The Solar System

Modelling the Solar System
A GET Senior Phase Module

1 Starters

1.1 Background

Many people living thousands of years ago in what is now the Middle East, India and China were keen observers of the night sky and recorded their observations. These early astronomers had no telescopes or other instruments to help them find the position of these points of light or stars: they merely looked at where they were relative to each other. They certainly didn't know what these points of light were and assigned mythical creatures and gods to various groups. Today we call these groups of stars constellations. They studied the night sky for many years and found that:

- the Moon moved across the sky at a different speed to the stars,
- nearly all the stars they saw in the night sky did not move relative to each other,
- they also noticed that a different pattern of stars became visible after sunset in the course of a year, but that the same pattern repeated itself year after year,
- five of the stars moved at a different speed to the rest of the stars, and the Greek astronomers called these the *"planetes"* or the wanderers.

If you looked at the night sky just for a few days, you would immediately see that the Moon moves quite a lot each night compared to the background stars which stayed in the same position relative to each other.

If you looked in the east after Sun had set in the west you would see stars in the sky. They might well form a pattern. If you looked at the same part of the sky at the same time of day a month or so later, you would see a different group or pattern of stars. But the same group or pattern would appear year after year at the same time. It is this repetitive cycle that gives us our year.

1.2 The Planets

There were also five 'stars' that moved differently to the background stars and these are what we now know to be five of the eight planets in orbit around the Sun. These five planets are:

Mercury, Venus, Mars, Jupiter and Saturn,

The planets beyond the orbit of Saturn are so far away that they can only be seen with the help of a telescope and so the above five planets are often called the "naked eye" planets, meaning that they can be seen with the unaided eye. The last two planets were discovered with the aid of a telescope

- Uranus was discovered by Sir William Herschel in 1781,
- Neptune was discovered in 1846 by Verrier and d'Arrest,

Recently several other large objects that could be called planets have been discovered in an area called the "Kuiper Belt" see later notes. The objects are: Sedna and Quaoar. Another, popularly called the tenth planet has to be named. It is best to contact the observatory or look at the Internet to find out the most recent discoveries.

Glossary Box

Orbit

The path of one celestial body around another. This could be:

1 The Earth, or another planet, around the Sun,
2 The Moon around the Earth
3 A comet around the Sun,
4 A satellite around the Earth.

1.3 The Number 7

Careful observation has shown that there are five planets visible to the naked eye and these observations also showed that the Moon and Sun also move at a different rate across the sky. The ancient observers knew then that there were seven objects that moved differently to the stars. Many religions and faiths have the number seven occurring frequently in their writings. Today there are seven days in a week, and it is possible that this is because of these seven objects that moved differently to the stars. For magicians, fortune tellers and mystics the number seven had special and significant properties. When asked to choose a number between 1 and 10, many people will choose either three or seven,.

1.4 Drawing Ellipses

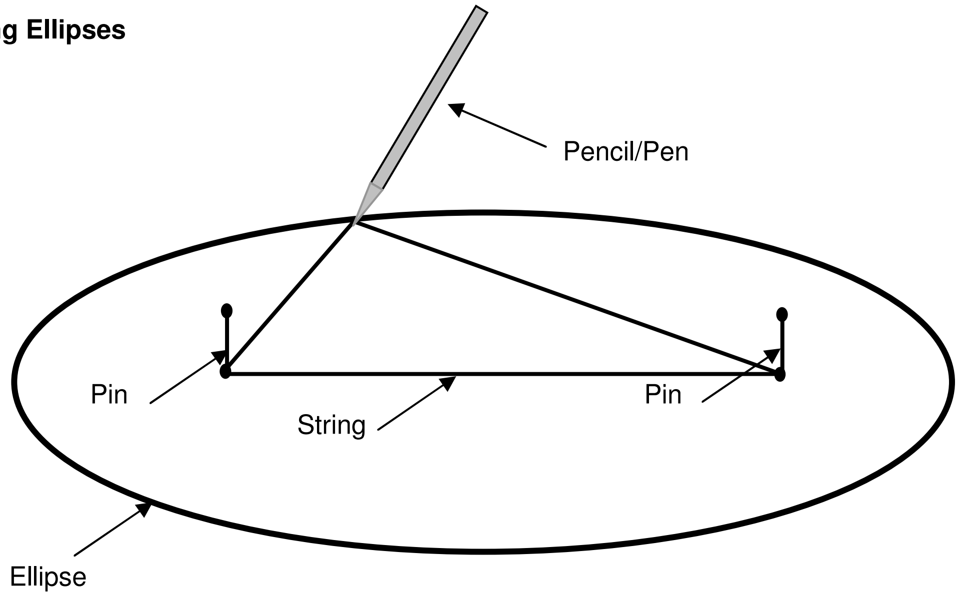


Fig. 1

Put a piece of paper onto some soft board or wood and then stick two pins through the paper and into the board. Take a piece of string, tie it so that it makes a loop and put the loop around the pins. Now take a pencil, put the point into the loop and move the pencil so that the loop is taught. Move the pencil carefully, keeping the string taught and the pencil will now draw an ellipse on the paper.

Experiment by moving the pins closer together and further apart and change the size of the loop.

You should find that, with the same loop, the closer the pins are together, the more “round” or “circular” the ellipse becomes.

Keeping the pins fixed but changing the size of the loop you should find that the larger (longer the loop) the “rounder” the ellipse becomes.

If the pins are right next to each other (better still use one pin) by moving the pencil it will draw out a circle.

1.5 Some interesting facts about circles and ellipses

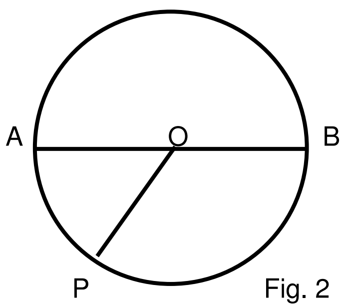


Fig. 2

Circle

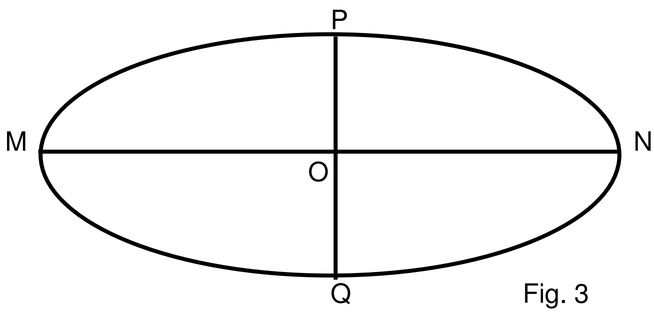


Fig. 3

Ellipse

Diameter	AB = D or d
Radius	OP = R or r
Circumference	$2\pi R$, $2\pi r$, πD or πd*
Area	πR^2 or πr^2

* Since D = 2R and d = 2r

Semi-major axis	MO or ON = a
Semi-minor axis	PO or OQ = b
Circumference	$2\pi\sqrt{½ (a^2 + b^2)}$ **
Area	πab

** This is only approximate.

You should notice that if your ellipse was such that the semi-major axis and the semi-minor axis are the same,

$$\text{ie. } a = b$$

that the circumference and the area become the same as those of a circle – which is of course what you would expect!

1.6 Planetary Orbits

It was believed, as early as 600 BCE, that the Earth was the centre of, not only the solar system, but the Universe. This was known as the Geocentric or the Ptolemaic system, after Claudius Ptolemeus of Alexandria (127 – 145 CE) more commonly known as Ptolemy (pronounced tol-le-mee). In order to explain the motions of the planets he believed they moved in circles around the Earth and developed a complex system of *epicycles*, to predict the positions of the planets.

A Greek mathematician and astronomer, Aristarchus (~ 270 BCE) believed the Sun was at the centre of the solar system, but this idea was rejected by Hipparchus (~127BCE), probably the greatest astronomer of antiquity, and for over a 1000 years the system developed by Ptolemy, using the data of Hipparchus, was believed to be correct.

But the Polish astronomer Nicolaus Copernicus (1473 – 1543) used mathematics to revive the model created by Aristarchus and he showed that the Sun was at the centre of the solar system and that Earth moved around the Sun: the heliocentric model.

Glossary Box

Geocentric – Earth centred

Heliocentric – Sun centred

Orbit – the path followed by a smaller body around a larger one. For example a planet around the Sun, or the Moon around the Earth.

Note. This is not the same as the movement of an electron around the nucleus of an atom. That is known as an ***orbital***

The Danish astronomer Tycho Brahe (1546 – 1601) spent most of his life Observing from an observatory, specially built for him on the island of Hven, 32 km northeast of Copenhagen. The last two years of his life were spent in Prague where he worked briefly in Prague with the Polish astronomer Johannes Kepler (1571 – 1630). The two disagreed strongly on whether Nicolaus Copernicus (1473 – 1543) was right in thinking that the Sun was the centre of the solar system. Brahe firmly believed the Earth to be at the centre of the solar system whilst Kepler firmly believed Copernicus to be right.

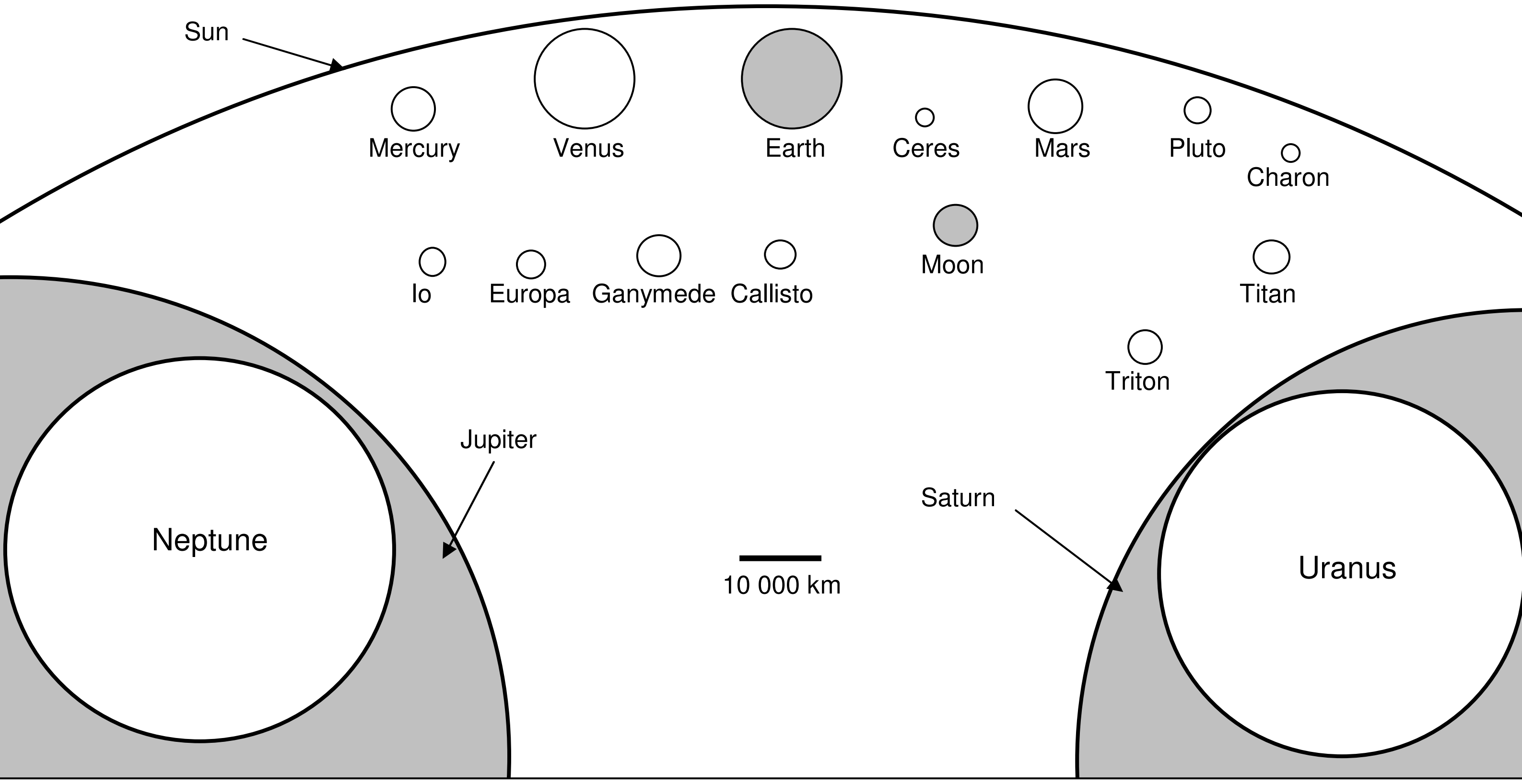
After Brahe died Kepler inherited all Brahe's observational data and he used this to show that the orbit of Mars was an ellipse rather than a circle around the Sun. However the difference between the orbit being an ellipse rather than a circle is extremely small and difficult to calculate.

We normally draw the orbits of the planets much like the ellipse in Fig. 3 above, but in fact the difference is only a few percent – hardly noticeable in a drawing of this size. Such exaggerations often lead to misconceptions, such as what causes the seasons, (see module on Seasons). The only planet that has a noticeable elliptical orbit is that of Pluto and most of the more recently discovered objects in orbit around the Sun, (see below).

2 Planetary Data Sheet

	Diameter (in km)	Mass (kg)	Surface Gravity ($m.s^{-2}$)	Number of Moons	Distance from Sun (km)	Length of Year (Earth = 1)	Length of Day (Earth = 1)	Surface Temp. (^oC)	Atmosphere
Mercury	4 878	3.18×10^{22}	3.8	0	5.79×10^{10}	0.241	58.65	427	none
Venus	12 104	4.88×10^{24}	9.1	0	1.08×10^{11}	0.615	243.01	482	CO_2
Earth	12 750	5.98×10^{24}	9.8	1	1.50×10^{11}	1	1	15	N_2, O_2
Mars	6 787	6.42×10^{23}	3.8	2	2.28×10^{11}	1.881	1.029	- 63	CO_2
Jupiter	142 800	1.90×10^{27}	25.4	60+	7.78×10^{11}	11.862	0.411	- 153	H_2, He
Saturn	120 660	5.68×10^{26}	10.8	40+	1.43×10^{12}	29.458	0.428	- 185	H_2, He
Uranus	51 118	8.68×10^{25}	9.1	15+	2.87×10^{12}	84.01	0.748	- 197	H_2, He
Neptune	49 528	1.03×10^{26}	11.9	8	4.50×10^{12}	164.79	0.802	- 225	H_2, He

3 Comparative Sizes of the Sun and Planets



The above sketch shows the approximate relative sizes of the planets and some of their larger moons. The small strip in the lower centre represents a distance of 10 000 km.

The Sun is so large that only a small arc can be shown on a diagram this size. Ceres is the largest asteroid in the Asteroid Belt, a ‘belt’ of rocks and dust in orbit around the Sun between Mars and Jupiter.

Additional Data for some of the larger moons in the Solar System

	Host Planet	**Diameter (km)**	**Mass (kg)**	**Distance* from host Planet**	**Atmosphere**
Moon	Earth	3 476	7.35×10^{22}	384 400	none
Io	Jupiter	3 630		421 600	Sulphur Dioxide
Europa	Jupiter	3 140		670 900	None
Ganymede	Jupiter	5 260		1 070 000	None
Callisto	Jupiter	4 800		1 883 000	None
Titan	Saturn	5 150		1 221 850	Nitrogen
Triton	Neptune	2 700		354 800	Nitrogen, Methane

* Average distance from the planet.

Solar Data.

Mass	2×10^{30} kg
Diameter	1.4×10^{8} km
Surface Temp.	5 800 ^{o}C
Core Temp.	1.5×10^{7} ^{o}C

4 Modelling the Solar System

This is a popular activity and clearly illustrates how small the planets are when compared to how far they are away from each other. Usually only the first few planets can be demonstrated within any school ground, but it does very quickly convey the idea. There are several ways to model this, ranging from sophisticated physical models that can be put on permanent display to simple paper and card ones to be used on a school open day for example. See below.

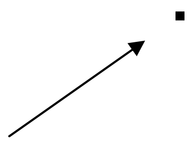
Object	Size (mm)	Distance (m)	Use to Model
Sun	300	0	Soccer ball
Mercury	1	12	Pinhead/bead
Venus	2.5	22	Bead, B/bearing
Earth	2.5	30	Bead, B/bearing
Moon	0.25	0.08	Pinprick!
Mars	1.5	46	Bead, B/bearing
Jupiter	30	156	Large marble
Saturn	25	286	Large marble
Uranus	10	574	Marble
Neptune	10	900	Marble

These are approximate and rounded figures that can be used. Obviously they can be scaled up or down to suit the available space. Pluto (no longer a planet) is a problem since its orbit is extremely elliptical and sometime is inside that of Neptune. However as it is unlikely that any school, will ever be able to get that far it doesn't really matter too much, but certainly anything from 900m to 1 500m is fine.

What can be done very successfully is to use printed A4 sheets with the planet's name on it with a dot representing the planet to scale. Any other information can be added. The sheet can then be placed on a piece of stiff card which in turn is stuck on a stick. The stick is then placed at the appropriate distance.

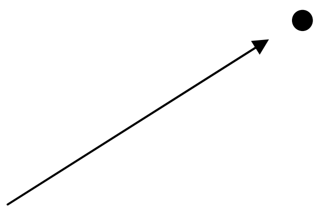
The Earth and the Moon can be put onto one sheet, see below.

Mercury



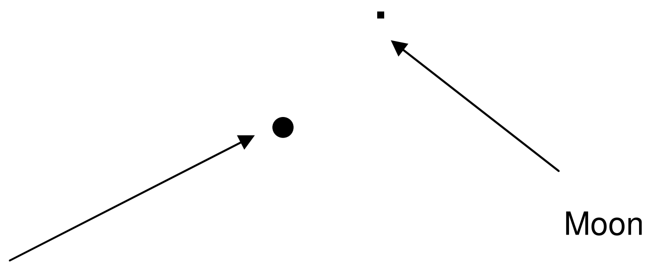
Distance from Sun	**60 million km**
Diameter	**4 878 km**
Mass	**0.06 Earth Masses**
Moons	**None**
Surface temperature	**450 ^{o}C to -150 ^{o}C**
Atmosphere	**None**

Venus



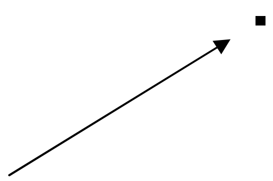
Distance from Sun	108 million km
Diameter	12 104 km
Mass	0.8 Earth Masses
Moons	None
Surface temperature	450 ^{o}C
Atmosphere	Carbon Dioxide, 90 x as dense as Earth's with Clouds of Sulfuric Acid

Earth



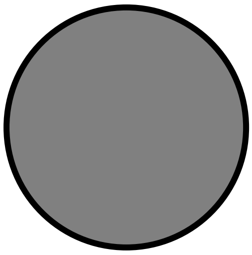
Distance from Sun	**150 million km**
Diameter	**12 750 km**
Mass	**1 Earth Mass**
Moons	**One**
Surface temperature	**50 ^{o}C to - 50 ^{o}C**
Atmosphere	**Oxygen (20%) and Nitrogen (78%)**

Mars



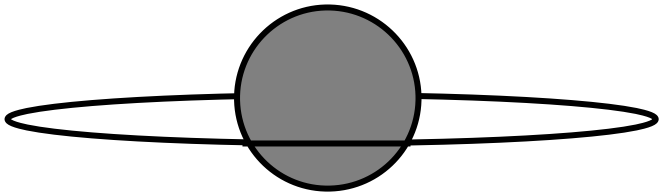
Distance from Sun	240 million km
Diameter	6 787 km
Mass	0.1 Earth Masses
Moons	Two, very small: Deimos and Phobos
Surface temperature	15 ^oC to -150 ^oC
Atmosphere	Carbon Dioxide 1/100th that of Earth's

Jupiter



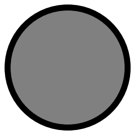
Distance from Sun	**800 million km**
Diameter	**142 800 km**
Mass	**318 Earth Masses**
Moons	**4 large (Moon size) known as the Gaelilean moons: Io, Europa, Ganymede and Callisto. There 60+ smaller ones.**
Surface temperature	**-153 ^{o}C**
Atmosphere	**Hydrogen, Helium and Methane**

Saturn



Distance from Sun	**1 400 million km**
Diameter	**120 660 km** **270 000 km for the rings**
Mass	**95 Earth Masses**
Moons	**One large moon, Titan, and 50+ smaller ones.**
Surface temperature	**-180 ^{o}C**
Atmosphere	**Hydrogen and Helium**

Uranus



Distance from Sun 3 000 million km

Diameter 51 118 km

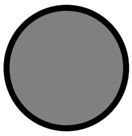
Mass 14.5 Earth Masses

Moons A few large ones and many smaller ones

Surface temperature -197 ^{o}C

Atmosphere Hydrogen, Helium and Methane

Neptune



Distance from Sun	**4 500 million km**
Diameter	**49 528 km**
Mass	**17 Earth Masses**
Moons	**One large, Miranda, and several smaller ones**
Surface temperature	**-225 ^{o}C**
Atmosphere	**Hydrogen and Helium**