Gleniffer High School

National 4

Dynamics and Space

Summary Sheets

Speed and Acceleration

Average Speed

The **average speed** of a moving object can be found by measuring the **distance** it travels and the **time** it takes to travel that distance. Average speeds are usually measured over large distances or long times. **Metre-sticks** or **trundle wheels** would normally be used to measure the distance in an average speed experiment. The time would normally be measured using a handheld **stopwatch**.

The following equation is used to calculate average speed: -

average speed = distance / time

where,

average speed is measured in metres per second (ms^{-1})
distance is measured in metres (m)
time is measured in seconds (s)

Example

A marble takes 4 seconds to travel 50 cm across a desk. What is the average speed of the marble?

average speed = ?   distance = 50 cm = 0.5 m   time = 4.0 s

average speed = distance / time
average speed = 0.5 / 4.0
average speed = 0.125 ms^{-1}

When much larger distances or longer times are used it is often necessary to use a different set of units for average speed calculations. These are shown below: -

Average speed is measured in kilometres per hour (kmh^{-1})
Distance is measured in kilometres (km)
Time is measured in hours (h)

Example

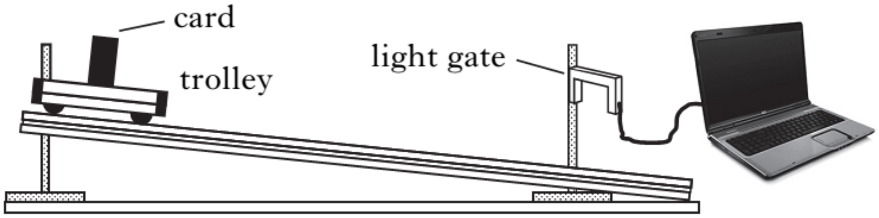
A cyclist travels 7000 m in 30 minutes. What is her average speed?

average speed = ?   distance = 7000 m = 7 km   time = 30 minutes = 0.5 h

average speed = distance / time
average speed = 7.0 / 0.5
average speed = 14 kmh^{-1}

Instantaneous Speed

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.

<u>Example</u>

A trolley is fitted with a card 0.10 m in length. The trolley is set in motion and the card cuts a light gate. The time on the timer is 0.025 seconds. Calculate the speed of the trolley when it passes the light gate.

Instantaneous speed = length of card / time on timer

Instantaneous speed = 0.10 / 0.025

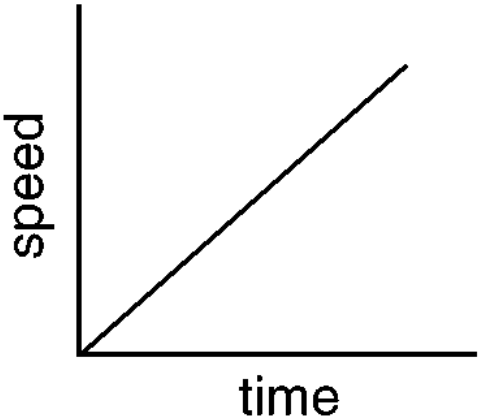
Instantaneous speed = 4 ms^{-1}

Speed-time Graphs

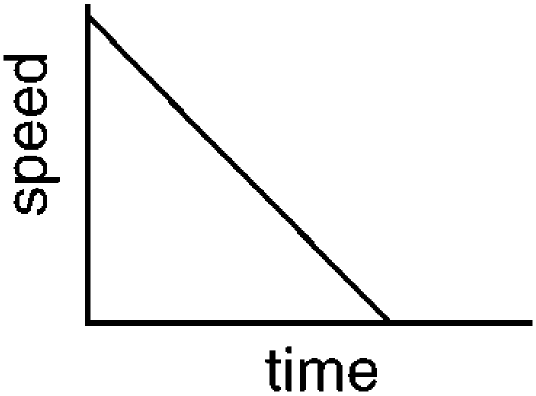
A speed-time graph is a useful way to describe the movement of an object. The shape of the graph shows whether the object is…

- accelerating/speeding up
- decelerating/slowing down
- moving with a constant (steady) speed

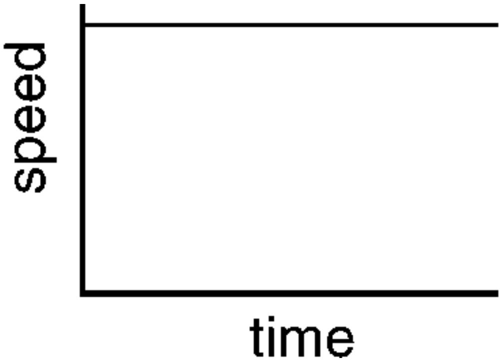
Speed-time graph for acceleration.



Speed-time graph for deceleration



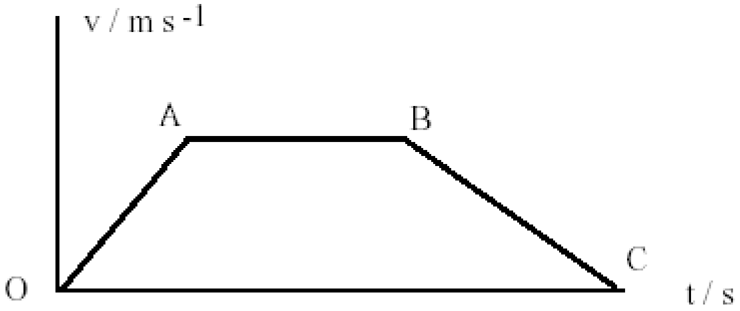
Speed-time graph for constant speed



The **distance travelled** by an object can be calculated from the **area under** a speed-time graph.

Example

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



Distance travelled = Area under graph

This graph can be split into two triangles and one rectangle. So,

Distance travelled = area under OA + area under AB + area under BC

Distance travelled = (½ x b x h) + (l x b) + (½ x b x h)

Distance travelled = (0.5 x 2 x 4) + (4 x 4) + (0.5 x 4 x 4)

Distance travelled = (4) + (16) + (8)

Distance travelled = 28 m

Acceleration

Acceleration is the change of speed of an object in one second.
If an object is getting faster, it is accelerating – the speed of the object is increasing.
If an object is getting slower, it is decelerating – the speed of the object is decreasing.

Acceleration and Car Performance

Car manufacturers often state a value of their car’s acceleration.to indicate its performance. The usual performance figure quoted is the time in seconds it takes the car to increase its speed from rest to 60 mph. The smaller the time, the higher the acceleration and the higher the performance.

The table below shows performance figures for some makes of car.

Make of Car	Increase in Speed	Time for Increase
Vauxhall	0 to 60 mph	10.5 seconds
Volvo	0 to 60 mph	9.6 seconds
Ford	0 to 60 mph	8.1 seconds
Jaguar	0 to 60 mph	6.1 seconds

Example

Which car has the greatest acceleration?
Explain your answer.

Answer

The car with the greatest acceleration is the Jaguar because it has the shortest time to make the same increase in speed as all the others.

Acceleration Calculations

Acceleration can be calculated using the following equation: -

acceleration = change in speed / time taken for change

This equation can also be written as shown below: -

$$a = \frac{\Delta v}{t}$$

This equation shows that the unit for acceleration will be the unit of speed (ms^{-1}) divided by the unit for time (s). This means the unit for acceleration is written as ms^{-2}. This unit is a short way of writing metres per second per second.

Example

A car accelerates from rest to a speed of 8 ms^{-1}. If this takes 3.2 seconds, what is the acceleration of the car?

acceleration = ? change in speed = 8 – 0 = 8 ms^{-1} time = 3.2 s

acceleration = change in speed / time taken for change
acceleration = 8 / 3.2
acceleration = 2.5 ms^{-2}

The equation for acceleration can also be written as: -

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

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

Example One

A car is moving at 15 ms^{-1}, before it accelerates tot 23 ms^{-1}. Calculate the acceleration of the car if the change in speed takes 4 s.

a = ?
v = 23 ms^{-1}
u = 15 ms^{-1}
t = 4 s

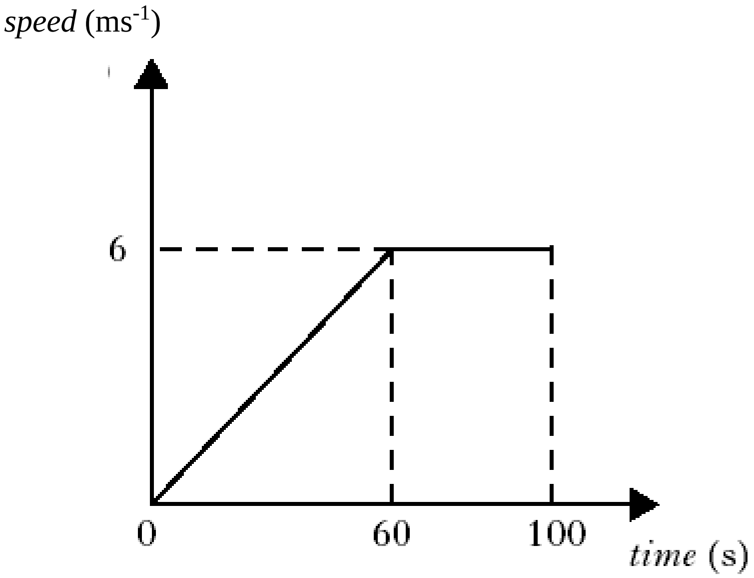
a = (v – u) / t
a = (23 – 15) / 4
a = (8) / 4
a = 2 ms^{-2}

Note

In examples where the final speed is smaller than the initial speed, 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.



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

a = (v – u) / t
a = (6 – 0) / 60
a = (6) / 60
$a = 0.1\ ms^{-1}$

NEWTON’S LAWS

Forces

Effect of forces

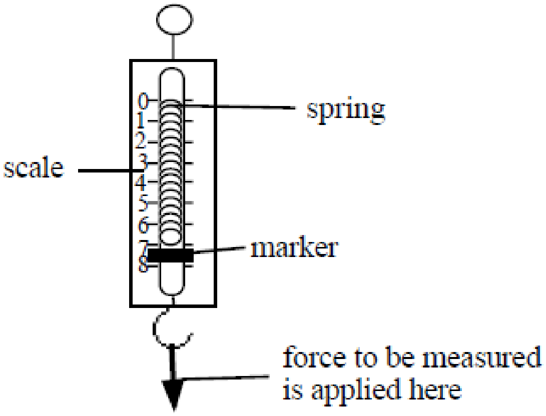
Forces can only be detected by their effects.

They can change:
- the shape of an object (stretch it, squeeze it etc)
- the speed of an object
- the direction of movement of an object

Measurement of Forces

Forces are measured in units called **Newtons (N).**

Forces can be measured with a **Newton balance**. This instrument depends on the effect of a force on the shape (length) of a spring.



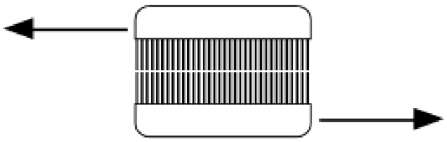
A Newton balance has a spring inside. The force to be measured is applied to the hook which is attached to the spring. The force causes the spring to stretch. The greater the force, the greater the stretch of the spring and the further the marker moves across the scale.

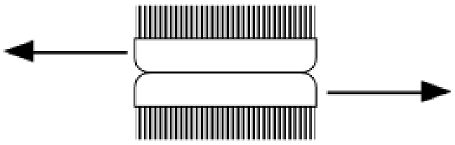
In this unit the names of some of the common forces covered are:

- Weight
- Friction
- Engine force
- Air resistance

Friction

Friction causes a force that opposes the motion of a body. The force of friction can stop a moving object or slow it down. The force of friction can also keep objects from starting to move. Friction is caused by the contact of two surfaces. If objects do not slide across each other easily, the force of friction between the surfaces of two objects is high. If objects slide easily, the force of friction is low.


High Friction


Low Friction

High friction – it is difficult to slide the bristles of two brushes across each other.

Low friction – it is not difficult to slide the back of two brushes across each other.

Changing Friction

The force of friction can be increased by making the surfaces rougher or by pressing the surfaces harder together e.g. the brakes on a bicycle.

The force of friction can be reduced by making the surfaces smoother or lifting the surfaces away from each other. Lubrication, for example, uses oil which lifts two surfaces apart and reduces the force of friction. Air can also be used to lift surfaces apart, e.g. a hovercraft or air hockey.

Changing Friction – Streamlining

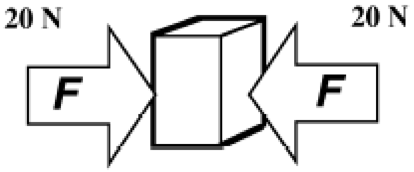
When an object moves through the air, the air ribs against the object causing friction. This air friction is called air resistance. Streamlining is when you change the shape of an object to reduce the air resistance.

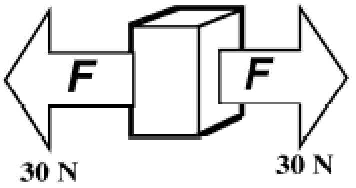
The shape of a vehicle can be made more curved, ideally like a teardrop or an aeroplane wing, to reduce air resistance. Sometimes a spoiler can be fitted to the back of a vehicle to make it more streamlined. Another way to reduce air resistance is to make the vehicle closer to the ground.

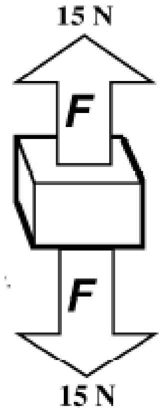
Newton’s First Law of Motion

When two forces are the same size as each other and act on the same object but in opposite directions, they balance each other. The forces are called **balanced forces.**

Examples of Balanced Forces





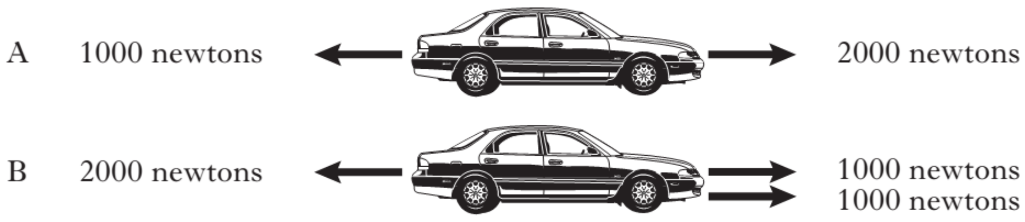


Newton’s first law of motion can be written as,

> “When forces on an object are balanced it will remain stationary or move with a constant speed (velocity).”

<u>Example</u>

Which car, A or B, will be moving to the right with a constant speed?



<u>Solution</u>

Car B – it has balanced forces (2000 N to the right and 2000 N to the left) acting on it.

Newton's Second Law of Motion

From research Newton was able to find the relationship between the variables **force (F), mass (m) and acceleration (a).**

He showed that...
… the **acceleration** of an object will **increase** when the **force** acting on it **increases.** (Assuming no change in mass.)
…the **acceleration** of an object will **decrease** when the **mass** of the object **increases**. (Assuming no change in force.)

This work helped to form his **Second Law of Motion**, which is normally written as the following equation:

$$F = ma$$

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

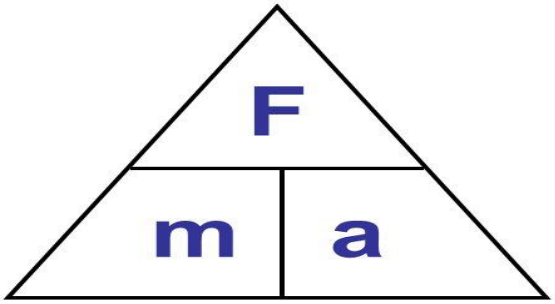
This equation can also be written as a triangle:

also:

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

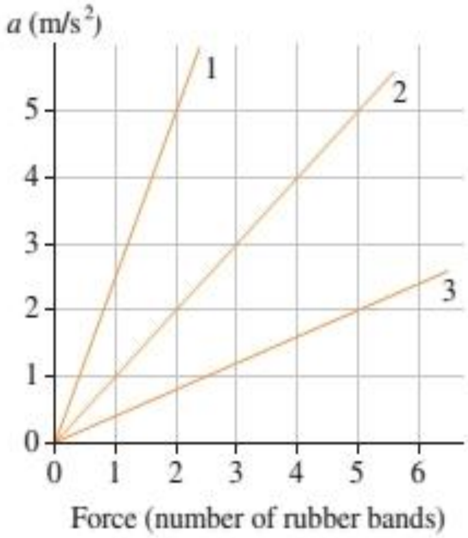
and:

$$\text{mass} = \frac{\text{force}}{\text{acceleration}}$$



Example One

An experiment to investigate newton's Second Law is carried out using three Physics trolleys and a set of rubber bands. The results of the investigation are shown in the following graph.



a) State the acceleration of the trolley 1, when 2 rubber bands are used in the experiment.
b) State the number of rubber bands needed to give trolley 2 an acceleration value of 4 m/s^2.
c) Which trolley had the greatest mass? Explain your answer.

Solution
a) 5 m/s^2
b) 4
c) Trolley 3 has the greatest mass, because it has the smallest values for acceleration.

Example Two

A car of mass 1000 kg has an unbalanced force of 1600 N acting on it. Calculate the acceleration of the car.

Solution
F = 1600 N
m = 1000 kg
a = ?

F = m x a
1600 = 1000 x a
a = 1600 / 1000
a = 1.6 ms^{-2}

Example Three

An unbalanced force acts on a mass of 5 kg, which makes it accelerate at 4 ms^{-2}. Calculate the unbalanced force acting on the mass.

$F = ?$
$m = 5$ kg
$a = 4$ ms^{-2}

$F = m \times a$
$F = 5 \times 4$
$F = 20$ N

WEIGHT

Mass measures how much matter there is in an object. Mass is measured in **kilograms**. The mass of an object stays the same at all places.

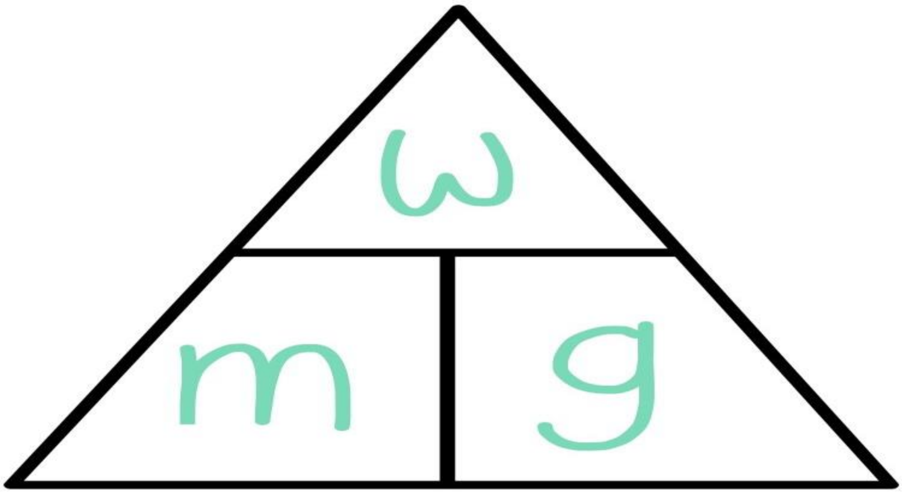
Weight is a force. The weight of an object always acts downwards. Weight is measured in **Newtons**. The weight of an object can change.

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 9.8 Newtons per kilogram (9.8 Nkg^{-1}) on planet Earth.

Weight = mass x gravity
$W = m \times g$

where,

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



TO HELP YOU REMEMBER:
WHERE'S MY GLASSES?

Example

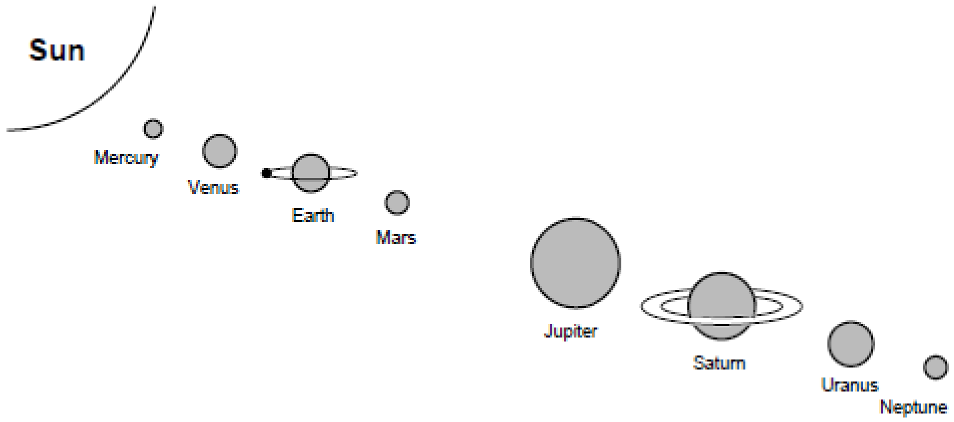
A pupil has a mass of 60 kg. Calculate their weight on planet Earth.

W = ?
$m = 60$ kg
$g = 9.8$ Nkg^{-1}

W = m x g
W = 60 x 9.8
W = 588 N

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 800 kg, takes off on its return flight from Venus. Calculate the following:

a) weight of probe when leaving Venus
b) mass of probe when it lands on planet Earth
c) weight of probe when it lands on planet Earth

Solution

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

b) 800 kg (mass does not change – assuming no parts fall off the probe!)

c)
W = m x g
W = 800 x 9.8
W = 7840 N

SPACE EXPLORATION and COSMOLOGY

Early history

The naked eye is used and observations were carried out to predict the future on Earth.

Ancient Greece

Planets were noted to behave differently from stars; observations still based on the Earth being at the centre of the Universe.

Ptolemy (2nd Century AD)

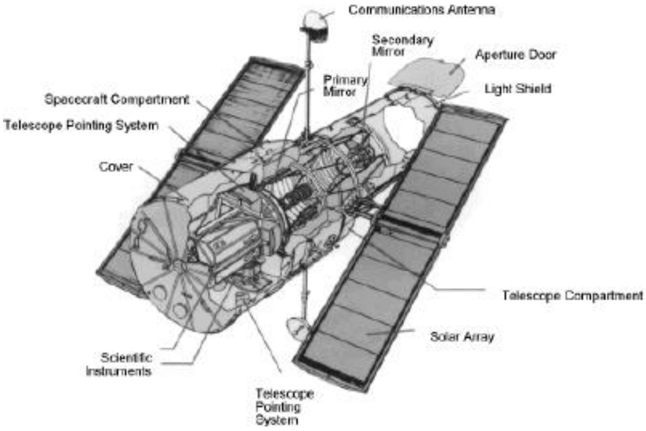
Accurate prediction about the speed and movement of the Sun, the moon and known planets are made; observations still based on the Earth being at the centre of the Universe.

Copernicus (1540AD)

Proposes the theory that the Sun is the centre of the known Universe.

From this point in history telescopes keep getting better and more accurate observations get made.

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.

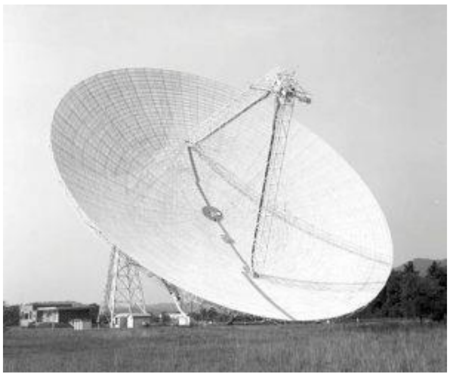


The Hubble Space Telescope (HST) is a reflecting telescope and is currently the largest space telescope there is. It is 43 feet long (13.1 meters) and weighs 24,250 pounds (11,000kg). Its reflector is 94.8 inches in diameter (240cm). The Hubble Space Telescope was launched into space on April 24, 1990, from the Space Shuttle Discovery. It is still operational. It has had some work performed on it from time to time, such as installing new state-of-the-art cameras. This wonderful telescope has brought a wealth of information to researchers here on Earth. It has taken numerous spectacular pictures of faraway galaxies, nebulae, a green space blob, beautiful dying stars (one that looks like a butterfly), and amazing infrared and ultraviolet pictures that show an incredible amount of detail. These pictures have allowed researchers to greatly expand our knowledge of the universe.

The HST is not the only telescope used by astronomers to explore space…

Radio

Radio telescopes detect noise from radio wavelengths in space. It turns out that objects in space give off radio noise. These telescopes are able to listen to all this noise and process it into information for researchers to study. A radio telescope can produce a picture from an object it is listening to from the noise is picks up from that object.



X-Ray

X-ray telescopes are used to study mainly the Sun, stars and supernovas. X-ray telescopes work better at very high altitudes on the Earth's surface, like on top of a very tall mountain where the atmosphere is thinner. They work even better in space. This is because the Earth's atmosphere interferes with the x-ray signals they receive.

Gamma Ray

Gamma ray telescopes are best used at high altitudes like the x-ray telescopes. This is also because gamma ray signals are disrupted and become weaker when they enter the Earth's atmosphere. Gamma ray telescopes detect bursts of gamma rays. They help astronomers confirm events in outer space like supernovas, pulsars and black holes.

Optical Telescopes

An optical telescope gathers and focuses light mainly from the visible part of the electromagnetic spectrum in order to directly view a magnified image for producing a photograph or collecting data via electronic image sensors.

The light gathering power of a telescope and its ability to resolve minute detail is directly related to the diameter of the objective lens. The larger the objective lens then a brighter image is obtained and it can resolve finer detail.

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

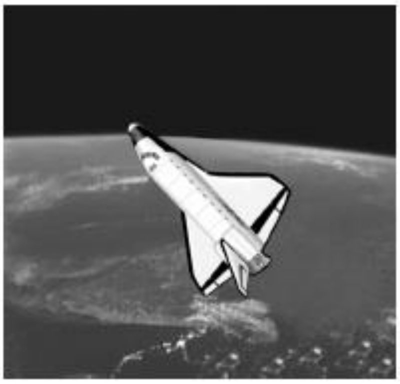
Space Travel

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 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 13.8 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.

Measurements in Space

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

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

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

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…

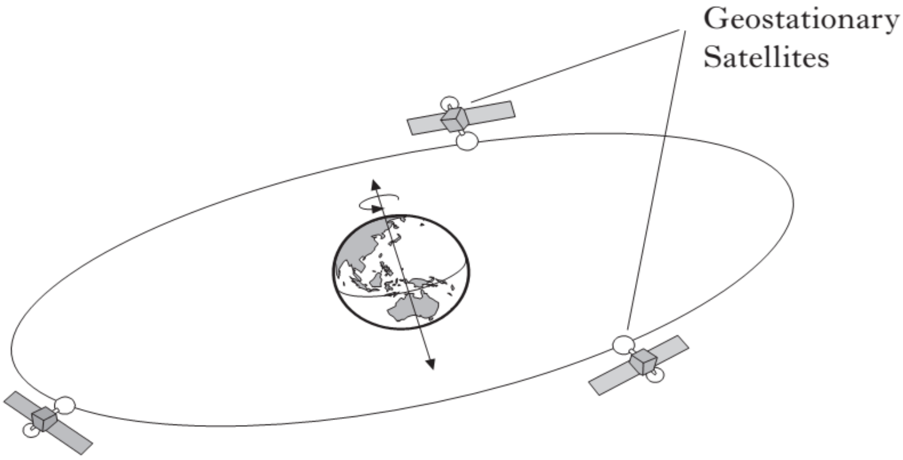
distance = speed x time
distance = (speed of light) x (number of seconds in a year)
distance = $(3 \times 10^8) \times (365 \times 24 \times 60 \times 60)$
distance = 9.46×10^{15} m

In other words, one light year = 9.46×10^{15} m

SATELLITES

Worldwide communication over a long distance can be difficult because of the curvature of the Earth. Newton realised that satellites could overcome this difficulty and developed a theory for satellite motion. It was this theory, along with advances technology, that put an artificial satellite into orbit outside Earth's atmosphere in the late 1950s.

When satellites are launched into space they are used for specific jobs. The higher a satellite is above the Earth, the longer is its **period** (the time it takes to make one revolution round the Earth). Communications satellites usually have higher orbits and longer orbital periods. But weather satellites usually have lower orbits and shorter orbital periods. Communications and weather satellites are amongst the most common uses of approximately 1000 satellites that are orbiting the Earth.



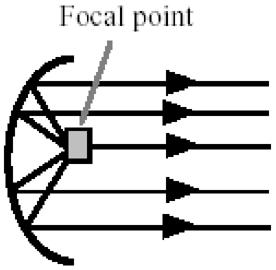
Communication satellites are a good example of **geo-stationary satellites**. This means they remain above a fixed point on the Earth's surface giving them an orbital period of **24 hours**. Most communication satellites are located **36000 km** above their fixed point on the earth's surface.

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.

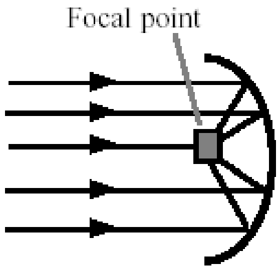
Item	Use
Aerials and Receivers	To send and receive signals (usually radio waves or microwaves) from the Earth or other satellites.
Solar Panels	To convert energy from the Sun into electricity.
Batteries	To store electrical energy that is generated by the solar panels.
On-board Processors	To allow the 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.

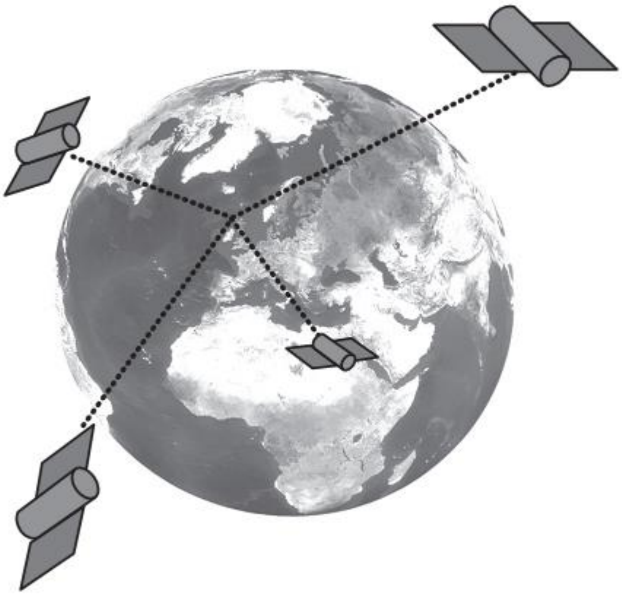
Global Positioning System (GPS) is another satellite based technology that is now in common use. This US government owned system uses 24 satellites to give complete worldwide coverage. Each GPS satellite continually broadcasts a navigation message consisting of two parts:

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.

Example

A satellite navigation system receives radio signals transmitted by satellites in orbit around the Earth.



The satellite navigation system finds its location by calculating the distance the transmitted signals travel. The average time travelled by a transmitted signal to travel is 0.118 s.

a) State the speed of radio waves.
b) Calculate the average distance travelled by a transmitted signal.

Solution

a) 300 000 000 metres per second

b)
speed = 300 000 000 metres per second
time = 0.118 s
distance = ?

distance = speed x time
distance = 300 000 000 x 0.118
distance = 35 400 000 m

The following table gives some up to date space definitions.

Term	Definition
Planet	A large object (like Earth) moving in an orbit round a star (like the Sun)
Star	A very large, hot luminous object in space.
Sun	The star at the centre of our Solar System
Solar System	A star and all the planets that orbit it
Galaxy	A system of billions of stars with gas and dust held together by gravitational attraction.
Universe	A collection of galaxies.
Habitable Zone	An area at the correct distance from a star for liquid water to exist.
Astronomical Unit	The standard unit for measuring distance within our Solar System.
Light Year	The distance light travels in one year.
Moon	A natural satellite of a planet
Satellite	A small object which orbits a larger object (like the moon orbits the Earth)
Exoplanet	A planet that is outside our Solar System.
The Big Bang	A possible theory to explain the beginning of the Universe

Relationships required for Unit Test:

distance = speed x time

d = v x t

acceleration = change in speed ÷ time

$$a = \frac{\Delta v}{t}$$

Force = mass x acceleration

F = m x a

Weight = mass x gravitational field strength

W = m x g