Astronomy

Introduction

This topic explores the key concepts of astronomy as they relate to:

- the celestial coordinate system
- the appearance of the sky
- the calendar and time
- the solar system and beyond
- space exploration
- gravity and flight.

Key concepts of astronomy

The activities in this topic are designed to explore the following key concepts:

Earth

- Earth is spherical.
- ‘Down’ refers to the centre of Earth (in relation to gravity).

Day and night

- Light comes from the Sun.
- Day and night are caused by Earth turning on its axis. (Note that ‘day’ can refer to a 24-hour time period or the period of daylight; the reference being used should be made explicit to students.)
- At any one time half of Earth’s shape is in sunlight (day) and half in darkness (night).

The changing year

- Earth revolves around the Sun every year.
- Earth’s axis is tilted 23.5° from the perpendicular to the plane of the orbit of Earth around the Sun; Earth’s tilt is always in the same direction.
- As Earth revolves around the Sun, its orientation in relation to the Sun changes because of its tilt.
- The seasons are caused by the changing angle of the Sun’s rays on Earth’s surface at different times during the year (due to Earth revolving around the Sun).

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Earth, the Moon and the Sun

- Earth, the Moon and the Sun are part of the solar system, with the Sun at the centre.
- Earth orbits the Sun once every year.
- The Moon orbits Earth in one lunar month (about twenty-eight days). The Moon is Earth's only natural satellite.
- The Moon turns on its axis at a rate that means we always see the same face.
- The Moon orbits Earth at an angle to the plane in which Earth and the Sun are located.

The phases of the Moon and eclipses

- The Moon is visible because it reflects light from the Sun.
- The Sun always illuminates half of the Moon's sphere.
- The Moon appears to change shape each month (its phases) because we see different amounts of the illuminated surfaces of the Moon at different times each month due to the relationship between the positions of Earth, the Sun and the Moon at a particular time.
- The phases of the Moon occur in a regular pattern.
- Eclipses occur in two ways: when Earth lies between the Sun and the Moon causing a shadow—full or partial—over the Moon (that is, a full or partial eclipse), or when the Moon lies between Earth and the Sun and casts a shadow—full or partial—over part of Earth (that is, a full or partial solar eclipse). These occur regularly.

The solar system and stars

- Stars emit light. The Sun is a star. The Sun emits light.
- The Sun is the centre of the solar system and is the only body in the solar system that emits light.
- The Sun is the solar system's main source of energy.
- The planets orbit the Sun. Some planets, other than Earth, have their own moons (natural satellites).
- The planets are great distances from Earth, but relatively much closer than the stars, apart from the Sun.

The universe

- The solar system is only a small component of one particular galaxy, the Milky Way, which is made up of millions of stars.
- Even the nearest stars (apart from the Sun) are gigantic distances away compared to the planets.
- The universe (which is everything that exists) comprises countless galaxies. Our galaxy, the Milky Way, is not the centre of the universe.

Students' alternative conceptions of astronomy

Research into students' ideas about this topic has identified the following non-scientific conceptions:

The seasons

- The seasons are caused by the elliptical orbit of Earth. When Earth is closest to the Sun it is summer.
- Summer occurs when Earth is tilted towards the Sun and is therefore closer to it.

The Moon

- The Moon is not in free fall.
- The Moon gives off its own light.
- Earth blocks the Sun's light, casting a shadow on the Moon.
- The different shadow effects are due to Earth's tilt, its rotation or its revolution around the Sun.
- The amount of light reflected off Earth onto the Moon causes the changed shapes.
- The side of the Moon reflecting the Sun's light affects the shapes.

Gravity

- The force that acts on an apple is not the same as that acting on the Moon.
- The gravitational force is the same on all falling objects.
- There are no gravitational forces in space.
- The gravitational force on a space shuttle is nearly zero.
- The gravitational force acts on one mass at a time.
- The Moon stays in orbit because the gravitational force on it is balanced by the centrifugal force.
- There is no gravity in a vacuum.
- Earth's spinning motion causes gravity.
- Gravity only acts on things that are falling.
- Free-falling objects can only move downwards.

Comets

- Comets' tails are created as comets burn up passing through Earth's atmosphere.
- Comets only appear to have long, fiery tails; this is due to their speed and/or that they are really ball-shaped.
- Comets are made up of gases and/or dust (these gases are stated or implied to be burning).

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Space travel

- Spacecraft travel in straight lines from one planet to another.
- Spacecraft can be launched any time to travel from one planet to another.
- Spacecraft are not affected by the Sun.
- Jets can fly in space.
- Weightlessness means there is no gravity.
- Rockets need something (like air) to push against.

Stars and outer space

- Stars reflect light from the Sun.
- Stars are planets.
- Stars seem to have points because they are a long distance from us.
- The composition of stars explains the points, for example, burning balls of hydrogen whose flames appear as points.
- Space is not something.
- Black holes are big.
- Light always travels in straight lines.
- Things in space make sounds.
- If the Sun were to become a black hole, Earth would get sucked into it.

Tides

- Tides are caused by the Moon orbiting Earth every twenty-four hours.
- There is only one high and one low tide each day.
- The elliptical orbit of the Moon around Earth causes the tides; when the Moon is closer to Earth, it is high tide.
- High tides occur when the Moon is visible (maybe only at night).
- High tide occurs on the opposite side of Earth to the low tide.
- The Sun has no effect on the tides.

The planets

- The morning and evening star is not equated with the planet Venus, but is believed to be a star.
- Planets give out their own light.
- The planets contain dust and rocks and a gaseous atmosphere and water.
- The planets are all similar in structure to Earth.
- Planets’ orbits are circular.
- All the planets revolve about the Sun, taking the same period of time.
- Revolution is the same as rotation.

Resources

Many of the following websites contain curriculum materials to use in the classroom. They are in no particular order, so as you begin 'surfing' these sites, make detailed notes of their relevance to you, particularly if you are looking for curriculum materials.

Amazing space

http://amazing-space.stsci.edu/
A collection of K–12 Web-based interactive astronomy lessons complete with student activities and teacher guides. There are several different units, with topics on black holes, galaxies, stars, the solar system, telescopes and the Hubble Space Telescope.

Ask an astronaut

http://www.starport.com/
One can ask a real astronaut about life as an astronaut or about aspects of the space program.

Athena: Earth and space science for K–12

http://www.athena.ivv.nasa.gov/
This contains Instructional Material for use by students and teachers in the classroom. Major scientific topics include oceans, Earth resources, weather, space.

Centre for Science Education

http://cse.ssl.berkeley.edu/
This includes lesson plans, bulletin boards and interactive learning units from the University of California's Berkeley Space Sciences Centre.

Exploratorium

http://www.exploratorium.edu/learning_studio/cool/astronomy.html
This site contains ten 'cool' astronomy sites for children interested in astronomy.

Exploring planets in the classroom

http://www.soest.hawaii.edu/SPACEGRANT/class_acts/index.html
This site offers hands-on activities, ideas and resources for activities in the study of astronomy, some online.

NASA kids site for stars

http://kids.msfc.nasa.gov/Space/Stars/

NASA spacelink

http://spacelink.nasa.gov/.index.html
This site links to NASA's online educational materials about astronomy and space technology.

NASA's learning technologies project

http://learn.ivv.nasa.gov/

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NASMA, the national air and space museum

http://www.nasma.com/

Planetarium

http://www.mov.vic.gov.au/planetarium/index.html
Now part of Scienceworks, the new Planetarium's online site has lots of useful information about the solar system and what you will see in the skies over Melbourne this month.

Practical astronomy in schools

http://www.eia.brad.ac.uk/rti/nuffield/
This site explores practical astronomy in schools with the Bradford Robotic Telescope.

Space and astronomy

http://athena.wednet.edu/curric/space/index.html
This site offers instructional material and lessons about the planetary system, the Sun, space, physics and some background material, with plenty of images and teacher discussion guides.

Star child

http:/starchild.gsfc.nasa.gov/docs/StarChild/
Learn about space from this site for young astronomers from NASA, including information about astronauts and the solar system, and a glossary.

Star stuff

http://www.starstuff.com/
This large site is suitable for junior primary children and beyond. Topics include astronomy, solar system, planets and telescopes.

Windows to the universe

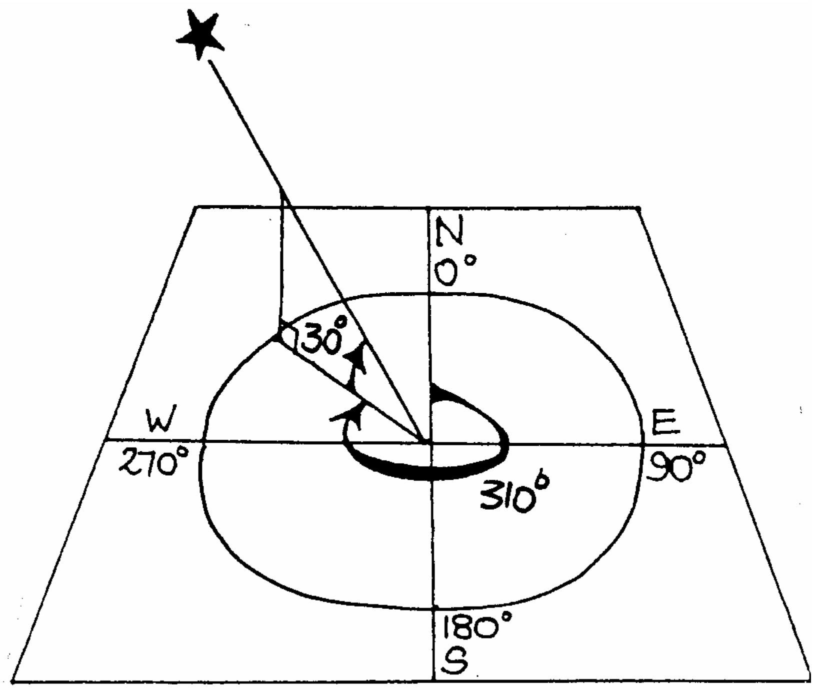
http://www.windows.ucar.edu/
This site explores Earth and space sciences at intermediate and advanced levels. Topics include astronomy, solar system, planets, asteroids and comets.

The celestial coordinate system

To locate and describe objects that we see in the sky, we need to refer to their position in the sky with some reference system. For objects on Earth, we use a geographical or terrestrial coordinate system that incorporates longitude and latitude coordinates.

For objects in the sky, we can use a local coordinate system that uses altitude and azimuth. Altitude is the angular measure from the horizon to the object in the sky. If you can imagine a line drawn from the object in the sky directly down to a point on the horizon, the azimuth is the clockwise angle from due north to this point. An example is given in Figure 1.

FIGURE 1: LOCAL COORDINATE SYSTEM OF A STAR WITH ALTITUDE 30˚ AND AZIMUTH 310˚



The local coordinate system can only be interpreted when the position of the observer is known. It is therefore not as effective as another coordinate system, called the ‘celestial coordinate system’, that is independent of the observer. The celestial coordinate system has a number of similarities to the terrestrial coordinate system.

ACTIVITY: A VIEW OF THE WORLD FROM YOUR LOCATION

Determine the longitude and latitude of your town by referencing an atlas or, better still, access this information through the website <http://life.csu.edu.au/geo/vicfind.html>.

This site gives the longitude and latitude of any town in Victoria. For example, Melbourne has longitude 144.96˚ east and latitude –37.82˚ (the negative sign denotes a southern latitude).

The website ‘Earth and Moon Viewer’ <http://www.fourmilab.ch/earthview/vplanet.html> features a satellite view of Earth specified by latitude, longitude and altitude or above various cities around the globe. Access this site and view your town from different altitudes.

This site offers a lot more, as the following descriptions (from the website) provide:

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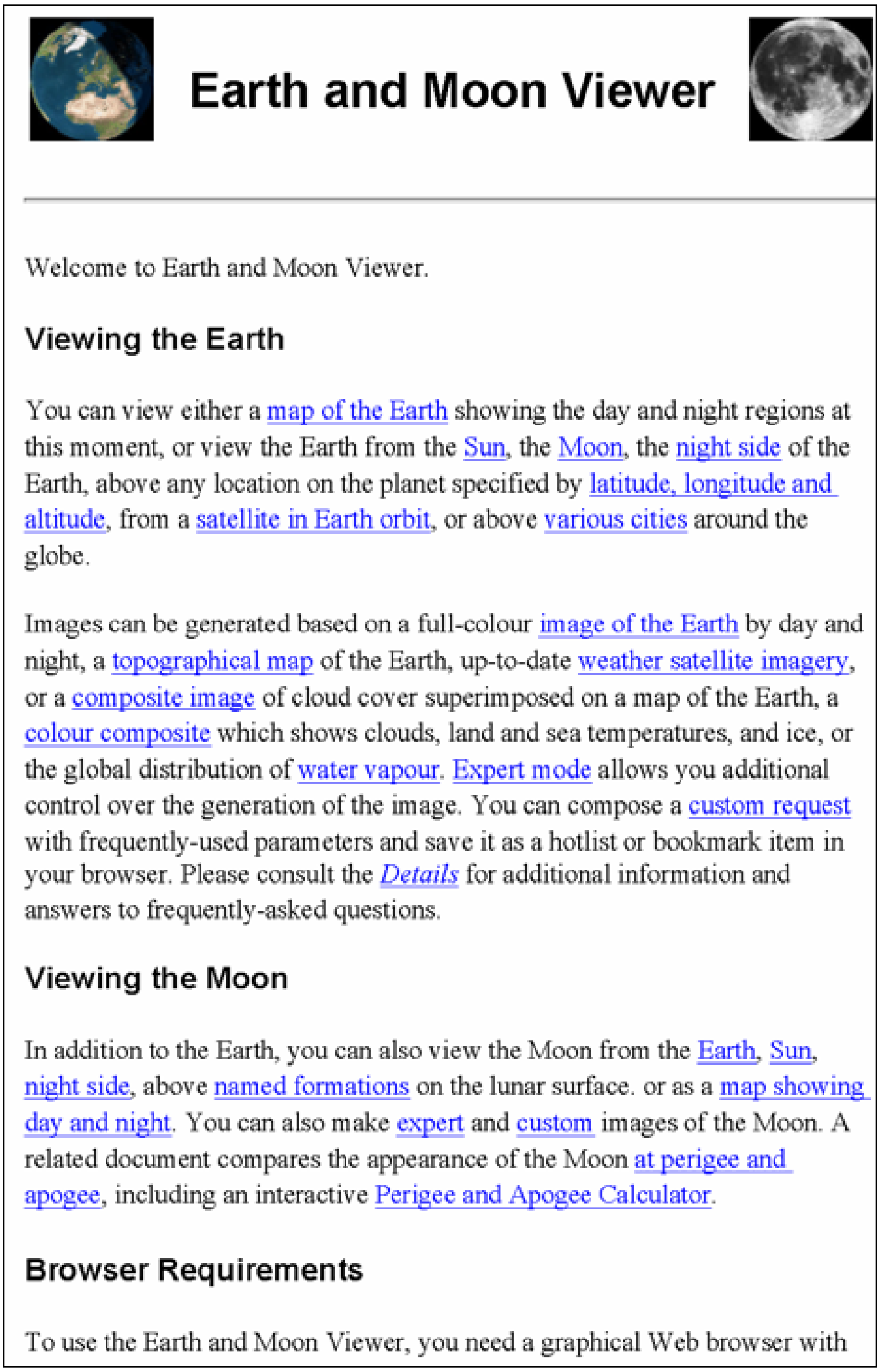
FIGURE: EARTH AND MOON VIEWER



Earth and Moon Viewer

Welcome to Earth and Moon Viewer.

Viewing the Earth

You can view either a map of the Earth showing the day and night regions at this moment, or view the Earth from the Sun, the Moon, the night side of the Earth, above any location on the planet specified by latitude, longitude and altitude, from a satellite in Earth orbit, or above various cities around the globe.

Images can be generated based on a full-colour image of the Earth by day and night, a topographical map of the Earth, up-to-date weather satellite imagery, or a composite image of cloud cover superimposed on a map of the Earth, a colour composite which shows clouds, land and sea temperatures, and ice, or the global distribution of water vapour. Expert mode allows you additional control over the generation of the image. You can compose a custom request with frequently-used parameters and save it as a hotlist or bookmark item in your browser. Please consult the *Details* for additional information and answers to frequently-asked questions.

Viewing the Moon

In addition to the Earth, you can also view the Moon from the Earth, Sun, night side, above named formations on the lunar surface. or as a map showing day and night. You can also make expert and custom images of the Moon. A related document compares the appearance of the Moon at perigee and apogee, including an interactive Perigee and Apogee Calculator.

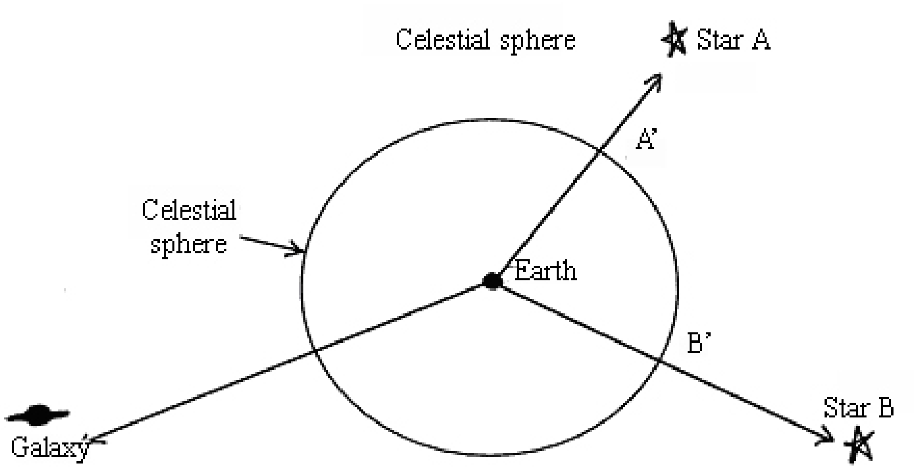
Browser Requirements

To use the Earth and Moon Viewer, you need a graphical Web browser with

Celestial sphere

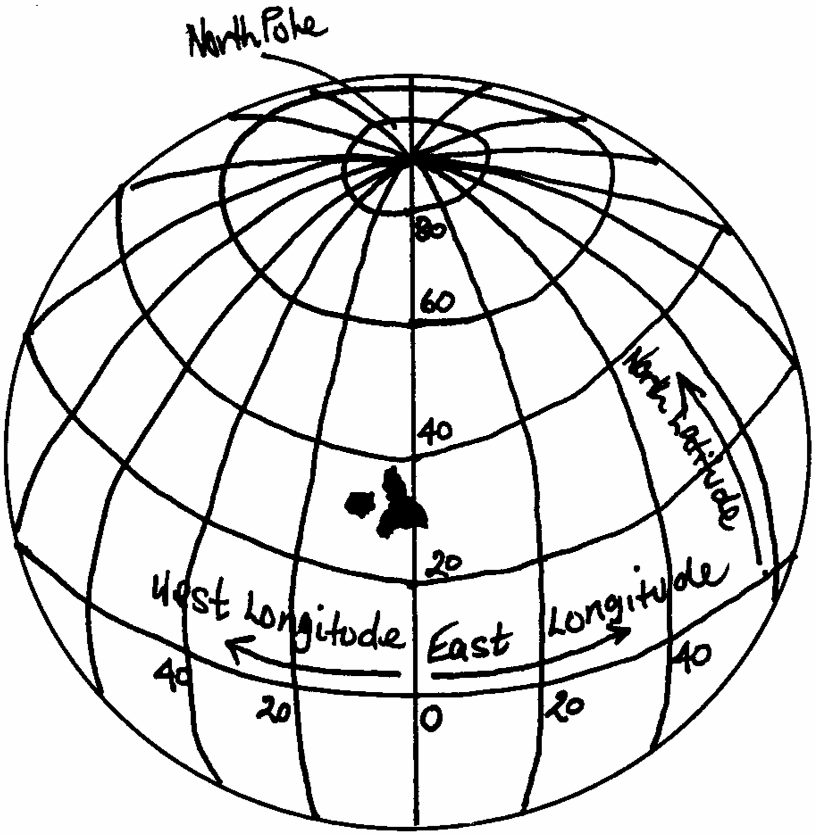
Imagine a huge sphere centred on Earth with a radius much larger than the dimensions of our solar system. We can imagine the Sun, Moon, planets and stars being fixed on this sphere so that from an observational point of view all stellar objects are the same distance from Earth. We call this sphere the celestial sphere. In Figure 2, stars A and B are projected onto the celestial sphere as points A’ and B’. The angular separation of A and B is unchanged by this projection. This is good, as we only consider the relative positions of stellar objects in terms of angles.

FIGURE 2: CELESTIAL SPHERE



Astronomers and geographers share the need to set up coordinate systems to designate the positions of places in the sky or on Earth. The geographer's system uses longitude and latitude. Lines (actually half-circles) of longitude, called 'meridians', run from the North Pole to the South Pole. The meridian that defines the zero longitude runs through the former site of the Royal Greenwich Observatory in England. The longitude of an object is then the number of degrees (up to 180˚) east or west from the meridian that passes through Greenwich. Latitudes are parallel circles that run around Earth, all parallel to the equator. Zero degrees of latitude correspond to places on the equator. Northern latitudes can range from 0˚ (equator) to 90˚ (North Pole), whereas southern latitudes range from 0˚ (equator) to 90˚ (South Pole). See Figure 3.

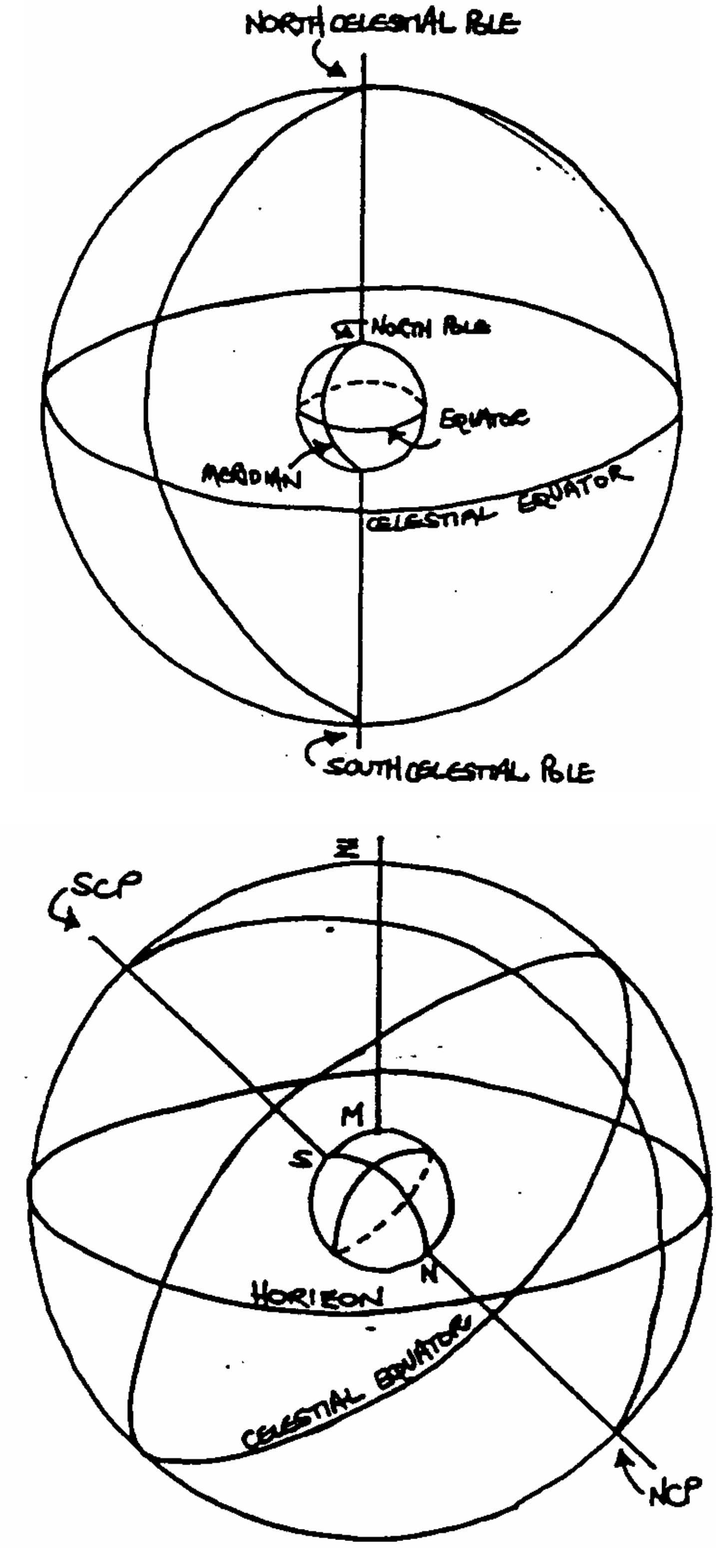
FIGURE 3: EARTH'S TERRESTRIAL COORDINATE SYSTEM



If we take Earth's terrestrial coordinate system consisting of North and South Poles, equator and lines of longitude and latitude onto the celestial sphere, then we have made a celestial coordinate system.

The projection of Earth's North and South Poles onto the celestial sphere gives the celestial poles. The projection of Earth's equator onto the celestial sphere gives the celestial equator. Both coordinate systems are shown in Figure 4.

FIGURE 4: CELESTIAL COORDINATE SYSTEM



The bottom diagram in Figure 4 has been notated to place an observer at a southern latitude typical of Victoria at the top of Earth, at M, and their zenith in the sky at Z. The zenith is the point on the celestial sphere that is directly above the observer.

Right ascension and declination

The meridians from the North Celestial Pole to the South Celestial Pole are termed ‘lines of right ascension’ and the lines parallel to the celestial equator are ‘lines of declination’. An object on the northern part of the celestial sphere has a positive declination (between 0˚ and +90˚), whereas an object in the southern part of the celestial sphere has a negative declination (between 0˚ and –90˚). See Figure 5.

The 0˚ line of right ascension is not the projection of the 0˚ longitudinal line that passes through Greenwich. If this was the case, then the celestial sphere would have to rotate to keep pace with Earth and this of course would make it difficult if you wanted to use the sphere as a reference system. To set the zero for right ascension measurements, it is necessary to have a fixed point in space in much the same way as Greenwich is a fixed point on the surface of Earth. This point in the sky is called ‘the first point of Aries’, named after a star in the constellation of Aries that occupied this point on the celestial sphere about 4300 years ago.

Right ascension values are measured east from the meridian that passes through the first point of Aries. However, instead of using angle measure in terms of degrees, minutes and seconds, another system is used that pertains to time units. This system uses hours, minutes and seconds. One full revolution of the celestial sphere is 360˚ and is equivalent to twenty-four hours. Therefore, every 15˚ (360˚/24 hours = 15˚) is equivalent to one hour of right ascension. As each angle measure of 1˚ divides into sixty minutes and each minute divides into sixty seconds, the same applies to divisions of every hour of right ascension. The meridian that passes through the first point of Aries has right ascension 0 hours 0 minutes and 0 seconds and is written as 0:0:0. See Figure 5.

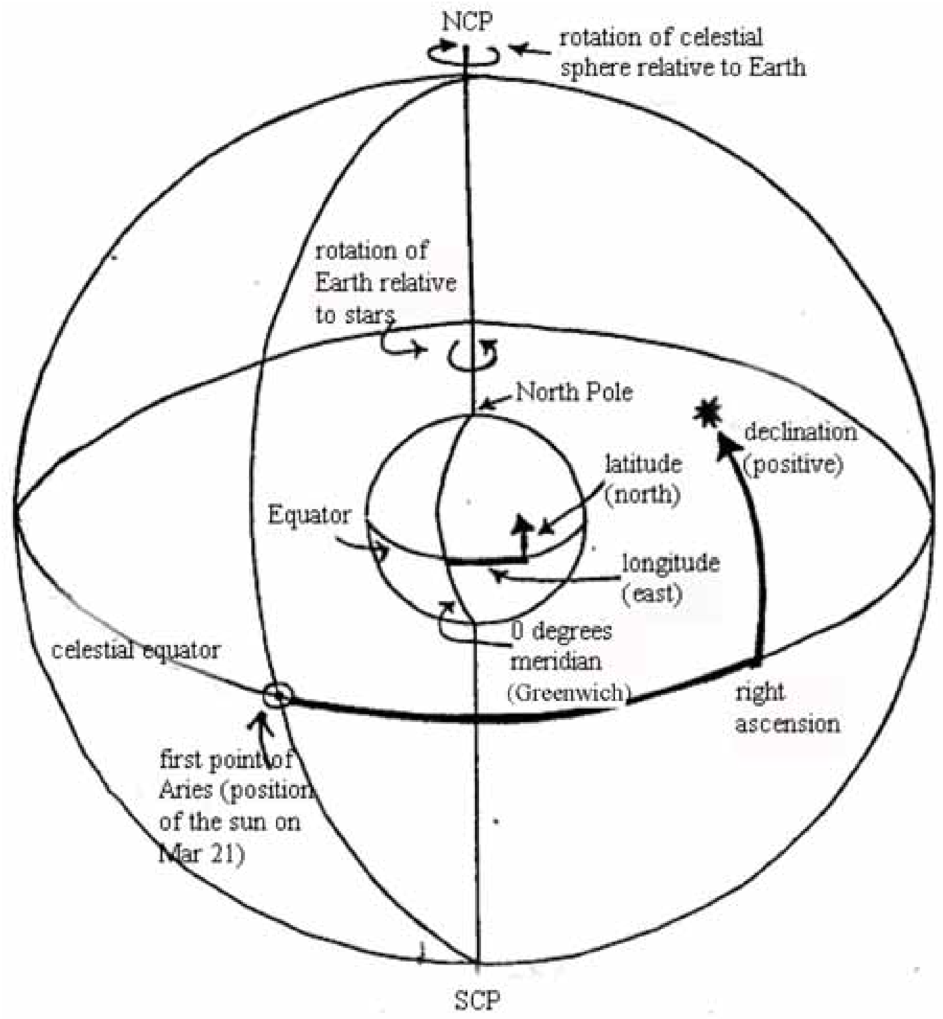
Table 1 compares coordinates of the terrestrial and celestial coordinate systems.

TABLE 1: TERRESTRIAL AND CELESTIAL COORDINATE SYSTEMS

Terrestrial coordinate system	**Celestial coordinate system**
South Pole	South Celestial Pole (SCP)
North Pole	North Celestial Pole (NCP)
equator	celestial equator
longitude	right ascension (RA)
latitude	declination (dec)

Figure 5 provides a more detailed view of both coordinate systems.

FIGURE 5: EARTH AND CELESTIAL COORDINATE SYSTEMS



Each place on Earth has a fixed longitude and latitude. Similarly, each star has a unique right ascension and declination and so is fixed on the celestial sphere. However, three factors will change the coordinates of stars ever so slightly over time (they may be considered negligible for most observers):

- As Earth revolves around the Sun there is a very small change in position of some of the closest stars to Earth.
- Over a period of thousands of years, there will be some relative movement of the stars (see to Figure 6).
- Earth's axis wobbles very slowly, making one full wobble every 26 000 years. This gives observers on Earth a different perspective of the heavens over time.

Although the stars are fixed in their positions on the celestial sphere (that is, they have unique right ascension and declination coordinates), the positions of the Sun, Moon and planets are not. Over the period of one month the Moon's position passes through the whole range of right ascension. The Sun will pass through the entire range of right ascension over a period of a year. The planets pass through the entire range of right ascension at varying periods depending on their motion with respect to Earth and the Sun.

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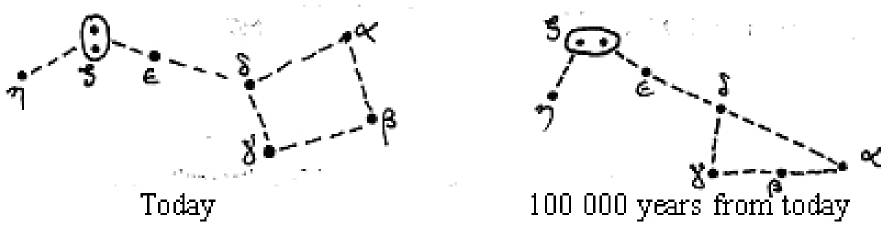


FIGURE 6: RELATIVE MOTION OF THE 'BIG DIPPER' OVER THOUSANDS OF YEARS

ACTIVITY: CELESTIAL COORDINATES

You will need:

- **longitude and latitude for your location**
- **access to the internet.**

Access the website 'Your Sky' by John Walker, <http://www.fourmilab.ch/yoursky/> (viewed 7 September 2004)

This site constructs star maps for your location. It uses the terrestrial coordinate system (you need to indicate your location with values for longitude and latitude), a local coordinate system giving altitude and azimuth values of objects in the sky, and the celestial coordinate system giving right ascension and declination values of stars and planets.

Produce the star map for tonight's viewing from your location. Use the pointer to find the right ascension and declination for various stars that are shown. Which stars will be due south at the time you have indicated for viewing the stars?

Appearance of the sky

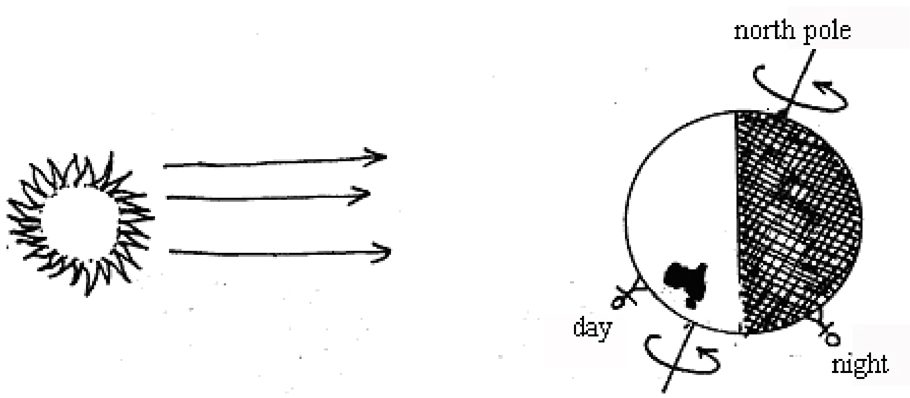
The appearance of the night sky changes throughout the night, as well as from one night to the next. In addition, the Sun is high in the sky in summer and low in winter; the Moon can sometimes be seen in daylight hours. Three features of Earth's motion in space cause such observations:

- Earth's rotation about its axis
- Earth's orbital motion about the Sun
- tilt of Earth's axis relative to the plane of its orbit.

Earth's rotation about its axis

The regular observations of day and night are due to Earth's rotation about its axis every twenty-four hours. This is termed 'diurnal motion'. Earth is (approximately) spherical (it's actually oblate and flattened at the poles), and so the Sun will always illuminate half of Earth. As Earth rotates on its axis, observers on the surface of Earth will experience regular periods of day (illumination) and night (darkness). Using a globe of Earth and a torch in a darkened room, you can simulate when particular locations on Earth will be in daylight conditions or not. Earth rotates from east to west, so in this simulation the east coast of Australia will be illuminated first. Try it!

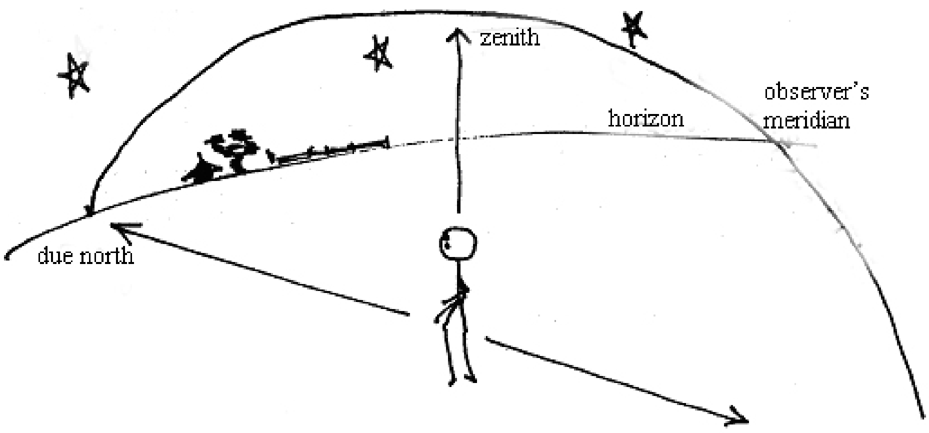
FIGURE 7:
DAY AND NIGHT



Each observer on Earth's surface has a line of longitude through their position. If you project this line onto the celestial sphere it is called the 'observer's meridian'. If you face due north or south, the observer's meridian can be imagined to be the line that begins at a point on the horizon that is due north, passes directly overhead and ends at a point on the horizon that is due south.

An observer on Earth gets the impression that the celestial sphere rotates about its axis. With this rotation, the observer's meridian rotates so that the meridian is continually changing its position on the celestial sphere. The zenith is the direction from the centre of Earth through the observer onto the celestial sphere. See Figure 8.

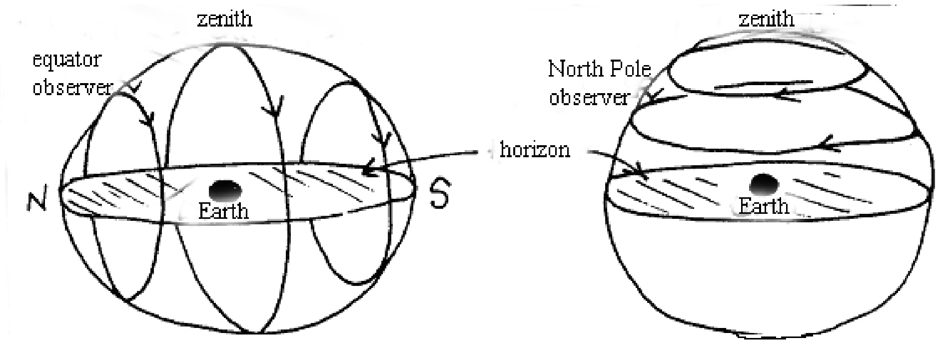
FIGURE 8:
OBSERVER'S MERIDIAN AND ZENITH



As Earth rotates, observers located in Victoria (latitudes 35˚ to 38˚) see some stars on the celestial sphere that are always in the night sky, some stars that are seen for parts of the year, and still other stars that can only be seen from a more northerly location on Earth. These other stars can only be seen from a more northerly location on Earth In order to understand this situation, it is best first to visualise simple cases. If we were standing on the equator, the stars would rise perpendicular to the horizon (see Figure 9). The North Celestial Pole would lie exactly on the horizon in the north, and the South Celestial Pole would lie exactly on the horizon in the south. Each star would rise somewhere on the eastern half of the horizon; each would remain 'up' for twelve hours, and then would set. We would be able to see all the stars, no matter what their declination, for twelve hours a day. The Sun, no matter what its declination, would also rise and set twelve hours apart, so the day and night would each last twelve hours.

If, on the other hand, we were standing on the North Pole, the North Celestial Pole would be directly overhead (our zenith), and the celestial equator would be on the horizon (see Figure 9). All the stars would move around the sky in circles parallel to the horizon. Since the celestial equator is on the horizon, we could see only the stars with northern declinations. The stars with southern declinations would never be visible.

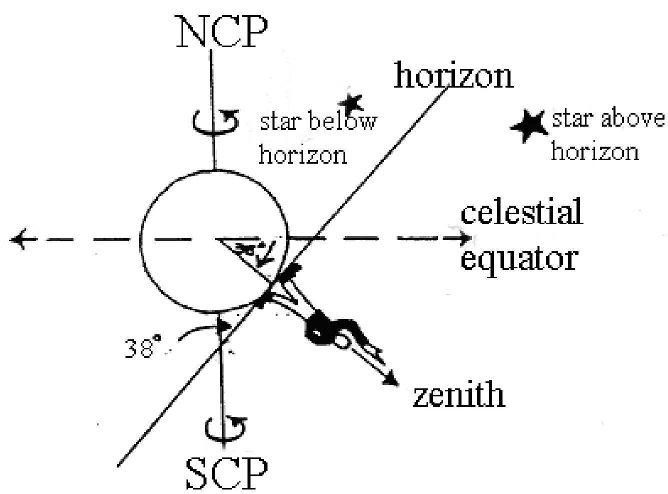
FIGURE 9: OBSERVER AT THE EQUATOR AND AT THE NORTH POLE



For observers at latitudes that are not the equator or North Pole (Melbourne for example, latitude 38˚), there will be some stars that will always be seen in the night sky and still others that can never be seen. Figures 10 and 11 show that for an observer at latitude 38˚ south (Melbourne):

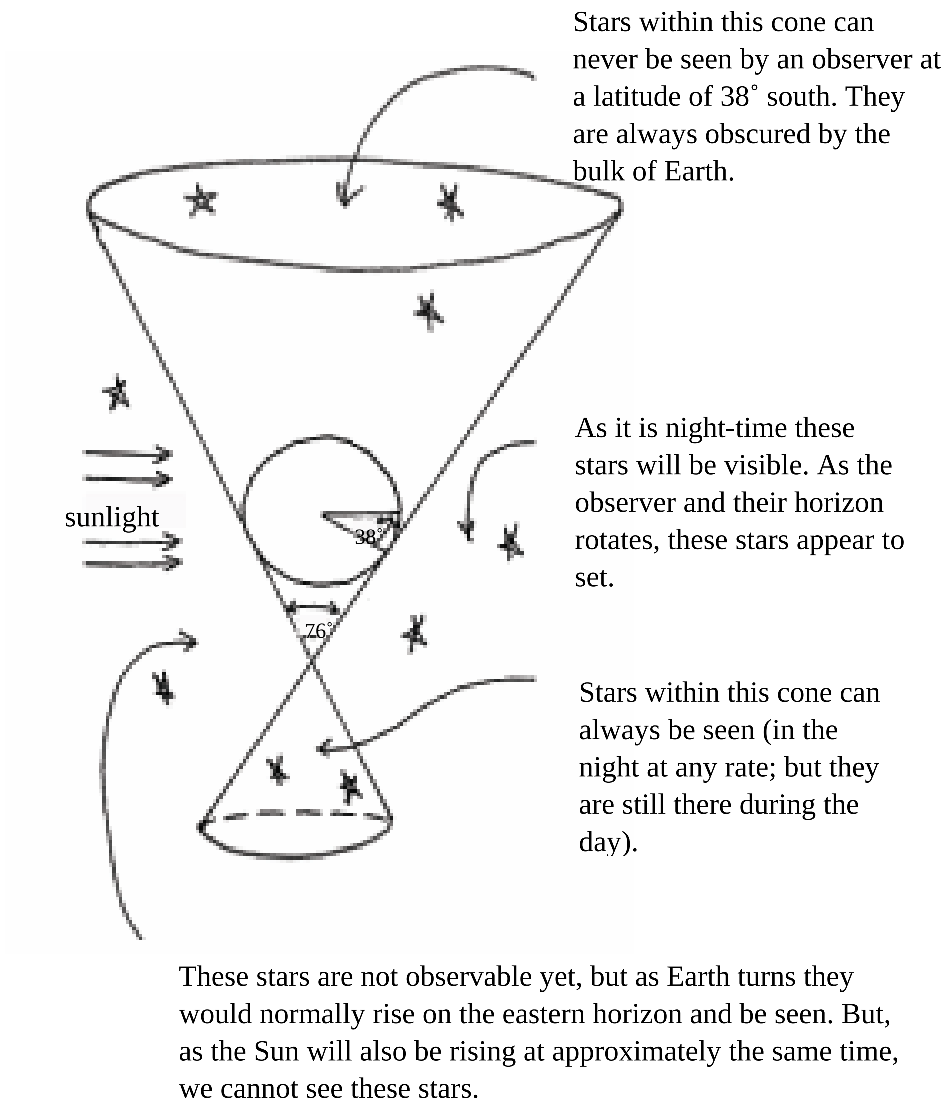
- the South Celestial Pole will always be seen in the night sky at an angle of elevation 38˚ to the horizon
- stars with declination –52˚ to –90˚ on the celestial sphere will always be in the night sky
- stars with declination –52˚ to +52˚ on the celestial sphere will be seen in the night sky during some part of the year
- stars with declination +52˚ to +90˚ on the celestial sphere will never be seen.

FIGURE 10: OBSERVER AT MELBOURNE



As the observer at Melbourne rotates, their horizon rotates with them and in doing so generates a double cone (see Figure 11).

FIGURE 11: APPEARANCE OF STARS IN THE NIGHT SKY FROM MELBOURNE



ACTIVITY: DIURNAL MOTION OF EARTH

You will need:

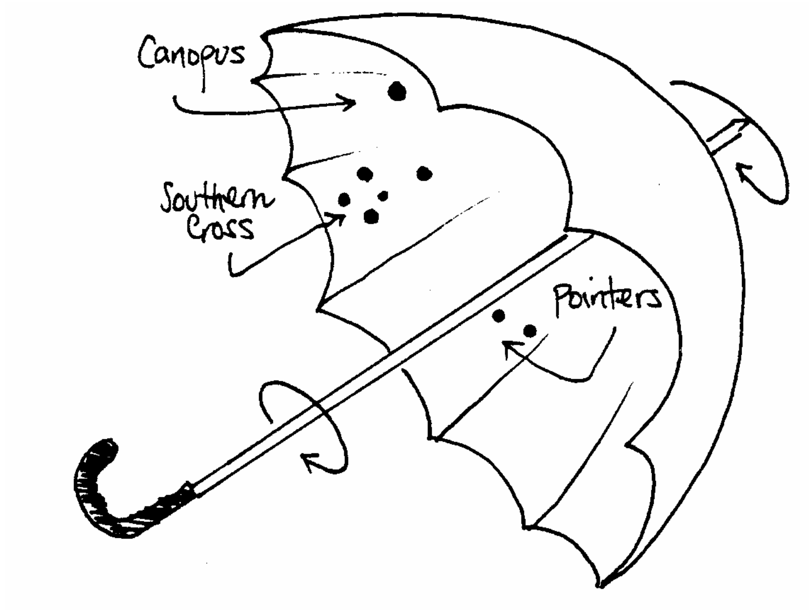
- **a black umbrella**
- **white circular stickers.**

A night-time observer from Melbourne will see the stars in the southern section of the sky rotate about a point in the sky, called the 'South Celestial Pole', every twenty-four hours. From Melbourne, the South Celestial Pole is at an angle of 38˚ to the southern horizon.

If you open the umbrella and twirl it at an angle of approximately 38˚ to the horizontal then the inside of the umbrella can model the rotating celestial sphere in the sky. The shaft of the umbrella passes through the South Celestial Pole. See the figure below.

Place the white stickers in their appropriate positions to represent the Southern Cross, its Pointers and Canopus (refer to your planisphere or star maps to get the orientation of the stars correct). By holding the umbrella at an angle of 38˚ to the horizontal and rotating it clockwise, you can model the motion of the southern stars as observed from Melbourne. By holding the umbrella vertically, you can model the movement of the stars as observed from the South Pole.

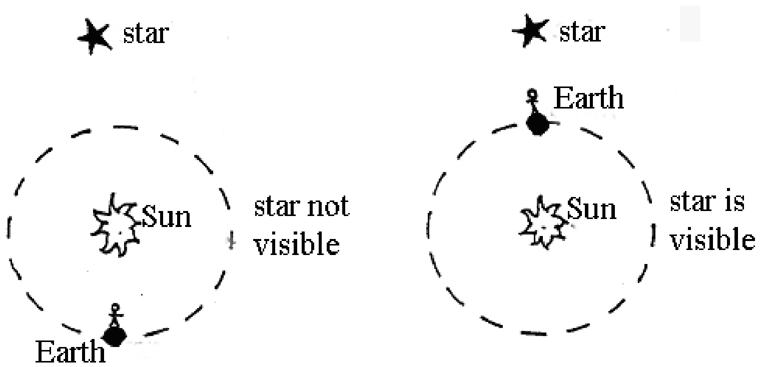
FIGURE: CELESTIAL SPHERE MODEL



Earth's orbital motion about the Sun

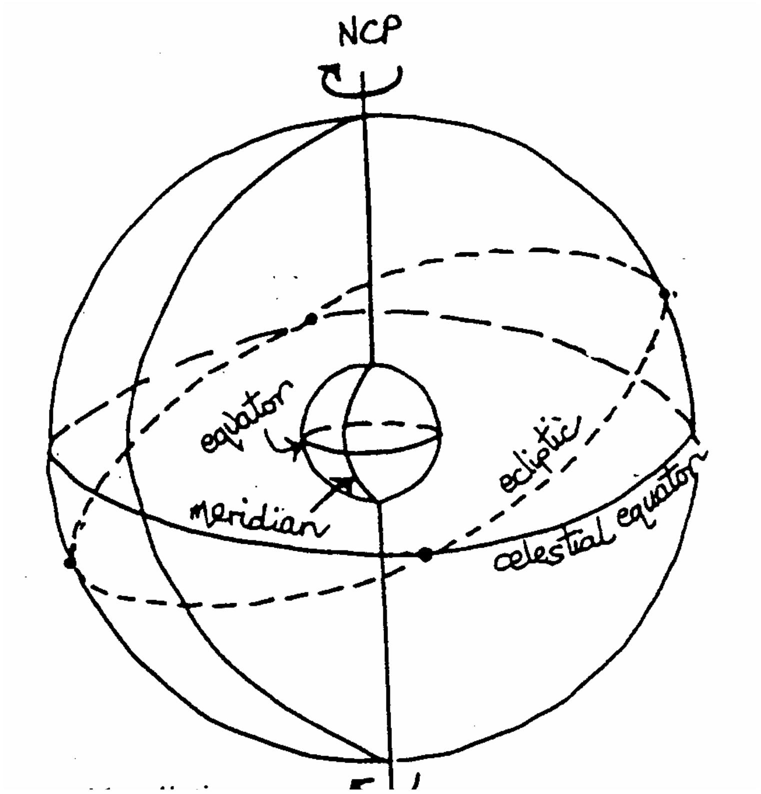
When can the 'daytime' stars be studied? Earth revolves around the Sun every year. So, over this time, the Sun blocks out a part of the sky for a few months, after which the stars in that portion of the sky become observable. See Figure 12.

FIGURE 12: RELATIVE POSITIONS OF THE SUN, STARS AND EARTH



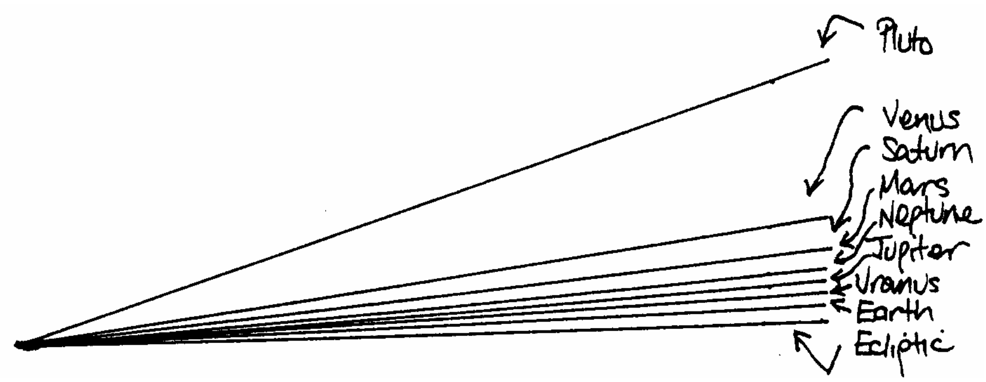
Earth's orbital motion around the Sun effectively puts the Sun on a different point on the celestial sphere from day to day and hour to hour. The change in position of the Sun on the celestial sphere amounts to about 1˚ per day. This is because over the period of one year (365 days) the Sun will pass through the full range of right ascension (360˚ or twenty-four hours). The path of the Sun on the celestial sphere is the ecliptic. The ecliptic lies close to the celestial equator but is not directly on it. The reason for this is that Earth's axis relative to the plane of its orbit is tilted (this will be explained more in the next section). Figure 13 shows the celestial sphere with the ecliptic included.

FIGURE 13: CELESTIAL SPHERE WITH ECLIPTIC



As the Sun, Moon and planets all lie approximately on the same plane (with the exception of Pluto) on the celestial sphere, the Moon and planets follow the same path as the Sun. Figure 14 shows that the orbits of the planets, with the exception of Pluto, have only small inclinations to the ecliptic path.

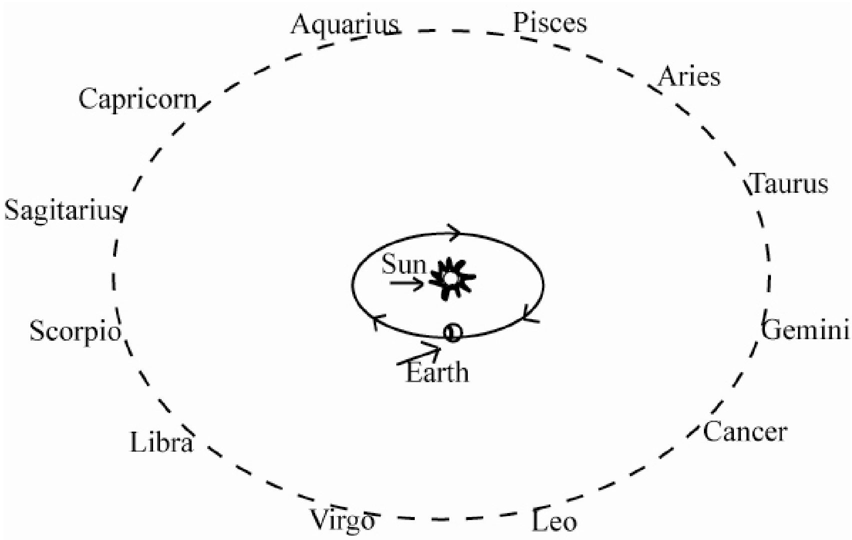
FIGURE 14: INCLINATIONS OF THE PLANETS TO THE ECLIPTIC



Constellations

The whole celestial sphere divides into eighty-eight sections and the stars within each section form what are termed ‘constellations’. Twelve constellations cover the circular strip of the celestial sphere that includes the ecliptic. These constellations are also known as the zodiacal constellations. From an astrological perspective, the zodiacal constellations are given a specific period in the year. This period refers to the time in the year when a specific zodiacal constellation will be seen on the ecliptic during the night. However, this is only for northern latitude observers. For southern latitude observers, our particular zodiacal constellation will be close to the Sun around the time of our birthday and therefore cannot be seen. This situation is shown in Figure 15.

FIGURE 15: OBSERVING THE ZODIACAL CONSTELLATIONS



ACTIVITY: CONSTELLATIONS

Ancient civilisations such as the Egyptians and Greeks divided the sky into regions containing distinct groups of stars. These groups, called 'constellations', were given names and stories were attached, perhaps to aid in remembering them.

You will need:

- **star charts**
- **black cardboard**
- **aluminium foil**
- **white chalk or crayon**
- **sticky tape or glue.**

Research a particular constellation for its graphic interpretation and mythology. How did different civilisations interpret the constellations? Compare the interpretations.

From star charts select the prominent stars within a constellation and construct your own graphic interpretation.

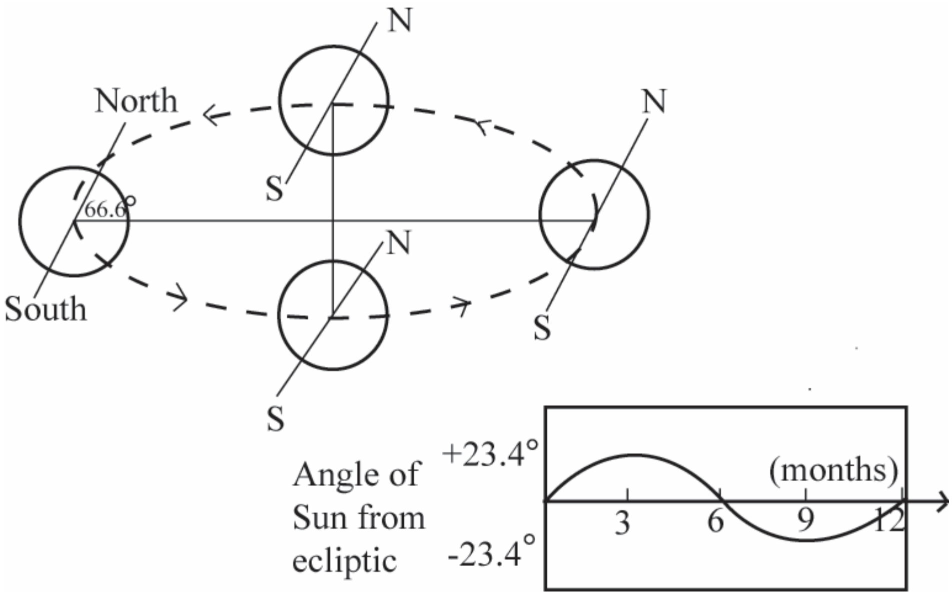
Make models of constellations with black cardboard, aluminium foil and white chalk or crayon. Select a constellation and make three-dimensional stars out of the foil by rolling them into spheres; ensure that the brighter stars are larger than the less bright. Adhere the stars to the cardboard and label it with the name of the constellation. With a white pencil or chalk or crayon draw lines joining the stars so that the constellations can be more easily identified.

The tilt of Earth's axis relative to the plane of its orbit

The tilt of Earth's axis relative to the plane of its orbit is responsible for the seasons (winter, spring, summer and autumn).

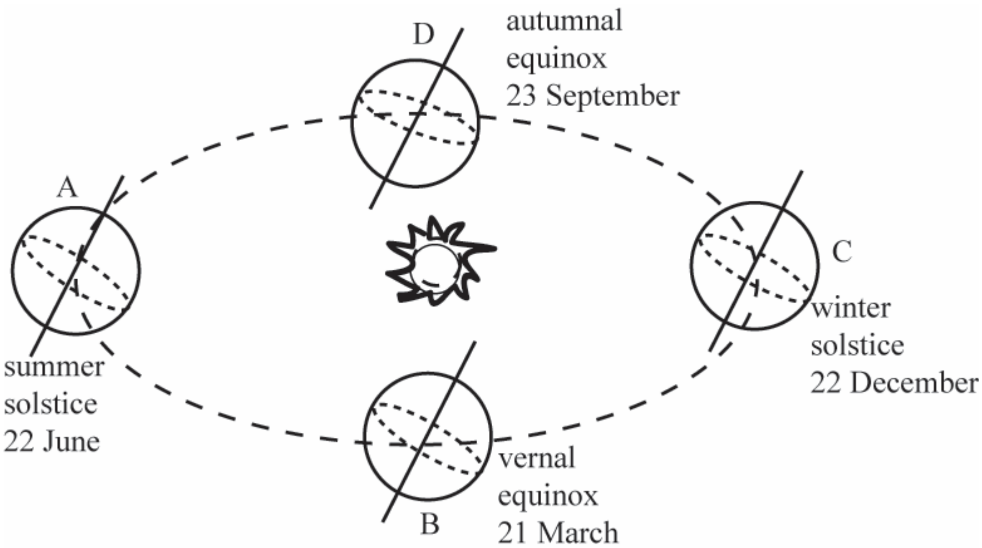
To plot the ecliptic on the celestial sphere, we need to consider the tilt of Earth to its orbital plane. The axis of Earth is inclined at an angle of 66.6˚ towards the plane of its orbit (see Figure 16). In Figure 16, an observer at the equator would not see the Sun directly overhead each day. This will occur on only two days of the year. For the other days, the Sun will be north for six months and south for the other six months. If the observer uses their zenith as a reference point and measures the angle that the Sun makes with their zenith at the exact moment the Sun is on their meridian for each day of the year, a curved graph will be obtained. This is shown in Figure 16.

FIGURE 16:
THE SUN'S PATH IN THE SKY



From Figure 16, there are clearly four very important dates for Earth. These are reproduced in the Figure 17.

FIGURE 17:
SOLAR DATES IN THE YEAR



In Figure 18, at position A (from Figure 17), the midday Sun is directly overhead in a northern latitude (23.5˚ north). This represents midsummer in the Northern Hemisphere. In contrast, for places in the Southern Hemisphere, the midday Sun is low in the sky. Therefore, the light from the Sun, with its radiant heat, is more concentrated in the Northern Hemisphere than in the Southern Hemisphere. In addition, at position A, the Sun in the Northern Hemisphere will spend more time in the sky (longer day) than in the Southern Hemisphere.

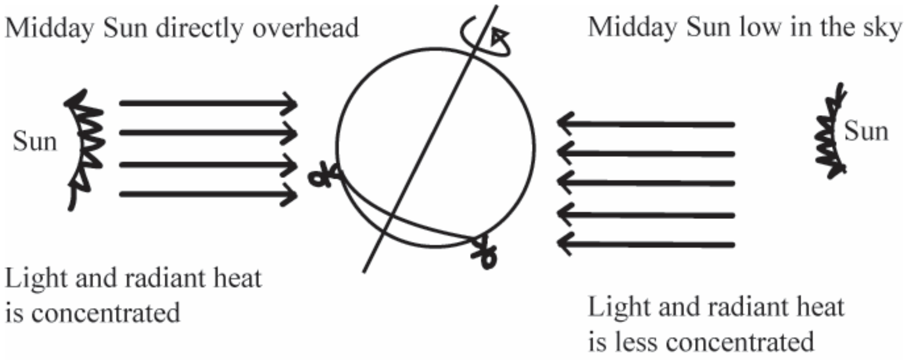


FIGURE 18: MIDDAY SUN IS HIGH IN SUMMER AND LOW IN WINTER

At position C, the midday Sun will be directly overhead at a southern latitude (23.5˚ south). At this time, the Southern Hemisphere will be in summer and the Northern Hemisphere will be in winter.

The points A and C are called the ‘solstices’ (winter and summer). On the celestial sphere these are points on the ecliptic that are furthest from the celestial equator. The names are in reference to the Northern Hemisphere observers, where the midsummer solstice is the longest day (22 June) and winter solstice is the shortest day (22 December). For Southern Hemisphere observers, the converse is true. For these observers, 22 June represents the shortest day, whereas 22 December is the longest day.

As Melbourne is further south than 23.5˚, the midday Sun will never be overhead. It is always in a northerly direction. The midday Sun at Melbourne drops as low as 28.5˚ to the horizon in winter (22 June) to as high as 75.5˚ to the horizon in summer (22 December).

The points B and D are called the ‘equinoxes’ (vernal and autumnal). On the celestial sphere these are points of intersection of the ecliptic and the celestial equator. The derivation of equinox comes from Latin, where *equi* means equal and *nox* means night, so *equinox* translates as ‘equal day and night’. The vernal equinox occurs on 21 March and the autumnal equinox occurs on 23 September.

Figure 19 shows the celestial sphere with the ecliptic drawn in. The Sun occupies the points A, B, C and D. The point D on the celestial sphere (vernal equinox and intersection of the celestial equator and the ecliptic) is also called the first point of Aries (the ‘first point of Aries’ is the zero measurement of right ascension in the celestial coordinate system). The first point of Aries now lies in the constellation Pisces. This is because of another rotational effect of Earth known as a ‘precession of Earth’s axis’.

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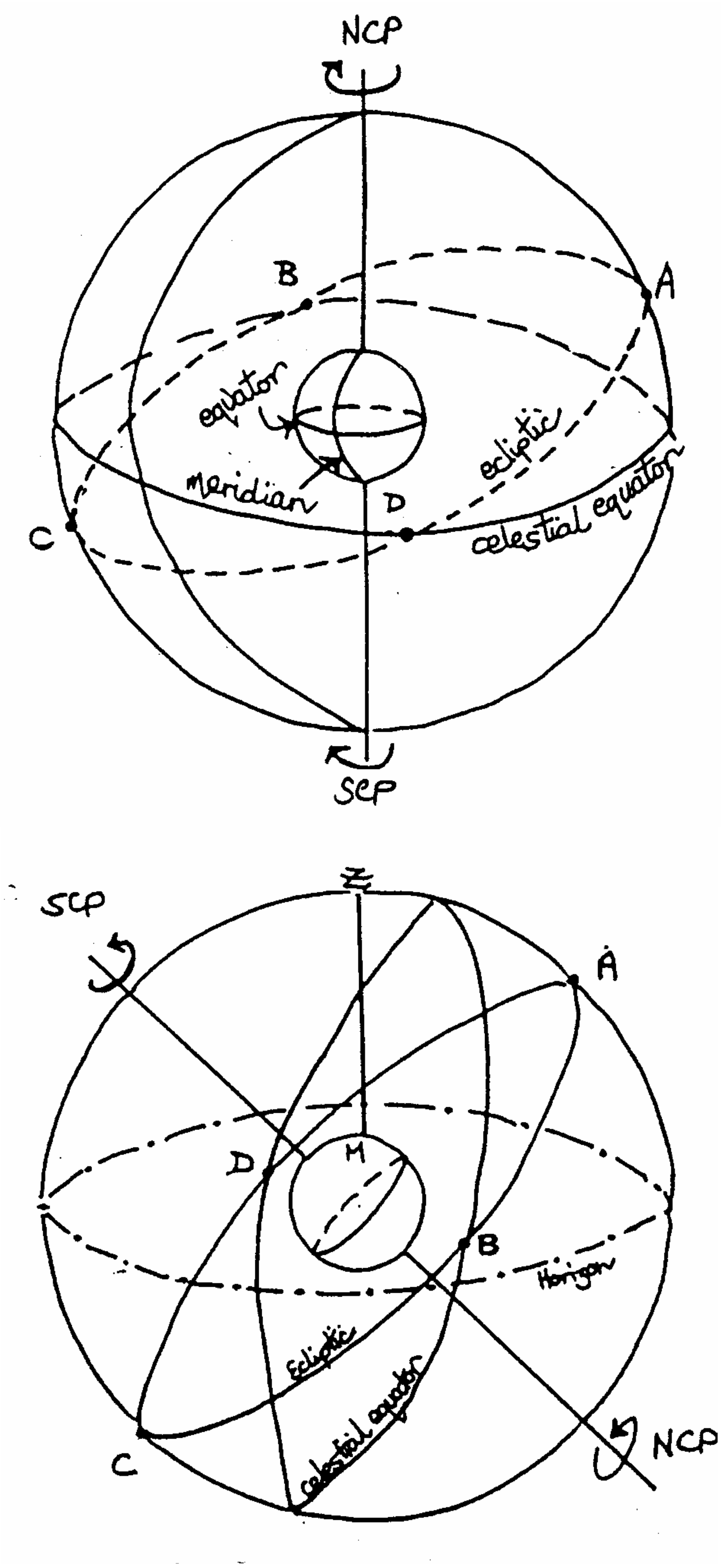
FIGURE 19: CELESTIAL COORDINATE SYSTEM



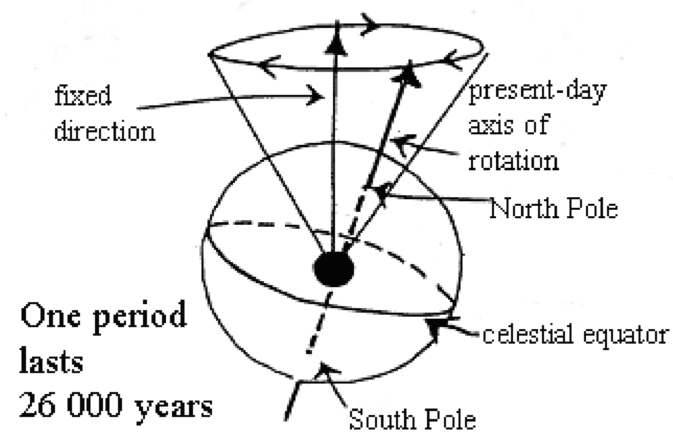
Precession of Earth's axis

The Moon's gravity, primarily, and to a lesser extent the Sun's gravity, act on Earth's oblateness (Earth is slightly flattened at the poles) and try to move Earth's axis perpendicular to the plane of Earth's orbit. However, due to Earth's rotation, its poles do not 'right themselves' to a position perpendicular to the orbital plane. Instead, they precess at 90˚ to the gravity force that is applied.

This precession causes the axis of Earth to describe a circle with a 23.5˚ radius relative to a fixed point in space over about 26 000 years—a slow wobble similar to the wobbling of the axis of a spinning top swinging around. Figure 20 shows this effect.

The precession of Earth's axis means that the stars move a full 360˚ on the celestial sphere every 26 000 years. For most observations of the sky, this does not present a problem. However, for very powerful telescopes a slight correction needs to be made to star charts constructed at a particular time in the past. The precession also means that in 13 000 years the tilting effect will be such that the Southern Hemisphere will have winter during December, while the Northern Hemisphere will have summer.

FIGURE 20: PRECESSION OF EARTH'S AXIS



Observations of astronomical behaviour

The various motions of Earth as it rotates and revolves around the Sun with a tilt explain the following phenomena (when observed from latitudes similar to Melbourne, 38˚ south):

- Celestial objects (the Sun, the Moon, stars, planets) appear to rise in the eastern horizon and set in the west on a daily basis.
- Earth goes through regular periods of day and night.
- The midday Sun is high in the sky in summer and low in winter.
- Different stars are visible in summer and winter.
- Days are shorter in winter than in summer.
- In the night sky some stars are always visible.
- In the night sky some stars on the celestial sphere are never visible.
- The moon and planets appear in different positions relative to the background of stars each night.
- A full moon travels high in the sky in winter and low in summer (contrast this with the Sun).
- A planet on the observer's meridian at midnight is high in the sky in winter and low in summer.
- The Sun is never directly overhead but always in a northerly direction.

The calendar and time

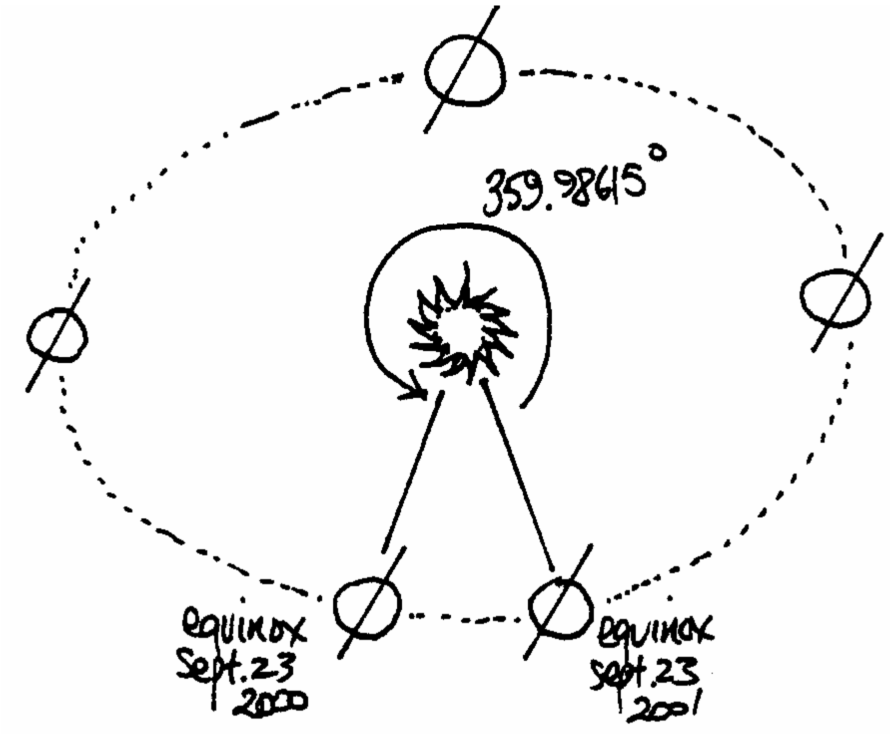
Tropical year and sidereal time

The year as we know it is taken from the period of time for Earth to revolve around the Sun. However, because of the precession of its axis, two separate years are defined: the sidereal year and the tropical year.

The sidereal year is the time taken for the Earth–Sun radius to sweep through 360˚ (see Figure 21): one sidereal year equals 365.2564 days.

While the sidereal year represents the time for Earth to complete one full revolution around the Sun, an observer does not see the same stars in the exact position in the night sky every sidereal year. This is because of the precession of Earth's axis. Because of the wobbling effect of Earth's axis the stars in the night sky come to their same position 0.0142 days less than the sidereal year of 365.2564 days. Due to the precession of Earth's axis, the 'first point of Aries' makes a complete 360˚ every 26 000 years. In one year the 'first point of Aries' then moves on by 360˚ divided by 26 000 = 0.01385 degrees. This represents 0.0142 of a day per year. Figure 21 shows an exaggeration of the phenomenon.

FIGURE 21: SIDEREAL AND TROPICAL YEAR



The time from equinox to equinox in successive years is the calendar or tropical year. The tropical year may also be defined as the time between successive transits of the stars annually. The tropical year lags 0.0142 days behind the sidereal year: one tropical year equals 365.2422 days.

Calendar makers keep in step with the tropical year instead of the sidereal year. An accurate calendar must account for the fact that, on average, the length of the year is 365.2411 days.

History of the calendar

The apparent motion of celestial bodies such as the Sun, Moon, planets and the stars provided ancient civilisations a reference for measuring the passage of time to determine seasons, months and years. Five thousand years ago the Sumerians had a calendar that divided the year into thirty-day months, the day into twelve periods, each of which had thirty parts. Not much is known about Stonehenge, built over four thousand years ago in England, but its alignments show that its purposes apparently included the determination of seasonal or celestial events, such as lunar eclipses and solstices.

The earliest Egyptian calendar was based on the Moon's cycles, but later the Egyptians realised that the Dog Star in the constellation Canis Major, which we call Sirius, rose next to the Sun every 365 days, about when the annual inundation of the Nile began. Based on this knowledge, they devised a 365-day calendar that seems to have begun about 4236 BC, the earliest recorded year in history.

In Babylonia (Iraq), a year of twelve lunar months (some 31-day and some 30-day) was observed before 2000 BC, giving a 354-day year. In contrast, the Mayans of Central America relied not only on the Sun and Moon, but also the planet Venus, to establish a 365-day calendar.

Julian and Gregorian calendars

The genesis of our current calendar, called the 'Gregorian calendar', comes from the Roman civilisation. The Romans were aware that their calendars of 365 days drifted out of synchronisation with the seasons and so in 46 BC Julius Caesar decreed a 445-day year in order to catch up, and defined a calendar, the Julian calendar, that would be more accurate. This calendar added an extra day every fourth year, called then, as it is now, a 'leap year'. The Julian calendar had an average year consisting of 365.25 days. However, this was a longer period than the tropical year by 0.0078 days every year. Even this small error can accumulate so that the calendar is in error by 1 day every 128 years. From its inception to the sixteenth century the Julian calendar had accumulated an extra twelve days.

This discrepancy of twelve days was large enough to cause serious concern for the Catholic Church in Europe and the field was cast open for suggestions for improvement. Copernicus (a Polish astronomer who first stated that the Sun was at the centre of the solar system) maintained that further observations were needed and that the length of the tropical year was not known with great accuracy. Vatican astronomers set out to determine this. In 1582, Pope Gregory XIII made the following changes thus forming the Gregorian calendar that we use today:

- excess accumulated days in the Julian calendar were to be eliminated
- years with the date divisible by 4 were to be 366 days, except for the century years: 1700, 1800, etcetera
- century years were to be leap years only if divisible by 400. Therefore, 2000 was a leap year but 1900 was not.

Now, on average, the length of the Gregorian calendar year is 365.2425 days, differing from the tropical year by only 0.0003 days and therefore requiring 3000 years to go out of step by one day! Further reforms to our present calendar are not intended to improve its approximation to the tropical year, but to make it more symmetrical and to arrange that any particular date of the year will fall on the same day of the week. One such reform suggested frequently is the thirteen-month calendar.

Calendar reform

The thirteen-month calendar contains thirteen months of twenty-eight days each. Each month begins on a Sunday and ends on a Saturday; therefore, all months are identical. However, 13 × 28 = 364, so it is necessary to add an extra day at the end of the thirteenth month: a year-long holiday or extra Saturday. During the leap year another extra day would need to be added. Another possibility for calendar reform is the world calendar that includes the same twelve months as we have now, but the year is divided into four equal quarters where the first month in each quarter has thirty-one days and other months have thirty days each As with the thirteen-month calendar, we need to add an extra day in non-leap years and two extra days in leap years.

A good history of the Gregorian and Julian calendars can be found at the following websites:

A history of the Julian and Gregorian calendars

http://serendipity.magnet.ch/hermetic/cal_stud/cal_art.htm

Calendars

http://astro.nmsu.edu/~lhuber/leaphist.html
A history by LE Doggett of different calendars including the Julian, Gregorian, Hebrew, Islamic, Indian and Chinese calendars.

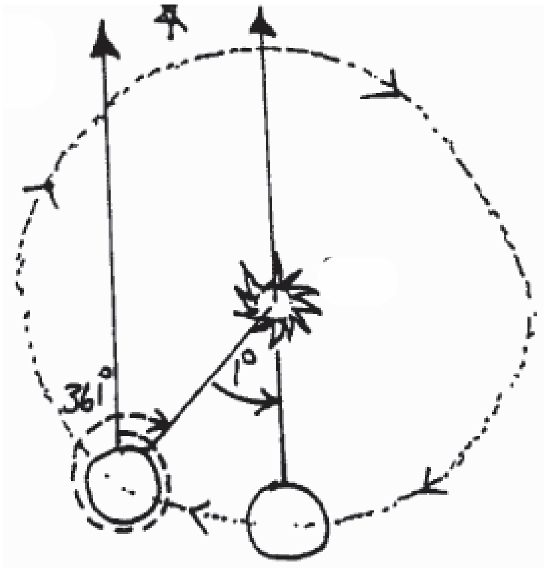
The Gregorian calendar

http://olympus.athens.net/~hartman/essay58.htm.

Time

As with the year, there are various interpretations for the length of the period we call the day. Each interpretation gives a slightly different length day. The sidereal day is the time taken for Earth to rotate through 360˚ or the time between successive transits of a fixed star on the observer’s meridian. In this case, the precession of Earth gives a negligible difference between these two definitions for the sidereal day. However, the time taken for successive transits of the Sun on the observer’s meridian, called the ‘solar day’, produces a different time period than the sidereal day. Due to Earth revolving around the Sun, the solar day represents a rotation of approximately 361˚. This is shown in Figure 22.

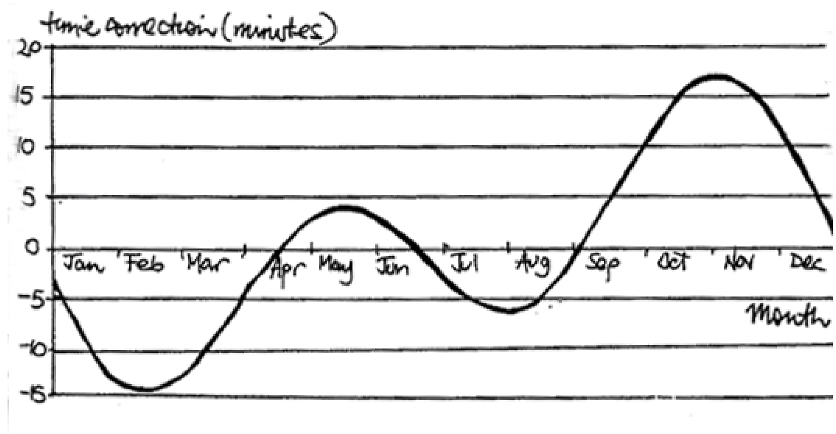
FIGURE 22: THE SOLAR DAY



The sidereal day sweeps out 360˚. The solar day sweeps out 361˚ on average.

The tilting of Earth’s axis and the ellipticity of Earth’s orbit cause small variations in the solar day. Hence, we speak of a ‘mean solar day’. It is the mean solar day that we speak of in everyday life. The longest and shortest solar days are both within a half a minute of the mean solar day, but over a two-month period, the cumulative effect can produce a difference of as much as sixteen minutes between solar and mean solar day. The cumulative difference is shown in Figure 23. Such a graph is called the ‘equation of time’ and is used in conjunction with readings from sundials.

FIGURE 23: EQUATION OF TIME



Local (or observer’s) solar time is measured from the passage of the Sun transiting the meridian that is 180˚ from the local observer. Local solar time is then 00:00 hours. When the Sun is transiting the local meridian, the local solar time is 12:00 hours on average. Since over certain periods a cumulative difference of sixteen minutes can occur between local solar time and mean solar time, then we can consider that the Sun is not an accurate clock. This means that at 12:00 hours the Sun may be anywhere between sixteen minutes before being on the observer’s meridian to being sixteen minutes after transiting the observer’s meridian. To determine the discrepancy we need to refer to the equation of time.

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Ordinary clocks are designed to keep mean solar time. A clock that is set to keep mean solar time at a given longitude will be valid at that longitude only and the time it keeps is called ‘Local Mean (solar) Time (LMT)’. For people on the eastern side of Australia the local mean time is designated for a longitude of 150˚ east of Greenwich. At different times of the year, for observers on a longitude 150˚ east, the Sun will cross the meridian at times varying between sixteen minutes before and after 12:00 by such a clock.

For convenience in everyday life, whole zones (generally spanning 15˚ of longitude) adopt the local mean time of some representative meridian within the zone. This zone relates to Greenwich Mean Time. This is known as standard time (or zone time). Victoria’s time is Eastern Australian Standard Time (EAST). This is the local mean time for the meridian 150˚ east from Greenwich. Since the whole of Victoria lies to the west of this meridian, and since each degree corresponds to four minutes of time, then LMT at longitude L˚ is given by the rule: LMT = EAST—(4 × [150 – L] minutes).

For example, if EAST reads 12:00 on a clock in Mildura (longitude 142.16˚ E) then the LMT at Mildura is 12:00 – 4 × (150 – 142.16) minutes = 11:29 am. This means that in Mildura the Sun will rise thirty-one minutes later and set thirty-one minutes later as designated by the times given in the newspaper. Based on the longitude of your town, determine how many minutes your LMT will deviate from EAST.

Local sidereal time is measured from the passage of the ‘first point of Aries’ across the observer’s meridian. At this point the local sidereal time is defined as being 00:00. At the vernal equinox (21 March), zero sidereal time is at midday and six months later it is about midnight. At the solstices (22 June and 21 December) it is at 06:00 and 18:00 respectively, local solar time.

The relationship between sidereal time and solar time depends only on the position of the Sun on the ecliptic. Hence, a table can be drawn up giving the sidereal time at any given LMT for the whole year, regardless of the locality of the observer. Table 2 gives the sidereal time from the EAST or LMT.

TABLE 2: SIDEREAL TIME FROM EAST OR LMT

Date	EAST or LMT (hours)													
	18:00	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**00:00**	**01:00**	**02;00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**
Jan-05	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jan-21	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Feb-05	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Feb-20	4	5	6	7	8	9	10	11	12	13	14	15	17	18
Mar-07	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Apr-06	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Apr-22	7	8	9	10	11	12	13	14	15	16	17	18	19	20
May-02	8	9	10	11	12	13	14	15	16	17	18	19	20	21
May-22	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Jun-06	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Jun-22	11	12	13	14	15	16	17	18	19	20	21	22	23	1
Jul-07	12	13	14	15	16	17	18	19	20	21	22	23	1	2
Jul-22	13	14	15	16	17	18	19	20	21	22	23	1	2	3
Aug-06	14	15	16	17	18	19	20	21	22	23	1	2	3	4
Aug-22	15	16	17	18	19	20	21	22	23	1	2	3	4	5
Sep-06	16	17	18	19	20	21	22	23	1	2	3	4	5	6
Sep-21	17	18	19	20	21	22	23	1	2	3	4	5	6	7
Oct-06	18	19	20	21	22	23	1	2	3	4	5	6	7	8
Oct-21	19	20	21	22	23	1	2	3	4	5	6	7	8	9
Nov-06	20	21	22	23	1	2	3	4	5	6	7	8	9	10
Nov-21	21	22	23	1	2	3	4	5	6	7	8	9	10	11
Dec-06	22	23	1	2	3	4	5	6	7	8	9	10	11	12
Dec-21	23	1	2	3	4	5	6	7	8	9	10	11	12	13

Note: for intermediate dates add on four minutes per day. For example, 8 Dec. at EAST 05:00 hours (5 am) is sidereal time 11 hours + 2 × 4 minutes = 11 hours, 8 minutes.

Star charts and sidereal time

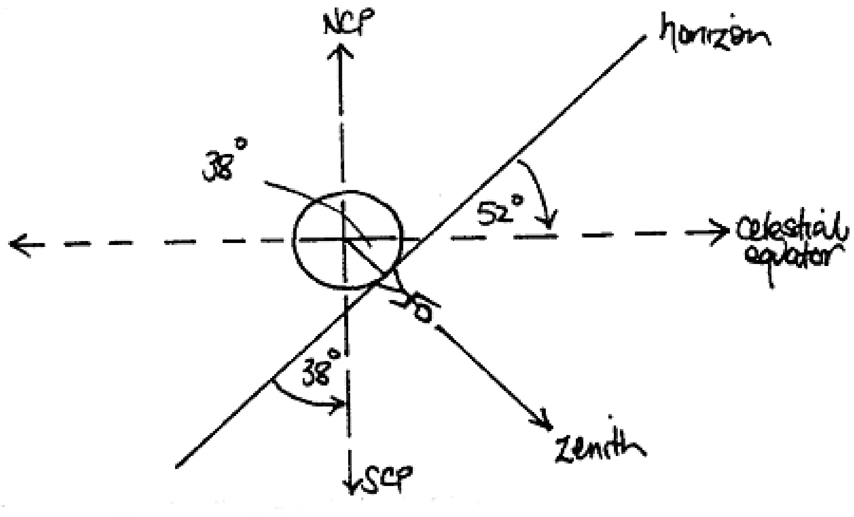
By knowing your longitude and latitude and sidereal time you can determine what part of the celestial sphere is overhead. That is, the range of declination and right ascension coordinates of the sky can be known for any sidereal time. Alternatively, if you have a set of star maps then it is possible, through taking observations of the stars, to determine the longitude and latitude of an observer’s position.

By definition, the zero of sidereal time (00:00) corresponds to the passage of the first point of Aries on the observer's meridian. This means that when the first point of Aries crosses the north–south line that passes overhead, the sidereal time will be 00:00. In addition, the right ascension of the first point of Aries is defined as (00:00 hours, 0 minutes). Therefore, when the sidereal time is 00:00 any star on the observer's meridian will have a right ascension coordinate which is also 00:00. As time progresses, the sidereal time and the right ascension of any star on the observer's meridian remain the same and so the following general rule applies: sidereal time equals right ascension of any point on the observer's meridian. Alternatively, the right ascension of a star on the observer's meridian is the sidereal time at that moment.

To explain how you can determine what stars will be visible at a particular location and time of night, consider the following example. It is 11 pm EAST (in daylight-saving time this refers to 12 midnight) on a clear night on 21 December in Melbourne (longitude 145˚ east and latitude 38˚ south). This example is only valid where the EAST is the same as the LMT. As EAST is only valid for a longitude of 150˚ east, then a small correction needs to be made. If we consider that the observer has an unobstructed view of the horizon then they will be able to see half of the celestial sphere. This refers to an 180˚ range of declination values and a twelve-hour range of right ascension values.

In terms of the declination range, see Figure 24. The zenith is the point on the observer's meridian that is directly overhead. The South Celestial Pole will be at an elevation that is the same as the observer's latitude. The celestial equator is 90˚ from the South Celestial Pole. Therefore, Figure 24 shows that stars with declinations –90˚ to +52˚ can be seen on the observer's meridian.

FIGURE 24: OBSERVER AT MELBOURNE (LATITUDE 38˚)



In terms of right ascension range stars visible at 11 pm EAST, we only need to know the sidereal time. From the LMT and sidereal time table (Table 2), when the EAST is 11 pm, the sidereal time is five hours or 5:00. This means that at 11 pm EAST, the stars on the observer's meridian will have right ascension 5:00 (the same as the sidereal time). From the observer's meridian, the observer will be able to see stars that have right ascension that is six hours less as well as six hours more than the star on the observer's meridian. Therefore, the observer will be able to see stars with a right ascension range from 23:00 to 11:00. As star charts show the right ascension and declination values, you can predict where a star will be in the sky at any time of the day or night and on any day of the year.

As the planets, Moon and Sun are not fixed on the celestial sphere, they do not have fixed right ascension and declination coordinates and so you need to access a current ephemeris. An ephemeris is the computed positions (right ascension and declinations) of celestial objects, usually given in tables. By accessing the website ‘Solar System Live’ <http://ecco.bsee.swin.edu.au/cgi-bin/uncgi/Solar/action?sys=-Sf>, you can know the current celestial coordinates of the Sun, Moon and planets. This site also calculates the elevation and azimuth values of the Sun, planets and Moon if you provide the observer’s longitude and latitude coordinates.

‘Worldtime’ < http://www.worldtime.com> is a service featuring an interactive world atlas, information on local time, as well as sunrise and sunset times in several hundred cities, and a database of public holidays worldwide.

ACTIVITY:
LOST SAILOR

You will need:

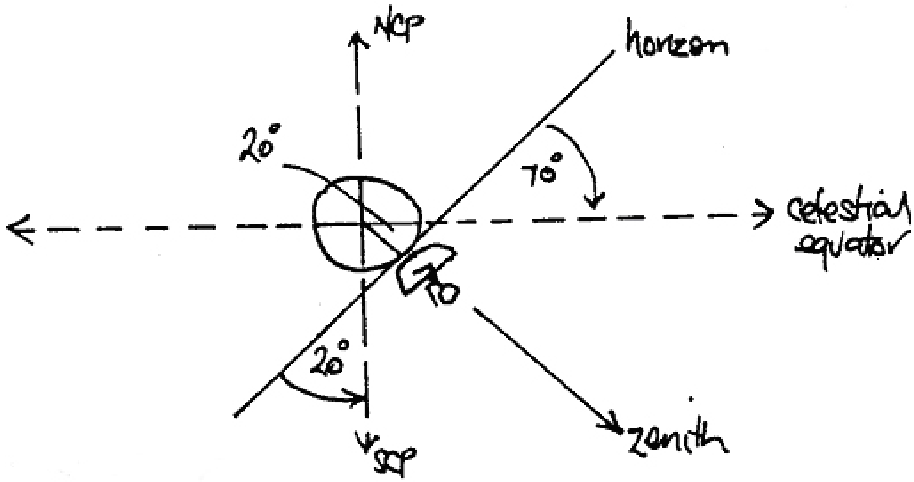
- **a set of terrestrial and star maps**
- **an accurate watch**
- **a copy of Table 2.**

Assume you are in a boat somewhere in the Pacific Ocean and you wish to know your longitude and latitude. You have with you a set of terrestrial and celestial star maps and an accurate watch. It is midnight EAST and you observe a bright star directly overhead (at your zenith). You know the name of the star and on the star charts you determine that its celestial coordinates are right ascension 4:00 and declination –20˚. The date is 21 December.

By constructing a similar diagram to that in Figure 24, you can see that in the figure *Observer in the o*cean the South Celestial Pole will be 20˚ above the horizon and so your latitude is 20˚ south. As the right ascension of a star on the observer’s meridian is also the sidereal time, the sidereal time is 4:00. As your watch reads midnight EAST on 21 December, then if you were situated on the longitude 150˚ east, from the EAST/sidereal timetable (Table 2) the sidereal time should be 6:00. This means that the star that you see overhead now will not be overhead for an observer at longitude 150˚ east for another two hours. In twenty-four hours Earth rotates 360˚, therefore in two hours it will rotate 30˚. Therefore, you will be at longitude 180˚ east. So you are no longer lost but are located at longitude 180˚ east latitude 20˚ south.

You then refer to your terrestrial map and find where you are located in the Pacific Ocean. Where would that be? You determine in which direction you should go to get to land but you have lost your compass. How can you determine your direction from looking at the stars? How can you determine your direction during the day?

FIGURE: OBSERVER IN THE OCEAN

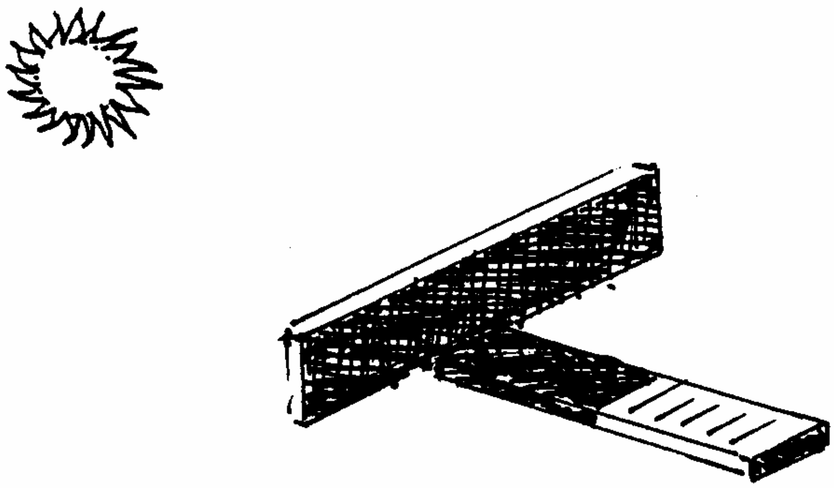


Sundials

From earliest times humans have used some form of time measurement, if only the seasons of the year or the phases of the Moon. This was all that was needed in simple nomadic or agricultural communities and precise enough for their daily needs. Timekeeping developed in civilisations concentrated around the Mediterranean, from the shadow stick to the water clock and sundial.

A shadow stick, in its simplest form, is just a vertical rod placed on some flat ground. Time was judged from the position and the length of the shadow. The Egyptians had a portable shadow stick called a 'T-stick' (see Figure 26). The T-stick was placed on some flat ground in such a way that the vertical section created a shadow along the horizontal part of the stick that had markings for graduations of time. By determining where the shadow ended on the stick, a person could determine the time.

FIGURE 26: EGYPTIAN T-STICK



ACTIVITY: MAKE YOUR OWN T-STICK

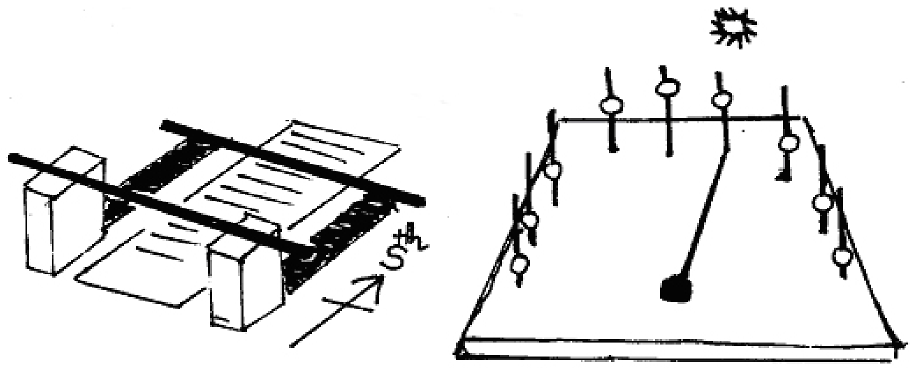
You will need:

- **two house bricks**
- **a stick (about one metre long)**
- **a strip of paper**
- **plastic needles**
- **polystyrene balls**
- **a polystyrene board.**

Make your own T-stick by placing a brick under each end of the stick and placing a strip pf paper under the stick and between the bricks. The stick should lie east to west and the paper north to south. To calibrate every half hour, mark the top of the stick's shadow on the paper. See the figure *Shadow stick clocks*.

A more sophisticated design for a sun clock uses plastic needles and polystyrene balls. With a little experimenting, you should be able to make the shadow of the ball fall on the central mark. Twelve midday is the central position. See the figure *Shadow stick clocks*.

FIGURE: SHADOW STICK CLOCKS



Shadow sticks may also be used to determine a north–south line. From Victorian latitudes the Sun is always in a northerly direction to the observer. Even the midsummer Sun is never directly overhead but in a northerly direction. This phenomena allows us to determine true north by observing shadows formed by the Sun.

ACTIVITY: FINDING 'TRUE' NORTH

You will need:

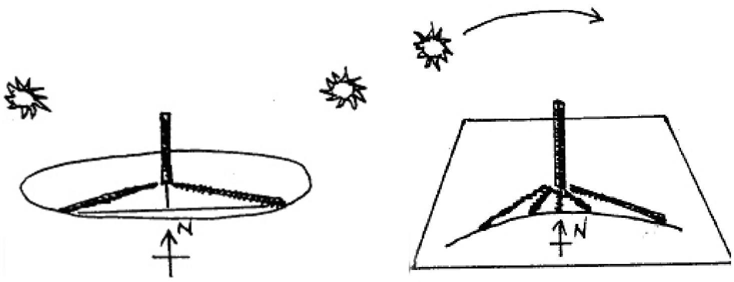
- **a straight rod**
- **a flat piece of horizontal ground**
- **drawing paper**
- **pens or pencils.**

Place a straight rod vertically into a flat piece of horizontal ground. Draw a circle on the ground with the rod as the centre. Mark the places on the circle where the outer end of the rod's shadow just touches the circle in the morning and again in the afternoon. Draw a line between the points on the circle and find its centre. Now join this point to the rod with a straight line. This straight line points north from one end, and south from the other. See the figure *True north*.

Alternatively, when the Sun is on the observer's meridian it is at its highest point and is due north of the observer. The Sun at this point will create the shortest

shadow of a vertical rod placed in the ground. Place a vertical rod into the ground with drawing paper and then around midday (12:00 EAST; remember to take account of daylight saving in the Summer months) mark the shadow end-points regularly over, say, a two-hour period. Draw a smooth curve through the shadow end-points to determine the closest point to the rod. Then draw a line from this closest point to the rod. This will be the north–south line. This method only works if over the observation period the shadows get shorter and then get longer. See the figure *True north*.

FIGURE: TRUE NORTH



Water clocks were used by the Greeks and by peoples of the Middle East. These clocks employed a mechanism that involved one container dripping water into another container.

ACTIVITY: MAKE YOUR OWN WATER CLOCK

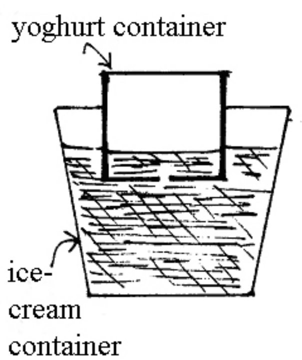
You will need:

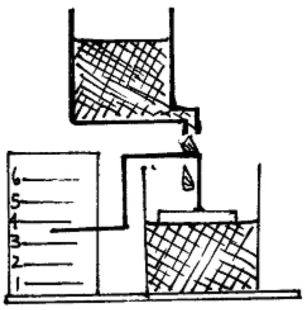
- **an ice-cream container**
- **a small yoghurt container**
- **water**
- **a needle or pin**
- **a small weight.**

Fill the larger container two-thirds full with water. Make as small a hole as possible in the base of the smaller container and place on the surface of the water in the large container. Watch the small container sink. The side of the small container can be calibrated in minutes or seconds depending on how long the container takes to sink. You may need a small weight to overcome surface tension. You can investigate different shaped containers. See the figure *Design for a water clock*.

A more sophisticated water clock makes use of a container that drips water into another container. One possible design is shown in the figure *Design for a water clock*.

FIGURE: DESIGN FOR A WATER CLOCK





Sundials on the Internet

Sundials have been used by a number of civilisations and are still in use today. The following websites will give you information about the history and types of sundials.

Sundials

http://www.sundials.co.uk/

http://cpcug.org/user/jaubert/jsundial.html

Site with multiple links to sundials

http://liftoff.msfc.nasa.gov/Cindex/searchkids.idq

ACTIVITY: MAKE A SUNDIAL

You will need:

- **access to the Internet**
- **materials for constructing a sundial**

Visit the following website for instructions on making a sundial. The site also contains a sundial template.

Building a sundial

http://liftoff.msfc.nasa.gov/academy/earth/sundial/sundial%2D constructsimple.html

Sundial template

http://liftoff.msfc.nasa.gov/academy/earth/sundial/sundialn.pdf

Construct a sundial and test it. Then consider the following questions (taken from http://liftoff.msfc.nasa.gov/academy/earth/sundial/Sundial-Questions.html):

- **When doesn’t a sundial work?**
- **Does your sundial match your watch time? Why?**
- **If Earth rotates every twenty-four hours (approximately), how many degrees does the Sun appear to move in one hour? In four minutes? (Hint: one full rotation of Earth is 360˚.)**
- **The Sun’s diameter in the sky is about 0.5˚. About how long does it take for the Sun to appear to move its own diameter across the sky?**
- **Why don’t we use local solar time instead of time zones in our everyday lives? Would it be easy to know what time your favourite TV program starts?**
- **Why do time zones generally run north–south instead of east–west?**
- **Does a sundial work the same north and south of the equator?**
- **What would be different about a sundial at the North Pole? The South Pole?**
- **Why didn’t the ancient Egyptians use watches instead of sundials and obelisks?**
- **Would your sundial read the same time as another sundial one hundred kilometres directly north of you? Would the shadows be the same length?**

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The solar system

The solar system is composed of a number of celestial objects including:

- a star we call 'the Sun'
- the seven planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto and their satellites (called 'moons')
- asteroids
- comets
- meteoroids
- interplanetary media.

Only brief comments about aspects of the solar system will be given here, as there are a number of excellent websites that provide a plethora of information. The websites provide up-to-date pictures and information about the celestial bodies present in the solar system.

Websites about the solar system

Cassini: voyage to Saturn

http://www.jpl.nasa.gov/cassini/
One of a number of NASA websites, containing excellent graphics.

Cambridge astronomy

http://www.ast.cam.ac.uk/
Images within this site have been taken from the Hubble Telescope.

Nine Planets

http://www.anu.edu.au/Physics/nineplanets/nineplanets.html
A comprehensive site providing the history, mythology and current scientific knowledge of each of the planets and their satellites in the solar system.

NASA resources on the solar system

http://pds.jpl.nasa.gov/planets/
Information on each of the planets that includes the most up-to-date images of features of the planets.

Exploring our solar system and beyond

http://www.soest.hawaii.edu/SPACEGRANT/class_acts/
Directory of websites on the solar system and individual planets.

Planetarium

http://www.mov.vic.gov.au/planetarium/index.html
The Melbourne Planetarium is now part of 'Scienceworks'. In addition to information about the solar system, this site provides information about what can be observed in Melbourne's night skies in the current month.

Planet scapes

http://planetscapes.com/
Comprehensive site that gives details and images of the solar system.

Windows to the universe

http://www.windows.ucar.edu/
Provides information at both an intermediate and advanced level.

Views of the Solar System.

http://www.solarviews.com/
This site provides a multimedia view of the solar system.

The Planets

http://www.bbc.co.uk/planets/
This site is a comprehensive guide to astronomy sites on the Internet. There are space exploration, astronomy and solar system websites. Each of the planets is examined and students can play a game called the 'Great Space Race'.

All About Atoms

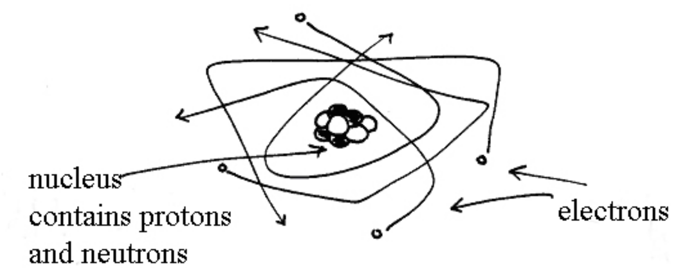
http://www.cebaf.gov/services/pced/atomtour/listofparticles.html
This site uses graphics to explain the parts of an atom.

To understand some of the processes that occur in our solar system and beyond it will be necessary to consider the following concepts.

Atoms

Atoms are the building blocks of all matter in the universe. Most of the mass is contained at the centre, called the 'nucleus', surrounded by small negatively charged particles called 'electrons'. The nucleus contains positively charged protons with neutrally charged neutrons. Most of the atom is space (see Figure 26).

FIGURE 26: MODEL OF THE ATOM



An element is matter that contains the same type of atom. Hydrogen is an element with the lightest of atoms; it is also the most abundant element in the universe. An atom is named according to how many protons it has in its nucleus. Hydrogen atoms have only one proton, whereas an atom of iron has 26 protons and an atom of uranium has 92 protons. There are well over 100 different elements. Atoms can contain differing numbers of neutrons as well. A uranium atom has 92 protons but may contain 143 or 148 neutrons. Different atoms that have the same number of protons but different numbers of neutrons are called 'isotopes'.

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Nuclear fusion

Nuclear fusion is a process where new nuclei are formed from the combining, or fusing, of smaller nuclei. This occurs within the cores of stars as well as in the explosions that occur in hydrogen bombs. Quite simply, nuclear fusion is where the nuclei of smaller atoms combine to form nuclei of larger atoms. Within the Sun, and the hydrogen bomb, the nuclear fusion reaction that occurs is where four hydrogen nuclei join together to form a helium nucleus. In the reaction, an enormous amount of energy is released. This is because some of the matter has been converted into pure energy as, according to Einstein's famous energy equation, $E = mc^2$. In this equation, E is energy, m is mass and c is the speed of light. Given that the speed of light is enormous (300 000 000 km/h), a very tiny amount of matter will convert to enormous amounts of energy.

Electromagnetic radiation

Stars give off visible light that is only a small part of what is termed the 'electromagnetic spectrum'. Visible light is electromagnetic radiation of a small range of energy. Electromagnetic radiation of different energies (in increasing order of energy) are radio waves, microwaves, infra-red radiation, visible light, ultraviolet radiation, X-rays and gamma radiation. Stars may give off any combination of these different types of radiation. Stars can therefore be 'seen' by looking at them in the visible part of the electromagnetic spectrum. However, to do so requires different types of telescopes. You should be familiar with the telescopes that concentrate visible light through lenses or mirrors. The Hubble Telescope concentrates visible light by reflecting it off a large curved mirror. To observe stars that give off radio waves we employ large parabolic dishes, called 'radio telescopes', such as that used in the recent film, *The Dish*.

The Sun

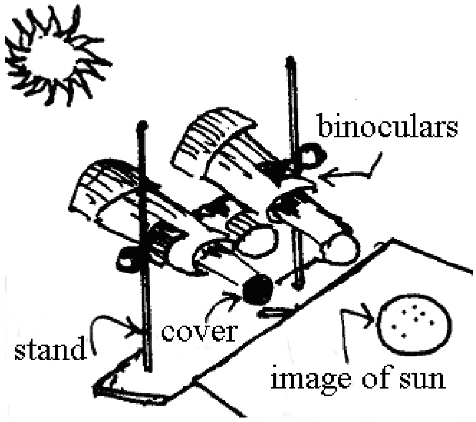
The Sun is best characterised as a typical star and is classified as a 'yellow dwarf'. It is one of 100 000 million stars that make up the galaxy we call the 'Milky Way'. Like other stars, it gives out energy produced by powerful nuclear reactions within its core. The temperature within the core of the Sun is about 15 million ˚C, compared with 6000 ˚C at its surface.

Within the core of the Sun, nuclear reactions take place. In the nuclear reactions, called 'nuclear fusion', the nuclei of the lightest atoms in the universe (hydrogen) combine to form bigger nuclei of heavier atoms (helium). About 600 million tonnes of hydrogen are converted to helium every second. This has been happening for about five billion years and will continue for another five billion years. The mass of the helium particles is less than the total mass of the hydrogen particles that make them.

The energy produced through the nuclear reactions radiates away from the Sun as electromagnetic radiation of varying energies. These include radiant heat, radio waves, visible light, ultraviolet light, X-rays and gamma rays. The Sun also emits cosmic rays that are charged particles such as electrons and protons. Cosmic rays travel at tremendous speeds to all parts of the solar system, including Earth.

The Sun dominates the gravitational field of the solar system; it contains 99.85 per cent of the solar system's mass. The Sun has no distinct surface. Like the planets, the Sun spins on its axis. However, it spins faster at the equator than at its poles. The polar regions take about thirty-four days to make a complete turn, whereas the equator takes about twenty-five days for one revolution. The Sun regularly contains sunspots that last for varying periods of a couple of weeks. These sunspots are areas on the surface of the Sun that are at a lower temperature (around 2000 ˚C cooler) and so appear darker than other areas in pictures taken of the Sun.

FIGURE 27: OBSERVING SUNSPOTS



ACTIVITY: FOLLOW THE SUNSPOTS

Warning: It is not safe to look at the Sun at any time. Sunglasses or welding goggles do not provide protection from eye damage. The following activity can be dangerous as it uses a telescope or binoculars to focus on the Sun. Looking at the Sun through a telescope or binocular is extremely dangerous and should not be undertaken at any time.

You will need:

- **binoculars or a telescope**
- **a mount**
- **cardboard.**

Project the image of the Sun onto a piece of card using a mounted pair of binoculars or a telescope. Locate the sunspots and draw them on a daily basis of thirty or more days. What can you notice when you look at changes from day to day? Do all the sunspots move at the same rate? Did any sunspots reappear after rotating out of sight behind the Sun? What does this tell you about the period of rotation of the Sun?

An interesting website about the Sun is 'The virtual tour of the Sun: astronomy' <http://www.astro.uva.nl/~michielb/sun/kaft.htm>.

A solar eclipse occurs on Earth when the Moon, Earth and Sun all lie in the one straight line. This occurs only rarely and so the plane of revolution of the Moon around Earth does not exactly match that of the plane of revolution of Earth around the Sun. If it did, then there would be a solar eclipse every month. The website 'Solar Eclipses' <http://www.solar-eclipse.org/en99/tutorials/tutorials/index.html> explains the phenomenon of solar eclipses using recent images from previous solar eclipses.

Planets and their satellites

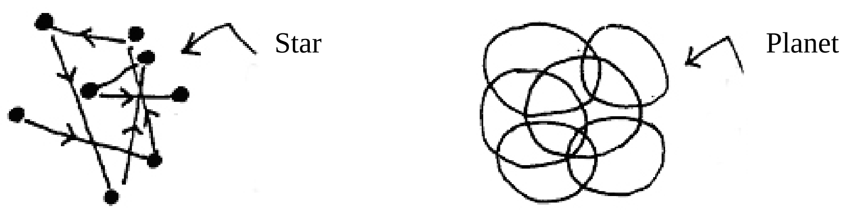
The planets, most of the satellites (or moons) of the planets, and the asteroids revolve around the Sun in the same direction, in nearly circular orbits. The Sun and the planets rotate on their axes. The planets orbit the Sun in or near the same plane, called the 'ecliptic'. Pluto is a special case in that its orbit is the most highly inclined (17˚) and the most highly elliptical of all the planets. Because of this, for part of its orbit, Pluto is closer to the Sun than is Neptune. A three-dimensional diagram of the orbits of the planets can be seen at 'Orbital paths of the planets' <http://liftoff.msfc.nasa.gov/academy/space/solarsystem/solarsystemjava.html>.

A star or planet?

From earliest times humans have seen regularity in the appearance and motion of celestial objects. The appearance of certain constellations foretold the coming of seasons. Whereas the stars always held the same position in the same constellation, five supposed stars did not. These were the planets. 'Planet' was a name Greek astronomers used to refer to wanderers or wandering stars. The five wandering stars of ancient times were the planets we call Mercury, Venus, Mars, Jupiter and Saturn (the planets of Uranus and Pluto cannot be seen with the naked eye).

Another difference between these planets and the other stars seen at night is that they do not twinkle. This is because the stars may be considered to be point sources of light, whereas the planets are small discs. The constantly changing atmosphere of Earth changes the direction of the light coming from celestial objects. As can be seen in Figure 28, the point source from a star moves about erratically and is observed as a star twinkling. The disc of the planet also moves around erratically but there is still some overlap of the disc and so planets do not twinkle (however, in some atmospheric conditions, planets twinkle as well). In space, away from Earth's atmosphere, the stars appear as point sources of light and do not twinkle.

FIGURE 28: STARS TWINKLE, PLANETS DO NOT



The changing position of the bright spot appears as a twinkling star

The overlap of discs maintains a bright spot

Planetary types

The terrestrial planets are Mercury, Venus, Earth and Mars. They are called 'terrestrial planets', because they have a compact, rocky surface like Earth. The terrestrial planets are the four innermost planets of the solar system and are also referred to as the inner planets or inferior planets. Of the terrestrial planets, Venus, Earth and Mars have significant atmospheres.

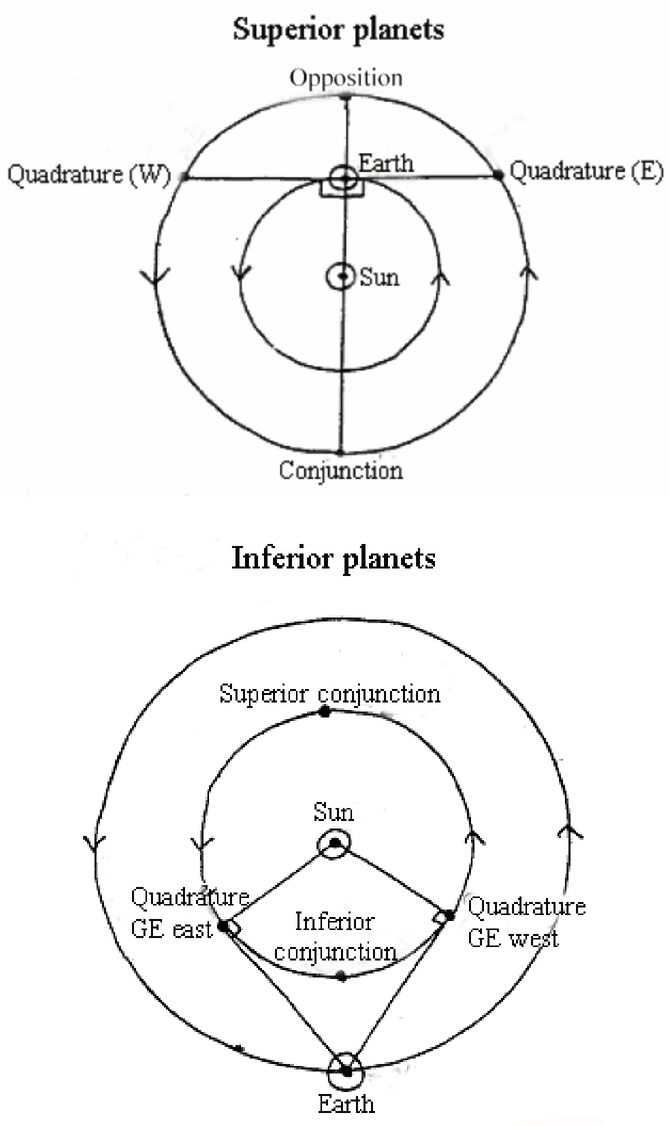
Jupiter, Saturn and Neptune are known as the 'Jovian' (Jupiter-like) planets, because they are all gigantic compared to Earth, and they have a gaseous nature. The Jovian planets are also referred to as the 'gas planets'. As these planets reside outside the orbit of Earth, they are also referred to as the 'outer planets' or 'superior planets'.

Planetary positions

Specific positions of the planets relative to Earth and the Sun are termed 'conjunction', 'quadrature' and 'opposition'. A superior planet is said to be in conjunction when the planet, Earth and Sun form a straight line with the Sun at the centre. If Earth is at the centre of this line, the planet is said to be 'in opposition'. The general term to describe an alignment of the Sun, Earth and another celestial object in a straight line is 'syzygy'. There are two positions in the orbit of a superior planet that are termed 'quadrature', when the Sun, planet and Earth angle is exactly 90˚. See Figure 29.

In the case of an inferior planet, where Earth and the Sun form a straight line, inferior conjunction occurs when the planet is at the centre and superior conjunction occurs when the Sun is at the centre. The positions of quadrature are defined in the same way as that for a superior planet. See Figure 29.

FIGURE 29: PLANETARY POSITIONS



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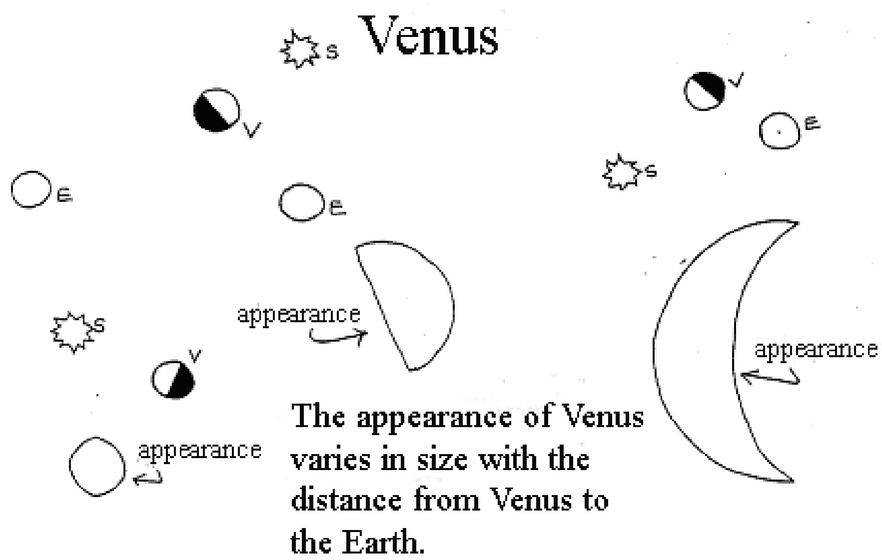
Phases and retrograde motion of the planets

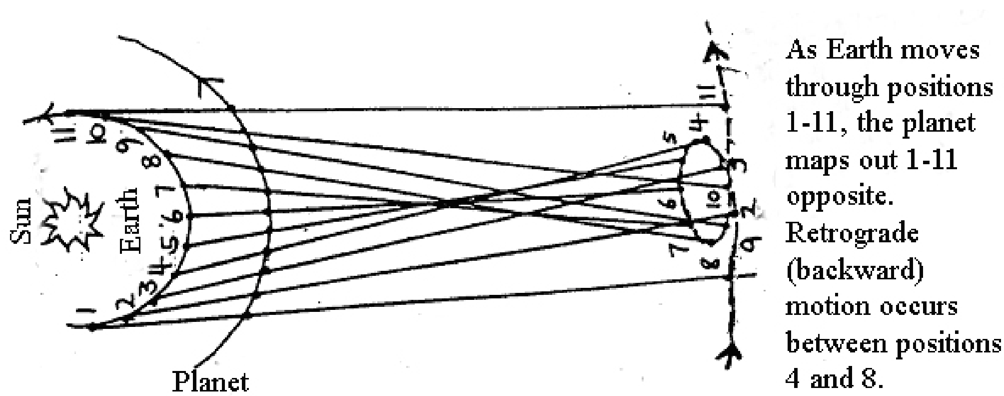
The inferior planets, because they are closer to the Sun, undergo phase changes similar to that of the Moon. The planets do not emit their own light and can only reflect light from the Sun. The Sun will only illuminate half of each planet, as they are all spherical. When a planet is in quadrature (see Figure 29), an observer from Earth will observe the planet as half illuminated and half in darkness. To the naked eye, the planet appears to be whole, but through a telescope the planet will appear to be a semicircular illuminated disc. That is, it will be 'in phase'. As the planet moves to inferior conjunction, its phase will become more acute. See Figure 30. For a superior planet, an observer from Earth will always see a fully illuminated disc through a telescope.

FIGURE 30: PHASE CHANGES FOR AN INFERIOR PLANET



The orbital motion of a planet is said to be direct when moving from west to east. This occurs nightly and over the period of the year for each of the stars. However, planets can, at times, move from east to west. Such motion is called 'retrograde motion'. Retrograde motion occurs when the planet is in opposition (see Figure 31). As Earth passes a planet in its orbit around the Sun, the planet appears to move backwards in the sky relative to the motion of the stars. This effect is shown in Figure 31.

FIGURE 32: RETROGRADE MOTION OF A PLANET



ACTIVITY: HOW DOES THE SOLAR SYSTEM LOOK TONIGHT?

You will need:

- **a large piece of cardboard**
- **models of the planets, the Sun and the Moon (not to scale), or labels for each**

Refer to the 'Ephemeris' site (below) to determine the right ascension of all the planets, the Sun and the Moon at midnight today.

Ephemeris

<http://ecco.bsee.swin.edu.au/cgi-bin/uncgi/Solar/action?sys=-Sf>

Make up little models (not to size) or labels for each of the planets, the Sun and the Moon. Place Earth at the centre of the cardboard. Now, imagine that Earth is at the centre of a 24-hour clock face and then draw radial lines for each hour. Then, based on the right ascension coordinates of the planets, Sun and Moon on the celestial sphere, place them in appropriate positions around Earth. Ensure that the celestial bodies are in the correct order in terms of their distance from Earth.

Determine the sidereal time at midnight tonight (this can be determined by referring to Table 2). Which of the planets, or Moon, will be visible in the night sky from your model? (Objects that are six hours either side of the sidereal time will be visible in the night sky.)

Refer back to the 'Ephemeris' site to determine the positions on another day, say one month or six months from now.

Teaching note: Various models can be made to represent planetary distances and sizes. Here are just a few.

ACTIVITY: PLANETARY MODELS—COMPARING DISTANCES

You will need:

- **a metre rule or tape measure**
- **a ball of string**
- **markers showing the names of the planets**
- **two or three rolls of toilet paper.**

Using the distances of the planets to the Sun in astronomical units (AU) (in the table below 1 AU = distance from Earth to Sun), you can produce a distance model where 1 m = 1 AU. Fix the end of the string in a suitable position and place the Sun marker here. Measure the distances of the planets from the Sun along the string, using the table below. Mark them appropriately. In this model the nearest star would be 260 km away! (It is actually over 40 million million km away).

Another model can be made out of units of toilet paper. On this scale one square of toilet paper = 10 million km. Using the table below, mark the Sun and measure the distances from the Sun along the toilet paper. In this model, you would need more than four million sheets of toilet paper, or 10 000 rolls!

TABLE: DISTANCES OF PLANETS

Planet	Sun distance (million km)	Sun distance (AU)	Scale distance (m)	Scale distance (toilet paper sheets)
Mercury	57.9	0.40	0.4	6
Venus	108.2	0.70	0.7	11
Earth	149.6	1.00	1.0	15
Mars	227.9	1.50	1.5	23
Jupiter	778.3	5.20	5.2	78
Saturn	1427.0	9.50	9.5	143
Uranus	2869.6	19.20	19.2	287
Neptune	4496.7	30.0	30.0	450
Pluto	5899.0	39.50	39.5	590

ACTIVITY: PLANETARY MODELS—COMPARING DIAMETERS AND DISTANCES

You will need:

- **aluminium foil**
- **sticky tape or Blu-Tack**
- **different sized balls**
- **butcher's paper**
- **a metre rule or measuring tape.**

To visualise how spread out the solar system really is, cut out of aluminium foil a circle of 5.5 cm diameter and stick it to one end of a wall or fence (you may need to be in the schoolyard or on an oval for this activity). Take 475 steps away from this circle. This is how Earth looks from the Sun.

Use different types of balls to put this into perspective with the other planets. For example:

- **Mercury is marble-sized and 1m away from the Sun**
- **Venus is a tennis ball and 2 m away**
- **Earth is a tennis ball and 2.5 m away**
- **Mars is a ping-pong ball and 4 m away**
- **Jupiter is a basketball and 13 m away**
- **Saturn is a volleyball and 24 m away**
- **Uranus is a baseball and 50 m away**
- **Neptune is a baseball and 77 m away**
- **Pluto is a marble and 100 m away from the Sun.**

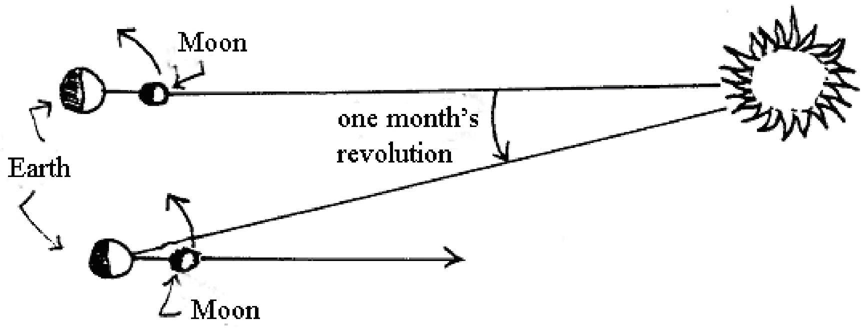
To get some idea of the true scale of the solar system, cut out from butcher's paper a circle (12 mm diameter) to represent Earth. Compared to this, how big is the Moon? How big is the Sun? (One is only 4 mm, while the other is 1.382 m in diameter.)

Cut out the other planets to this scale as well: Mercury is 5 mm, Venus 12 mm, Mars 7 mm, Jupiter 139 mm, Saturn 115 mm, Uranus 51 mm, Neptune 50 mm, and Pluto would be 6 mm.

Moon

Earth's only natural satellite is called 'the Moon'. Being a satellite, it revolves around Earth on a regular basis. The period of revolution can be defined in two ways: as giving rise to a sidereal period or sidereal month and a synodic month. The sidereal month is the time for the Moon to revolve around Earth with respect to the stars and is 27.3 days long. By the time the Moon has made one revolution with respect to the stars, Earth has moved about one-thirteenth of the way around the Sun. Thus, for the Moon to make one full revolution with respect to Earth, a period called the 'synodic month', it must travel for a longer time than given by the sidereal month. The synodic month is 29.5 days (see Figure 32).

FIGURE 32: SIDEREAL AND SYNODIC MONTHS



As well as revolving around Earth, the Moon rotates about its axis. This rotation is the same period as the synodic month. The Moon rotates on its axis at the same rate as it revolves around Earth. This means that an observer on Earth will always see only one side of the Moon. The reason for this is that Earth's gravity has locked onto a bulge in the distribution of the lunar mass, thus preventing the Moon from rotating freely.

To simulate the motion of the Moon as it revolves and rotates, consider the following role-play.

ACTIVITY: ROLE-PLAY OF THE MOON'S MOTION

You will need:

- **students to represent Earth, the Moon and the twelve signs of the zodiac.**

A person acting as Earth stands at the centre of a room. Surrounding Earth, at a distance of a few metres, are twelve people each representing a different zodiacal constellation. In order, these are Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricorn and Aquarius. To complete the simulation, a person acts as the Moon. This person will move around the Earth person at a distance of about one metre.

Now, if the Moon person moves around the Earth person in a direction to the front of the room, the Moon will have completed one revolution without rotating. In this situation the Moon person will continue to see the same constellation throughout the revolution. However, if the Moon person moves around the Earth person while at the same time locked in a direction towards Earth, the Moon person will have completed one revolution and one rotation. One full rotation is noticeable as during the motion each of the constellations is seen just once.

This role-play can become quite complex, if you incorporate a Sun. Apart from Earth rotating on its axis, Earth and the Moon will revolve around the Sun. Try it!

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ACTIVITY: A MODEL OF THE EARTH AND MOON

You will need:

- **modelling clay (a handful)**
- **a ruler**
- **a calculator.**

This activity is designed to test another person's perceptions of the relative sizes of the Moon and Earth, as well as their separation compared to their relative sizes. Provide the person with a handful of modelling clay. Ask them to divide the clay into two spheres so that one approximates the size of Earth and the other the size of the Moon so that both are in relative proportions to the actual Earth and Moon.

In terms of actual volume, Earth is fifty times the volume of the Moon. Therefore, to approximate the relative sizes of Earth and Moon, divide the modelling clay (about the same handful used by the person) into fifty equal parts. One part is used to form the Moon, while the other forty-nine parts are combined to form into Earth. Compare this model with the initial attempt.

Ask the person to predict the ratio of Earth's diameter to that of the Moon based on their observation of the models of Earth and Moon. Based on the actual diameters (Moon 3500 km and Earth 12 800 km), the ratio is approximately 4:1 (or, more accurately, 3.7:1).

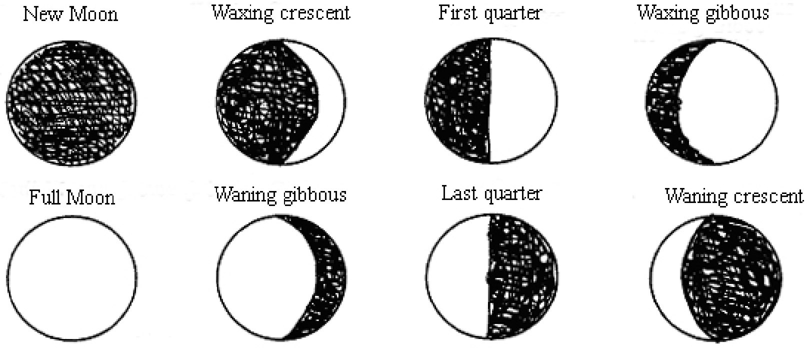
Using the models of Earth and Moon (50:1 ratio) get the person to place them at a distance to represent the actual Earth–Moon distance. The actual distance is about thirty Earth diameters. Place the models at this distance and compare with the estimated distance. Most people are amazed at the relative sizes of the Moon and Earth their separation. It is no wonder that eclipses are rare!

Now ask where the nearest planet would be (Venus) in relation to the model formed. At its closest approach, Venus is about 3000 Earth diameters away!

Phases of the Moon

Over the period of the synodic month, the Moon will be in different parts of the sky and in various phases. As the plane of the Moon's orbit around Earth is close to that of Earth's orbit around the Sun, the Moon follows approximately the same path in the sky as does the Sun. That is, it follows the ecliptic. The phases of the Moon (described in Figure 33) are due to the relative positions of the Sun, Moon and Earth and the fact that the Moon is not luminous and so only half of it is illuminated by that Sun. An animation that shows how the phases of the Moon occur is at the website 'Phases of the Moon' <http://www.astro.wisc.edu/~dolan/java/MoonPhase.html>.

FIGURE 33: MOON PHASES



ACTIVITY: PHASES OF THE MOON MODEL

This activity produces a model that demonstrates the phases of the Moon.

You will need:

- **a shoe box**
- **a Stanley knife**
- **a polystyrene ball**
- **wire**
- **black and grey paints or black cardboard**
- **a torch.**

Paint your shoe box black inside and out. Alternatively, you could cover it with black cardboard. Paint the polystyrene ball (Moon) dark grey. This is the colour of the Moon. Suspend the Moon so it is located in the centre of the box using the wire. On one end of the box cut out a hole large enough for the head of a torch to fit. Then, around each side of the box cut out small observation holes. Turn on the torch and observe the phase of the Moon inside the box.

FIGURE: PHASES OF THE MOON MODEL

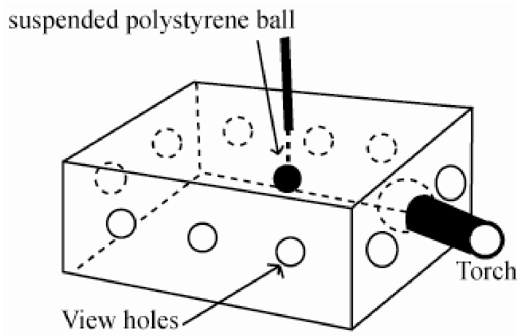
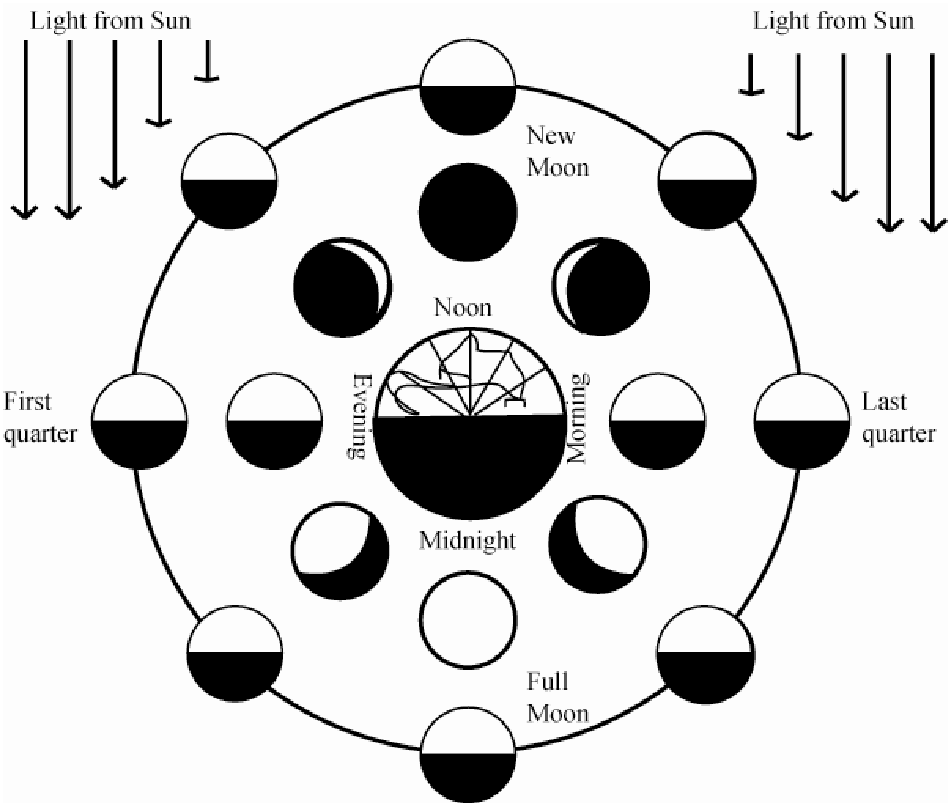


FIGURE 34: PHASES OF THE MOON



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ACTIVITY: WHERE IS THE MOON?

Using Figure 34, answer the following questions:

- **When the Moon is closest to the Sun, what is its phase?**
- **When the Moon is in orbit travelling towards the Sun is it waxing or waning? Draw diagrams to explain.**
- **Is it true that the Moon only comes out at night? Explain your answer.**

Tides

Earth's tides are due to the gravitational pull of the Moon, and to a lesser extent the Sun, on the oceans of Earth. To understand how this comes about, you need to consider that as the Moon revolves around Earth, Earth in turn revolves around the Moon. Earth and the Moon circle about their common centre of mass.

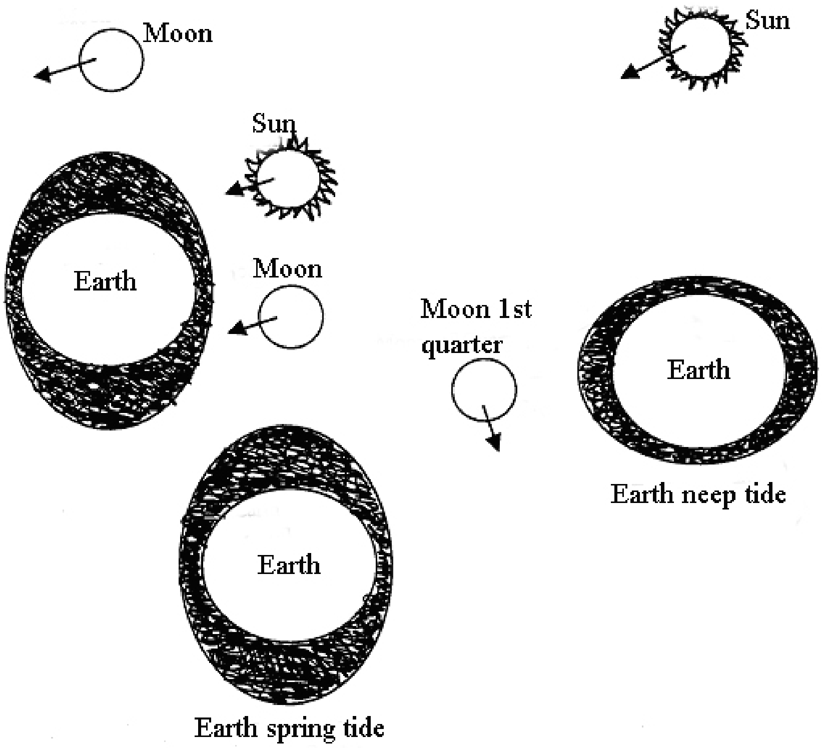
To understand a centre of mass, imagine a seesaw that holds a heavy child on one end and a light child on the other. By placing the heavy child closer to the pivot than the lighter child, the seesaw can be balanced. If the seesaw is balanced, the pivot point is called the 'centre of mass'. Now imagine that the balanced seesaw can rotate horizontally about its pivot point or centre of mass. In this situation both children are circling their common centre of mass. This also occurs with the Earth–Moon system, where the centre of mass is much closer to Earth than the Moon because Earth is heavier than the Moon.

As Earth revolves around the centre of mass of the Earth–Moon system, the Moon has a gravitational force of attraction on it. However, because of the size of Earth, the oceans that are closer to the Moon will have a slightly greater gravitational force on them than the main body of Earth. In addition, the oceans on the far side of Earth will have a gravitational force that is slightly less.

For a given speed, the greater the gravitational force on a revolving celestial object, the smaller its orbit will be. As the oceans and the main body of Earth are travelling at the same speed, the oceans near the Moon will move in a smaller orbit than the main body of Earth. Also, the oceans on the far side of Earth will move in a slightly greater orbit. This all means that the oceans on both sides of Earth bulge outwards.

This bulging effect stays in place as Earth rotates and so every twenty-four hours each place on Earth experiences a high tide twice. However, because of frictional effects in dragging around the bulge of water, the high tides do not occur directly in line with the Moon. Changes in the sea floor and the shape of land masses also affect the times and sizes of high and low tides at any place on Earth. The Sun's gravitational force of attraction also produces tides (about one-third the effect of the Moon). At new Moon and full Moon the effect of the Sun and Moon combine to produce larger than normal tides, called 'spring tides'. During the last and first quarters, the gravitational pull of the Sun negates the effect of the Moon and the tides are smaller than usual. Such tides are called 'neap tides'. See Figure 35.

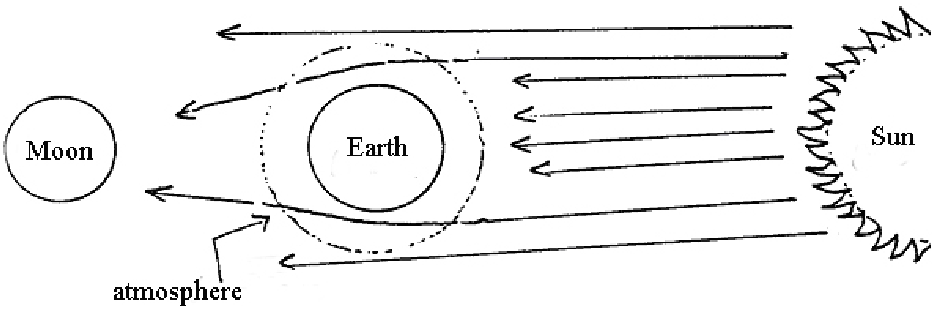
FIGURE 35:
TIDES



Lunar eclipse

As with solar eclipses, a lunar eclipse occurs when the Sun, Moon and Earth are in syzygy. For a lunar eclipse, Earth is in the centre. A full lunar eclipse is quite different to a full solar eclipse as the Moon can still be seen, whereas the Sun disappears. The reason for this is that Earth’s atmosphere acts like a lens so that light from the Sun is bent by Earth’s atmosphere and reaches the Moon even though Earth is directly in front of the Moon. As red light bends the most, the Moon appears red during the eclipse. See Figure 36. The website ‘Lunar eclipse’ <http://www.abc.net.au/science/space/moon/default.htm> provides information about lunar eclipses.

FIGURE 36:
LUNAR ECLIPSE



Asteroids, comets and interplanetary matter

Asteroids, also called ‘minor planets’, are rocky objects in orbit around the Sun. Most asteroids orbit the Sun between Mars and Jupiter, moving in the same direction as the planets. A current theory of the formation of the solar system suggests that the asteroid belt between Mars and Jupiter would have condensed into a planet had it not been for the strong gravitational forces from Jupiter. The huge gravitational pull of Jupiter accelerated these asteroids to about five kilometres per second—too fast to prevent violent collisions. Otherwise, they might have joined up to form ‘real’ planets. When asteroids collide, fragments sometimes are sent on a collision course with Earth and become meteors.

Asteroids range in size from a diameter of 1000 km, down to the size of pebbles. Sixteen asteroids have a diameter of 240 km or greater. Some asteroids, called ‘Apollo asteroids’, cross the orbit of Earth. It has been estimated that there are around a thousand Earth-crossing asteroids with a diameter of a kilometre or more.

Most comets are believed to be composed of rocky material and water ice. A few have highly elliptical orbits that bring them very close to the Sun and swing them deeply into space, often beyond the orbit of Pluto. The most widely accepted theory of the origin of comets is that there is a huge cloud of comets called the ‘Oort cloud’, of many billions of comets, orbiting the Sun at a distance of about 50 000 AU (just under a light year). These comets are near the boundary between the gravitational forces of the Sun and the gravitational forces of other stars with which the Sun comes into stellar proximity every several thousand years. According to theory, these stellar passings disrupt the orbits of the comets within the Oort cloud. As a result, some comets may be captured by the visiting star, some may be lost to interstellar space, and some may begin to ‘fall’ towards the Sun.

Comet Hyakutake can be seen in Victorian skies. It is between ten and twenty kilometres across and orbits the Sun every 15 000 years. It can be seen from anywhere in Victoria where night conditions are clear. It is the brightest ‘star’ in the northern sky until 5 or 6 am. See (http://www.jpl.nasa.gov/comet/hyakutake/index.html).

Meteoroids are small, often microscopic, solid particles in orbit around the Sun. We see meteoroids as bright meteors when they enter Earth’s atmosphere at high speed as they burn up from frictional heat. Any part of a meteor that reaches the ground is called a ‘meteorite’.

Nearly all the solar system by volume appears to be an empty void. Far from being nothingness, this vacuum of ‘space’ comprises interplanetary media. It includes various forms of electromagnetic radiation and at least two material components: interplanetary dust and interplanetary gas. Interplanetary dust consists of microscopic particles. Interplanetary gas is a flow of gas and charged particles, mostly protons and electrons—plasma—which stream from the Sun, called a ‘solar wind’.

Origin of the solar system

The age of our solar system is believed to be five billion years old, with Earth 4.6 billion years old. This has been calculated by determining the age of rocks on Earth and the Moon and, in particular, meteorites. The main method of determining the age of rocks has been to analyse their chemical content of radioactive materials and the accumulated decay products.

The solar system exhibits a number of regularities, and theories of its formation must account for them. These regularities include:

- the orbits of the planets are almost circular
- all the planets revolve around the Sun in the same direction, which is the same direction as the Sun rotates
- all the planets and planetary satellites rotate in the same direction
- some planets have satellites that revolve around them in the same manner as the planets revolve around the Sun.

A number of theories have been suggested as to the origin of the solar system. The current theory suggests the Sun and the planets were born from the dust and gas that littered space. Similar interstellar clouds of dust and gas, called 'nebula', can now be detected in many locations of our galaxy. The dust and gas in the nebula that formed our solar system were remnants from earlier supernova explosions of stars, as there are heavy elements such as iron and uranium present today. Such elements can only form within large stars, much larger than our present Sun.

The formation of the solar system began as the interstellar gas cloud collapsed under its own gravity. The gas falling inwards created a rotating eddy, like water emptying from a basin. The rotating gas flattened into a thin spinning disc with a higher concentration of the gas in the centre. The condensing gas at the centre converted gravitational potential energy into kinetic energy. The faster gas particles meant that the gas became hotter. The temperature within the centre of the disc became so great that nuclear reactions began. This stopped further contraction of the nebula and the Sun was created.

While the Sun was forming, the outer parts of the disc broke up into whirlpools of gas and dust, thus forming the planets and their satellites (moons). Each newborn planet was wrapped in a thick layer of atmosphere. However, radiation from the newly glowing Sun acted on the inner planets, blowing the lighter gases away. This is why the inner planets (terrestrial planets) are more dense than the outer planets (Jovian planets).

The area between Mars and Jupiter did not condense into a planet, possibly due to the large gravitational effect of both the Sun and Jupiter. This left the asteroid belt. The radiation from the Sun blew gas away from the solar system, thus forming the Oort cloud which forms the comets. We see in the rings of Saturn and other planets how the solar system formed as a disc. Pluto and its satellite Chiron are different to the other planets in that they don't revolve on the same plane as the other planets. One theory suggests that Pluto and Chiron were once satellites of Neptune and were somehow displaced in their orbit. Another theory is that they were once comets that were displaced from their orbit through a collision with a planet.

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Beyond the solar system

Beyond the solar system there is a vast array of different celestial objects. These include stars in various stages of life from nebulae, white and red and brown dwarfs, red giants, white and yellow supergiants, black holes, nova, supernova, quasars, neutron stars, antimatter, galaxies and dark matter. A surf of the following sites give a lot of information, particularly the photographs.

Photographing the stars

http://www.aao.gov.au/images.html/
Photographs from the Anglo Australian Laboratory of Astronomy: galaxies, nebulae, supernovae, star clusters, unusual stars.

Origins: Galaxies, stars, planets ... and life

http://eis.jpl.nasa.gov/origins/
NASA explores the origins of our universe.

Stars

We now explore the evolution and various characteristics of stars. For most of the stars that we observe there are only two basic measurements that we can make. These are their brightness and the electromagnetic radiation they emit (this includes the colour of the star). Yet, with these two measurements and current theories, we can determine such characteristics as surface temperature, size, chemical composition, age, speed relative to Earth and distance from Earth. Consider the following websites.

Star stuff

http://www.starstuff.com/
Provides information about stars at many levels from primary school level and beyond.

Stars and universe

http://library.thinkquest.org/25763/

http://www.universetoday.com/html/directory/index.html
Includes links to many sites.

Cosmiverse online

http://www.cosmiverse.com/
A virtual journey into the universe.

Stanford Solar Centre

http://solar-center.stanford.edu/

The Sun

http://www.astro.uva.nl/demo/sun/kaft.htm

Extreme science: the Sun

http://www.extremescience.com/sun.htm

Life cycle of a star

Stars are born out of huge balls of condensing gas. The gas condenses because of gravitational attraction. When our galaxy was condensing, gas broke into smaller balls of gas that then became individual stars. The cluster of stars formed when our galaxy was beginning contains about 100 000 stars. These clusters are called ‘globular clusters’. Recently formed clusters do not contain as many stars (few thousand) and are termed ‘open clusters’.

A star forms when gas, which is mostly composed of hydrogen atoms, condenses due to gravitational attraction. At this time the potential energy of the gas particles converts into kinetic energy. The increased kinetic energy of the particles means they move about a lot more and so the temperature of the new star, called a ‘protostar’, increases.

As the protostar continues to condense, its core temperature and pressure increase to the point that nuclear fusion occurs. The basic fusion process fuses four hydrogen nuclei into one helium nucleus. In this process, a tremendous amount of energy is released in the form of electromagnetic radiation. One form of this electromagnetic radiation is the visible light and radiant heat we receive from our own star, the Sun.

At the point where nuclear fusion occurs, a star is born. The nuclear fusion process stops the star from collapsing any further. The more mass a star has, the hotter its core becomes before it generates enough pressure to counteract the gravity. The hotter core leads to a higher surface temperature. Different surface temperatures are observed as different colours.

The fate of a star depends on its mass at the formation stage. The following table provides the different properties and eventual fate of the different sized stars.

TABLE 3: FATE OF DIFFERENT STARS

Property of star		**When burning hydrogen**		**Eventual fate**	
Mass (cf Sun)	**Lifetime (million years)**	**Brightness (cf Sun)**	**Surface temp.**	**Initially expands to become**	**Core finally collapses to**
25	3	80 000	40 000 blue-white	white supergiant	black hole
16	15	10 000	33 000 blue-white	yellow supergiant	neutron star
6	100	600	17 000 white	orange giant	neutron star or white dwarf
3	500	60	9200 white	red giant	white dwarf
1.5	2000	6	6600 yellow-white	red giant	white dwarf
1	10 000	1	5500 yellow	red giant	white dwarf
0.8	20 000	0.4	4200 orange	red giant	white dwarf

Lightweight stars

As Table 3 shows, stars less than about four solar masses (one solar mass equals the mass of our Sun) have a similar fate. When the core of these stars have converted all their hydrogen into helium, the nuclear reactions cease and the core begins to cool. Before, the nuclear reactions ensured the star would not collapse under its own gravity and so, when the nuclear reactions cease, the core begins to collapse. This contraction changes gravitational potential energy into kinetic energy and so once again the core of the star heats up. Paradoxically, soon after the nuclear reactions in the core stops, the core becomes even hotter and nuclear reactions occur again within the core. This time the helium nuclei join together to form the larger nuclei of oxygen atoms. Some of the energy that is released goes into expanding the outer shell of the core. The outer shell still has hydrogen and so nuclear reactions occur at the same time as the shell is expanding. The star now looks red and is given the term ‘red giant’.

Eventually, the outer shell separates from the core to form nebulae once again. These nebulae are called ‘planetary nebulae’ because hundreds of years ago they appeared similar to the planets Uranus and Neptune when viewed through a small telescope. The core ceases its nuclear reactions and continues to contract. The core now consists of about two-thirds its original mass but compressed into a globe about the size of Earth. It becomes a ‘white dwarf’. One matchbox of matter in a white dwarf would weigh several tonnes! White dwarfs have some heat stored that they radiate as very faint stars. But, after some time, the white dwarf emits nothing and so becomes a burned-out hull called a ‘black dwarf’. It will be billions of years before our own Sun becomes a white dwarf and then many billions more before the black-dwarf stage.

Middleweight stars

Middleweight stars have masses between four and eight solar masses. These stars use up their stores of hydrogen very quickly and during the expansion of their outer shells, they become very bright and become ‘supergiants’. The core has more mass than lightweight stars and so the nuclear reactions continue so that larger and larger nuclei are formed. Eventually, the heavy nuclei of iron atoms are formed. Whereas the production of smaller nuclei creates energy, the formation of iron takes up energy. In this situation the temperature of the core drops and it begins to contract, still heating up more than before. Once the core is made up of iron, within a very short period of time a fantastic explosion occurs, called a ‘supernova’. The outer layers of the star are flung in all directions at incredible speeds of 15 000 km/h. At this point the explosion produces a brightness greater than a thousand million suns. Supernova outshine everything else in the sky except for the Sun and Moon. However, they fade after a few years. The supernova remnants contain nuclei of heavy elements that spread throughout the galaxy. The heavy nuclei present on Earth, and within our own bodies, were formed in a dying star long ago and came to us through a supernova explosion. Prior to our birth, we may or may not have been a twinkle in our parent’s eye but we were certainly a twinkle in the night sky!

While the outer shell of the star explodes, the inner core contracts further, producing fantastic temperatures and pressures. The protons and electrons within the core fuse together to produce neutrons. The core's density becomes greater than a white dwarf and is composed of neutrons. The core may be only 10 km in radius and yet could contain up to two or three solar masses. The star becomes a neutron star. A teaspoonful of neutron star could weigh as much as a billion tonnes!

Another common feature of neutron stars is the very large magnetic fields that surround them in the shape of a doughnut. As some neutron stars rotate, the rotating magnetic fields act like a dynamo and give off electromagnetic radiation in the form of radio waves. The orientation of the magnetic fields means that pulses of radio waves are emitted as the neutron star rotates (some pulse X-rays and gamma rays). When first discovered, these pulsating radio wave sources were called 'pulsars'. However, the latest theory suggests they are rotating neutron stars, leftover cores from a middleweight star.

Heavyweight stars

We have seen that the fate of a star's core with mass less than three solar masses is a very dense object, a dwarf star if the mass is less than 1.4 solar masses and a neutron star if larger. However, if the core exceeds three solar masses, the gravitational collapse may be so great that radiation from the star can no longer escape into space. The star has withdrawn from the observable universe, in that we can no longer receive radiation from it. We say that the star has become a 'black hole'. The contraction of the star may be that great that the outer shell may not explode into a supernova, instead contracting with the core to produce the black hole.

Evidence of black holes comes from the behaviour of stellar objects near them. Black holes, by virtue of their great gravitational pulling power, attract matter, and the matter accelerates towards them. Some of the matter will be pulled directly into the black hole, never to be seen again. But other matter will go into orbit around the black hole, and will orbit at great velocity. At great velocities this mass will give off great amounts of X-ray radiation that can be observed from Earth.

The theory of black holes developed when astronomers observed discs of great swirling mass that developed around what seemed to be nothing. The gravitational force that created this effect was determined to come from objects with masses larger than several solar masses, and yet astronomers observed nothing from the point in space where the large mass should exist. A feasible explanation was the massive gravitational collapse of a heavyweight star to produce a black hole. It would appear at first that black holes continue to attract matter and so would become greater and greater and eventually consume whole galaxies. However, a recent theory by the famous Cambridge physicist Stephen Hawking suggests that black holes do not last forever; they slowly 'evaporate'. A black hole gradually loses mass as an outward stream of electrons and other subatomic particles. As a result, it will become lighter and will eventually dissipate altogether.

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Colour and temperature of stars

The stars we see at night come in different colours. However, when we view stars at night they all appear the same colour. The reason for this is that the retinas of our eyes have two types of light-detecting cells: one type detects colours, while the other type detects shades of black and white. During dim conditions, as at night, the light is not strong enough for the coloured cells to be activated. Therefore, at night we see in shades of black and white.

The different colours of the stars provide information about their temperature. When you put an iron poker into a fire, it first glows dull red. Then it gets a brighter red and as it gets hotter it becomes yellower and then whiter. If the poker could get hotter without melting it would turn blue-white. Just as the poker goes through a series of colour changes depending on its temperature, the colour of a star will be determined by its temperature. The reddish star Betelguese, thus, is a comparatively cool star, while the blue-white star Sirius is very hot. The blue and white stars are hot (between 7500 C and 50 000 C); yellow stars, such as the Sun, are warm (between 5000 ˚C and 7500 ˚C); and orange and red stars are cool (between 2000 ˚C and 5000 ˚C).

Astronomers have divided up stars into seven main types, which can be best remembered with the mnemonic ‘oh, be a fine guy/girl, kiss me’. Table 4 describes each star type.

TABLE 4: STAR TYPES

Star type	Colour	Description	Example
O	Blue	Hottest and rare	
B	Blue-white	Hot and bright	Spica
A	White	Contribute most light in galaxy	Sirius
F	Yellow-white	A bit hotter than the Sun	Canopus
G	Yellow	Like our Sun	Alpha Centauri
K	Orange	Cooler than our Sun	Arcturus
M	Red	Cool	Betelguese

Distances to the stars

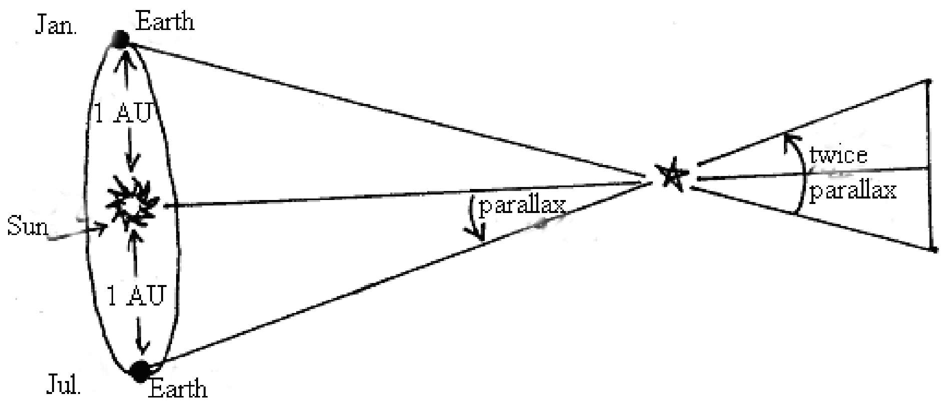
The distances to stars and other celestial objects outside the solar system are enormous and more convenient units of distances are used instead of kilometres. Within the solar system, distance measurements are sometimes given in astronomical units (AU). The astronomical unit is defined as the average distance Earth is away from the Sun. Therefore, 1AU = 150 000 000 km. While you may consider this distance large, it is very tiny when compared to the distances to stars within our own galaxy, the Milky Way, and to distant galaxies. For these distances, the ‘light year’ is used. The light year is the distance light will travel in a year. Given that light travels 300 000 000 km every second, then the light year is indeed an enormous distance. In terms of kilometres, one light year equals 9 500 000 000 000 km. To give you some idea of the vastness of our universe, see Table 5

TABLE 5: THE VASTNESS OF OUR UNIVERSE

Celestial Object	**Distance (light years)**
Nearest star (except Sun) to Earth	4.2
Length of Milky Way galaxy	100 000
Extent of universe	300 000 000

As well as using the light year, astronomers use the parsec. The parsec comes from a method to determine the distance to planets and nearby stars. This method is called ‘trigonometric parallax’. As Earth moves from one side of its orbit around the Sun, an observer will be seeing celestial objects from two different angles. This means that close objects, like planets, will appear to be in a different position relative to distant stars every six months. The same can be said for stars that are close to Earth. However, the nearby stars’ positions relative to distant stars are only marginally different. The straight line joining the points from which we observe the stars is called the ‘baseline’ (see Figure 37).

FIGURE 37: TRIGONOMETRIC PARALLAX



The baseline has a length of 2 AU. The angle that the star makes with the baseline is defined as twice the parallax. So by knowing the parallax angle and using trigonometry, you can calculate the distance to the star. As the distance to even nearby stars is very much larger then the baseline, the parallax is a very small angle. By definition, when an object is at a distance so that the parallax angle measures one second of arc (there are 3600 seconds in one degree), the distance to the object is one parsec (see Figure 37). One parsec is related to the light year by this relationship: 1 parsec = 3.26 light years in distance. Note that parsecs and light years are actual distances, just like kilometres and miles, even though their names contain references to their definition in terms of angles and time.

This trigonometric parallax method can only be used to measure the distances to nearby stars. However, by using very accurate instruments, distances as far as 200 light years away (60 parsecs) can be determined by this method.

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Brightness of stars

The most obvious feature of a star is brightness. The scale used to determine the brightness of a celestial body is complex and is called 'apparent magnitude'. Most of the stars that are observable at night range in apparent magnitude from a scale of 1 through to 6. A star of apparent magnitude 1 is brighter than a star of apparent magnitude 2 or 3. For each increase of 1 in magnitude the star is about two-and-a-half times less bright. Our Sun, Moon and some planets are brighter than the stars and so have negative apparent magnitudes. Table 6 gives the brightness of some celestial objects.

TABLE 6: BRIGHTNESS OF CELESTIAL OBJECTS

Celestial object	**Brightness (apparent magnitude)**
Sun	–26.8
Moon	–12.6
Venus (when closest to Earth)	–4.4
Mars (when closest to Earth)	–2.8
Sirius (brightest star)	–1.4
Canopus (2nd brightest star)	–0.7
Faintest star observable with naked eye	–6
Brightest quasar	–12.8
Maximum brightness of Pluto	–14.9
Faintest observable star from largest telescope on Earth	–24.5

You should notice from the table that the brightest objects in the night sky are the Moon and the planets of Venus and Mars.

While the apparent magnitudes of stars give a measure of how bright stars are to an observer from Earth, they do not give an indication of how bright the stars actually are. To make a comparison one would need to have stars at the same standard distance from Earth. The standard distance is 10 parsecs (32.6 light years). We define the absolute magnitude of a star as the brightness of the star if is was at a distance of 10 parsecs from the observer. Absolute magnitudes of stars range from –7 to +17. Our own Sun has an absolute magnitude of +5. This means if our Sun was at a distance of 10 parsecs from Earth, it would have an apparent magnitude of +5.

To determine the absolute magnitude of a star, you would need to know the distance of the star from Earth. The relationship between absolute magnitude, apparent magnitude and distance away is a complex mathematical relationship. But if you are mathematically inclined, the relationship is given by the formula $m - M = 5\log(r/10)$**,** where M is absolute magnitude, m is apparent magnitude and r is distance away (in parsecs).

Brightness and colour of stars

Astronomers have found a connection between the brightness and colour of stars. The brightness of a star (in terms of apparent magnitude) and the colour of a star can be readily determined from instruments on Earth. By knowing the colour of a star, astronomers can determine the surface temperature of the star which in turn gives a measure of the mass of the star.

Astronomers measured the distances to the nearest stars using the trigonometric parallax method and were then able to calculate their absolute brightness. They then graphed the brightness of these stars in terms of absolute magnitudes against their colour or surface temperature. Such a graph is called a ‘Hertzsprung-Russell diagram’. From this diagram, it was found that stars with the same colour had the same absolute magnitude in brightness. Therefore, an astronomer needs only to determine a distant star’s colour and apparent brightness to find the absolute brightness of the star and finally the distance to the star.

Galaxies

Galaxies are huge collections of stars held together by gravity to form an ‘island’ in space. The largest galaxies contain thousands of billions of stars and may be several thousand light years in diameter. The galaxy that contains our own solar system is called the ‘Milky Way galaxy’. It contains a few hundred billion stars. In spite of their great size, most galaxies can only be seen with the aid of telescopes. Only the nearest large galaxy, the Andromeda galaxy, and two small companions to the Milky Way, the Magellanic clouds, can be seen as faint patches of light in the sky with the unaided human eye. An estimated 50 billion galaxies are visible to modern telescopes.

Most galaxies are part of smaller clusters. These clusters may have a handful of galaxies or may contain hundreds of members. The smaller cluster of galaxies that contains our own Milky Way galaxy has two dozen or so members and is called the ‘Local Group’. However, small clusters of galaxies such as the Local Group are part of super clusters of galaxies that may contain as many as ten thousand galaxies. The super cluster of galaxies that contains our own Local Group is called the ‘Virgo super cluster’.

Most of the known galaxies are elliptical and may range from being nearly circular to very elongated. Another common shape is the spiral galaxy. Our Milky Way is spiral. Our own solar system is located on an outer arm, called the ‘Orion Arm’, of the Milky Way. Excellent telescopic pictures of different galaxies can be found at ‘Photographs from the Anglo Australian Observatory’ <http://www.aao.gov.au/images.html/general/galaxy_frames.html>.

The children’s storybook *My place in space* (Hirst 1988) provides a good astronomical story for children and adults, and offers enjoyable insight provides an enjoyable insight into our location within the universe. The story is about two children who provide a bus driver far more details of their home address than is necessary. They give their address as:

> ‘12 Main Road, Gumbridge, Australia, Southern Hemisphere … Earth … Solar System … Solar Neighbourhood … Orion Arm … Milky way Galaxy … Local Group of galaxies … Virgo Super Cluster … The Universe …’
>
> (Hirst 1988, p. 22)

Cosmology

Cosmology deals with the study of the universe as a whole. Therefore, aspects of cosmology are the theories of the formation and fate of the universe. Theories about an eternal and unchanging universe were widely held until the 1920s. However, the night sky is dark and so, if the universe was infinite, then every line of sight from an observer from Earth should end on the surface of a star. In this case the sky should not be dark but bright in all directions. This paradox came to be known as Olbers’ Paradox, named in honour of a nineteenth-century German astronomer, Heinrich Olbers, who wrote a landmark paper discussing the paradox.

The current, universally accepted, theory as to the formation of the universe is called the ‘big bang theory’. This theory suggests that the universe came into being at a definite moment in time some fifteen billion years ago, in the form of a superhot, superdense fireball of energetic radiation. The best evidence for this theory is that scientists have developed a technique to determine the speed of galaxies and have found that these galaxies are all moving away from each other. So the universe is expanding. Given this scenario, scientists have used the speeds of the galaxies to backtrack in time to a point when all mass was concentrated in one point.

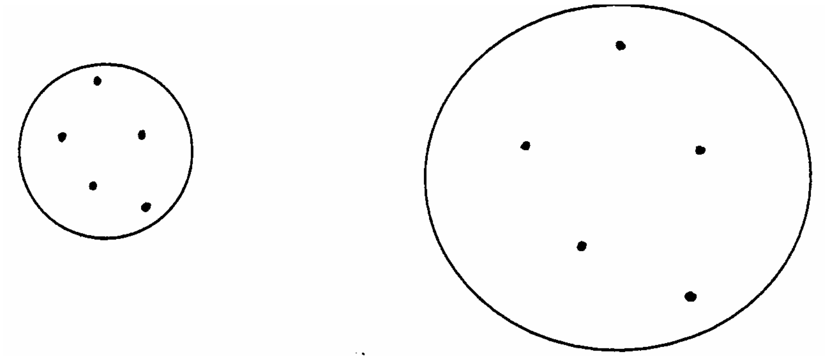
The theory suggests that minutes after the superdense fireball occurred, the universe began to expand rapidly. As it expanded the simplest atoms of the universe, hydrogen and helium, were formed. As the universe expanded, it cooled to allow the base elements of hydrogen and helium to condense into stars and galaxies. As the universe continued to expand, the original radiation cooled. Based on the present size of the universe, the big bang theory suggests that the temperature of the residual radiation should now be about 3° Kelvin (this is 3° hotter than the lowest temperature possible, being –273 ˚C). In recent times (1960s) this residual radiation, called the ‘cosmic background radiation’, has been found by scientists thus further confirming the big bang theory.

The biggest question that leads from the big bang theory is ‘what was there before it happened?’. According to Einstein’s theories, time and space are inextricably linked, so when the universe began, so did time. Therefore, time did not exist before the big bang!

The big bang theory also suggest that the galaxies are not expanding into space that already exists. Space is created as the universe expands. This idea can best be imagined from a balloon model. Imagine that all the galaxies are points on the surface of a balloon. The surface of the balloon represents space. It is important *not* to think of the air within the balloon as space. As the balloon is inflated, you can observe that points on the surface of the balloon (galaxies) are moving away from each other and, as the surface is increasing in area, this model demonstrates the increase in space. Just as the surface of the balloon has no central point (remember that you should not think of the air within the balloon as constituting space), then there is no centre of the universe either. The surface of the balloon is finite, just as the space within the universe is finite. In the model you can trace a straight path in any direction from a point on the surface directly back to your starting point. In our own universe if you travel in a straight line in any one direction, you will eventually reach your starting point.

Galaxies are represented by dots on the surface of the balloon. Space is represented by the surface of the balloon (not the air within the balloon).

FIGURE 38: A BALLOON MODEL OF AN EXPANDING UNIVERSE



A closed or open universe

While there is universal acceptance that the universe is expanding from a big bang, one of the unresolved problems in the expanding universe model is whether the universe is open or closed. An open universe will keep expanding forever and a closed universe will contract again, resulting in a big crunch. From the closed universe idea comes an oscillating universe theory where the universe oscillates in a cycle of big bang and expansion to contraction and big crunch.

A solution to this unresolved problem is to determine the density (amount of mass per unit volume of space) of the universe. If the universe contains enough matter for the space that it contains, then, after a period of time, the gravitational pull of this mass will result in the galaxies no longer receding from each other but advancing towards each other in a closed universe. However, if the density of the universe is low, then the gravitational pull of the mass may not be enough to stop the galaxies receding from each other, thus producing an open universe.

On present calculations of the amount of visible mass, the density is found to be only five to ten percent of the value required for a closed universe. Proponents of the closed universe theory suggest that substantial invisible matter, the so-called 'dark matter', inhabits the universe. Dark matter is the name given to the non-luminous material that cannot be detected by observing electromagnetic radiation. Determining if it exists, and in what quantity, is one of the most challenging problems for astronomers. There are several possible candidates for dark matter. These include black holes, undetected brown dwarf stars and exotic subatomic particles whose properties preclude detection by observing electromagnetic radiation.

The following websites provide further information about cosmology.

Expanding universe

http://www.mtrl.toronto.on.ca/centres/bsd/astronomy/index.html
A classified search tool for astronomy. Can be searched by browsing the topic headings or alphabetically.

Stephen Hawking's universe: physics & astronomy

http://www.pbs.org/wnet/hawking/html/home.html
The cosmos, universe, and mysteries; explanation of black holes; 'Ask the experts'; based on the TV series.

Space exploration

We have been exploring space for many years now and while we have only physically travelled to our nearest celestial neighbour, the Moon, we have sent probes to a number of planets. The global communication networks we enjoy today are attributed to the many artificial satellites we have sent into outer space to orbit Earth. The latest venture in outer space is the new International Space Station where scientists will be able to conduct an array of experiments in 'micro gravity' environments. In this section we will explore some of the objects that we send into outer space and some concepts related to their function. The following websites are related to space exploration in general:

Classroom of the future (COTF)

http://www.cotf.edu/
Contains information in relation to space exploration, among other things.

Centre for Earth and planetary studies

http://www.nasm.edu/ceps/
This site is a great collection of space shuttle photographs including Shark Bay, the Grand Canyon and Mt Etna, as well as the National Air and Space Museum.

Eye on the universe: the Hubble Space Telescope.

http://www.thetech.org/hyper/hubble/

http://www.thetech.org/exhibits_events/online/hubble/

NASA

http://quest.arc.nasa.gov/

NASA human spaceflight

http://station.nasa.gov/index-n.html

NASA news today

http://www.nasa.gov/today/index.html

NASA observatorium

http://observe.ivv.nasa.gov/
This public-access site for Earth and space data has pictures of Earth, planets and stars along with information on aeronautics, spaceflight and space science.

Mt Wilson Observatory

http://www.mtwilson.edu/
This site has some good information. The virtual tour of Mt Wilson Observatory is very good. It also has information on the Sun, different types of telescopes and the history of the area at Mt Wilson.

Space Telescope Science Institute (STScI)

http://www.stsci.edu/
The Space Telescope Science Institute (STScI) is the astronomical research centre responsible for operating the Hubble Space Telescope as an international observatory.

Space place

http://spaceplace.jpl.nasa.gov/spacepl.htm
A NASA site for students, about space and space travel.

Artificial satellites

Artificial satellites are objects (made by humans) that orbit Earth, the Sun, planets and their natural satellites (moons). The websites below provide a lot of information about artificial satellites:

Satellite site

http://www.thetech.org/exhibits_events/online/satellite/
All you ever wanted to know about satellites from the Tech Museum of Innovation.

Space satellites: stories from orbiting satellites

http://www.tui.edu/STO/Satellites.html

International space station overview

http://www.boeing.com/defense-space/space/spacestation/
overview/index.html

Space station: facts and figures

http://www.boeing.com/defense-space/space/spacestation/overview/facts.html
Several different types of satellites serve a number of functions. They are mainly used for:

- communications
- earth remote-sensing
- weather
- global positioning
- scientific research.

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Communication satellites

Communication satellites act as relay stations in space. There are more than one hundred communication satellites orbiting Earth. People use them to bounce messages from one part of the world to the other. These messages include telephone calls, television pictures and internet connections. Communication satellites are in geosynchronous orbits above Earth. This means that they orbit over the one spot above Earth's surface. The time for each revolution, or period of revolution, is therefore twenty-four hours. Scientists have found that the period of a satellite is related to its distance from the object that it is orbiting. This means that as all geosynchronous orbiting satellites have the same period then they are the same distance from Earth. This distance is 35 900 km above the surface of Earth. The area in which each communication satellite can receive and send signals is called the satellite's 'footprint'. Multiple communication satellites are placed so that their footprints overlap to cover the entire Earth's surface.

Earth remote-sensing satellites

Remote-sensing satellites study Earth's surface. At altitudes of about 480 km they scan Earth's surface using powerful cameras. These satellites send back data about Earth's environment such as plant cover, chemical composition and surface water. People who work in mining, farming and many other industries find the information very helpful. Scientists use the data from these satellites to monitor the changing face of Earth due to human influence, such as destruction of rainforests.

Weather satellites

Weather satellites record weather patterns around the world. We are very familiar with the satellite photographs displayed every night in the weather segment of the news. Scientists and meteorologists use information from a number of satellites in geosynchronous orbits to obtain a global picture of weather patterns. The information from satellites is incorporated into powerful computer models to forecast the weather.

Global positioning system satellites

The global positioning system (GPS) is a group of satellites that can tell you your exact latitude and longitude. The military developed the GPS initially but it is now used extensively for navigation almost everywhere on Earth.

Science research satellites

Many satellites in orbit conduct scientific experiments and observations. There are satellites that orbit other celestial bodies than Earth, for example, the Moon, Sun, Venus and Mars. There are satellites that house astronauts for various periods of time. These are called 'space stations'. One of the most famous space stations is the Russian-built MIR space station that was recently decommissioned and brought down to Earth. In its place is the very new International Space Station (ISS), which is still in its building phase.

ISS is an international space station involving the support of sixteen countries. In partnering to build and operate the ISS as a world-class research centre in the unique environment of space, the participating nations are striving to:

- find solutions to crucial problems in medicine, ecology and other areas of science
- lay the foundation for developing space-based commerce and enterprise
- create greater worldwide demand for space-related education at all levels
- foster world peace through high-profile, long-term international cooperation in space.

Facts and figures about the ISS can be found at the following website:

ISS facts and figures
http://www.boeing.com/defense-space/space/spacestation/facts.html

Orbits of satellites

A satellite's orbit depends on its task, speed and distance from Earth. These orbits are described as:

- low Earth orbits (LEO)
- polar orbits
- geosynchronous orbit (GEO)
- elliptical orbits.

A satellite in LEO is close to Earth's surface (320–800 km altitude). Being in LEO, these satellites must travel at speeds of around 30 000 km/h to ensure that the gravitational pull of Earth does not bring them down to the surface. Satellites in LEO circle Earth every ninety minutes. A polar orbit is a particular LEO. A satellite in polar orbit passes over the poles of Earth. As Earth spins, satellites in polar orbits can eventually scan the entire Earth's surface. Therefore, satellites that monitor the global environment, such as remote-sensing and weather satellites, are nearly always in polar orbits. GEO satellites, as has already been mentioned, have a period of twenty-four hours and are 35 900 km above the surface of Earth. At this great altitude they have a large 'footprint' of Earth. A satellite in an elliptical orbit follows an oval-shaped path. One part of the orbit is closest to the centre of Earth (perigee) and the other is furthest away (apogee). A satellite in this orbit takes about twelve hours to circle the planet.

Travelling to outer space

The difficulty in sending spacecraft and probes to the Moon and other planets is that you have a moving target. To appreciate this, consider the following activity.

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ACTIVITY: LUNAR LANDINGS

You will need:

- **a metre tape or ruler**
- **a bucket or waste-paper basket**
- **a small globe of Earth**
- **a ping-pong ball.**

Place the globe on a table and spin it slowly with your hand. Earth spins 365 times in one year (this is why there are 365 days in a year). Pretend to be the Moon and walk around Earth by walking around the table with the globe on it (the Moon moves around Earth every month). Ask another student to walk around like the Moon while you spin Earth. Make sure they always face Earth as this will give an idea of the movements of Earth and the Moon.

Now fire a 'rocket' and try to land it on the Moon by pretending you are Earth and a student holding the bucket is the Moon. The ping-pong ball is the rocket. Next ask the student holding the bucket (Moon) to move three metres away from you (Earth). Have ten tries to land the ball (rocket) into the bucket (Moon). Count the number of times the rocket landed safely on the Moon.

Try to do this another ten times, but this time the Moon must move *slowly* around you as you throw (remember to keep a distance of three metres at all times). Count the number of safe landings.

To make it a little more real, try again while the Moon is moving and you are spinning around on the spot (don't forget that three metres). Again, count the number of safe landings.

ACTIVITY: SURFING NASA

The following website provides an enormous amount of curriculum materials related to space and space flight. The materials can be obtained in electronic format and may be printed and copied as needed. Spend some time exploring the site.

NASA educational products

Each year NASA produces new educational products, which are used by NASA education staff at NASA-sponsored workshops and events. Electronic versions of these products are available on NASA Spacelink and may be printed and copied as needed. Limited quantities of the published versions may be available through the NASA Educator Resource Center (ERC) that serves your state. A listing of some of the curriculum material is given in the table below (taken from http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html.

Title	Audience	Grade Level
International space station crew return.	Educators	5–8
International space station docking.	Educators	5–12
Microgravity – fall into mathematics.	Students	5–12
Space shuttle glider.	Educators & Students	5–12
The mathematics of microgravity	Educators	5–12
X1 paper glider kit: investigating the basics of flight with a model of the first supersonic aircraft	Educators & Students	5–12
X gliders: exploring flight research with experimental gliders	Educators & Students	K–4
Aeronautics: an educator’s guide with activities in science, mathematics and technology	Educators & Students	K–4
Amateur radio in space: a teacher’s guide with activities in science, mathematics, and technology	Educators & Students	K–4
The brain in space: a teacher’s guide with activities for neuroscience	Educators	5–12
Exploring meteorites: a teacher’s guide with activities for earth and space sciences.	Educators	5–12
Exploring the Moon: a teacher’s guide with activities for Earth and space sciences.	Educators	4–12
Is there water on Mars? An educator’s guide with activities for physical, Earth, and space sciences.	Educators	9–12
Microgravity: a teacher’s guide with activities in science, mathematics, and technology.	Educators	5–12
Microgravity demonstrator.	Educators	5–12
NASA student glovebox: an inquiry-based technology educator’s guide.	Educators & Students	5–12
Our mission to planet Earth: a guide to teaching Earth system science.	Educators	K–4
Planetary geology: a teacher’s guide with activities in physical and Earth sciences.	Educators	5–college
Rockets: a teacher’s guide with activities in science, mathematics, and technology.	Educators	K–12
Space based astronomy educators 5–8.	Educators	5–8

Space food and nutrition: an educator's guide with activities in science and mathematics.	Educators	K–8
Suited for spacewalking: a teacher's guide with activities for technology education, mathematics and science.	Educators	5–12
Teachers and students investigating plants in space: a teacher's guide with activities for life sciences.	Educators & Students	5–12
NASA's great observatories kit.	Educators & Students	5–12
757 glider kit.	Educators & Students	5–12
Solar system puzzle kit: an activity for Earth and space science.	Educators & Students	5–12

Information on additional NASA educational services is available in the Spacelink Educational Services area 'Spacelink Educational Service' <http://spacelink.nasa.gov/Educational.Services>.

The following table lists some of the recently launched spacecraft that have been sent into outer space. They have had various missions varying from flying past, orbiting or landing on members of the solar system.

Spacecraft	Classification	Mission	Launched
Voyager 1 & 2	Flyby spacecraft	Jovian planets and interstellar space	1989
Magellan	Orbiter spacecraft	Venus mapping	1989
Ulysses	Orbiter spacecraft	Study Sun's polar latitudes	1990
TOPEX/ Poseidon	Orbiter spacecraft	Global view of Earth's oceans	1992
Pioneers 10 and 11	Flyby spacecraft	Jupiter, Saturn and interstellar space	1972, 1973
Viking Lander	Lander spacecraft	Survey Mars landscape	1975

To explore this large topic further, it would be best to leave you with a NASA website that links to almost anything related to astronomy. NASA has been at the forefront of space exploration for many years. Access the 'NASA spacelink' <http://spacelink.nasa.gov/.index.html> site and search some of the key topics listed below:

- human space flight
- exploration and development of space
- astronauts
- living and working in space
- microgravity science and experiments
- aerospace technology
- NASA projects
- NASA Human Spaceflight Program history
- Apollo missions
- telescopes
- shuttle
- Skylab.

Search for extraterrestrial life

Since very early times humans have wondered if life exists on other planets and in other parts of the universe. The number of star systems within the universe is unimaginably big and so it would be very likely that life forms would exist in other parts of the universe. However, the huge distances between stars means that space travel between star systems is practically impossible. For example, our nearest star is 4.5 light years away. So even if a spacecraft could travel at, say, one-thousandth the speed of light (this is 300 000 kilometres per second or 1 million kilometres per hour!) it would still take 4500 years to travel that distance!

Radio signals, which travel at the speed of light, take many years to travel between star systems. However, in spite of these difficulties scientists are very serious about exploring the night skies for evidence of life in other star systems. The development of telescopes has been such that planetary systems orbiting stars have been detected. Evidence of other planetary systems leads to the possibility of other life forms, although life has yet to be detected on any of the other planets or their moons within our solar system. Despite all the perceived difficulties in travelling to and communicating with other parts of the universe, scientists are very serious about looking for life outside our planet. They have set up an institute called SETI (Search for Extra-Terrestrial Intelligence) Institute, whose aim is to detect signs of life and also to send messages. Refer to the website addresses below for a lot more information.

SETI (Search for Extra Terrestrial Intelligence) Institute

http://www.seti-inst.edu/
The home page of the SETI (Search for Extra Terrestrial Intelligence) Institute.

Science: Life on Mars

http://www.aaas.org/science/mars/prerelease.htm
This site contains the original announcement and article about the possibility of life on Mars.

 © Deakin University

Life on Mars

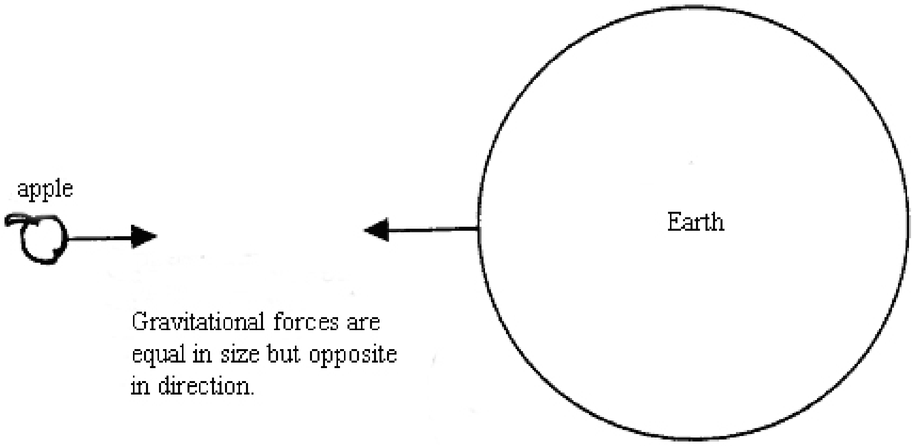
http://www.fas.org/mars/

This site has a collection of information about the controversial report on life on Mars, as well as a collection of links to further Mars information.

Gravity and flight

Gravity is just the attractive force that exists between two objects. The size of the gravitational force depends on the combined mass of the two objects and the distance that separates them. The largest gravitational force on you is the force of attraction to Earth. This is because Earth has an enormous mass. However, we do have gravitational forces of attraction to other objects as well, like the people around you. You do not feel these forces as they are negligible compared to the attractive force of Earth. Just as we are attracted to Earth, Earth in turn is attracted to us. To understand this mutual attraction, see Figure 39. In this figure, the size of the gravitational force of attraction on the apple due to Earth is equal in size to the gravitational force of attraction on Earth due to the apple. But why does the apple fall to Earth, you may ask? Try pushing a billycart and then a stationary truck. Which one can you move even though you are applying the same force on each? As Earth is much more massive than the apple, it will not budge, whereas the apple will.

FIGURE 39: GRAVITATIONAL FORCE ON EARTH AND THE APPLE



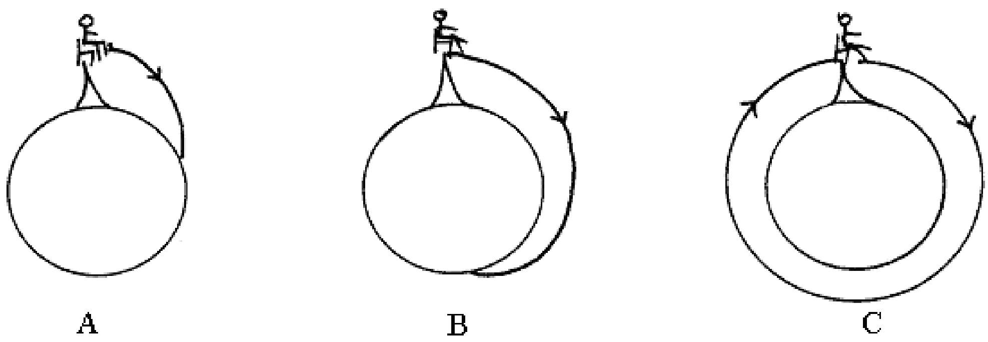
Generally, the gravitational forces on two objects bring them together. For example, a ripe apple will fall to the ground. However, if one of the objects has a sideways motion then the gravitational force will put the object into circular motion. This is the case with the Moon. Imagine yourself walking in a straight line and someone pushes you sideways. You will veer in another direction. If someone continues to push you sideways while you are walking forwards you will trace out a circular path. The Moon has a sideways pull from Earth. This is circular motion. The force of gravity in our solar system is greatest from our Sun due to its massive size. This gravitational force pushes planets and other objects into orbit around it.

Weightlessness

A common misconception is that there is no gravity in outer space or there is no gravity on the Moon. On the Moon, the gravitational force is about one-sixth that of Earth. This is because the Moon weighs less than Earth. In space stations there is still a significant amount of gravity as space stations are only a few hundred kilometres from Earth's surface. However, astronauts do feel weightless as if there was no gravitational force pulling them to the floor of the space stations. The gravitational force from Earth pulls both the space station and the astronauts continually sideways to their forward motion. This results in the space station and the astronauts moving into circular orbits around Earth. In a sense, the space station and the astronauts are continually falling sideways. They are in continual free-fall. This effect can be experienced on Earth in a freely falling lift. As the lift falls to the ground you will feel weightless.

Another way to understand weightlessness as similar to free-falling is to imagine yourself sitting on a chair on top of a very high mountain. As you sit on the chair you can feel the chair underneath you. Now imagine being pushed sideways off the mountain with some speed. As you fall you will not feel the chair underneath you. You and the chair will trace out a curved path before you and the chair hit the ground (see Figure 40). The greater your initial sideways speed the greater the distance you will travel away from the top of the mountain (see Figure 40:B). However, if you and the chair are given an enormous initial sideways speed then you and the chair will keep falling right round the entire Earth. If there is no mountain to get in the way on the return journey and there is air resistance (no atmosphere) then, given the right altitude above Earth's surface and right speed, an object can continually free-fall around Earth. In practical terms, to send spacecraft into orbit around Earth you need to send them to an altitude of a few hundred kilometres with a speed of around 30 000 kilometres per hour. Without this speed you cannot get away from the surface of Earth.

FIGURE 40: ORBITING IN FREE-FALL



 © Deakin University

Flight

Objects fly because they are able to overcome the gravitational pull of Earth. To understand how things fly you need to have an understanding of force and pressure. Some interesting and informative websites on this topic include:

Flight: how things fly

http://www.nasm.edu/galleries/gal109/NEWHTF/HTF030.HTM
has information in the form of questions and answers about flight and aerodynamics. Includes information on birds, aeroplanes, balloons, and explanation of terms such as 'draft', 'lift' and 'air pressure'.

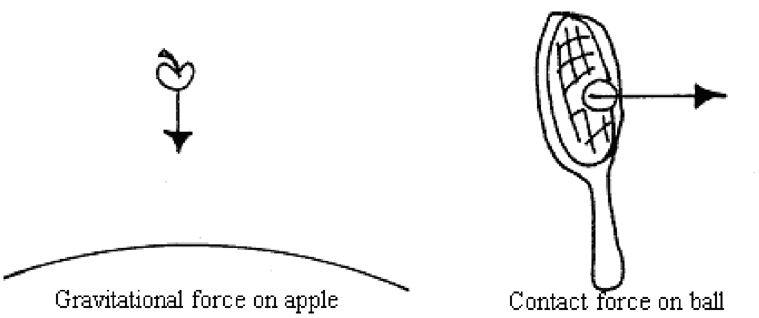
Beginners' guide to aeronautics

http://www.lerc.nasa.gov/WWW/K-12/airplane/index.html
A NASA site with lots of information: aeroplanes, propulsion, and forces.

Forces

A force is simply a push or a pull. For example, Earth has a gravitational pull, or gravitational force, on all objects near Earth. A tennis racquet applies a contact push, or force, to the ball when it hits it. Forces can be shown diagrammatically as arrows where the arrowhead shows the direction of the force and the length of the arrow gives a measure of the strength of the force. (See Figure 41).

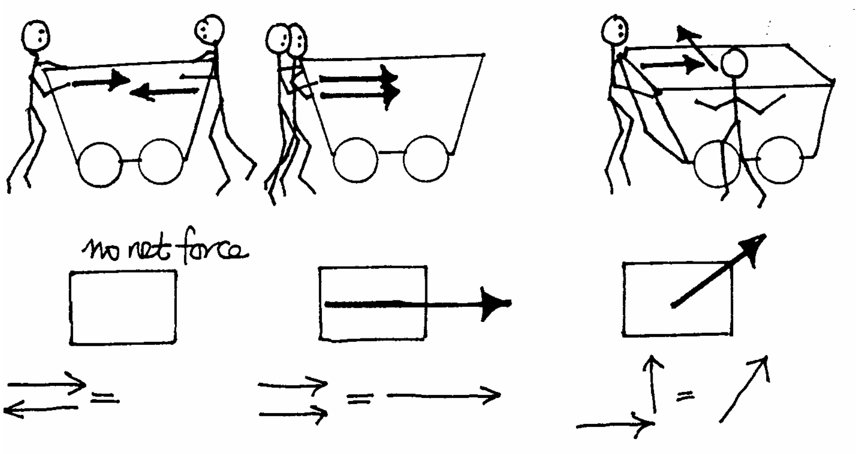
FIGURE 41: FORCES ON OBJECTS



An object can have two or more forces on it. The final state of an object (whether it moves and/or changes direction) depends on the overall or net force. The net force is determined by adding all the forces on the object. Figure 42 shows how two forces on a object can produce an overall different net force which would result in a different final state for the object.

Figure 42 shows an example of two people pushing on a trolley. In the first instance the two forces oppose each other and so the net force is zero. In this circumstance the trolley will not move. In the second example the two forces are in the same direction and will add up to one large net force. This will result in the trolley speeding up in the direction of the net force. In the third example, the two forces are applied in different directions. This will result in a net force at a different angle to the other two forces. The trolley will then speed up in the direction of this net force. Notice that the size of the net force when the two forces are not in the same direction is less than when the forces are in the same direction.

FIGURE 42: ADDING FORCES ON A TROLLEY

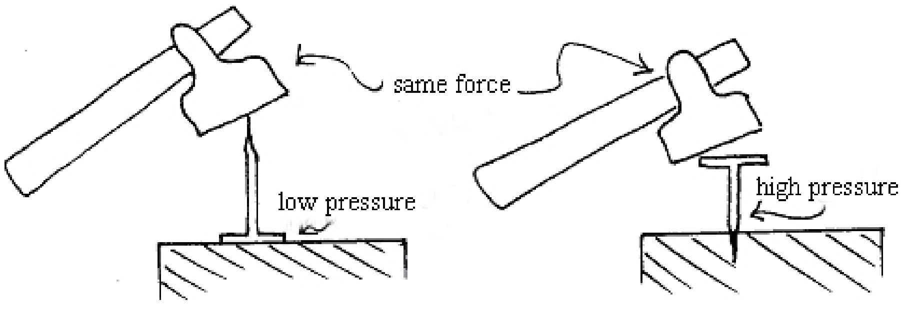


Pressure and air pressure

For an object to fly, it must have an upward force to oppose the gravity force that tends to pull it towards Earth. This upward force is called ‘lift’. For objects that fly through Earth’s atmosphere, lift is produced by a difference in air pressure on one side of the object compared to the other.

Pressure is just the force applied to an object per area of contact. Force and pressure are related but they are different concepts. For example, you can apply the same force to an object and produce different pressures. I can hit a nail into a piece of wood in two ways, by hitting the flat end or by hitting the sharp end of the nail. By hitting the flat end of the nail I am applying a greater pressure on the wood even though I hit the nail in the two situations the same (see Figure 43). An elephant walking on parquetry flooring does less damage to the floor than a woman in stiletto shoes. The stiletto heels apply a greater pressure to the floor than the elephant’s feet.

FIGURE 43: SAME FORCE, DIFFERENT PRESSURES



Air pressure on an object is caused by the many particles in the air moving rapidly and colliding with the object. These collisions result in many forces acting on an object in all directions. This will result in a net force that is zero and the object will not move. The air pressure on each side of the object is the same. However, if one side of an object has a greater air pressure than the other side, this pressure difference will cause the object to move in a direction towards the region of less air pressure. This is the principle of flight. For an object, like a plane, to fly, one creates a pressure difference on either side of the plane’s wings.

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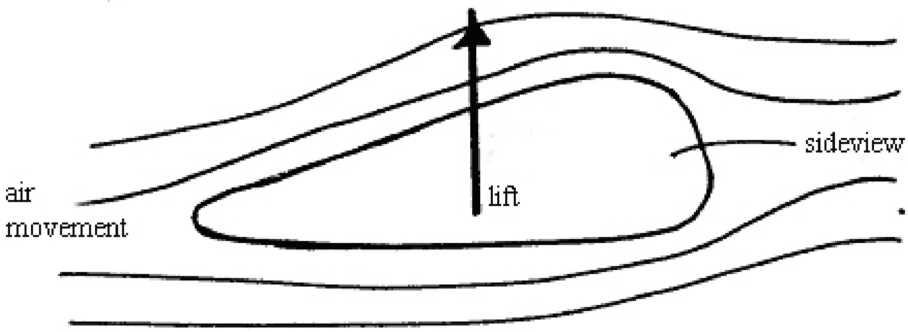
In Figure 44 the side of a plane's wing, or air foil, is shown. As the plane moves forward, air rushes over both sides of the air foil. The shape of the air foil is such that the rushing air travels a greater distance travelling over the top of air foil than the bottom. The air particles are more spread out over the top of the air foil and this results in less air pressure on the top than on the bottom. This pressure difference amounts to an overall force upwards: the lift. Another way to interpret air pressure difference is that one side of the air foil has more collisions with the air particles than the other. The greater the forward speed of the air foil, the greater the pressure difference and the greater the lift.

FIGURE 44: FORCES ON AN AIR FOIL



Teaching note: In the following activities the phenomenon that is observed results from air pressure difference. Think about what is creating the pressure difference. Remember, the object moves where the air pressure is less.

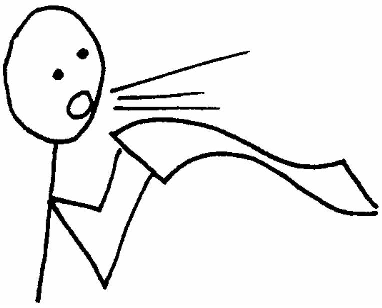
ACTIVITY: PAPER LIFT

You will need:

- **a strip of paper.**

Place a strip of paper in front of your lips and blow over the top of the paper (see the figure *Paper lift*). The paper strip will rise into the air. Can you explain why?

FIGURE: PAPER LIFT



ACTIVITY: FRIENDLY CANS

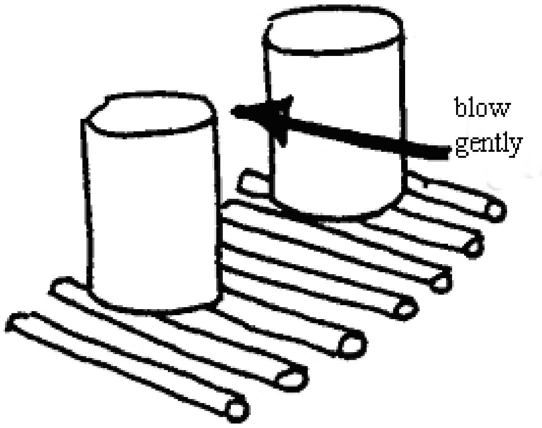
You will need:

- **two aluminium cans**
- **a number of plastic straws.**

Place two empty cans about 3 cm apart on a set of straws placed parallel so the cans can roll easily towards and away from each other. Blow gently between them.

What do you observe? Can you explain your observation?

FIGURE:
FRIENDLY CANS



ACTIVITY:
HOVERCRAFT

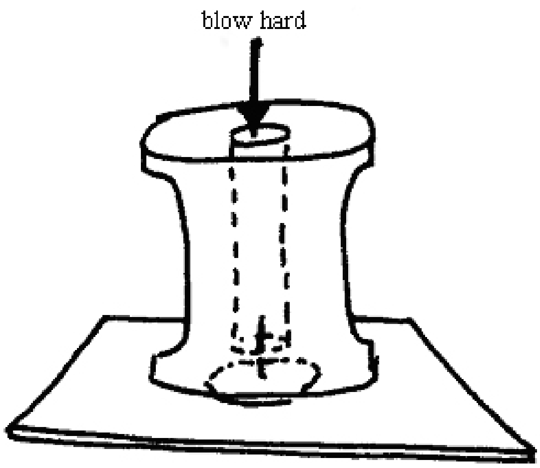
You will need:

- **a cotton reel**
- **a drawing pin**
- **a square piece of cardboard.**

Make sure the card is a true square. Draw diagonal lines across from one corner to the other to find the centre of the card. Push the drawing pin carefully through the card's centre. Hold the end of the cotton reel close to your mouth. Hold the card against the other end of the reel, with the point of the pin inside the hole of the reel. Blow hard through the hole and let go of the card.

What happens? What happens when you stop blowing? Can you explain your observations?

FIGURE:
HOVERCRAFT
MODEL



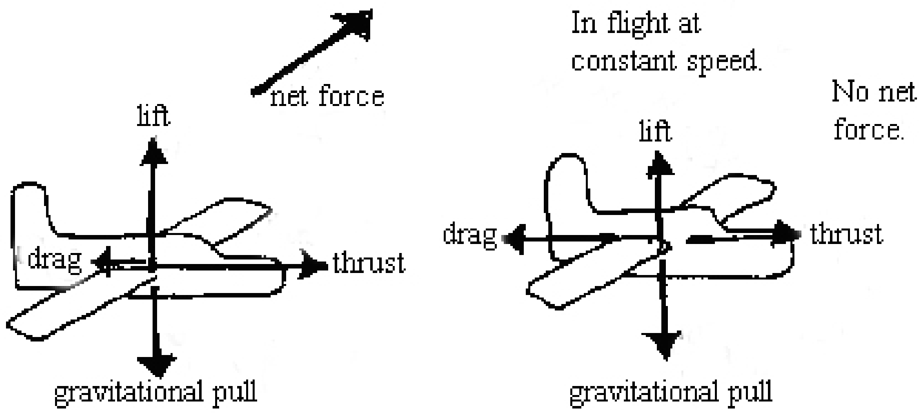
Aeroplane flight

To get an object such as a plane to fly, it initially requires a forward push, called 'thrust'. For a paper plane, thrust is obtained from your hand. The initial pushing motion by the hand gives the plane enough speed for air to rush over the wings and create lift. In most paper planes the pressure difference is created as the plane is not exactly horizontal to the ground, so the air rushing over the top of the plane takes a greater path than the air rushing under the plane.

Modern aeroplanes have jet engines that suck in air in the front of the engines and expel it out the back. By pushing on the air being expelled out the back of the plane, the expelling air, in turn, pushes back on the plane. It is this backwards push from the expelling air that gives the plane its forward thrust. The difference between the paper plane and aeroplanes is that the paper plane only requires an initial push forwards, whereas the aeroplane needs to continually push air through its engines.

While flying, the aeroplane has large forces of air resistance, or drag, trying to slow the plane down. So if the aeroplane did not continually push air through its engines it would slow down. This slowing down would result in less difference in air pressure on the wings and the plane would lose altitude. When flying at constant speed the aeroplane has four forces acting on it (gravity, thrust, lift and drag) and the net force is zero. Figure 45 shows the forces acting on the plane initially and later when flying with constant speed. In the initial phase the net force on the plane gives an overall force upwards which results in the plane accelerating in that direction. After reaching a designated speed, all the forces cancel and the plane reaches constant speed.

FIGURE 45: FORCES ON AN AEROPLANE



ACTIVITY: STRAW ROCKET

You will need:

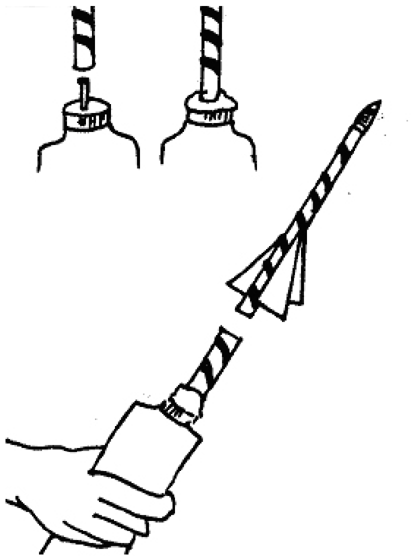
- **two straws (one big enough to slide over the other)**
- **an empty detergent bottle**
- **glue**
- **card**
- **sticky tape**
- **scissors**
- **plasticine**

Glue the thin straw to the top of the detergent bottle. Pack some plasticine around the base of the straw where it joins the cap. This will help seal it. Cut out three cardboard triangles. Tape them to one end of the thick straw. These triangles form the rocket's fins. Give your rocket a nose of plasticine. Make sure it is firmly in place.

Slide your rocket over the thin straw on the squeezy bottle. Let the thin straw poke very lightly into the plasticine nose cone. Give the bottle a quick, hard squeeze. Watch your rocket fly into the air.

Explain how your rocket flies in terms of the changing pressures inside the detergent bottle. What effect do the fins have on the flight of the rocket? Try the rocket without fins.

FIGURE:
STRAW ROCKET



ACTIVITY:
BALLOON
ROCKET

You will need:

- **a long balloon**
- **heavy paper**
- **scissors**
- **sticky tape.**

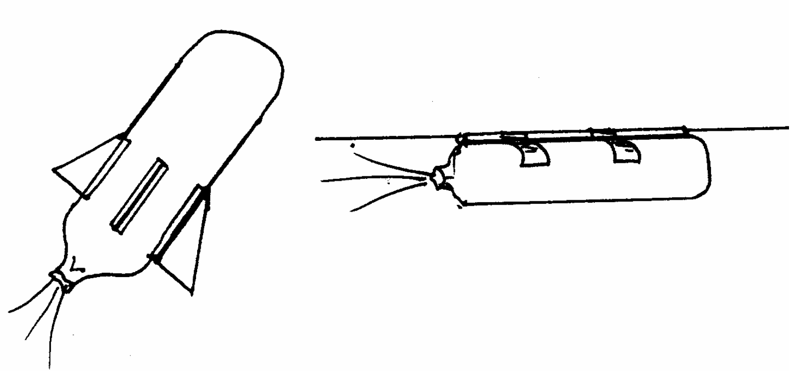
Cut four paper triangles from heavy paper. Fold one edge of each triangle at right angles. These triangles will be the fins for your rocket balloon.

Blow the balloon up about half way. Attach the fins around the back end of your balloon. Try to space them equally. Blow up the balloon the rest of the way. Hold the rocket upright and let it go.

Explain why the balloon flies. Is it the same mechanism as the straw rocket? What effect do the fins have on the flight of the rocket?

For a controlled flight, remove the fins and replace with a plastic straw attached to the side of the balloon. Place a long piece of string through the straw and attach at both ends. Ensure that the string is taut. By releasing an inflated balloon, it will follow the path of the string.

FIGURE:
BALLOON ROCKET



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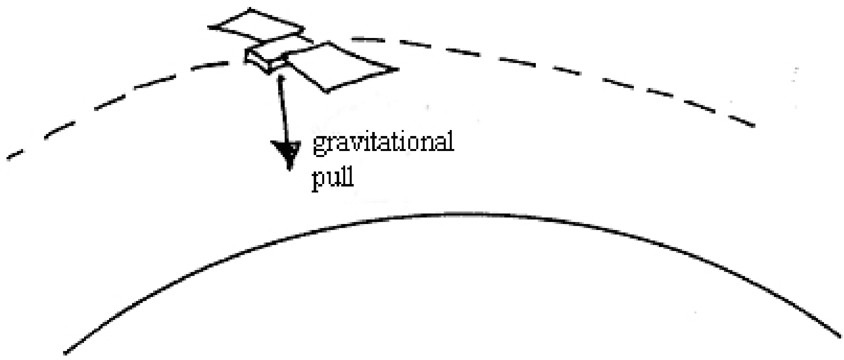
Motion of spacecraft and satellites

The forces on spacecraft, satellites and space stations while in Earth's atmosphere are the same as those forces acting on aeroplanes. Rockets, attached to the spacecraft or satellites, expel the gas from burning fuel. The expelling gas, in turn, pushes the rocket. As the spacecraft or satellite leaves Earth's atmosphere, the forces change.

When satellites reach outer space they do not need any more thrust through expelling gas from rockets. There is no longer any drag to slow the craft down (no atmosphere) but there is still a gravitational pull on the craft. Satellites have a sideways motion to Earth's surface and if there was no gravitational pull from Earth the satellite would continue to drift in a straight line away from Earth. Gravity continually pulls the satellite sideways resulting in a circular orbit of Earth. See Figure 46.

FIGURE 46: FORCES ON A SATELLITE



In ideal situations, satellites and space stations should orbit Earth indefinitely without the need for engines to expel gas and provide thrust. However, in real situations the satellites and space stations do hit small particles that slow them down. This slowing down brings the object into lower orbits. To observe this effect, try out the activity *Orbiting satellites*.

The natural satellites of the solar systems are the planets and their moons. The planets are the satellites of the Sun as they orbit it on a regular basis. Likewise, the moons of the planets are satellites of the planets orbiting at various speeds and distances away. Earth has many artificial satellites, some only a few hundred kilometres away from Earth and others as much as 50 000 km away.

Each satellite orbits the central body for two reasons: because of a gravitational pull and a sideways speed. If the satellite did not have a sideways speed, it would fall directly into the central body. Alternatively, if the satellite had a sideways speed that increased, it would orbit at a greater distance to the central body. Conversely, if the sideways speed decreased, the satellite would achieve a smaller orbiting distance from the central body. The activity *Orbiting satellites* demonstrates these points.

ACTIVITY: ORBITING SATELLITES

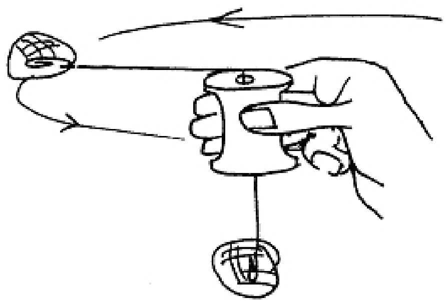
You will need:

- **two paperclips**
- **fishing line (1 m)**
- **a handful of plasticine**
- **a large cotton reel.**

Twist the two paperclips into rough shapes (the exact shape is not important). Slip the fishing line through the cotton reel and tie a paperclip to each end. Stick a lump of plasticine around each paperclip. Make one of the lumps about four times as large as the other. Hold the cotton reel with the smaller lump of plasticine on top. Spin the reel to make the top lump swing around. Try not to let the line rub against your hand. Swing the plasticine in a circle quickly. You will see it spin outwards, away from the reel. As the small lump spins slower and slower, hold the larger lump steady.

The larger lump is always pulling down on the line. It is trying to pull the smaller lump back to the reel. Its pull is constant, like the pull of gravity. It does not matter whether the small lump is near the spool or far away from it. The larger lump still has the same pull on the line. The spinning lump holds the large lump in place.

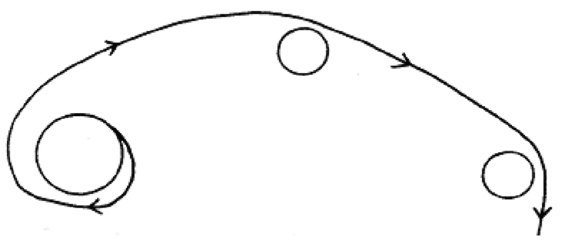
FIGURE: SATELLITE MODEL



The activity *Orbiting satellites* shows that an orbiting object needs a force towards a central body.

Once spacecraft that travel to the Moon and other planets leave the gravitational pull of Earth, they will drift in a straight line indefinitely without needing to have the engines working. However, if you require the spacecraft to change direction, its engines need to engage so that fuel is burnt and gases are expelled. The expelled gas pushes back on the spacecraft, providing thrust that can make the spacecraft go faster, slower or change direction. Space probes that travel to distant planets also use other planets to propel them into different directions. In a type of slingshot motion, the spacecraft is initially pulled towards the planet. It then swings behind the planet and is propelled in another direction. See Figure 47.

FIGURE 47: SPACECRAFT MOTION AROUND PLANETS



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