# Gleniffer High School

# National 5

# Dynamics and Space

# Summary Notes

**Name:** ______________________________

# DYNAMICS

## VECTORS and SCALARS

Physical quantities can be divided into two groups:

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

**Distance** is a **scalar** quantity. Distance is the total path length. It is fully described by magnitude (size) alone,
**Displacement** is a **vector** quantity. Displacement is the direct length from the starting point to the finishing point. To fully describe displacement both magnitude and direction must be given.

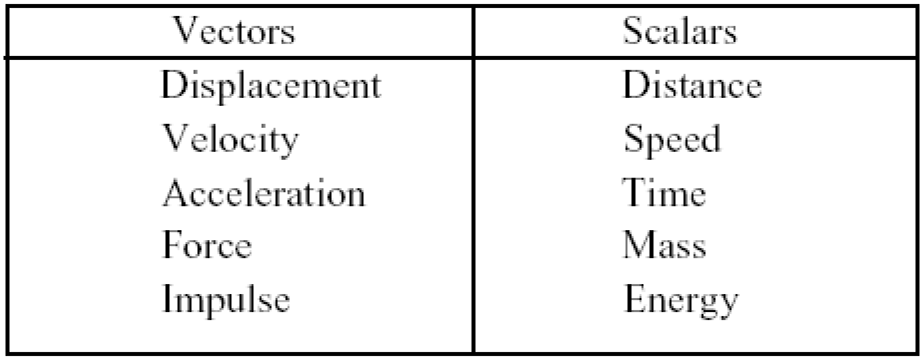
**Speed** is another example of a **scalar** quantity. **Velocity** is another example of a **vector** quantity. Speed and velocity are described by the equations below.

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

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

The direction of the velocity will be the same as the direction of the displacement.

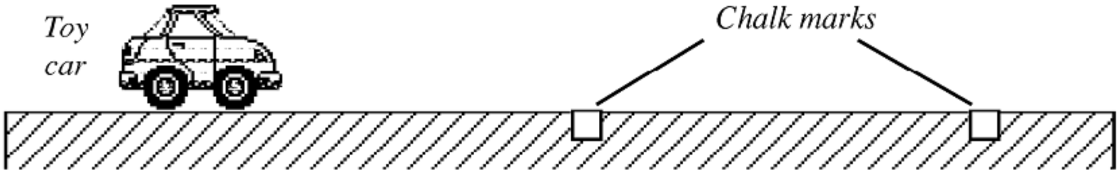
A summary table of common scalars and vectors is shown below.



| Vectors | Scalars |
|---|---|
| Displacement | Distance |
| Velocity | Speed |
| Acceleration | Time |
| Force | Mass |
| Impulse | Energy |

**Average Speed** (Revision from Level 4 and N4)

To measure the average speed of a toy car rolling across the floor of the laboratory carry out the following experiment.



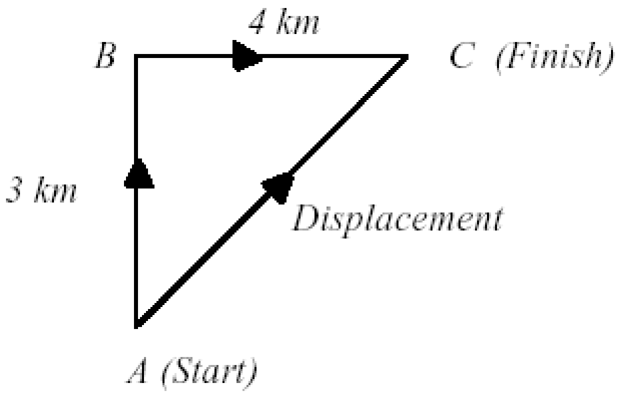
Using a metre stick measure the distance between the chalk marks.
Using a stopwatch measure the time from when the toy car crosses the first chalk until it passes the second chalk mark.

The data can then be enetered into the following equation and the average speed can be calculated.

$$d = \bar{v}t$$

Where $\bar{v}$ represents the average speed

**Example**
A woman walks 3km due North, and then 4km due East. This takes her 2hours. Find her:
a) distance travelled.
b) displacement from her starting point.
c) average speed.
d) average velocity.



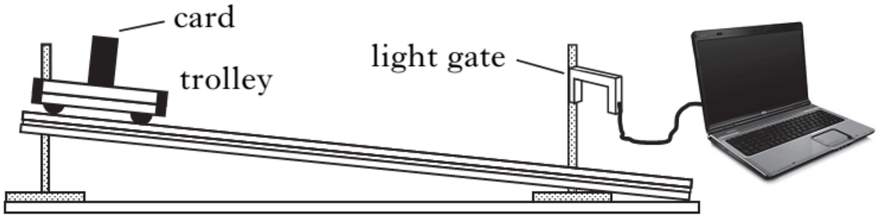
**Solution**
a)
Distance travelled = (3 + 4) km = 7km
b) Displacement could be found by using a scale diagram or Pythagoras to get the magnitude and SOHCAHTOA to get the bearing.

| | |
|---|---|
| $a^2 = b^2 + c^2$ | tan x = opp/adj |
| $a^2 = (3)^2 + (4)^2$ | tan x = 4/3 |
| $a^2 = (9) + (16)$ | tan x = 1.33 |
| $a^2 = 25$ | $x = 53^0$ |
| a= 5km | |

Displacement = 5km on a bearing of 053.
c)
average speed = distance/time
average speed = 7/2
average speed = 3.5kmh$^{-1}$
d)
average velocity = displacement/time
average velocity = 5/2
average velocity = 2.5kmh$^{-1}$ on a bearing of 053

**Instantaneous Speed** (Revision from Level 4 and N4)

To measure the instantaneous speed of a trolley rolling down a slope carry out the following experiment.



Use a ruler to measure the length of the card.
Note the time on the timing app on the PC. This is the time for which the beam of light in the light gate is cut by the card.

The data can then be entered into the following equation and the instanteous speed can be calculated.

$$\text{Speed of vehicle} = \frac{\text{length of card or vehicle}}{\text{time to cut beam}}$$

In this equation the’ speed of vehicle’ represents an instantaneous speed because the time interval is so small.

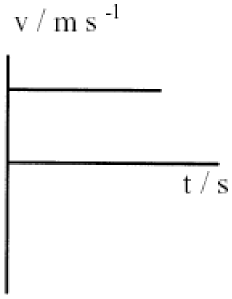
**The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.**

| Year | Section One | Section Two |
|---|---|---|
| 2015 | 14 and 15 | 7a)i) ii) |
| 2016 | 14 | 9 |
| 2017 | 14 and 16 | 8a) and c) |
| 2018 | 12 | 1a)i) and 2a) |
| 2019 | 1 | 1 not d) |

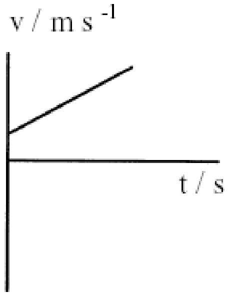
## VELOCITY-TIME GRAPHS

Plotting a graph of velocity versus time is a useful way to display an object’s motion. The three basic shapes are shown below.

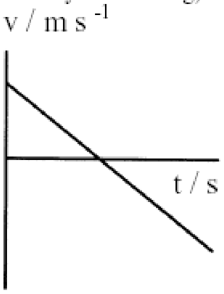
Constant velocity



Constant positive acceleration
(velocity increasing)



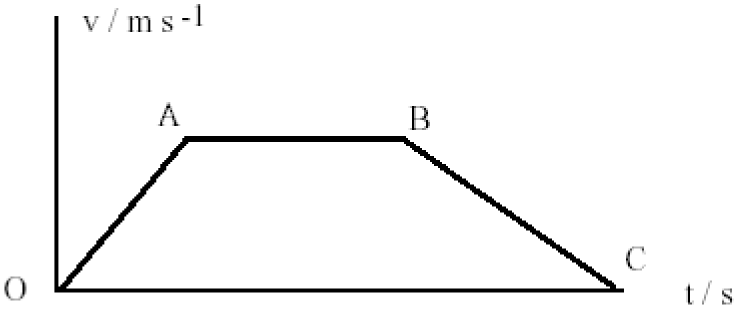
Constant deceleration
Constant negative acceleration
(velocity decreasing)



The displacement of an object can be calculated from the area under a velocity-time graph.

**Example**

An object starts from rest and reaches a velocity of $4 ms^{-1}$ after 2s. It continues at $4 ms^{-1}$ for a further 4s, before decelerating to rest after another 4s. Calculate the object’s displacement from its starting point.



Displacement = Area under graph

This graph can be split into two triangles and one rectangle. So,
Displacement = area under OA + area under AB + area under BC
Displacement = (½ x b x h) + (l x b) + (½ x b x h)
Displacement = (0.5 x 2 x 4) + (4 x 4) + (0.5 x 4 x 4)
Displacement = (4) + (16) + (8)
Displacement = 28m

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| Year | Section One | Section Two |
|---|---|---|
| 2015 | No examples | 10a) |
| 2016 | 15 | 10b) |
| 2017 | 1 and 15 | 8b)i) |
| 2018 | No examples | 2b) and c) |
| 2019 | 3 | 2 b) |

## ACCELERATION

Most objects do not travel at the same velocity all the time. If they speed up, they are said to accelerate. If they slow down, they decelerate.
Acceleration is the Physics quantity used to describe **the rate of change of velocity**. An object with an acceleration of 3ms$^{-2}$, will be increasing its velocity by 3ms$^{-1}$ every second.
Although acceleration is a **vector** quantity, only objects traveling in straight lines and in one direction will be considered in this course.

The formula used to calculate acceleration can be displayed on two ways.

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

$$\boxed{v = u + at}$$

where,
a is the acceleration in ms$^{-2}$
v is the final velocity in ms$^{-1}$
u is the initial velocity in ms$^{-1}$
t is the time taken for the velocity to change in s

**Example One**

A car is moving at $15ms^{-1}$, when it starts to accelerate at $2ms^{-2}$. Calculate the velocity of the car if it accelerates at this rate for 4s.

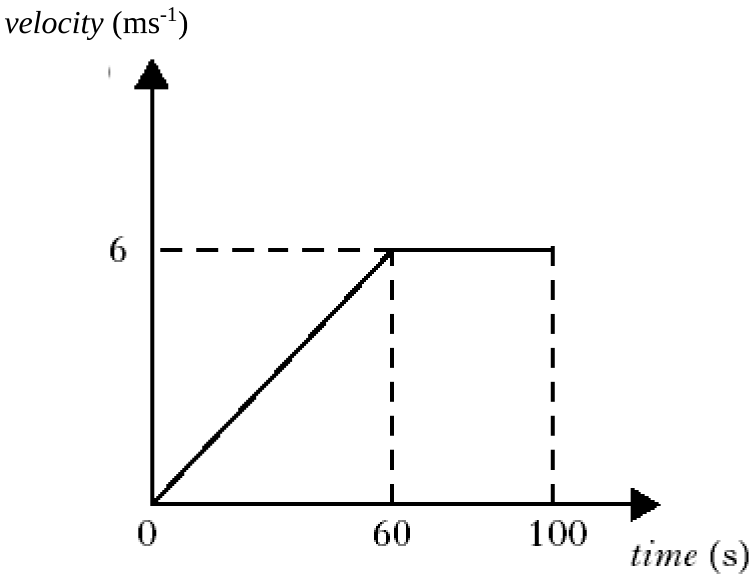
$a = 2ms^{-2}$
$v = ?$
$u = 15ms^{-1}$
$t = 4s$

$v = u + at$
$v = 15 + (2 \times 4)$
$v = 15 + 8$
$v = 23ms^{-1}$

**Note**
In examples where the final velocity is smaller than the initial velocity, the value for the acceleration will be a negative. A negative acceleration is called a deceleration.

**Example Two**

Calculate the acceleration for the motion graph shown below.



The upward sloping line represents the acceleration. So,

$a = ?$
$v = 6ms^{-1}$
$u = 0ms^{-1}$
$t = 60s$

$v = u + at$
$6 = 0 + a \times 60$
$6 = a \times 60$
$a = 6/60$
$a = 0.1ms^{-2}$

As the **gradient of a v-t graph is equal to acceleration** this provides an alternative solution to the above example.

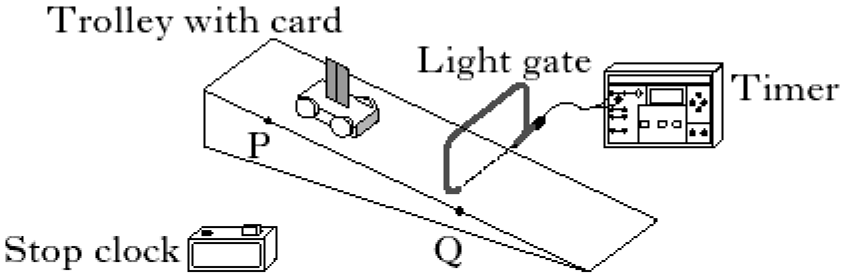
$$\text{Gradient} = \text{acceleration} = \frac{\text{Change in ‘y’ co-ordinates}}{\text{Change in ‘x’ co-ordinates}}$$

$$\text{Gradient} = \text{acceleration} = \frac{(6 - 0)}{(60 - 0)}$$

$$\text{Gradient} = \text{acceleration} = 6 / 60$$

$$= 0.1\text{ms}^{-2}$$

There are a number of experimental methods that can be used to measure the acceleration of a moving object.



In the experiment shown above the length of the card would be measured before the trolley was released from point, P.
At the same time as the trolley is released from rest the stop clock would be started. The stop clock would be stopped when the trolley reaches point, Q.
At point, Q, the card breaks the beam of light in the light gate and the timer records how long the beam is broken.
When the experimental data has been collected it can be used in the following equation to calculate the acceleration.

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

v is calculated by dividing the length of the card by the time shown on the timer
u is zero as the trolley started from rest
t is the time taken to travel from P to Q shown on the stop clock
a can now be calculated by inserting the data into the equation

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|---|---|---|
| 2015 | 15 | 8 |
| 2016 | No examples | 10a) |
| 2017 | 16 | 8b)ii) |
| 2018 | No examples | 2a)iii) |
| 2019 | 2 | 2 a)i) |

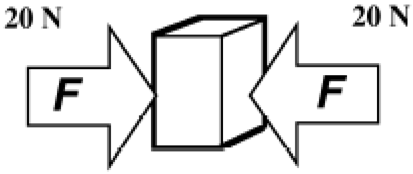
## NEWTON'S LAWS

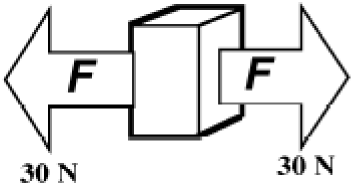
### Newton's First Law of Motion

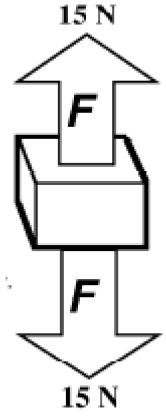
Newton's first law of motion can be written as,

> "When forces on an object are balanced it will remain stationary or move with a constant velocity."

Example of Balanced Forces





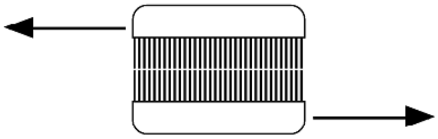


In this unit the names of some of the common forces covered are:-

Weight Engine Force Friction Air Resistance

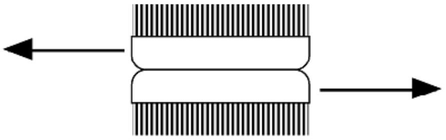
**Friction**

Friction is a force that acts in the opposite direction to the motion of the object. Friction acts between any two surfaces in contact. The magnitude (size) of the force of friction depends on the surfaces in contact, e.g. a rough surface will give a lot of friction.



***High Friction***

*Sliding rough surfaces is like sliding the bristles of two brushes - it is difficult.*



***Low Friction***

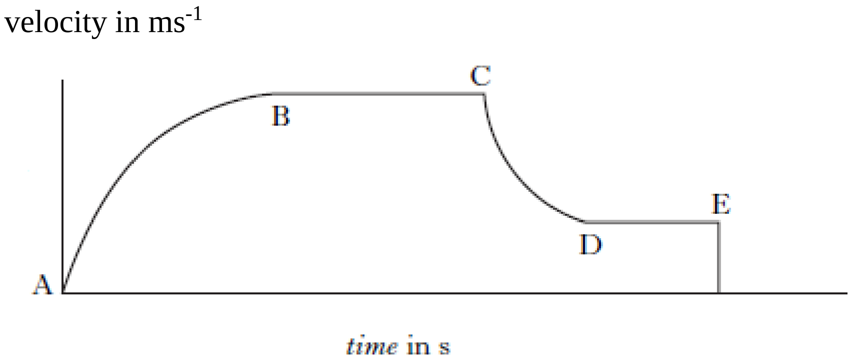
*Sliding smooth surfaces is like sliding the backs of two brushes - it is easy.*

When the friction is due to air it is usually called air resistance. Air resistance increases as the velocity of the object increases.

As the sky diver, shown above, leaves the aircraft he is in **free fall** and his velocity will increase. This will cause the air resistance acting against him to increase. Eventually his downward force (weight) will be the same as his upwards force (air resistance). As the forces acting on the sky diver are now balanced he will be travelling with a constant velocity known as a **terminal velocity.**

If the sky diver was to open his parachute the air resistance acting against him would increase. Eventually, his downward force (weight) and his upward force (air resistance) will balance again and the sky diver will now have a reduced terminal velocity.

This is shown in the graph below.



Newton’s First Law of Motion applies to sections B to C and D to E.

## Newton's Second Law of Motion

This law deals with situations when there is an unbalanced force acting on an object.

In this situation the velocity of the car cannot remain constant. This will result in the car having an acceleration.
As the unbalanced force is increased, assuming mass remains constant, the acceleration of the car will increase.
If the mass of the car if increased, assuming the unbalanced force remains constant, the acceleration will decrease.

These statements can be summarized in the following equation which is a statement of Newton's Second Law of Motion.

Unbalanced force = mass x acceleration

**F = m x a**

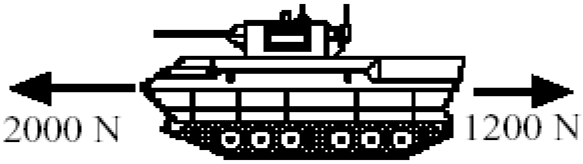
where,

F is the unbalanced force measured in Newtons(N)
m is the mass measured in kilograms(kg)
a is the acceleration measured in metres per second per second(ms$^{-2}$)

This equation also allows the Newton to be defined as the force which makes a 1kg mass accelerate at 1ms$^{-2}$.

**Example One**

Calculate the mass of the vehicle shown, if the engine force is 2000N and the force of friction is 1200N. The acceleration of the vehicle is 0.04ms$^{-2}$.



**This is a typical assessment calculation question that would be worth 4 marks. This should tell you that the solution needs a calculation and an extra step.**

In this example the extra step needs you to find the unbalanced force before you attempt the calculation.

### Solution

$F = F_{engine} - F_{friction}$
F = 2000 – 1200
F = 800N
a = $0.04ms^{-2}$
m = ?

F = m x a
800 = m x 0.04
m = 800 / 0.04
m = 20,000kg

### Example Two

The forces acting on a parachutist at a point during her jump are shown below. If the mass of the parachutist is 50kg, calculate her acceleration.

**This is a typical assessment calculation question that would be worth 4 marks. This should tell you that the solution needs a calculation and an extra step.**

In this example the extra step needs you to find the unbalanced force before you attempt the calculation.

### Solution

$F = F_{downward} - F_{upward}$
F = 700 – 600
F = 100N
m = 50kg
a = ?

F = m x a
100 = 50 x a
a = 100 / 50
a = $2ms^{-2}$

### Weight

**Weight is a force**. The weight of an object always acts downwards. Weight is measured in **Newtons**. The weight of an object can change.

**Weight to mass ratio is usually called gravity**. Gravity is the shortened version of gravitational field strength. **Gravity is measured in Newtons per kilogram ($Nkg^{-1}$)**. Gravity can vary but is quoted as 9.8Newtons per kilogram ($9.8Nkg^{-1}$) on planet Earth.

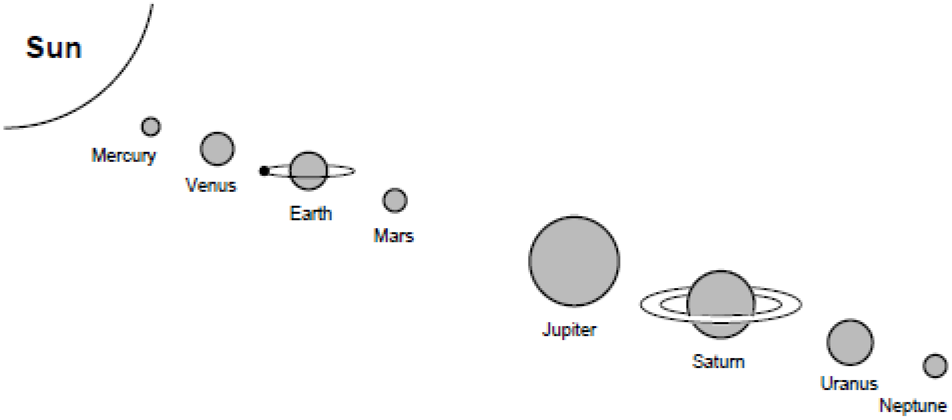
Weight = mass x gravity
W = m x g

where,

W is weight measured in Newtons(N)
m is mass measured in kilograms(kg)
g is measured in Newtons per kilogram($Nkg^{-1}$)

Gravity is one of the four fundamental forces of nature and is the attraction between two objects that have a mass. This attraction, or pull, between the objects will depend on two things:

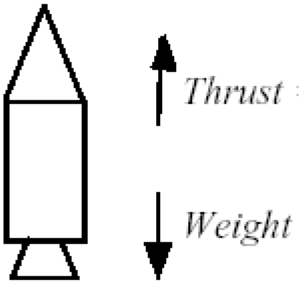
1. The mass of both of the objects. The larger the masses the stronger the pull of gravity.
2. The distance between the objects. The closer the objects are the greater the pull of gravity.



This means an object's weight, which depends on gravity, will depend on where it is in our solar system. The table below shows how gravity can vary in our solar system.

| Celestial Body | g value at surface of Celestial Body ($Nkg^{-1}$) |
|---|---|
| Moon | 1.6 |
| Venus | 8.8 |
| Mars | 3.7 |
| Sun | 274 |

**Example**
A space probe, mass 800kg, takes off on its return flight from Venus by using a thrust (upward force) of 20,000N. Calculate the initial acceleration of the space probe.



**Solution**

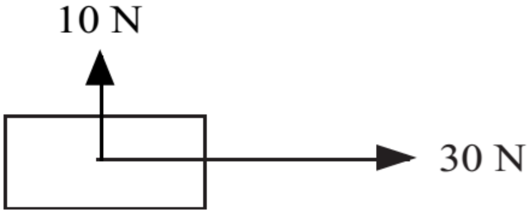
W =m x g
W = 800 x 8.8
W = 7040N

$F = F_{up} – F_{down}$
F = Thrust – Weight
F = 20,000 – 7040
F = 12,960N

F = m x a
12,960 = 800 x a
a = 12,960 / 800
$a = 16.2ms^{-2}$

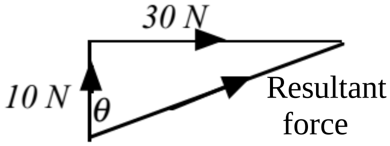
**Combining Forces**

Two forces acting on an object at right angles to each other can also be combined to produce a **resultant force**.



To do this a vector addition (the ‘tail’ of one vector is added to the ‘head’ of the previous vector) should be followed by Pythagoras and SOHCAHTOA calculations. These calculations will provide the magnitude and direction of the resultant force vector.

The vector addition for the above forces produces the following diagram:



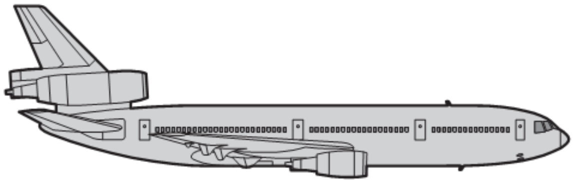
Pythagoras and SOHCAHTOA calculations are as shown.

$a^2 = b^2 + c^2$
$a^2 = (10)^2 + (30)^2$
$a^2 = (100) + (900)$
$a^2 = 1000$
a= 31.6N

$\tan \Theta = O / A$
$\tan \Theta = 30 / 10$
$\tan \Theta = 3$
$\Theta = 72^{o}$

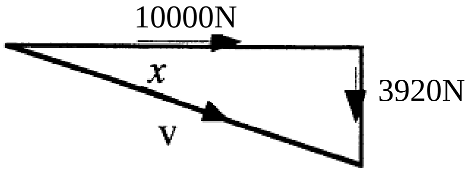
The resultant force is written as 31.6N at 072.

**Example**
An aircraft is flying horizontally at a constant speed.



During this part of the  flight the aircrft's engines produce a force of 10000N due East. The aircraft encounters a crosswind of 3985N, blowing from North to South.
Calculate the resultant force on the aircraft.

**Solution**
The vector diagram for this part of the flight is



Pythagoras and SOHCAHTOA calculations are as shown.

$a^2 = b^2 + c^2$
$v^2 = (10000)^2 + (3985)^2$
$v^2 = (1 \text{ x } 10^8) + (1.5 \text{ x } 10^7)$
$v^2 = 1.15 \text{ x}10^8$
$v = 1.1 \text{ x } 10^4\text{N}$

tan x = O /A
tan x = 3985 / 10000
tan x = 0.3985
$x = 21^o$

Before writing the resultant force you must remember that the direction should be quoted as a bearing.
All bearings are quoted from North, so the direction of the resultant force is (90 + 21) = 111.

The resultant force is $1.1 \text{ x } 10^4$N at 111

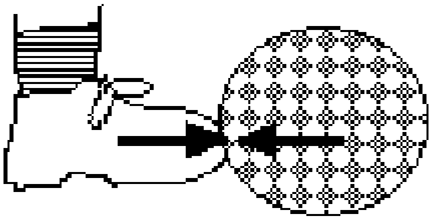
## Newton's Third Law of Motion

Newton's Third Law of Motion can be written as,

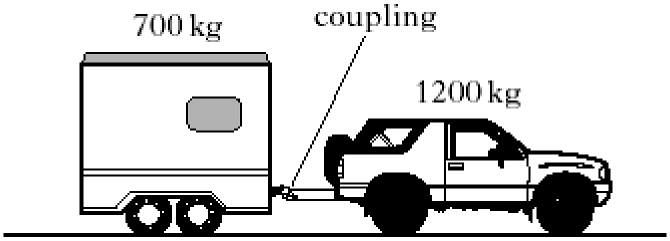
> "For every action force there is an equal and opposite reaction force."

This means that forces will occur in Newton Pairs. Some examples are shown below.

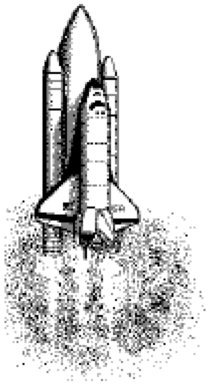
When the player strikes the ball, his foot exerts a force to the right on the ball. At the same time, the ball exerts a force to the left on the player's foot.



When the car exerts a force on the coupling, the coupling exerts a force on the car in the opposite direction.



At take-off for a space shuttle, when the launch rocket pushes the gases backwards, the gases push the launch rocket forwards.



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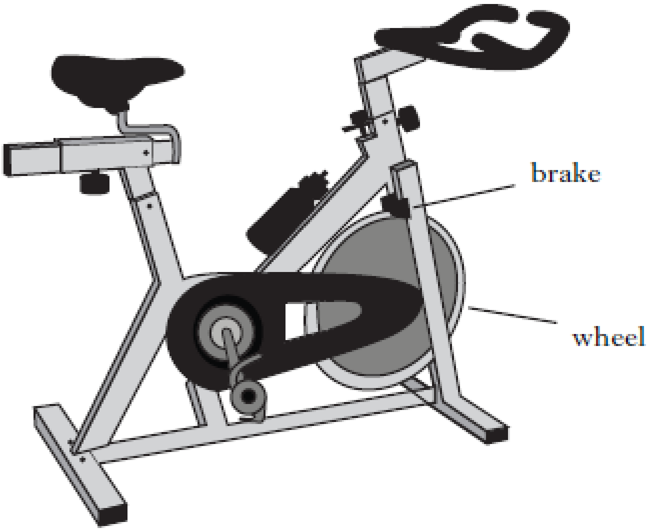
| 2017 | 14 | 9 |
| 2018 | 3 | 1a)i) ii) |
| 2019 | No examples | 1 d) and 2 a)ii)iii) |

## ENERGY

### Principle of Conservation of Energy

Energy cannot be created or destroyed, but it can be changed from one type into another type. All forms of energy are measured in the same unit –the **Joule (J)**.

Machines can be used to change one type of energy into another type of energy. For example, an electrical motor will change electrical energy into kinetic energy. However not all the electrical energy which is supplied to the motor will be changed into the final useful form of energy. Some electrical energy will be changed into heat energy due to friction and some electrical energy will be changed into sound energy. This makes the machine inefficient.
In this machine there will be friction between the wheel and the brake.



Efficiency is measured by expressing the useful energy output as a percentage of the total energy input.

*Formula for efficiency*

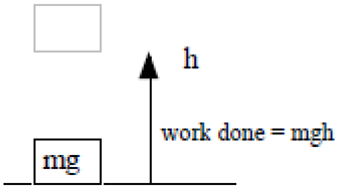
$$\boxed{\%\ \text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times \frac{100}{1}}$$

Power is the rate of energy transfer. This means the above equation can also be applied to power rather than energy.

## Gravitational Potential Energy

An object which is raised up to a high position is said to have gravitational potential energy. The work done against gravity to raise it equals the energy transformed into potential energy.

Imagine a mass of m kg lifted through a height of h metres:



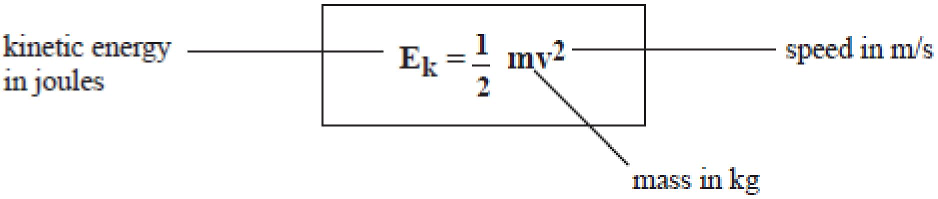
Force needed = weight of m kg = mg newtons
Work done = force x distance = mg x h
**potential energy = mgh joules**

$$E_p = mgh$$

where,
$E_p$ is gravitational potential energy measured in Joules (J)
m is mass measured in kilograms (kg)
g is gravitational field strength, which has a value of $9.8 Nkg^{-1}$ on planet Earth
h is the height measured in metres (m)

## Kinetic Energy

Kinetic energy is the energy associated with a moving object. It is measured in joules and has the symbol $E_k$.
The kinetic energy of a moving object depends on the mass of the object and on the square of its speed.



Notes
The unit of kinetic energy is the **Joule** which is normally written as a **J.**
The unit for speed is **metres per second** which is normally written as **$ms^{-1}$**.

REMEMBER
THE PRINCIPLE OF CONSERVATION OF ENERGY STATES THAT, THE TOTAL ENERGY REMAINS CONSTANT DURING ENERGY CHANGES. ENERGY CANNOT BE CREATED OR DESTROYED BUT IS CHANGED INTO ONE OF ITS MANY TYPES.

### Example One

A student lifts a 0.35kg textbook, 0.9m from the floor to her desk.
a) What is the value of the gravitational potential energy gained by the textbook?
b) The textbook falls of the desk, with what speed will it hit the floor?

a)

$E_p = ?$ $m = 0.35\text{kg}$ $g = 9.8\text{Nkg}^{-1}$ $h = 0.9\text{m}$

$$E_p = mgh$$
$$E_p = 0.35 \times 9.8 \times 0.9$$
$$E_p = 3.087$$
$$E_p = 3.1\text{J}$$

b)
By applying the principle of conservation of energy, the gravitational potential energy lost by the textbook will be equal to the kinetic energy that it gains.

$$E_p \text{ lost} = E_k \text{ gained}$$

$E_k$ gained = 3.1J $m = 0.35\text{kg}$ $v = ?$

$$E_k = 0.5 \times m \times v^2$$
$$3.1 = 0.5 \times 0.35 \times v^2$$
$$3.1 = 0.175 \times v^2$$
$$v^2 = 17.7$$
$$v = 4.2\text{ms}^{-1}$$

**Example Two**

An electric motor that transfers energy at a rate of 400Js$^{-1}$ is to be used to lift a 190kg crate on to the back of a van. The crate must be 1.6m above the ground before it can be loaded onto the van. If the motor operates for 8seconds, can the crate be placed on the back of the van?

Firstly calculate the energy supplied by the electric motor.

$P = 400W \qquad t = 8s \qquad E = ?$

$$E = P \times t$$
$$E = 400 \times 8$$
$$E = 3200J$$

Assume all the energy supplied is changed into gravitational potential energy. (This is very unlikely as the motor will be making heat energy and sound energy.)

$$E \text{ supplied} = E_p \text{ gained}$$

$E_p = 3200J \qquad m = 190kg \qquad g = 9.8Nkg^{-1} \qquad h = ?$

$$E_p = m\,g\,h$$
$$3200 = 190 \times 9.8 \times h$$
$$3200 = 1862 \times h$$
$$h = 1.7m$$

As 1.7m is greater than 1.6m the crate will be able to go on the back of the van.

**Work**

The work done is a measure of the energy transformed. It is equal to the force multiplied by the distance the force moves. The force and distance must be measured in the same direction. Work is measured in the same units as energy: joules. The symbol for work is $E_w$.

The equation for calculating work done is…

$$\mathbf{E_w = F \times d}$$

where,
$E_w$ is the work done (or energy transferred) measured in Joules (J)
F is the force measured in Newtons (N)
d is the distance in metres (m)

**Example**

A dog pulls a 4kg sledge for a distance of 15m using a force of 30N.
How much work does the dog do?

$$F = 30N \quad d = 15m \quad E_w = ?$$

$$E_w = F \times d$$
$$E_w = 30 \times 15$$
$$E_w = 450J$$

**The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.**

| Year | Section One | Section Two |
|---|---|---|
| 2015 | 16 | 11a) |
| 2016 | 16 | No examples |
| 2017 | No examples | 11c) |
| 2018 | 4 | 3a) and b) |
| 2019 | No examples | 9 c) |

## PROJECTILES

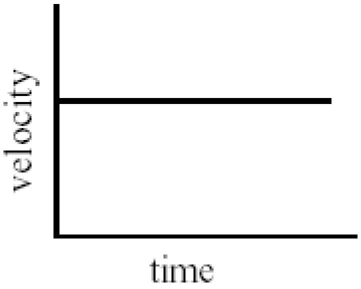
### Projectile Motion

A projectile is an object which has been given a forward motion through the air, but which is also being pulled downward by the force of gravity. This results in the path of the projectile being curved.

**A projectile has two separate motions at right angles to each other.**
**In calculations each motion must be treated independent of the other.**

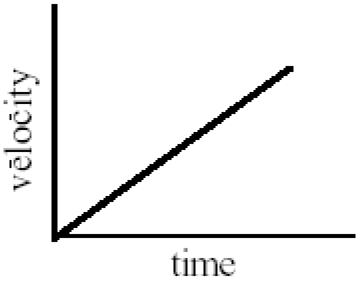
Horizontal

- constant speed
- for calculations use $d = v_h \times t$
- velocity graph



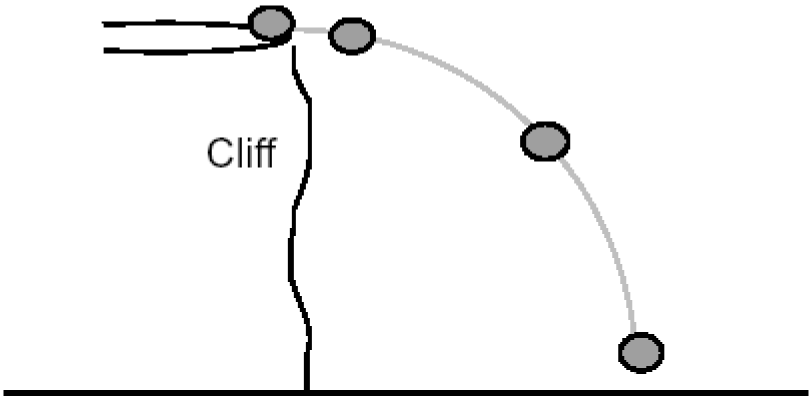
Vertical

- constant acceleration
- for calculations use $v = u + at$, where $u = 0ms^{-1}$ and $a = 9.8ms^{-2}$
- velocity graph



**Example One**

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



a) What horizontal distance did it travel in the 2seconds?
b) What was its vertical velocity just before it hit the ground?

**Solution**

a)
$v_h = 5ms^{-1}$
$d = ?$
$t = 2s$

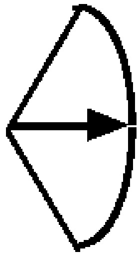
$d = v_h \times t$
$d = 5 \times 2$
$d = 10m$

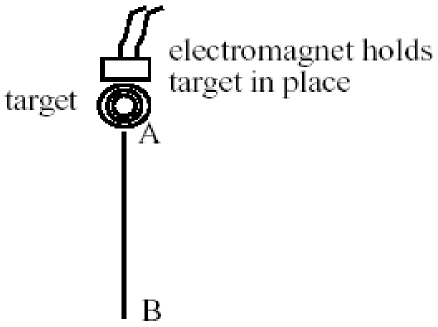
b)
$u = 0ms^{-1}$
$v = ?$
$a = 9.8ms^{-2}$
$s = ?$
$t = 2s$

$v = u + at$
$v = 0 + 9.8 \times 2$
$v = 19.6ms^{-1}$

**Example Two**

In the experimental set-up shown below, the arrow is lined up towards the target. As the arrow is fired, the circuit supplying the electromagnet is broken, and the target falls downwards from A to B.





Explain why the arrow will hit the target.

**Solution**

The arrow and the target have the same initial velocity (u = $0ms^{-1}$), and they both have the same vertical acceleration (a = $9.8ms^{-2}$).
As they both start to fall from their high points at the same time they will meet directly under the electromagnet. So the arrow will hit the target.
(This is an example of the "Monkey and hunter" experiment.)

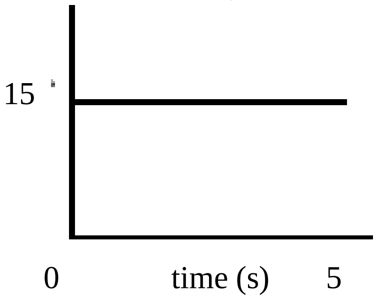
**Example Three**

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

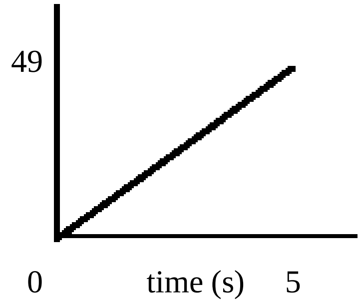
a) horizontal velocity against time
b) vertical velocity against time
c) from the graphs calculate the horizontal and vertical distances travelled.

**Solution**

a)
horizontal velocity ($ms^{-1}$)



b)
vertical velocity ($ms^{-1}$)



v = u + at
v = 0 + 9.8 x 5
v = $49ms^{-1}$

c)
horizontal distance = area under graph
horizontal distance = l x b
horizontal distance = 5 x 15
horizontal distance = 75m OR
d = v x t
d = 5 x 15
d =75m

vertical distance = area under graph
vertical distance = ½ x b x h
vertical distance = 0.5 x 5 x 49
vertical distance = 122.5m
vertical distance = 123m

**The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.**

| **Year** | **Section One** | **Section Two** |
|---|---|---|
| 2015 | No examples | 9 |
| 2016 | 18 | No examples |
| 2017 | No examples | 11a) and b) |
| 2018 | No examples | 3c) |
| 2019 | 4 | No examples |

## SPACE EXPLORATION

### Newton's Thought Experiment

Sir Isaac Newton imagined an experiment in which an object could be fired into orbit around the Earth. His argument went like this.

Imagine a large cannon that could fire an object many kilometres. The object would be a projectile and would have a constant horizontal speed and a constant vertical acceleration. He then imagined a cannon so large that it could fire the object beyond the horizon. This projectile would start to follow the curvature of the Earth before it hit the ground.

Finally he imagined a cannon so large that it could sit on top of the Earth. This cannon could fire an object with a horizontal speed that would be so fast that it would follow the curvature of the Earth without hitting it.

In other words, the object has become a projectile the orbits the Earth. The object will remain in orbit because it is always being pulled by gravity. This is how satellites remain in orbit.

### Newton's Thought Experiment (continued)

### Satellites

Although Newton's theory (from 1666) on satellite motion was correct, the technology to put an artificial satellite into orbit outside Earth's atmosphere did not exist until the late 1950s.

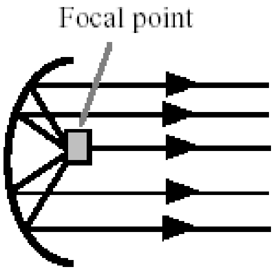
When satellites are launched into space they are used for specific jobs. Communications and weather satellites are amongst the most common uses of approximately 1000 satellites that are orbiting the Earth. Communication satellites are an example of **geo-stationary satellites**. This means they remain above a fixed point on the Earth's surface giving them an orbital period of **24hours**. Most communication satellites are located **36000km** above their fixed point on the earth's surface.

Each satellite will carry its own set of instruments which might detect long wavelength radio waves, microwaves, infra-red, visible light, UV, X-rays or high energy gamma rays. Every satellite does have some items in common with every other satellite.

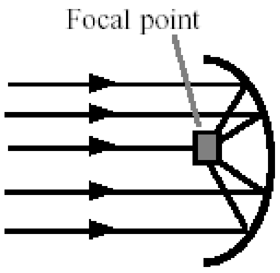
| Item | Use |
|---|---|
| Aerials and Receivers | To send and receive signals (usually radio waves or microwaves) from the Earth or other satellites. |
| Solar Panels | To convert energy from the Sun into electricity. |
| Batteries | To store electrical energy that is generated by the solar panels. |
| On-board Processors | To allow the satellite to interpret the signals received. |
| Rocket Motors | To alter the satellite position in space. |
| Fuel Tanks | To store fuel for the rocket motors. |

Satellites are controlled from ground stations. The ground stations use large dish aerials to send and receive signals from satellites.

To send signals a dish aerial would have a transmitter placed at its focal point. To receive signals an aerial would be placed at the focal point.



Transmitter placed at focal point.



Receiver placed at focal point

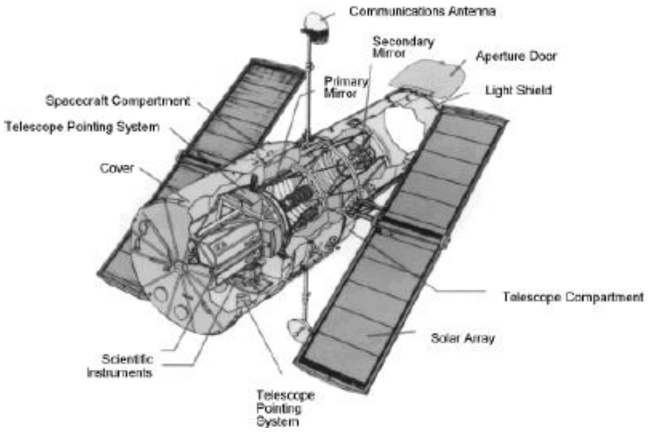
A benefit to society from the use of satellite technology has been the thousands of lives saved as a result of information from weather satellites. These low orbiting satellites provide data on tropical storms as well as monitoring the progress of other phenomena such as volcanic eruptions and forest fires.

Global Positioning System (GPS) is another satellite based technology that is now in common use. This US government owned system uses 24 satellites to give complete worldwide coverage. Each GPS satellite continually broadcasts a navigation message consisting of two parts:

1. the satellite's trajectory (its path in space)
2. the exact time of the broadcast

Combining these two pieces of information reveals the location of the satellite in space.
A GPS receiver on Earth listens to these messages, usually from 3 or 4 satellites, and calculates the receiver's position on Earth.

Astronomers have been studying space almost from the dawn of civilisation. The human eye provided the first observations and by the 17th century simple optical telescopes were widely used by those who studied the sky at night. Nowadays telescopes are much more complicated. The world's largest reflecting telescope – the Hubble Space Telescope - can provide data on distant galaxies.



Our knowledge of space is growing thanks to our use of satellites and space probes which orbit or land on other objects in our Solar System.

The most recent data that has been received from space exploration supports a theory proposed by a Belgian, George Lemaitre, in the early 1900s. He proposed that the Universe was expanding. This theory was built on by Edwin Hubble who discovered that distant galaxies were moving away from us more quickly than those closer to us. Hubble's research has also allowed us to work out that the Universe is approximately 13.7 billion years old

Lemaitre and Hubble's work could be explained if the origin of the Universe came from an explosion that blasted matter in all directions. This is the basis of the Big Bang theory. However, there are many ideas that are still being explored by astro-physicists including the existence of dark matter and exoplanets that could sustain life.

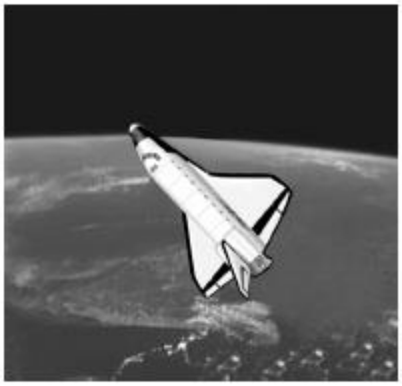
## Space Travel

There are many challenges to overcome to achieve space travel including**:**

- travelling large distances with the possible solution of attaining high velocity by using ion drive (producing a small unbalanced force over an extended period of time
- travelling large distances using a 'catapult' from a fast moving asteroid, moon or planet
- manoeuvring a spacecraft in a zero friction environment, possibly to dock with the ISS
- maintaining sufficient energy to operate life support systems in a spacecraft, with the possible solution of using solar cells with area that varies with distance from the Sun

When objects that have been exploring space return to our atmosphere they will encounter air resistance (friction). This will cause the object to slow down and in some cases "burn up" in the atmosphere.

This happens because moving objects have kinetic energy and when they are slowed down the kinetic energy has to be changed into some other form of energy. In this case the other energy is heat, and due to the air resistance there can be so much heat that the object will disintegrate in the Earth's atmosphere. This is a major problem for manned space missions!



For manned space missions it is necessary to cover the front and underside of the space craft with special tiles which have a high melting point. This will allow the tiles to withstand the high temperatures generated during re-entry. The tiles reflect and absorb the heat energy, providing a heat-shield which protects the occupants inside the space craft. Other risks associated with manned space flight include:

- fuel load on take-off
- potential exposure to radiation
- pressure differential

The following equations are useful when carrying out calculations on objects returning from space travel.

The kinetic energy of the moving space craft is calculated using……$E_k = ½ \times m \times v^2$

The work done against friction on re-entry is calculated using……$E_w = F \times d$

The heat energy absorb by the tiles is calculated using……$E_h = c \times m \times \Delta T$
(This equation will be explained in more detail in the Properties of Matter Unit)

**Example**
A space craft (mass 100,000kg) is travelling at 8000ms$^{-1}$ as it enters the Earth's atmosphere. At a point on its journey through the atmosphere, the 3000kg of tiles on the heat shield have absorbed 4.8 x 10$^8$J of energy and their temperature has increased by 160 $^0$C.
Calculate:

a) The kinetic energy of the space craft at the point of re-entry.
b) The specific heat capacity of the material used for the tiles on the heat shield.

**Solution**

a)
$E_k$ = ?
m= 100,000kg
v= 8000ms$^{-1}$
$E_k = ½ \times m \times v^2$
$E_k = 0.5 \times 100,000 \times (8000)^2$
$E_k = 50,000 \times 6.4 \times 10^7$
$E_k = 3.2 \times 10^{12}$J

b)
$E_h = 4.8 \times 10^8$J
c= ?
m= 3000kg
$\Delta T = 160^0$C
$E_h = c \times m \times \Delta T$
$4.8 \times 10^8 = c \times 3000 \times 160$
$4.8 \times 10^8 = c \times 480,000$
$c = 4.8 \times 10^8 / 480,000$
c = 1000Jkg$^{-10}$C$^{-1}$

**The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.**

| Year | Section One | Section Two |
|---|---|---|
| 2015 | No examples | No examples |
| 2016 | 17 | 12a) and c) |
| 2017 | 17 and 18 | No examples |
| 2018 | 5, 6, 7 and 8 | 4b) |
| 2019 | 6 and 7 | 4 c) |

## COSMOLOGY

### Measurements in Space

The distance from the Sun to the Earth is approx. 150,000,000km.

Astronomers call the distance from the Sun to the Earth one astronomical unit.

So,
1au = 150,000,000km
3au = 3 x 150,000,000 = 450,000,000km
6au = 6 x 150,000,000 = 900,000,000km

The astronomical unit is useful when dealing with distances in our Solar System but another unit is needed when measuring distances throughout the rest of the Universe.
A light year is a distance unit. A light year is the distance light travels in one year and can be calculated as shown…

distance = speed x time
distance = (speed of light) x (number of seconds in a year)
distance = $(3 \times 10^8) \times (365 \times 24 \times 60 \times 60)$
distance = $9.46 \times 10^{15}$m

In other words, one light year = $9.46 \times 10^{15}$m

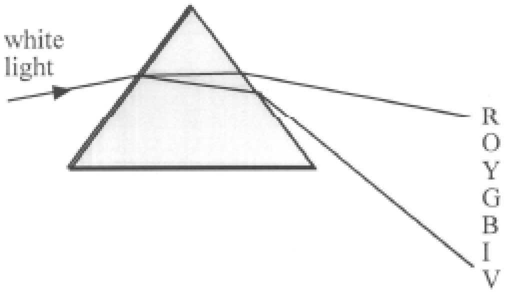
**Example**
The star Proxima Centauri is 4.3light years from planet Earth. Calculate the distance to Proxima Centauri in metres.

**Solution**
one light year = $9.46 \times 10^{15}$m
4.3light years = $4.3 \times 9.46 \times 10^{15}$
= $4.1 \times 10^{16}$m
The distance to Proxima Centauri is $4.1 \times 10^{16}$m.

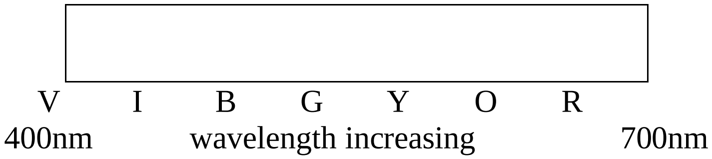
### Spectroscopy

A useful technique used in the study of space is spectroscopy. Spectroscopy involves the measurement of frequencies of **light** that are emitted, absorbed or scattered by materials. These measurements can be used to identify the materials.

In you separate white light into its component parts you get a **continuous** visible spectrum, all frequencies of visible light are present. This can be done using a triangular prism as shown in the next diagram.

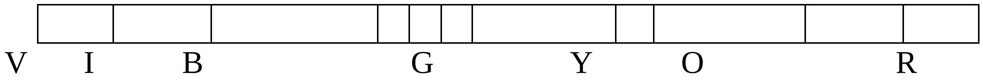


The continuous spectrum is normally displayed from the "blue" end to the "red" end as shown below.



(n is the prefix nano x $10^{-9}$)

Each element in the periodic table has a unique **line emission** spectrum.



Each line in the above diagram would correspond to the colour shown underneath it.
As each element has a unique set of lines in its spectrum, astronomers can collect light from a star and identify which elements are present in the star.

It is also possible to study the **absorption spectrum** for the atmosphere surrounding a star or planet.

Space spectroscopy has allowed the identification of the gas hydrogen as the main gas in stars, which is further evidence of the Big Bang theory.

Cosmology also involves the study of **radiations** from space. There are three main groups that have been studied.

1. Electromagnetic Radiation – produced by the motion of electrically charge particles.

| Gamma Ray | X-ray | Ultraviolet | Visible | Infrared | Microwave | Radio |
|---|---|---|---|---|---|---|

$10^{-12}$ $10^{-10}$ $10^{-8}$ $10^{-7}$ $10^{-5}$ $10^{0}$ $10^{3}$

(Approximate wavelength in metres)

2. Cosmic Rays – ionising radiations that collide with atomic nuclei to produce secondary radiation.
3. Neutrinos – electrically neutral subatomic particles.

The electromagnetic radiations from the Sun constantly bombard our atmosphere. Our atmosphere does let some of the electromagnetic radiations pass through it, e.g. visible light, but fortunately reflects or absorbs other radiations that are harmful to life.

| EM Radiation | Penetration of Our Atmosphere |
|---|---|
| Radio | Reach the surface |
| Microwave | Mostly absorbed 50km above surface; some can reach surface |
| Infra -red | Mostly absorbed 10km above surface; some can reach surface |
| Visible light | Reach the surface |
| Ultraviolet | Mostly absorbed 50km above surface; some can reach surface |
| X-rays | All stopped at 40km above surface |
| Gamma | All stopped at 50km above surface |

**The table below contains the details of the Past Paper examples for this area of the course. Past Papers, and their solutions, are free to download from the SQA website.**

| Year | Section One | Section Two |
|---|---|---|
| 2015 | 19 and 20 | No examples |
| 2016 | 20 | 13 |
| 2017 | 20 | 12a)ii) and b) |
| 2018 | 9 and 10 | 4a) |
| 2019 | No examples | 4 a) and b) |

## Space Exploration Glossary

**Star** – a massive ball of gas that emits light through the release of energy produced by nuclear reactions at its core

**Sun** – the star at the centre of our Solar System

**Planet** – an object that orbits a star

**Dwarf planet** – a small object orbiting a star that has enough gravity to form an almost round shape

**Asteroid** – a small rocky object that orbits the Sun

**Solar System** – a star and all the planets that orbit it

**Moon** – a natural satellite of a planet

**Satellite** – an object that orbits a planet

**Galaxy** – a collection of stars

**Universe** – the whole of space

**Exo-planet** – a planet outside our Solar System

**Black Hole** – an area of space from which no light can escape

## Cosmology Glossary

**Astronomical unit** – the standard unit for measuring distance within our Solar System

**Light Year** – the distance light travels in a year

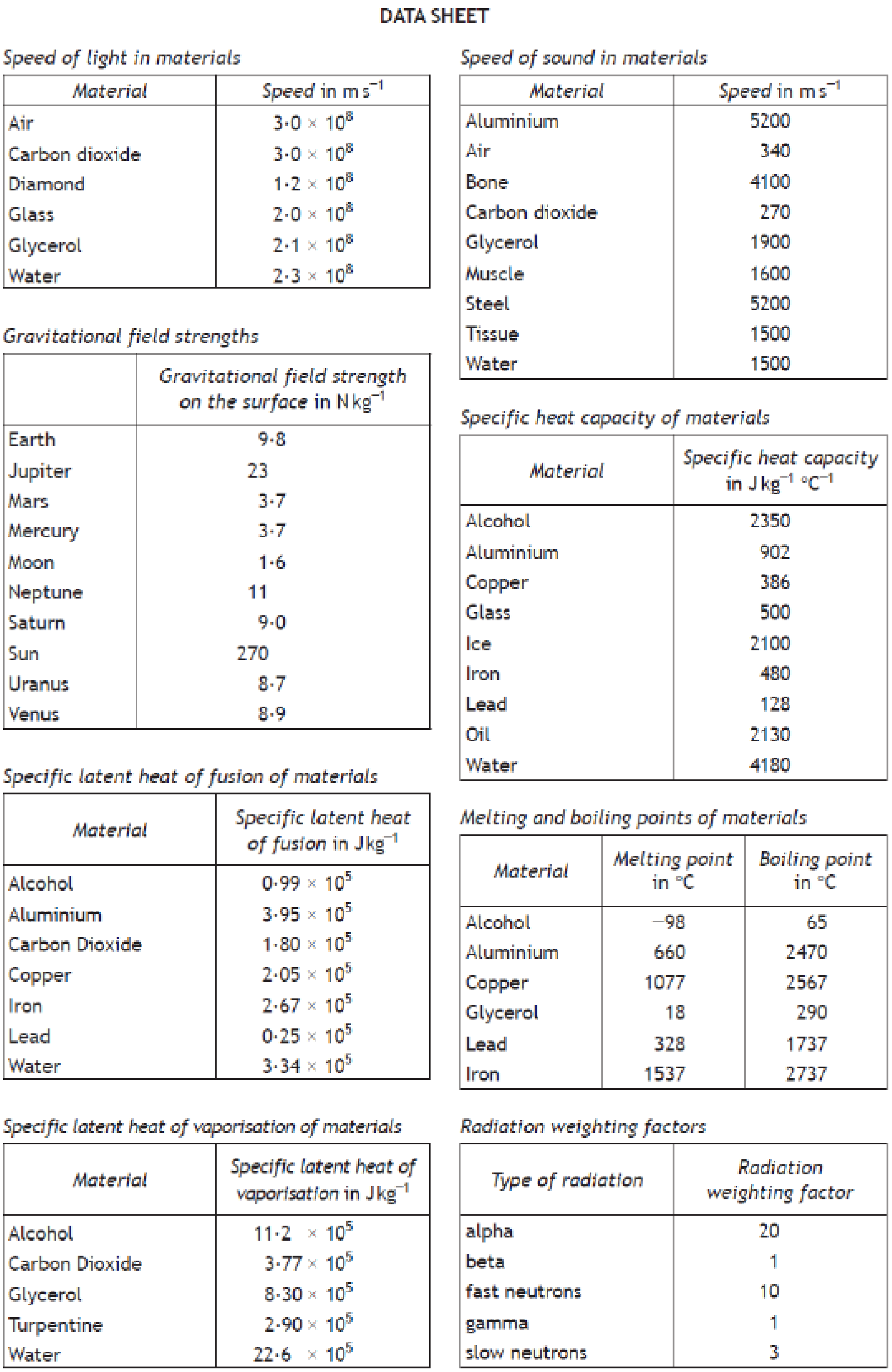
**Big Bang** – a possible theory to explain the beginning of the Universe which states that the Universe began from a singularity (single point) and is continually epanding

**Spectroscopy** – a scientific measuring technique used on light

**Continuous spectrum** – an unbroken band of coloured light from violet to red

**Line spectrum** – a spectrum that consists of discrete coloured lines

**Absorption spectrum** – a continuous spectrum that has dark lines due to the absorption of certain frequencies of light



DATA SHEET

*Speed of light in materials*

| *Material* | Speed in m s$^{-1}$ |
|---|---|
| Air | 3·0 × $10^8$ |
| Carbon dioxide | 3·0 × $10^8$ |
| Diamond | 1·2 × $10^8$ |
| Glass | 2·0 × $10^8$ |
| Glycerol | 2·1 × $10^8$ |
| Water | 2·3 × $10^8$ |

*Speed of sound in materials*

| *Material* | Speed in m s$^{-1}$ |
|---|---|
| Aluminium | 5200 |
| Air | 340 |
| Bone | 4100 |
| Carbon dioxide | 270 |
| Glycerol | 1900 |
| Muscle | 1600 |
| Steel | 5200 |
| Tissue | 1500 |
| Water | 1500 |

*Gravitational field strengths*

|  | *Gravitational field strength on the surface* in N kg$^{-1}$ |
|---|---|
| Earth | 9·8 |
| Jupiter | 23 |
| Mars | 3·7 |
| Mercury | 3·7 |
| Moon | 1·6 |
| Neptune | 11 |
| Saturn | 9·0 |
| Sun | 270 |
| Uranus | 8·7 |
| Venus | 8·9 |

*Specific heat capacity of materials*

| *Material* | *Specific heat capacity* in J kg$^{-1}$ °C$^{-1}$ |
|---|---|
| Alcohol | 2350 |
| Aluminium | 902 |
| Copper | 386 |
| Glass | 500 |
| Ice | 2100 |
| Iron | 480 |
| Lead | 128 |
| Oil | 2130 |
| Water | 4180 |

*Specific latent heat of fusion of materials*

| *Material* | *Specific latent heat of fusion* in J kg$^{-1}$ |
|---|---|
| Alcohol | 0·99 × $10^5$ |
| Aluminium | 3·95 × $10^5$ |
| Carbon Dioxide | 1·80 × $10^5$ |
| Copper | 2·05 × $10^5$ |
| Iron | 2·67 × $10^5$ |
| Lead | 0·25 × $10^5$ |
| Water | 3·34 × $10^5$ |

*Melting and boiling points of materials*

| *Material* | *Melting point* in °C | *Boiling point* in °C |
|---|---|---|
| Alcohol | −98 | 65 |
| Aluminium | 660 | 2470 |
| Copper | 1077 | 2567 |
| Glycerol | 18 | 290 |
| Lead | 328 | 1737 |
| Iron | 1537 | 2737 |

*Specific latent heat of vaporisation of materials*

| *Material* | *Specific latent heat of vaporisation* in J kg$^{-1}$ |
|---|---|
| Alcohol | 11·2 × $10^5$ |
| Carbon Dioxide | 3·77 × $10^5$ |
| Glycerol | 8·30 × $10^5$ |
| Turpentine | 2·90 × $10^5$ |
| Water | 22·6 × $10^5$ |

*Radiation weighting factors*

| *Type of radiation* | *Radiation weighting factor* |
|---|---|
| alpha | 20 |
| beta | 1 |
| fast neutrons | 10 |
| gamma | 1 |
| slow neutrons | 3 |

$$E_p = mgh$$

$$E_k = \frac{1}{2}mv^2$$

$$Q = It$$

$$V = IR$$

$$R_T = R_1 + R_2 + \ldots$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$V_2 = \left(\frac{R_2}{R_1 + R_2}\right)V_s$$

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

$$P = \frac{E}{t}$$

$$P = IV$$

$$P = I^2 R$$

$$P = \frac{V^2}{R}$$

$$E_h = cm\Delta T$$

$$p = \frac{F}{A}$$

$$\frac{pV}{T} = \text{constant}$$

$$p_1V_1 = p_2V_2$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$d = vt$$

$$v = f\lambda$$

$$T = \frac{1}{f}$$

$$A = \frac{N}{t}$$

$$D = \frac{E}{m}$$

$$H = Dw_R$$

$$\dot{H} = \frac{H}{t}$$

$$s = vt$$

$$d = \overline{v}t$$

$$s = \overline{v}t$$

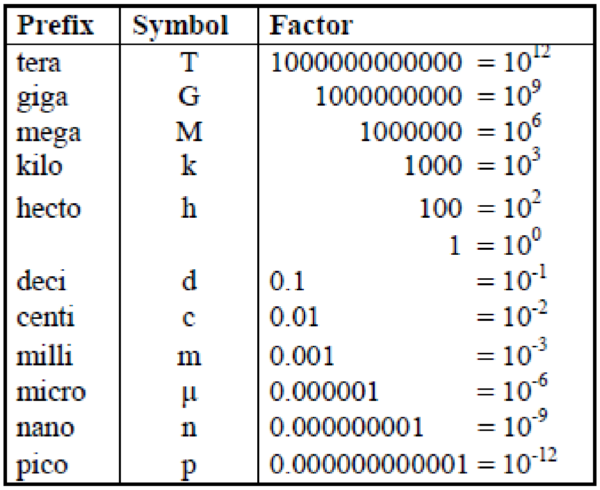
$$a = \frac{v-u}{t}$$

$$W = mg$$

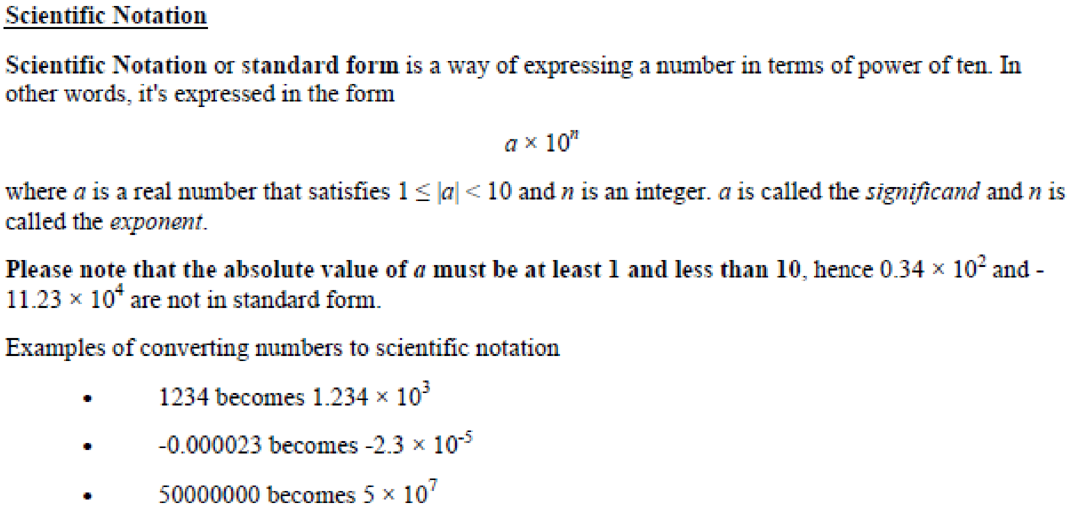
$$F = ma$$

$$E_w = Fd$$

$$E_h = ml$$



| Prefix | Symbol | Factor |
|---|---|---|
| tera | T | 1000000000000 = $10^{12}$ |
| giga | G | 1000000000 = $10^{9}$ |
| mega | M | 1000000 = $10^{6}$ |
| kilo | k | 1000 = $10^{3}$ |
| hecto | h | 100 = $10^{2}$ |
| | | 1 = $10^{0}$ |
| deci | d | 0.1 = $10^{-1}$ |
| centi | c | 0.01 = $10^{-2}$ |
| milli | m | 0.001 = $10^{-3}$ |
| micro | µ | 0.000001 = $10^{-6}$ |
| nano | n | 0.000000001 = $10^{-9}$ |
| pico | p | 0.000000000001 = $10^{-12}$ |



## Scientific Notation

**Scientific Notation** or **standard form** is a way of expressing a number in terms of power of ten. In other words, it's expressed in the form

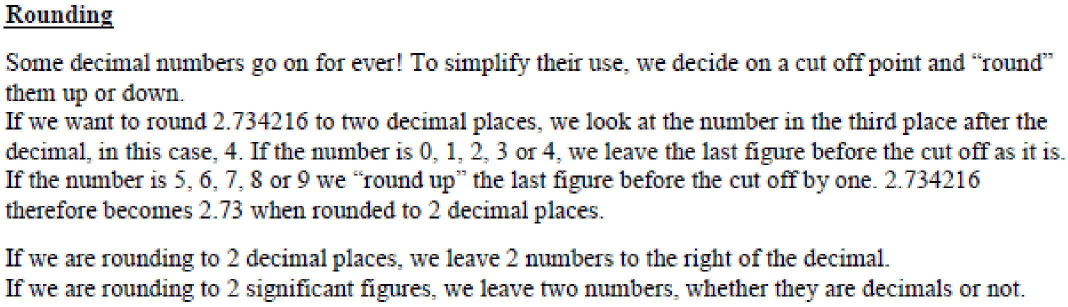
$$a \times 10^{n}$$

where $a$ is a real number that satisfies $1 \leq |a| < 10$ and $n$ is an integer. $a$ is called the *significand* and $n$ is called the *exponent*.

**Please note that the absolute value of $a$ must be at least 1 and less than 10**, hence $0.34 \times 10^{2}$ and $-11.23 \times 10^{4}$ are not in standard form.

Examples of converting numbers to scientific notation

- 1234 becomes $1.234 \times 10^{3}$
- -0.000023 becomes $-2.3 \times 10^{-5}$
- 50000000 becomes $5 \times 10^{7}$



## Rounding

Some decimal numbers go on for ever! To simplify their use, we decide on a cut off point and "round" them up or down.
If we want to round 2.734216 to two decimal places, we look at the number in the third place after the decimal, in this case, 4. If the number is 0, 1, 2, 3 or 4, we leave the last figure before the cut off as it is. If the number is 5, 6, 7, 8 or 9 we "round up" the last figure before the cut off by one. 2.734216 therefore becomes 2.73 when rounded to 2 decimal places.

If we are rounding to 2 decimal places, we leave 2 numbers to the right of the decimal.
If we are rounding to 2 significant figures, we leave two numbers, whether they are decimals or not.