9.2 Gravity, tides and orbits

Gravity is the pulling force that makes you fall off your skateboard or your chair. It causes rain to fall and rivers to flow to the sea, and it is the force that causes our tides.

INQUIRY science 4 fun

Drawing ellipses

Can you draw an accurate ellipse?

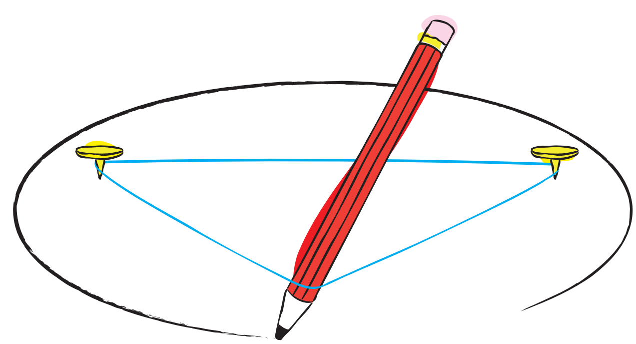
Yes

Collect this ...

- 2 pins
- sheet of cardboard or thick pad of papers (such as your workbook)
- length of string or cotton
- pencil or felt-tip pen

Do this ...

1. Stick the pins well apart into the cardboard or pad of papers.
2. Tie the string or cotton into a loop so that it fits loosely over the two pins.
3. Use the pencil or felt-tip pen to stretch the loop out.
4. Keeping the loop tight, ‘orbit’ the pins with the pencil or pen, drawing as you go.



Record this ...

Describe what happened.
Explain how this relates to the shape of orbits.

Gravity

While some forces make contact with the objects that they push or pull around, other forces act without touching. These **non-contact forces** act instead through **force fields**. As Figure 9.2.1 shows, magnets have magnetic force fields around them that attract objects containing iron and create pushes and pulls around other magnets.

Figure 9.2.1 Iron filings align (line up) with the field lines around a magnet, showing the direction and strength of its magnetic field.

Gravitational fields

Around every mass is a **gravitational force field** that attracts other masses. This attractive force is **gravity**, and it attempts to pull masses together. Matter is the stuff that everything is made up of, and matter has **mass**. You have mass, as does the person who is sitting next to you, the chair you are sitting on, and the pen you are writing with. They all have their own gravitational fields, and all of them are attracting each other. This force of gravity and its attraction is most obvious when you fall off your chair! The force of gravity between you and Earth is commonly called weight.

The effect of mass

Gravity is a force caused by mass. The bigger the mass, the stronger its gravitational field and the more it attracts other masses nearby. However, gravity is a very weak force, and a lot of mass is required before any attraction is noticeable: people, pens, chairs, and even cars, buildings and ships, are not massive enough to have much effect on other masses. This is why you don't get pulled towards the person sitting next to you or even a large skyscraper that you are walking past. Gravity is only noticeable when one of the objects is really massive, such as a planet, moon or star. These objects have strong gravitational fields around them that attract anything else that is nearby, including you. Earth has a gravitational field like that shown in Figure 9.2.2.

Figure 9.2.2 Fields lines are used to show the direction of a gravitational field around an object. Masses 'fall' in the direction of these field lines, which point towards the centre of the moon, star or planet.

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The effect of distance

The gravitational fields around planets, moons or stars rapidly get weaker as you move away from them. For example, Earth's gravitational field is a little weaker on the top of Mt Everest, its highest mountain, than at sea level. However, the difference is too small for you to notice and can only be detected by extremely sensitive instruments. By the time you get to the Moon, Earth's pull is weak and far lower than at Earth's surface.

Tides

The Moon is the closest big mass to Earth. Its gravitational pull drags all the water in the oceans and seas towards it, causing a bulge on the side of Earth that faces the Moon. As Earth rotates this bulge moves, so that it stays pointing towards the Moon. Another smaller bulge forms on the opposite side of Earth. The Sun also draws water towards it and changes the size of this bulge as it moves across Earth's surface. These moving bulges cause two high **tides** and two low tides per day as shown in Figure 9.2.3.

9.3

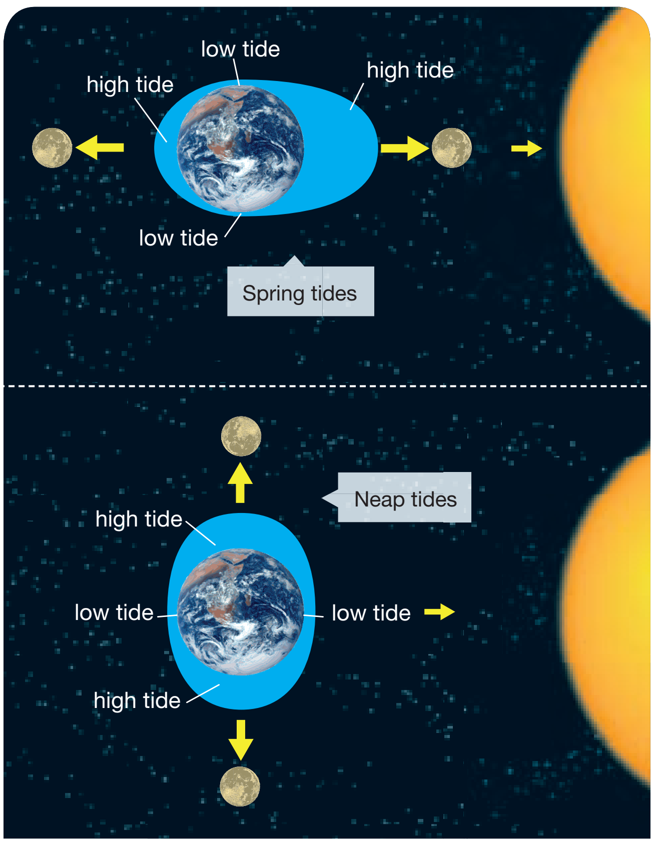


Figure 9.2.3 Spring tides are large because the gravitational pull of both the Moon and the Sun are in the same direction and the bulges from each add up. Neap tides are smaller because the Moon and Sun are pulling in different directions.

Orbits

The gravitational fields around planets, moons and stars are often strong enough to 'trap' other masses so that they travel continuously around them in a path known as an **orbit**. For example, Earth and the other planets of the solar system are 'trapped' by the gravitational field of the Sun and so they orbit it. Likewise, the Moon keeps orbiting Earth. This is shown in Figure 9.2.4. At least 63 moons orbit Jupiter, and millions of rock fragments, ice and dust form rings that orbit Saturn. You can see Saturn's rings in Figure 9.2.5.

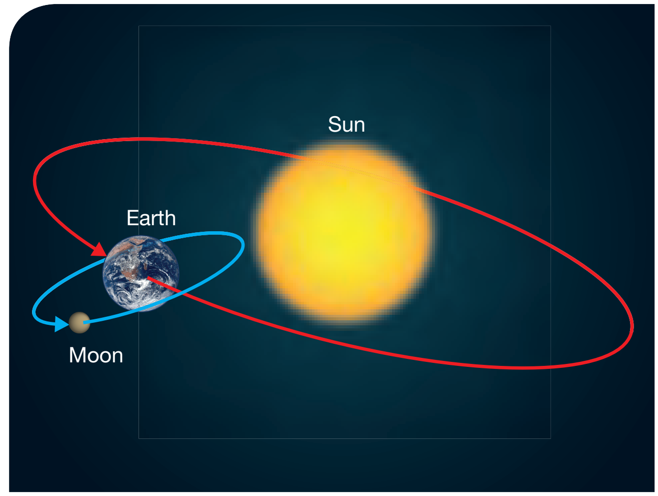


Figure 9.2.4 Earth orbits the Sun, and the Moon orbits Earth.

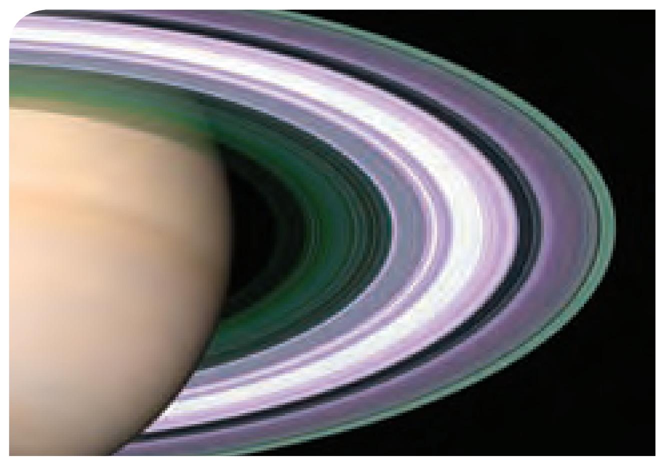


Figure 9.2.5 Fragments of rock, dust and ice orbit Saturn, forming a spectacular series of rings around the planet.

Objects that are in orbits like this are known as **satellites**. The planets of the solar system are **natural satellites** of the Sun, and the Moon is a natural satellite of Earth. Earth also has many **artificial satellites** orbiting it. Some are used to transmit information such as telephone and the internet, while others scan the Earth for everything from erosion and bushfires to espionage (spying). The largest artificial satellite in orbit around Earth is the **International Space Station** (ISS), shown in Figure 9.2.6 on page 338.

Figure 9.2.6 The International Space Station (ISS) is an artificial satellite orbiting Earth. It has a crew of six on board at all times.

2 p345

SciFile

Unstable orbits

If a satellite is travelling too slowly then it will slowly spiral in. This is what most artificial satellites eventually do. Likewise, if a satellite is travelling too fast then it will slowly spiral outwards. The Moon is doing this: it strays a tiny 3.8 cm away from Earth each year!

Orbit shapes

Orbits are elliptical in shape. **Ellipses** are oval-shaped closed loops, but some are almost circular. The orbit of the Moon around Earth, for example, is nearly circular, as are the orbits of Mercury, Venus, Earth and Mars around the Sun. Jupiter, Saturn, Uranus, Neptune and the dwarf planet Pluto have more oval-shaped ellipses as their orbits. Comets from deep space are sometimes trapped by the gravitational field of the Sun and sweep around it on long and thin elliptical orbits. Comets often orbit in a plane very different from that of the planets. A typical orbit of a comet is shown in Figure 9.2.7.

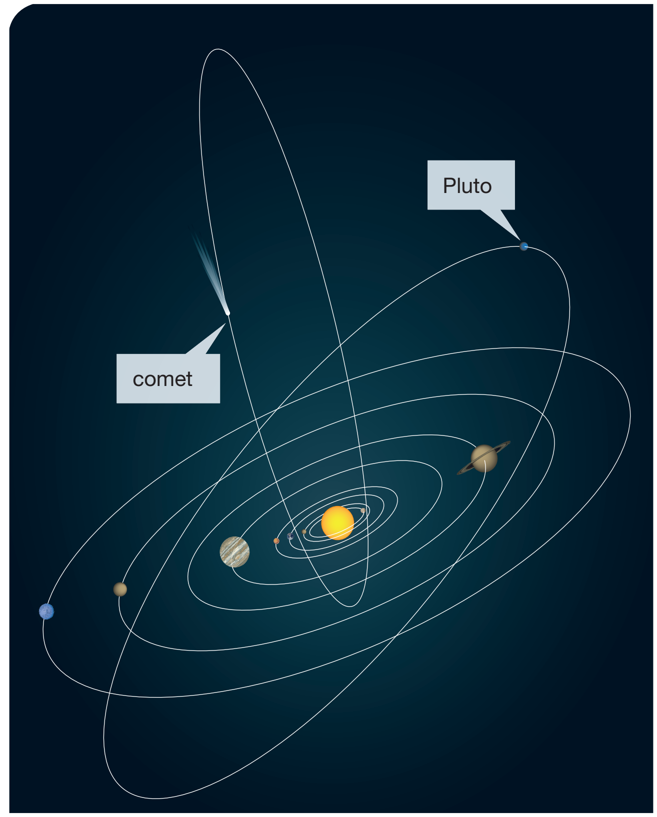


Figure 9.2.7 The dwarf planet Pluto orbits in a different plane to the rest of the solar system. Its long, thin elliptical orbit sometimes places Pluto closer to the Sun than Neptune. Comets usually orbit the Sun in a different plane too.

Explaining orbits

Imagine you are on the top of a tall mountain with a handful of tennis balls. Drop one and it will fall to your feet because gravity pulls it downwards. If you throw the ball horizontally, it still falls but it takes a curved path to the ground, landing at a distance away from you. Now imagine that you could throw the ball so fast that it kept on falling, never hitting the Earth. If you could do this then the ball would be in orbit. The ball will then keep ‘falling’ around Earth forever, needing no extra push or power to keep it orbiting. Figure 9.2.8 shows how. An orbit like this can only happen outside Earth’s atmosphere because there is no air resistance and therefore nothing to slow the satellite down.

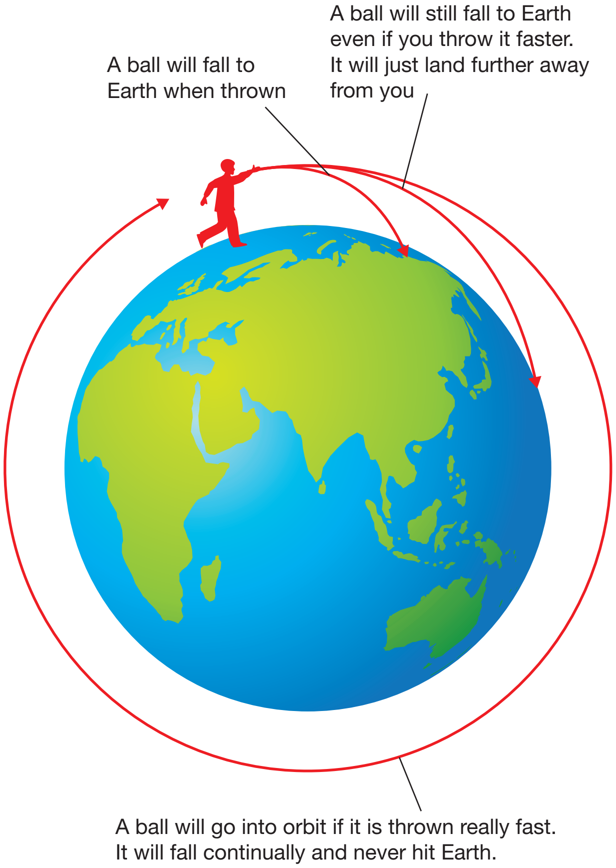


Figure 9.2.8 Throw an object slowly and it will land back on Earth. However, if you throw it from a high point and really fast, then it will continue to fall and keep missing the planet. The object will then be in orbit around Earth.

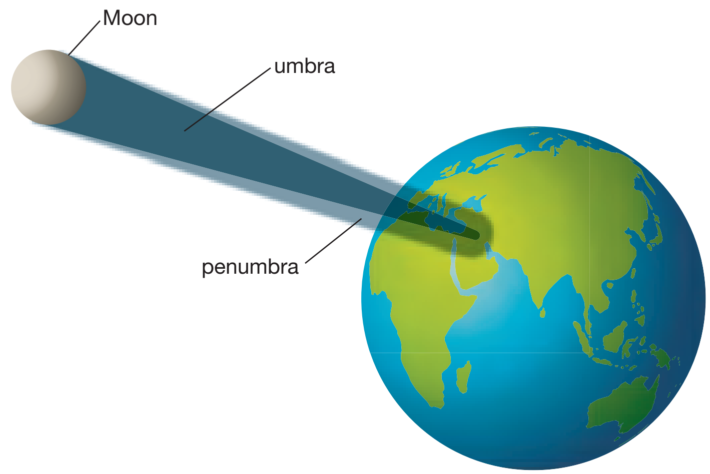


Figure 9.2.9 The Moon is too small to block light from the Sun over the entire Earth, and so its shadow falls on only part of Earth's surface. Only these parts experience a solar eclipse.

Eclipses

Sometimes the orbits of the Moon around Earth and Earth around the Sun cause all three bodies to align so that the Moon blocks sunlight from reaching Earth, or the Earth blocks sunlight from reaching the Moon. When this happens, as **eclipse** occurs.

Solar eclipses

A **solar eclipse** occurs whenever light from the Sun is blocked by the Moon, casting a shadow onto Earth like that shown in Figure 9.2.9. Whatever part of Earth's surface is in shadow is plunged into darkness until the Moon moves out of the way again. Figure 9.2.10 shows the view from Earth when it happens. Solar eclipses can be complete (in the **umbra**, where the shadow is full and dark) or partial (in the **penumbra**, where the shadow is less dense).

Figure 9.2.10 Astronomers use solar eclipses to view the corona or very outer layer of the Sun, and the solar flares that burst from it.

SciFile

A dragon ate the Moon!

The ancient Chinese and Vikings both thought that a lunar eclipse happened because the Moon was eaten: the Chinese thought a dragon did it, while the Vikings thought that a wolf ate it. Some American Indian tribes instead thought a bear was wandering throught the sky, fighting the Moon whenever it blocked the path.

Lunar eclipses

During a **lunar eclipse**, the Earth blocks light from reaching the Moon. As the Moon passes along its orbit, it first passes through the penumbra, causing a partial lunar eclipse. It then moves through the umbra, forming a total lunar eclipse, before moving back into the penumbra and then back into the sunlight. Figure 9.2.11 shows how this happens. You can see what the Moon looks like during a lunar eclipse in Figure 9.2.12.

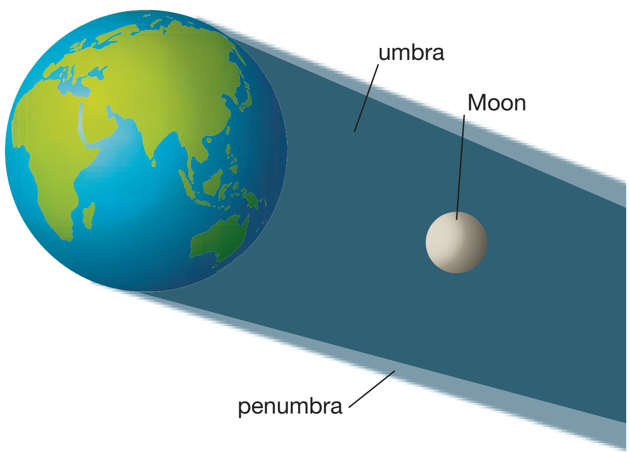


Figure 9.2.11 A lunar eclipse passes through different stages depending on what part of the Earth's shadow it is passing through.

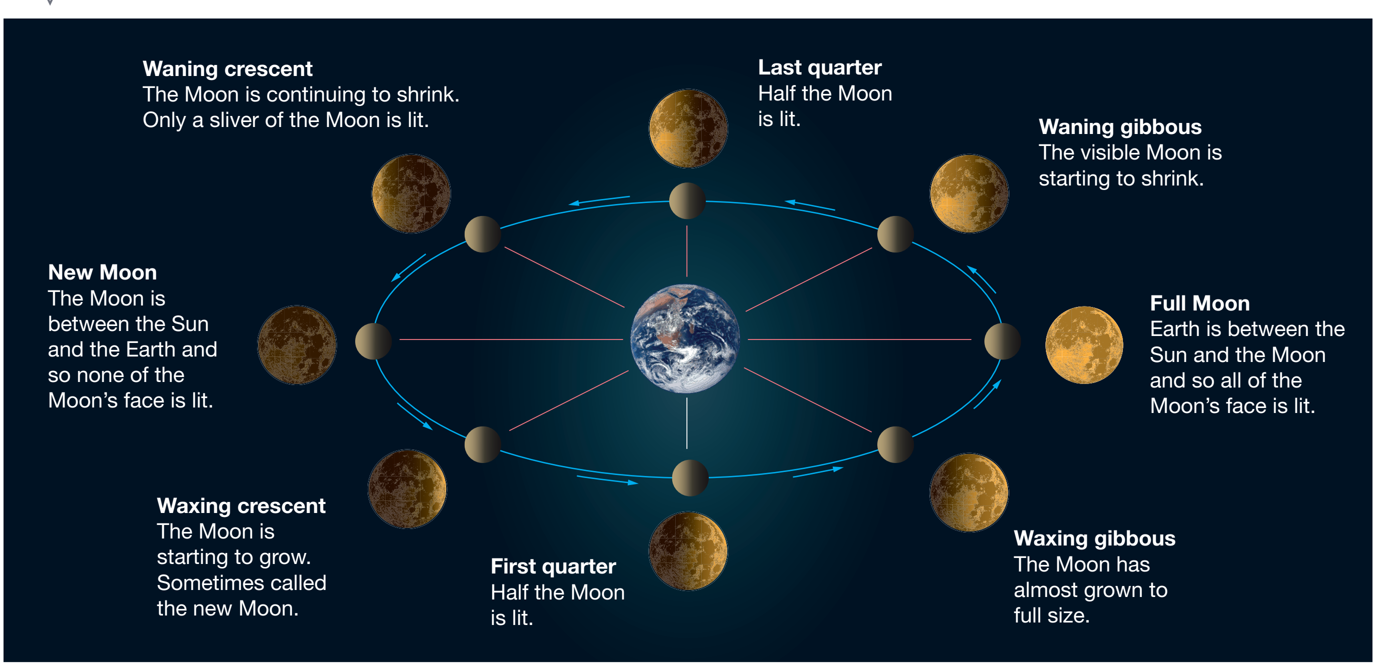
Figure 9.2.12 Five images of the Moon during a total lunar eclipse. The Moon does not disapper completely while it is in the umbra because it is lit by a little sunlight bent by Earth's atmosphere.

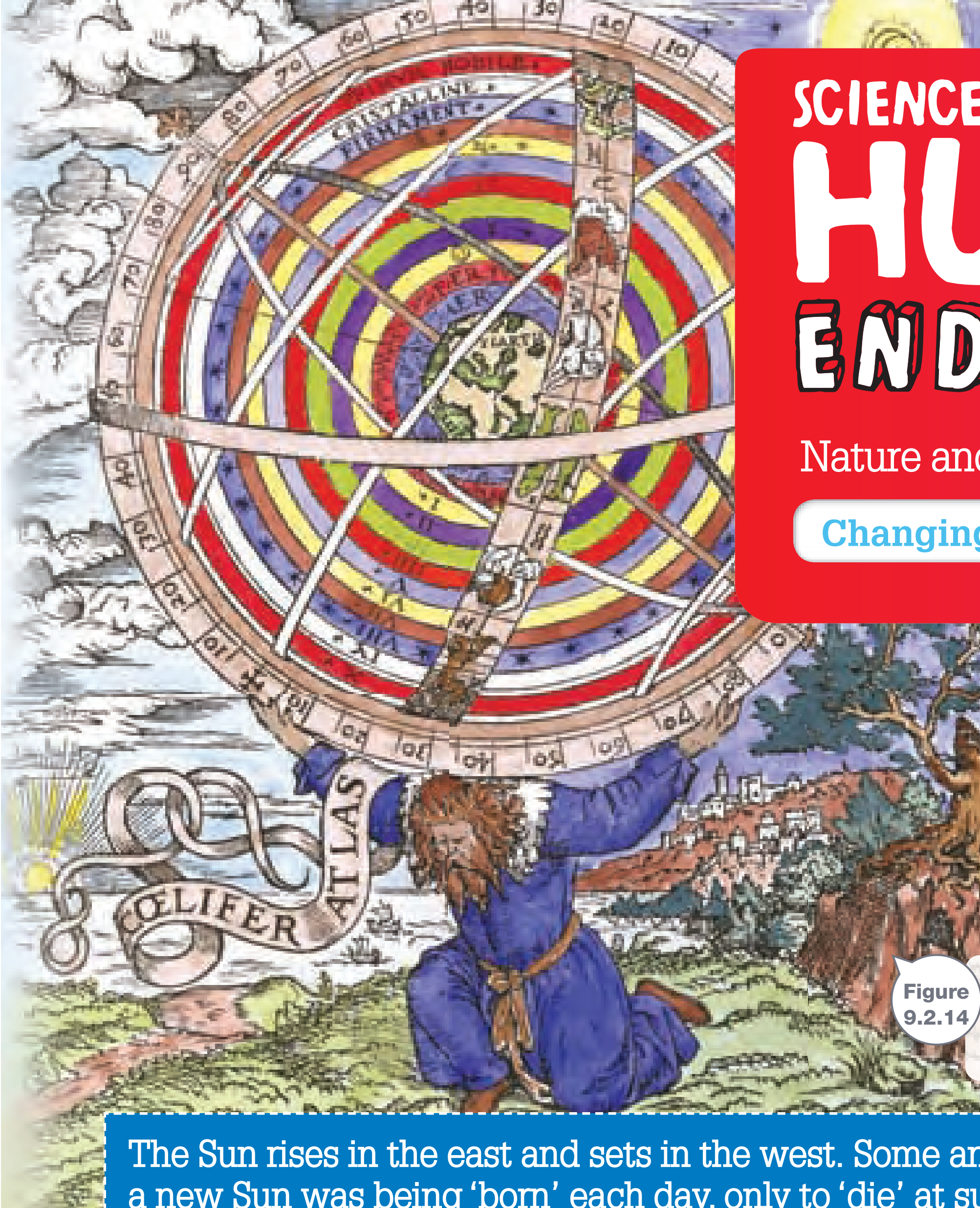
Phases of the Moon

Half of the Moon faces the Sun and is always bathed in sunlight (except during lunar eclipses). On Earth, however, we do not always see its full face. As Figure 9.2.13 shows, what we see depends on where the Moon is in its orbit and how much of the face is receiving light. The different shapes that we see are known as **phases** of the Moon.

9.5

Figure 9.2.13 The phases of the Moon depend on where it is in its orbit around Earth.





SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Changing ideas

Figure 9.2.14 According to the ancient Greeks, Atlas was the god who carried the universe on his back.

The Sun rises in the east and sets in the west. Some ancient cultures thought that a new Sun was being 'born' each day, only to 'die' at sunset. Another explanation had the Sun moving around Earth. This suggested that Earth was the centre of the universe, with everything revolving around it.

The geocentric model

If Earth was the centre of the universe, then it was logical that everything else must travel around it in orbits. This way of thinking is known as the **geocentric model**, pictured in Figure 9.2.15. This model obeyed two of the most important characteristics of any scientific model or theory:

- it was simple
- it explained all the evidence available at the time.

Although the geocentric model made sense to the ancients, they observed that the planets sometimes seemed to turn around and move backwards! This strange looped motion is shown in Figure 9.2.16 on page 342 and is known as **retrograde motion**. The geocentric model could explain retrograde motion, but only if complex changes were made to it.

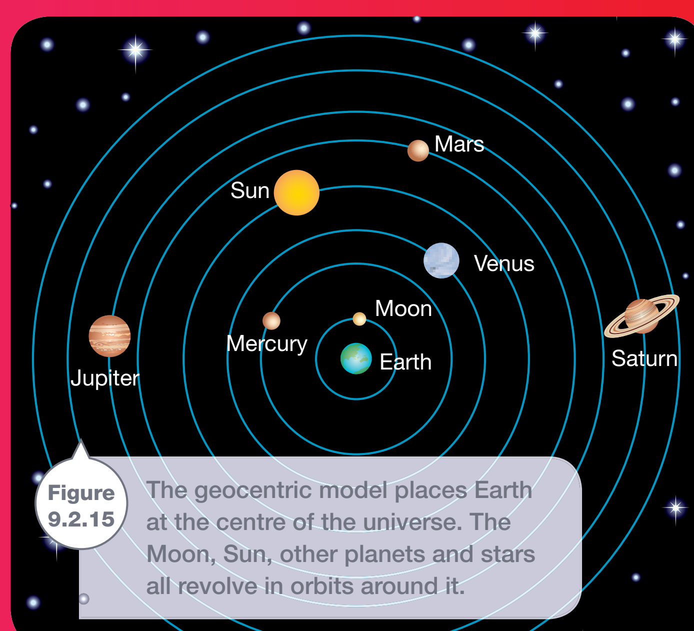


Figure 9.2.15 The geocentric model places Earth at the centre of the universe. The Moon, Sun, other planets and stars all revolve in orbits around it.

Figure 9.2.16 When viewed over a couple of months, the motion of Mars seems to loop back on itself: it shows retrograde motion. Without complex changes, the geocentric model cannot explain this motion.

Heliocentric model

An alternative model was able to explain all available evidence more simply. This model has the Sun at the centre of the solar system and is known as the **heliocentric model**. The model is shown in Figure 9.2.17. The heliocentric model explained retrograde motion easily: although all the planets are revolving in the same direction, the planets all move at different speeds. This changes their relative positions in space and sometimes makes planets appear to move backwards!

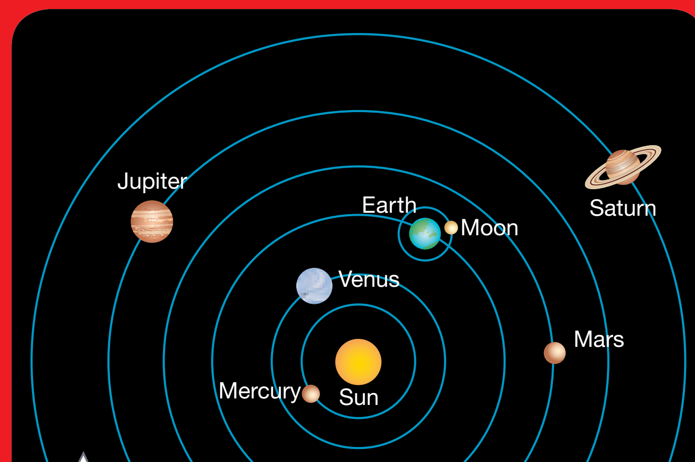


Figure 9.2.17 The heliocentric model of the solar system places the Sun at its centre. The Earth and other planets revolve around it.

9.4

Figure 9.2.18 An illustration from 1660 showing the heliocentric model with the Sun at its centre

9.2 Unit review

Remembering

1 **List** five things around you that are pulling you with a weak gravitational force.

2 **Name** one thing that is currently pulling you with a strong gravitational force.

3 **Name** one:
   a natural satellite of the Sun
   b natural satellite of Earth
   c artificial satellite of Earth.

4 **Recall** how gravity changes with distance by ranking the following from the place which would have the highest gravity to the place with the lowest gravity.
   A On top of Mt Kosciuszko (New South Wales), the tallest mountain in Australia (2228 m).
   B At the top of Q1 tower (Queensland), the tallest building in Australia (323 m)
   C On Bells Beach (Victoria) (sea level)
   D On the edge of the Lake Eyre (South Australia) (15 m below sea level).

5 **State** how many high tides and how many low tides will be experienced every day at the docks in Fremantle, Western Australia.

6 **Name** the model of the solar system that places at its centre:
   a the Sun
   b the Earth.

7 **List** the two most important characteristics of any scientific model.

Understanding

8 Give reasons to **explain** why you aren't pulled towards a wall despite there being a gravitational attraction between you and it.

9 The times for high and low tides differ around Australia. **Explain** why.

10 **Explain** what is different about the orbits of Pluto and comets around the Sun.

11 **Explain** why a satellite does not need to be powered to keep it in orbit.

12 **Explain** why the geocentric model was abandoned in favour of the heliocentric model.

Applying

13 **Identify** whether a neap or a spring tide produces greater changes in sea levels. Use a diagram to explain your answer.

14 **Use** a diagram to **explain** what retrograde motion is.

15 The painting on page 341 dates from 1160. It shows the ancient Greek god Atlas carrying the solar system on his back. **Identify** whether it shows the solar system as heliocentric or geocentric.

Analysing

16 **Contrast** a natural satellite and an artificial satellite.

Evaluating

17 Imagine that you shoot a gun horizontally off a tall mountain, the bullet going so fast that it goes into orbit around Earth. It could be extremely dangerous if you stay on top of the mountain. **Propose** why.

18 When half the Moon is visible, its phase is not called a half-moon but a quarter moon. **Propose** reasons why.

Inquiring

1 Research the following astronomers, classifying them as supporters of the geocentric model or the heliocentric model of the solar system:
   a Johannes Kepler
   b Heracleides
   c Pythagoras
   d Claudius Ptolemy
   e Nicolaus Copernicus
   f Galileo Galilei
   g Isaac Newton
   h Khayyan.

2 Search the internet to find and view:
   a simulations showing the orbits of the planets of the solar system
   b simulations showing the orbits of the Moon around Earth and Earth around the Sun
   c live vision on NASA TV from the International Space Station in orbit around Earth
   d animations showing how the heliocentric model explains retrograde motion.

9.2 Practical activities

1 Go jump!

Each planet in the solar system has a different mass and so gravity changes depending on which planet you are on. This means that you can jump different heights on different planets. This assumes that the surface is solid!

Purpose

To calculate how high you could jump on another planet.

Materials

- metre ruler or tape measure
- calculator

Procedure

1. Choose a safe and clear space, perhaps outside.
2. One of your laboratory partners needs to hold the metre ruler vertically, with the 'zero end' touching the ground.
3. Another needs to be crouched down, with their eyes level with the ruler.
4. Stand next to the ruler and jump as high as you can.
5. Your lab partner needs to measure the height your feet got to in the jump.
6. Repeat two more times and record your jump heights.

Results

1. Record all your jump heights in a table like the one shown above.
2. Calculate your average jump height by:
   - adding: Jump 1 + Jump 2 + Jump 3
   - dividing: by 3.
3. Calculate the height you could jump on the Moon and other planets by:
   - dividing: your average jump ÷ gravity.

Planet or moon	Gravity compared to Earth's (Earth = 1)	Predicted jump height (cm)
Earth	1	
Moon	0.16	
Mercury	0.38	
Venus	0.91	
Mars	0.38	
Jupiter	2.36	
Saturn	0.92	
Uranus	0.89	
Neptune	1.1	

Discussion

1. **Identify** the celestial body/bodies on which you could jump:
   a. the highest
   b. the lowest
   c. about the same as on Earth.
2. Astronauts on the Moon were able to jump higher than on Earth but not as high as you calculated above. **Propose** reasons why.
3. Find the world records for various athletics such as high jump and pole vault and **calculate** what they would be on the other planets.

2 Planetary orbits

Purpose

To construct a model of an orbit and to determine the effect of changing gravity.

Materials

- plastic casing of ball-point pen or short length of plastic or metal tubing
- string or strong cotton thread
- rubber bung with hole
- washers
- large open area

SAFETY

Make sure you have plenty of room.

Wear safety glasses at all times.

Procedure

1 Tie the string or cotton thread securely to the rubber bung by passing it through the hole a number of times and then knotting it tightly.

2 Pass the string or thread through the tubing and tie a couple of washers on the other end, as shown in Figure 9.2.19.

3 Find a place where there is plenty of room and swing the rubber bung horizontally around your head.

4 Swing it at a speed that keeps the washers away at a constant level below the tubing.

5 Add more washers and repeat.

6 Carefully observe what happens to the speed and radius of the 'orbit' as more washers are added.

Discussion

1 **Identify** which part of this model represents:
   a a satellite in orbit
   b the force of gravity
   c the planet around which the satellite orbits.

2 **Describe** what happened to the speed and radius of the orbit when the gravitational pull of the planet was increased.

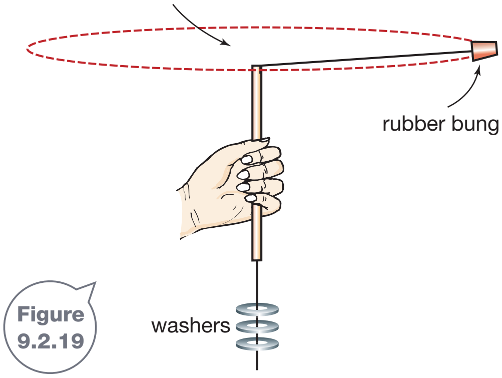


Figure 9.2.19