distance from a speed time graph an area calculation must be carried out.

Distance travelled = Area under graph

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



Calculate the distance travelled by the car for the entire 50 s.

Solution

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

Distance travelled = area under the speed-time graph
Distance = Area 1 + Area 2 + Area 2

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

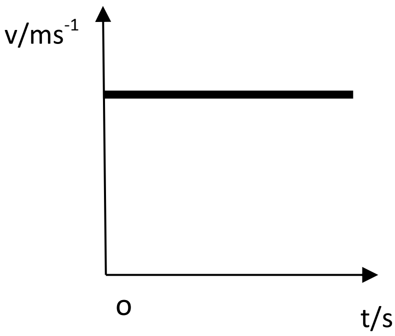
Distance travelled = 320m

N5

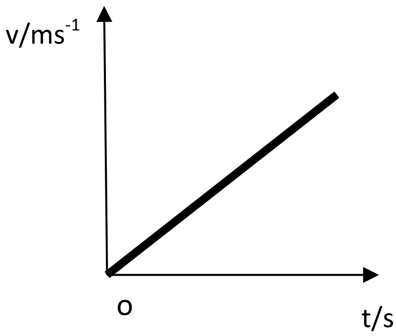
Velocity – Time Graphs

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.

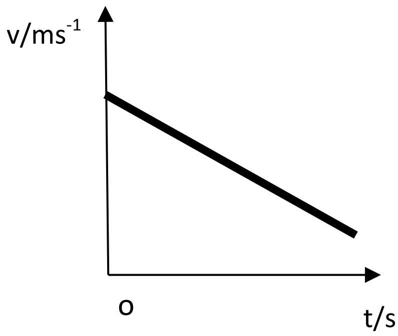
The graphs below illustrate the 3 types of motion you will study.



constant velocity



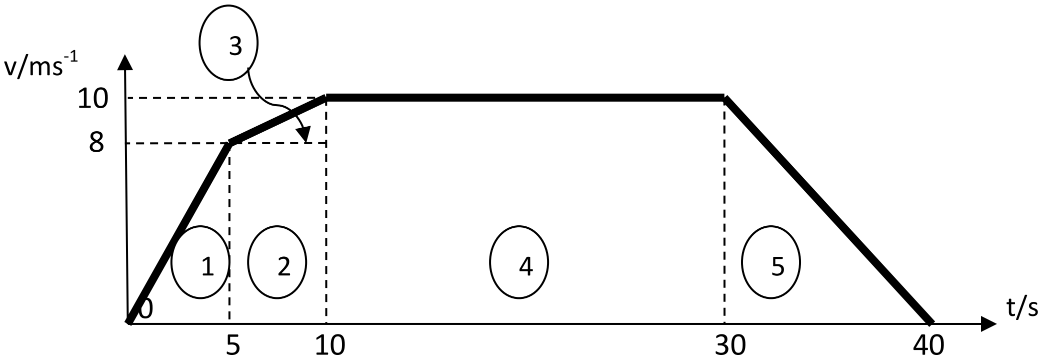
increasing velocity (constant acceleration)



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.**

Solution

a) Between **<u>0 and 5 s</u>** as the gradient of the line is greatest during this time interval.

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

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

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

<u>$a = -2\ ms^{-2}$ deceleration = $2 ms^{-2}$</u>

N5

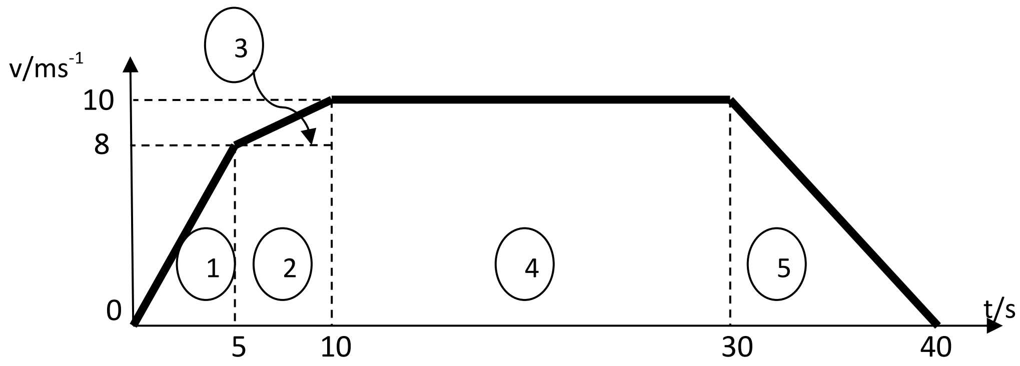
Displacement from velocity – time graphs

To calculate displacement from a velocity time graph the area under the graph must be calculated.

Displacement = Area under graph

Example

The velocity time graph represents the motion of a car over a 40s time interval.
Calculate the displacement of the car at 40s.



Solution

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**

N5

Velocity Time Graphs Showing Changes in Direction

When a moving object changes direction the sign of the velocity vector changes. By convention velocities to the right or upwards are positive and velocities to the left or downwards are negative.

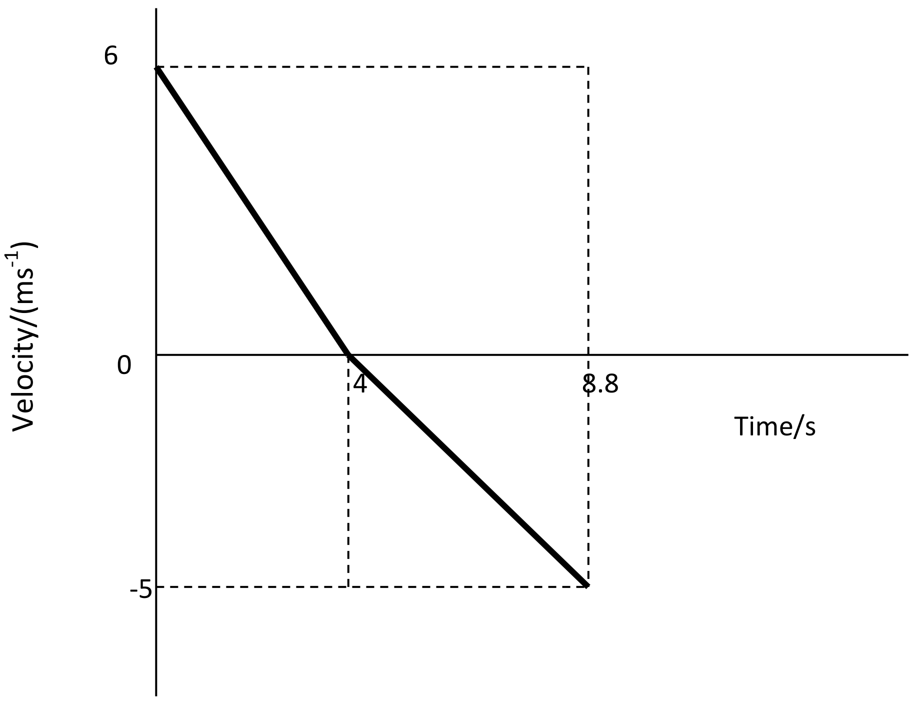
Example

A toy car is pushed up a slope and has an initial velocity of 6ms-1. It decelerates as it travels up the slope and comes to rest at its maximum distance up the slope after 4 seconds. It then starts to accelerate down the slope reaching a maximum speed of 5ms-1 and returns to its starting point after 4.8s.

a) Draw the velocity time graph that represents this motion.
b) Calculate the maximum deceleration.
c) Show that the total displacement after 8.8 s is 0 m.

Solution

a)



b) The maximum deceleration occurs between 0s and 4s, because this section of the graph has the steepest gradient.

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

$a = \frac{0-6}{4} = -1.5\text{ms}^{-2}$ so deceleration = **<u>1.5ms^{-2}</u>**

Solution Continued

c) The total displacement is equal to the total area under the graph.

Total Area = Area 1 + Area 2

Area 1 = ½ bh = ½ x 4 x 6 = 12m (up the slope)

Area 2 = ½ bh = ½ x 4.8 x -5 = -12m (down the slope)

<u>Total Area= total displacement = 12 + (-12) = **0m**</u>

Forces

Learning Outcomes

At National 4/5 you should be able to:

- ☐ Apply Newton's first law to explain constant speed making reference to frictional forces.
- ☐ State Newton's second law and use it to explain the movement of objects in situations with a constant acceleration.
- ☐ Carry out calculations using the relationship between force, mass and acceleration in situations where only one force is acting.
- ☐ Carry out calculations using the relationship between weight, mass and gravitational field strength.

National 5 candidates should be able to:

- ○ Apply Newton's first law to explain constant velocity making reference to frictional forces.
- ○ Calculate the unbalanced force acting when there is more than one force acting. These forces may act in the same direction, opposite directions, or be at right angles to each other.
- ○ Use a scale diagram, or otherwise, to find the magnitude and direction of the resultant of two forces acting at right angles to each other.
- ○ Apply Newton's second law to calculate accelerations using the unbalanced force and acceleration using the relationship $F_{un} = ma$.
- ○ Carry out calculations involving the relationship between work done(E_w), unbalanced force(F) and distance/displacement(s or d).
  $E_w = F \times s$
- ○ Carry out calculations involving the relationship between weight, mass and gravitational field strength on earth and different planets.
- ○ Use Newton's laws, in the context of space travel, to explain the launch and landing of a rocket.
- ○ State Newton's third law and use it to explain motion resulting from a 'reaction' force.

N4

Effects of Forces

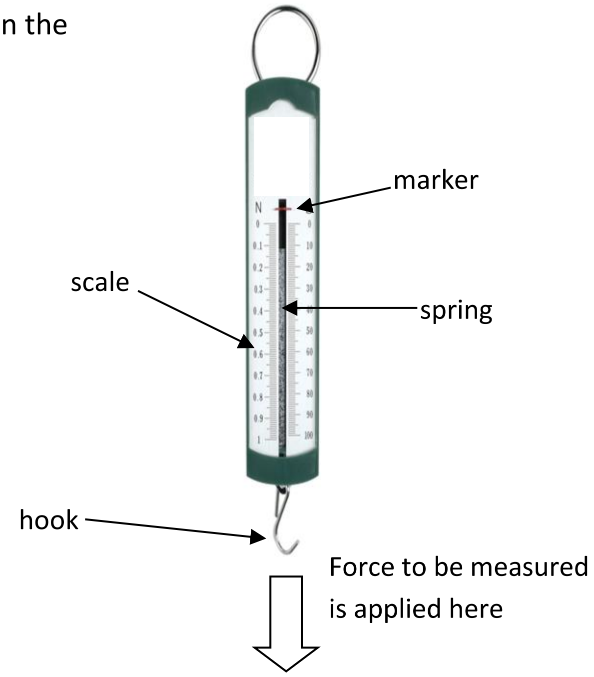
Forces can only be detected by their effects.
They can **change**:

- 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

N4/5

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).

N4/5

Increasing Friction

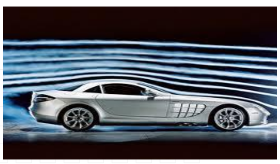
Where friction is used to **slow** an object down, it should be **increased**.
This can be achieved by:

- 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).



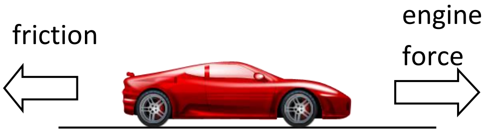
Newton's Laws of Motion (1 and 2)

N4/5

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.**



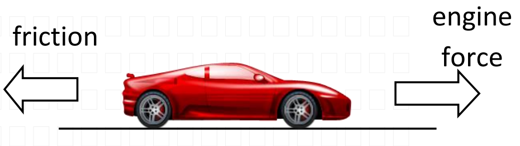
When the engine force = friction on the car the forces are balanced.

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.

N4/5

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.
There is an acceleration when an unbalanced force acts. The acceleration depends on:

- the mass (**m**) of the object
- the unbalanced force **(F_{un})**

Bigger unbalanced forces produce bigger accelerations.
For a constant unbalanced force a bigger acceleration is produced when the force is applied to a smaller mass.

Equation

$$F_{un} = ma$$

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

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

N4/5

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

F_{un} = ?
m = 10000 kg
a = $3.5ms^{-2}$

F_{un} = ma
F_{un} = 10000 x 3.5
F_{un} = 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, net** or **unbalanced** force.

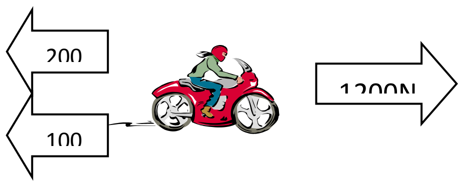
Example: Horizontal
A motorcycle and rider of combined mass 650 kg provide an engine force of 1200 N. The friction between the road and motorcycle is 100N and the drag value = 200N.

Calculate:

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

Solution

a) Draw a diagram



F_{un} = 1200 - (200 + 100)
F_{un} = 900 N to the right

b) F_{un} = 900 N   F = ma
a = ?   900 = 650 x a
m = 650 kg   a = 1.38 ms^{-2}

Resultant Forces (2) in the vertical direction will be considered after the introduction of weight.

Weight and Mass

N4/5

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

Mass measures the amount of matter in an object. It is measured in **kilograms (kg).**
The value of mass does not change from place to place.

N4 N5

Weight, Mass and Gravitational Field Strength Equation

Weight always acts downwards and depends on the mass of the object and the gravitational field strength at that place.

To calculate weights use the equation:

$$W = mg$$

W = weight of mass in Newtons (N)
m = mass of object in kilograms (kg)
g = gravitational field strength (Nkg^{-1})

Gravitational Field strength
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}.**

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 = ?
m = 70 kg
g = 9.8 Nkg^{-1}

W = mg
W = 70 x 9.8
<u>**W = 686 N**</u>

ii) W = ?
m = 70 kg
g = 1.6 Nkg^{-1}

W = mg
W = 70 x 1.6
<u>**W = 112 N**</u>

b) **m = 70 kg** (mass does not change)

N4/5

Weight on other Planets

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

- This means that the weight of a mass will depend on which planet it is on.
- The mass of the object does not change as this is a property of the object.

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 = ?
m = 20000 kg
g = 4 Nkg^{-1}

W = mg
W = 20000 x 4
W = 80000 N

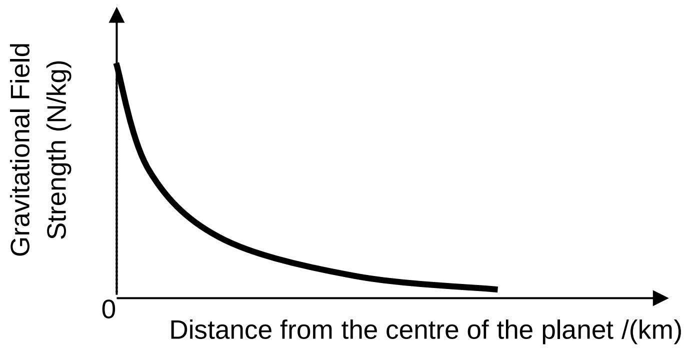
b) m = 20000 kg

c) Saturn and Uranus. The values for g on both planets are the same meaning the calculated weight will also be the same if the mass of the rocket remains constant.

N5

W eight and Distance from Planets

As the distance from a planet increases the gravitational field strength decreases.



This means that in deep space far away from planets the weight of objects decreases.

Newton's Laws of Motion (3)

N5

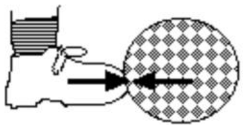
Newton's 3rd law of Motion and Rocket Propulsion

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.

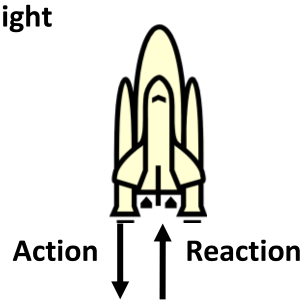
For example:

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 down**
Reaction: **The gases push the rocket up.**

The Space Rocket

N5

Resultant Forces (2)

In this section the resultant of a number of vertical forces will be calculated, in the context of a space rocket **launching.**

Example 1 - Launching

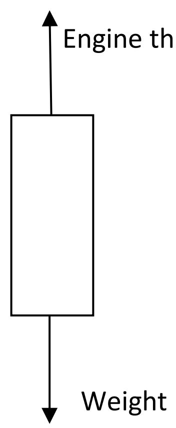
At launch, a rocket of mass 20 000 kg accelerates off the ground at 12 ms^{-2} (ignore air resistance)

a) Draw a diagram to show all the vertical forces acting on the rocket as it accelerates upwards.

b) Calculate the engine thrust of the rocket which causes the acceleration of 12ms^{-2}.

Solution

a)

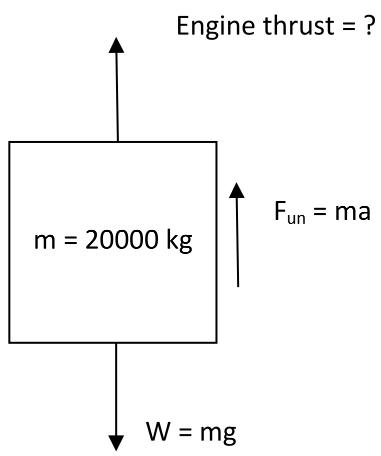


b) Calculate the unbalanced upward force (F_{un}) and the downward weight force (W)

F_{un} = m a
F_{un} = 20 000 x 12
F_{un} = 240 000 N

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

F_{un}= upward force (thrust) – downwards force (Weight)
240 000 = thrust – 196 000
<u>thrust = 436 000 N</u>



N5

Interplanetry Flight

During interplanetary flight there is no need for the engines to be kept on. This is because space is a vacuum where no frictional forces will act. Additionally, as the gravitational force is weak, the vehicle it will continue to move at a steady velocity as there are no unbalanced forces acting.

N5

During Flight

Example 2

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 deep space there is negligible gravitational force acting on it. Use 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 decreases the weight of the rocket.

b) Travelling at:

Constant speed: Thrusters are switched off and there are no unbalanced forces.

Accelerating: Thrusters on and the forces are unbalanced in the forward direction.

Decelerating: Reverse thrust producing an unbalanced force in the backward direction.

N5

Re-Entry into the Earth's Atmosphere

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 its velocity?
b) Explain your answer to part a)
c) What is the main energy change during re-entry.
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.

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 Equation

From the definition:

Work done = force x displacement

$$E_W = F \times s$$

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 = ?

F = 1000 N

s = 15 m

$E_W = F s$

$E_W = 1000 \times 15$

E_W = 15000 J

Projetile Motion and Free Fall

At National 5 you should be able to:

- ○ Explain the equivalence of acceleration due to gravity and gravitational field strength.
- ○ Explain the curved path of a projectile in terms of its horizontal and vertical motions.
- ○ Explain satellite orbits in terms of projectile motion.
- ○ Draw velocity-time graphs for horizontal and vertical projectile motion.
- ○ Solve numerical problems for an object projected horizontally.
- ○ Use Newton's laws to explain free-fall and terminal velocity.

N5

Falling Objects

Weight is the force which causes an object to accelerate downwards. and has the value mg, where g is the gravitational field strength.

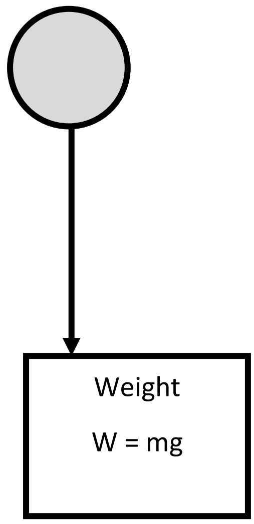
The value of the acceleration caused by weight can be calculated using the equation:

$\mathbf{F_{un} = ma}$

where F_{un} is equal to the weight (W).

N5

Acceleration due to gravity



Fun = ma

Fun = weight

Fun = mg = ma

ma = mg

<u>a = g</u>

The rate of acceleration in free fall is equivalent to the gravitational field strength "g".

The units of a or "g" can be given as: Nkg^{-1} or ms^{-2}

Note: The above analysis ignores any effects due to air resistance.

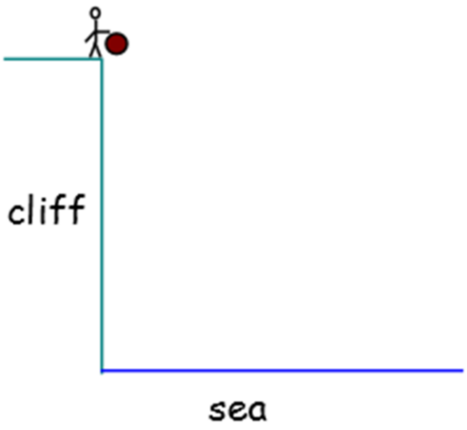
N5

Example

A ball was dropped from the top of a cliff. It landed in the sea 3.5s later.

Calculate a) The speed that the ball hit the water.

b) The height it was dropped from.



a) Vertical Motion

u = 0 m/s

v = ?

a = $9.8 ms^{-2}$ ("g")

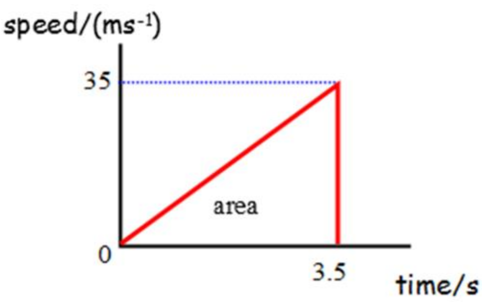
t = 3.5s

v = u + at

v = 0 + (10 x 3.5)

v = 35 ms^{-1}

b) To calculate the height the ball was dropped from, draw a speed time graph and calculate the area under the graph.



Area = ½ bh

Area = ½ (3.5 x 35)

Area = 61.25m

Height = 61.25m

N5

Projectile Motion

A **projectile** is an object which travels through the air with a **constant horizontal velocity** and is also **accelerated downwards** by its weight.

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.

The horizontal and vertical motions are **independent** of each other.

Points to note:

- The **horizontal velocity is constant** 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**)

Horizontal Displacement

$$s = vt$$

- 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).**

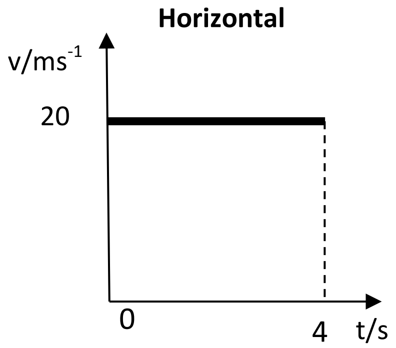
Vertical velocity

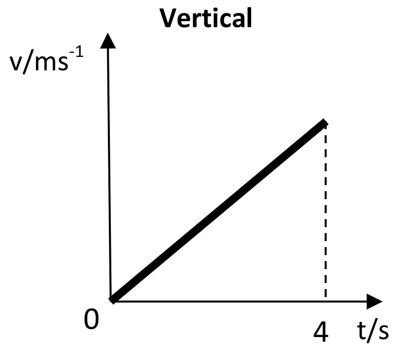
$$v = u + at$$

N5

Graphs of Horizontal and Vertical Motion

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. The graphs show that the horizontal velocity is constant and the vertical velocity of the projectile increases as it accelerates downwards





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 x 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.

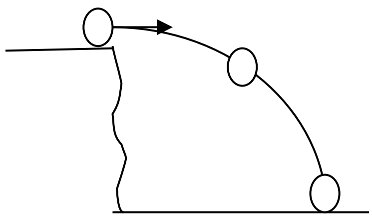
d) Height = area under the vertical velocity - time graph
= area of triangle
= ½ x 40 x 4
= 80 m.

N5

Projectile Motion Examples

Example 1:

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

s =?
v = 5ms^{-1}
t = 2 s

b) Vertical

v = ?
u = 0 (u will always be 0ms-1 for horizontally projected projectiles)
a = 9.8 ms^{-2} (= g on Earth)
t = 2s (time is the same for vertical and horizontal motion)

v = u + at
v = 0 + (9.8 x 2)
v = 19.6 ms^{-1}

Example 2

A life-belt is thrown off a harbour wall towards a person in the water. The person is 18 metres away from the wall, and the lifebelt is in the air for 2 s.

Calculate
(a) the horizontal speed of the lifebelt.
(b) its vertical speed as it hits the water.

Solution

(a) Horizontal:
s = v x t
18 = v x 2
v = 18/2 = **9 ms^{-1}**

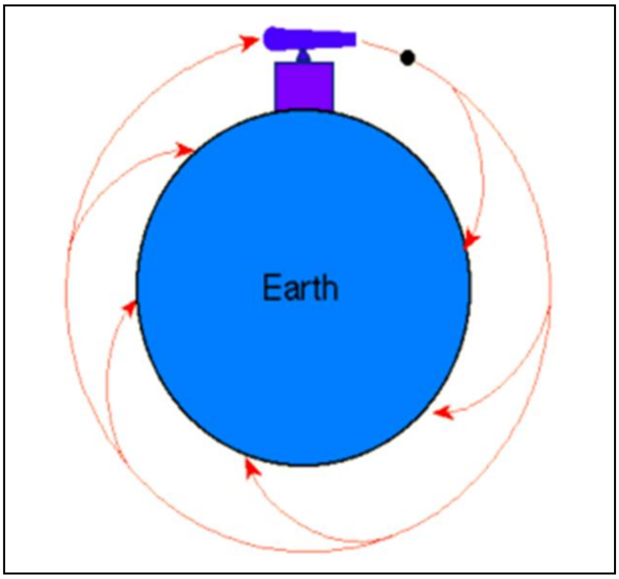
(b) Vertical:
v = u + at
v= 0 + 9.8x2
v = 19.6 ms^{-1}

N5

Satellites and Projectile Motion

A **satellite** is an object which **orbits another object**.

Newton's thought experiment allowed us to understand satellite orbits. In this experiment Newton imagined a cannon ball being launched by a giant cannon around the Earth.



If a projectile is launched with sufficient horizontal velocity, it will travel so far that the curvature of the Earth must be taken into account. The 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. If the horizontal velocity decreases its orbital height will decrease and eventually return to the surface of the Earth.

N5

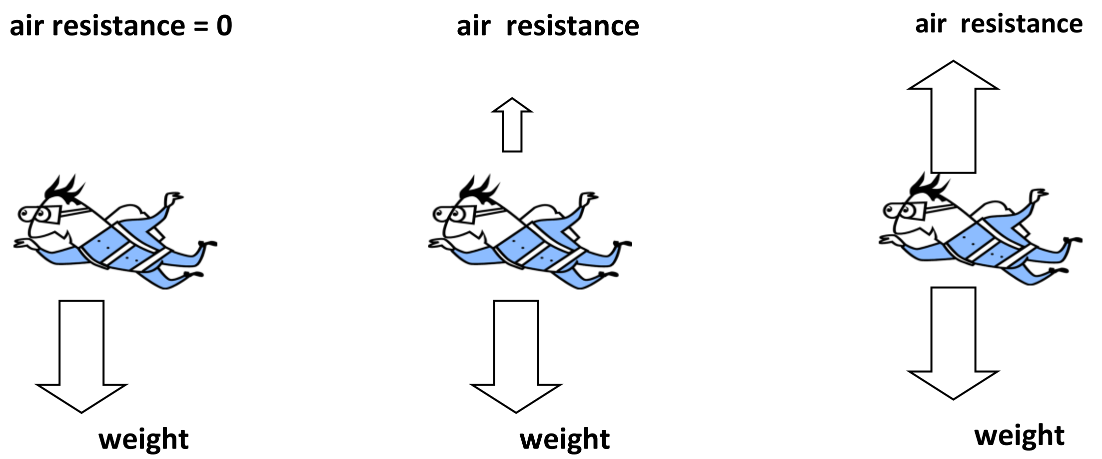
Falling Objects with Air Resistance

Free fall is the term used when an object is being acted upon only by the force of gravity (weight). However, when falling through the air, air resistance will oppose the motion. This air resistance force also increases as the speed of the object increases.

In many situations air resistance as well as the weight force must be considered.

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

A **As he jumps** | **B** **During Free Fall** | **C** **Terminal Velocity**



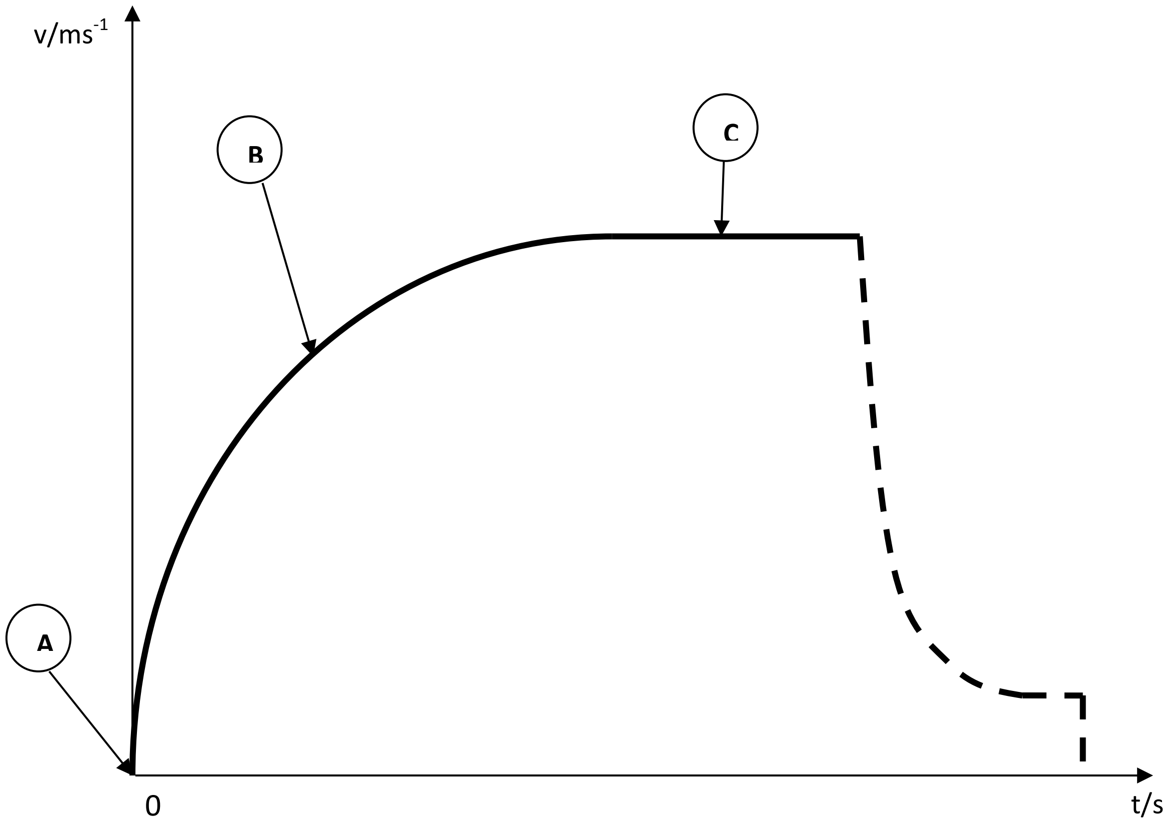
A	B	C
one force acting down	**weight > air resistance**	**weight = air resistance**
Unbalanced Force downwards (Newton's 2nd law)	**Unbalanced Force downwards (Newton's 2nd law)**	**Balanced Forces (Newton's 1st Law)**
maximum acceleration	**decreasing acceleration**	**acceleration = $0 ms^{-2}$ (constant 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

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?)

Learning Outcomes

At National 4/5 you should be able to:

- ☐ Describe the risks and benefits associated with space exploration.

- ☐ Explain the use of thermal protection systems to protect spacecraft on re-entry.

- ☐ Understand the relationship between height and orbital period of satellites, including geostationary and natural satellites.

- ☐ State some applications of satellites, including telecommunications; weather monitoring; the use of satellites in environmental monitoring.

- ☐ State that satellite's can be used in developing our understanding of the global impact of mankind's actions.

At National 5 candidates should be able to:

- ○ Describe how evidence from telescopes and space exploration supports our current understanding of the universe.

- ○ Give examples of the potential benefits of space exploration including associated technologies and the impact on everyday life.

- ○ Give examples of the risks and benefits associated with space exploration, including challenges of re-entry to a planet's atmosphere.

Space Exploration

N4/5

Satellites and Orbital Periods

Orbiting satellites carry many measuring instruments that collect information to enhance our understanding of the universe, including our planet.

The **period** of a satellite is the **time** taken for the satellite to **complete one** orbit and this depends on the orbital height of the satellite.

The **higher** the orbit of the satellite the **greater** the period.

N4

Geostationary Satellite

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

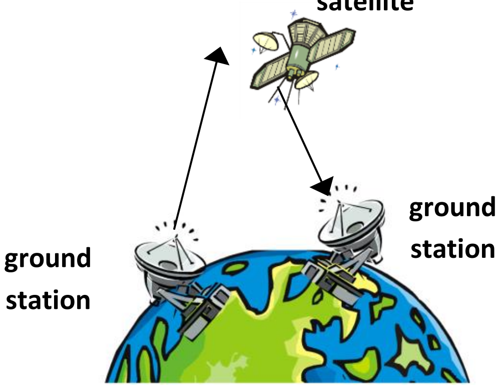
- has a period of 24 hours (the same time that it takes the Earth to rotate once about its axis).
- orbits at roughly 36000 km above the earth's surface
- stays above the same point on the earth's surface at all times.

N4

Transmitting and Receiving Data from Satellites

For transmission of signals between two points on the Earth a ground station sends microwave signals to the satellite using a transmitter and a curved dish transmitter to produce a directional signal. A curved dish on the satellite reflects the signal onto a receiver, at the focal point of the dish, to make the received signal stronger. The signal is then **amplified** and **retransmitted** (at a different frequency) back to the ground. The transmitting and receiving aerials are both placed at the **focal point of the curved reflector.**

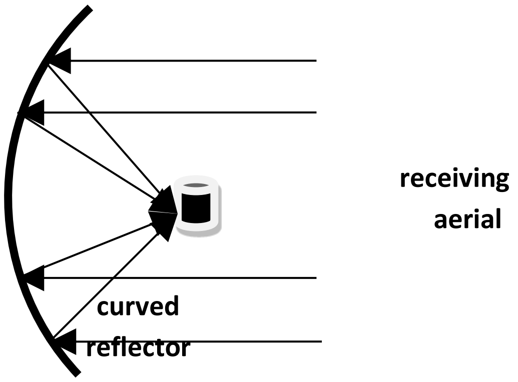
The signal is sent at a speed of 300 000 000 ms^{-1}. This allows the equation d = vt to be used with satellite communication.



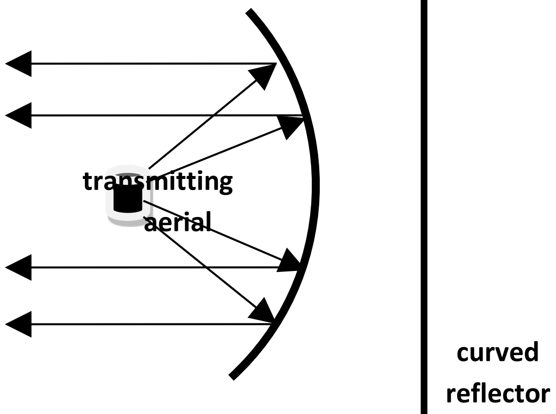
N4

How curved reflectors are used

Receiving the signal



Transmitting the signal



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.

N4/5

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.**
  Sporting events and news can be beamed around the world. Three geostationary satellites, placed in orbit above the equator permits worldwide communication with satellites communicating with ground stations in different continents.

- **Navigation (SATNAV)**
  There are many Global Positioning Satellite (G.P.S) systems available to put in a car so that you don't get lost.

- **Weather forcasting**
  The **weather satellite** is a type of satellite that is primarily used to monitor and predict the weather.

N4/5

Applications of Satellites Continued

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:

- 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
- a consequence of the impact of our actions.

N4 N5

What We Have Learned by Heading into Space?

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.

- 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 at about **14 billion years**.

N5

Understanding the Origin of the Universe

The **Big Bang theory** is an effort to explain what happened at the very beginning of our universe. Physicists think that the Universe did have a beginning about 14 billion years ago. Prior to this there was nothing; after that moment there was our universe.

Space exploration evidence to support this theory

- **Galaxies appear to be moving away from us** at speeds proportional to their distance. 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.
- "**Doppler red-shift**" also provides evidence that galaxies are moving away from us. The light from galaxies appears to be more red than it should be, and the decreased frequency of the light tells us that the galaxies are moving away from us.
- 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 degree Celsius] **Cosmic Microwave Background radiation (CMB)** which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.
- **The abundance of the "light elements" Hydrogen and Helium** found in the observable universe.

N5

Technologies developed because 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** use shock absorption technologies
.
- **Ear thermometers** use the same technology used to measure the temperature of stars and planets.

- **Water purification** systems make use of the same technology astronauts use to recycle water.

- **Heat resistant paints** originally developed for spacecraft during re-entry into the Earth's atmosphere.

N5

Risks Associated with Space Exploration

Human spaceflight is both risky and expensive. From the crash landing of the first manned Soyuz spacecraft in 1967 to the explosion of the space shuttle Columbia in 2003, 18 people have died. Problems developed with equipment during manned flight can also put astronauts in danger and astronauts on the Apollo 13 mission were luck to make it back to Earth. Astronauts also are exposed to higher levels of harmful cosmic radiation as they are not protected by the Earth's atmosphere and magnetic field.

N5

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 edges 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. The peak 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.

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^oC without changing the state of the substance. **High specific heat capacity** materials are used in the **thermal protection system** of space craft.

Specific Latent Heat of Vapourisation

The specific latent heat of vaporisation 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. During re-entery part of the heat shield vaporises in a process known as ablation. This removes heat energy from the craft –protecting the astronauts from excessive heat.

N5

Specific Heat Capacity
Equation and Calculations

$$E_H = mc\Delta T$$

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

Calculate the heat energy 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
ΔT = 50 – 30 = 20 ^oC

$E_H = mc\ \Delta T$
E_H = 1.5 x 800 x 20
E_H = 24 000 J

Cosmology

Learning Outcomes

At National 4 you should be able to:

- ☐ Understand the following terms: planet, moon, star, solar systems, exo-planet, galaxy and universe.
- ☐ Explain the meaning of the term ‘light year’.
- ☐ Use light years to understand the scale of the solar system and universe.
- ☐ State the conditions required for an exo-planet to sustain life.

At National 5 you should be able to:

- ○ Explain the term ‘light year’ and the conversion between light years and metres.
- ○ Describe the origin and age of the universe.
- ○ State how different parts of the electromagnetic spectrum can be used to obtain information about astronomical objects.
- ○ Identify continuous and line spectra.
- ○ Explain how spectral data for known elements can be used to identify the elements present in stars.

Cosmology

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 near 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** (extra solar) — A planet outside our Solar System. As of Jan 2014 there have been 973 exoplanets confirmed.
- **The Universe** — Consists of many Galaxies separated by empty space.

N4/5

The Light-year

Since distances in space are so enormous it is useful to think about how long it takes light to reach us from an object.

A useful measurement of distances in space is the light-year.

A light-year is the distance travelled by light in one year

Some examples of the time it takes light to travel from astronomical bodies to the Earth are listed below.

Object	**Time taken for light to reach Earth**
The Sun	8 minutes
Proxima Centura (nearest star outside Solar System)	4.3 years
Edge of Galaxy	100,000 years
Edge of known Universe	46 billion years

N5

Question
How far does light travel in one year?

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

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

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
- Liquid water and a temperature profile similar to Earth.
- The potential to build shelter
- The potential to grow and nurture a sustainable food source.

The Theory of the Origin of the Universe

N5

The Big Bang Theory

- **Our universe sprang into existence as a "singularity" around 13.7 billion** years ago.
- Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of Black Holes.
- Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is compressed into infinite density.
- Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense singularity.
- After its initial appearance, the universe inflated, expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe.
- 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.
- It continues to expand and cool to this day and we are inside of it!
- There is currently debate as to whether the universe will continue expanding, or whether it will start to contract.

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

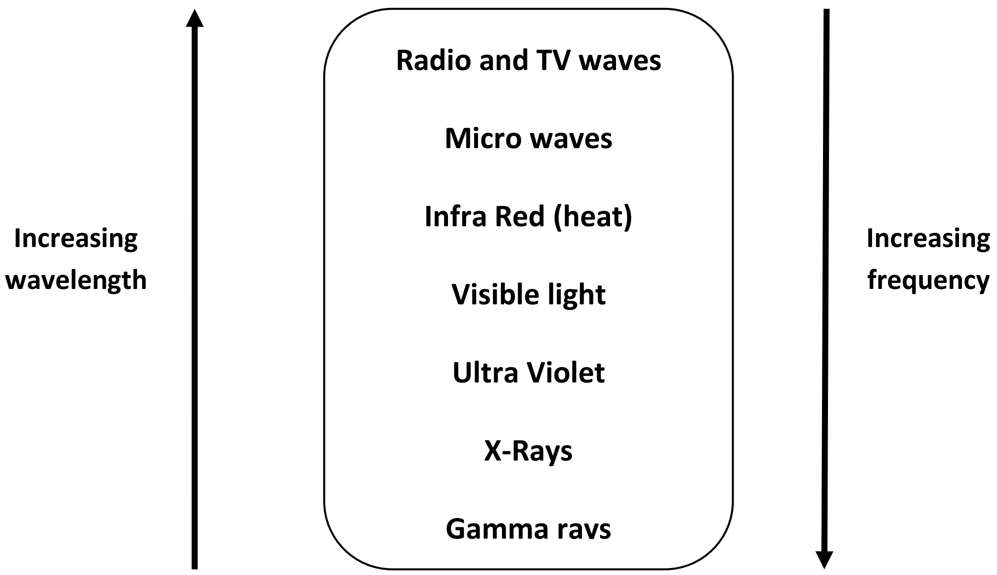
Electromagnetic Radiations

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.

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

Or remember the song.

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

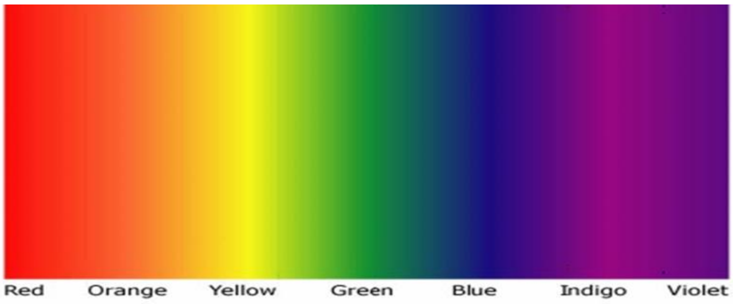
Spectroscopy

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. The line spectra can also be thought of as the bar code of an element.

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.

Unknown star

Hydrogen

Helium

Sodium

Calcium

Answer : Hydrogen and Helium.

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