6 Space science

In this chapter you will …

Science Understanding

- use Newton's second law ($F = ma$) to calculate the force of gravity on an object
- apply Newton's third law (action and reaction) to describe the operation of rockets
- identify the forces acting on an object in orbit

Science as a Human Endeavour

- gain an understanding of the problems of living in space

Science Inquiry Skills

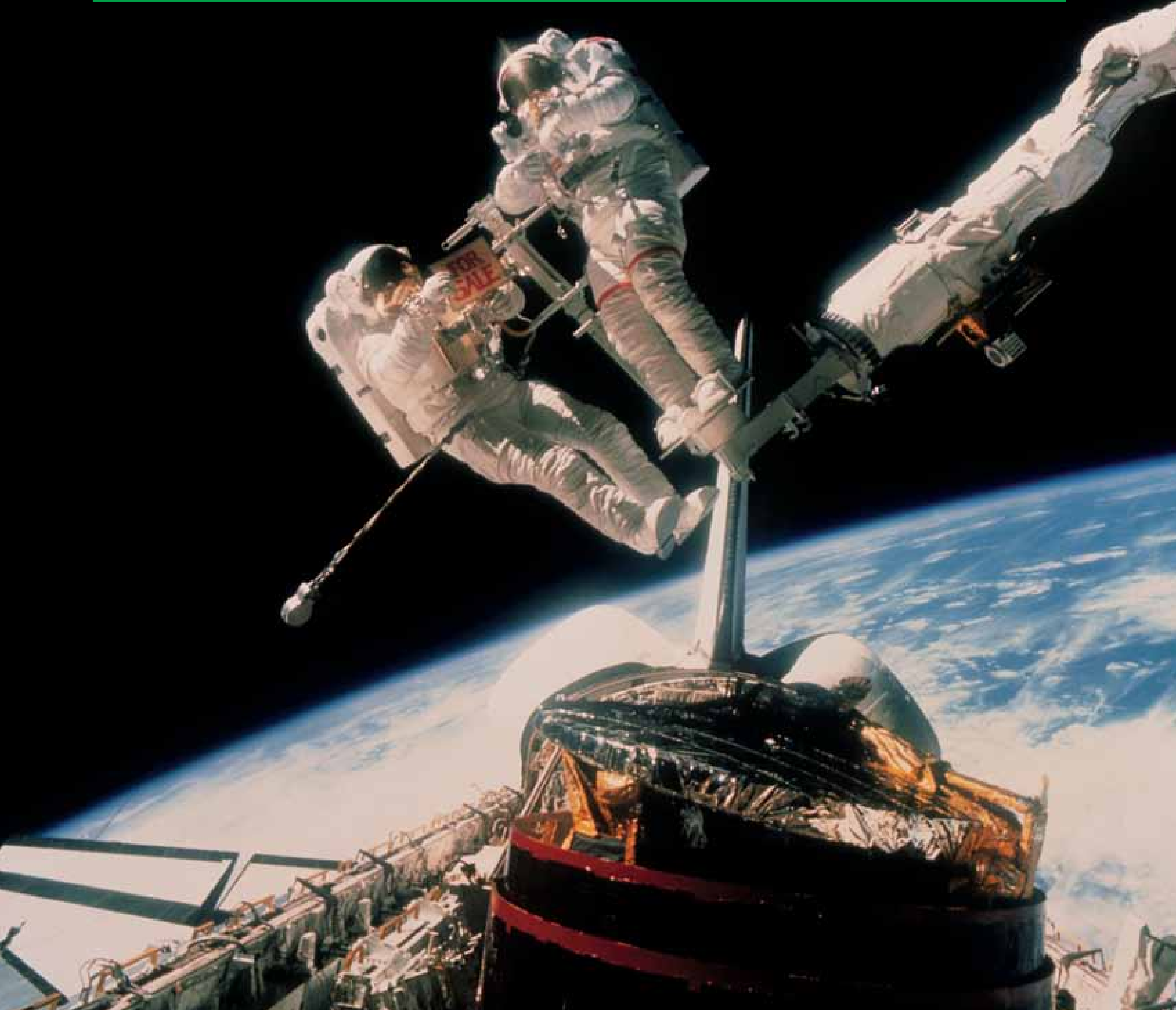
- use internet research to find out the latest on a replacement for the space shuttle
- design an experiment to be carried out on the International Space Station

Based on Australian Curriculum, Assessment and Reporting Authority (ACARA) materials

Getting started

Form a group of three or four people and discuss the questions below.

1. You are standing in a lift on a set of scales. The scales read 50 kg. Suddenly the lift moves upwards. What happens to the reading on the scales? Why?
2. You tie an object to a piece of string and whirl it around your head. You then let the string go. In which direction will the object travel? Draw diagrams to help your explanation.
3. You drop two objects at the same time from a very high cliff. They are the same size but one is five times as heavy as the other. Which reaches the ground first?
4. You are on a space walk alongside the space shuttle's cargo bay 400 km above the Earth. You let go of the handrail. Will you fall back to Earth? Explain.



6.1 Getting into space

How high can you jump vertically when you stand on the ground with your feet together? Fifty centimetres? The reason why you cannot jump any higher is because the force of gravity attracts you to the Earth. To get into space you have to overcome this force. To do this, rocket engines have to supply a force greater than the downwards force of gravity. When the engines in a rocket ignite, the force generated by the engines accelerates the rocket upwards.

Science as a Human Endeavour

The first rocketeers

The Chinese are credited with the invention of rockets, which were used in warfare and in religious ceremonies. The rockets were made of bamboo tubes filled with gunpowder. In warfare they were attached to arrows, and in ceremonies they were attached to bamboo sticks to help them steer a straight course.

The legend of Wan-hu

Legend has it that Wan-hu, a lowly government official in the Ming Dynasty (early 16th century), was intrigued with rocketry, and he thought rockets could be used for transportation. Wan-hu was also a keen astronomer and dreamed that rockets could take him to the stars.

He built a special chair with 47 rockets and two kites attached to it. At the appointed time, Wan-hu sat in the chair and gave the order for his assistants to light the fuses. Moments later there was a massive explosion. When the smoke and dust cleared, Wan-hu and the rocket chair were gone. The world's first want-to-be astronaut was gone.

Busting the myth of Wan-hu

The *Mythbusters* television team decided to try to recreate the Wan-hu rocket chair using the same sort of materials available to Wan-hu. They used a crash test dummy instead of a human.

The chair exploded on the launch pad and the dummy suffered severe burns. The team then tried modern rockets, but the chair only rose a few metres before going out of control and crashing. The team concluded that rockets cannot supply enough force to lift a rocket chair very far away from the Earth's surface.

WEBwatch

Go to www.**OneStopScience.com.au** and follow the links to the websites below.

Brief history of rockets

An interesting, easy-to-read account of the history of rocketry from early times to the present

Chinese fire-arrows

The story of Wan-hu, and links to the history of rocketry and other sites

The History of Rocket Science

Detailed information on the history of the science of rockets and rocket design

OneStopScience

Force, mass and acceleration

When the engines in a rocket ignite, the force generated by the engines accelerates the rocket upwards. How quickly a rocket lifts off depends on the mass of the rocket and the force generated by its engines.

In Chapter 2 you learnt that the acceleration of an object is directly proportional to the force acting on it and inversely proportional to its mass. That is:

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

$$a = \frac{F}{m}$$

$$\text{or} \quad F = ma$$

For example, the upwards force produced by a rocket of mass 10 000 kg being accelerated at 10 m/s^2 is:

$$\begin{aligned} F &= ma \\ &= 10\,000 \text{ kg} \times 10 \text{ m/s}^2 \\ &= 100\,000 \text{ N} \end{aligned}$$

Fig 1 The force generated by a rocket's engines accelerates the rocket upwards.

Weight is a force

If you hang an object on a spring balance, the spring stretches. This shows that there is a downwards force. If a larger mass is hung on the balance, the spring stretches further, showing that the force is greater. F = ma can be rewritten as:

$$W = mg$$

where **W** is the weight force and **g** is the acceleration due to gravity

Acceleration due to gravity

When you hang a 1 kg block on a Newton spring balance, the dial reads 9.8 N. This means the weight of the 1 kg block is 9.8 N. If the block is unhooked from the spring balance, it will fall to the ground. The acceleration of the block is:

$$\begin{aligned} g &= \frac{W}{m} \\ &= \frac{9.8 \text{ N}}{1 \text{ kg}} \\ &= 9.8 \text{ m/s}^2 \end{aligned}$$

So the acceleration due to gravity at the Earth's surface is 9.8 m/s^2.

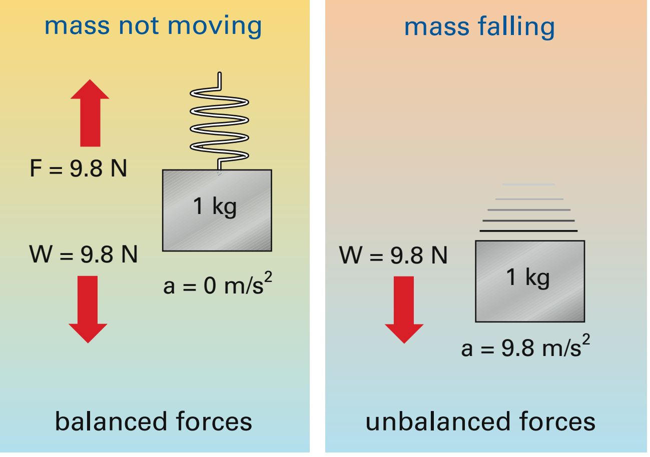


Fig 2 When the mass is hooked on the spring, the forces are balanced (in equilibrium) and there is no motion. When it is unhooked, it falls with an acceleration of 9.8 m/s^2.

What happens if a 2 kg block falls to the ground? When the block is attached to the spring balance, it reads 19.6 N. If the block is unhooked from the balance, the acceleration of the 2 kg block is:

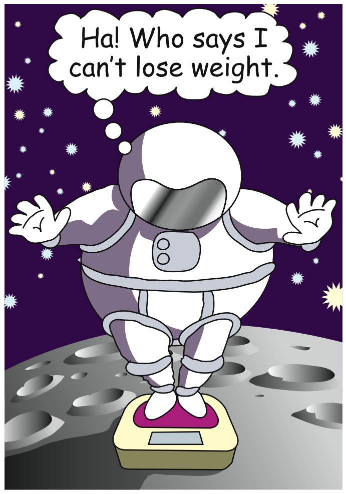
$$g = \frac{19.6\ \text{N}}{2\ \text{kg}}$$
$$= 9.8\ \text{m/s}^2$$

The heavier block still falls with the same acceleration as the lighter one. In general, the acceleration due to gravity is the same for all objects on the Earth's surface. Why then does a tennis ball fall faster than a piece of paper? Falling objects are slowed down by friction due to the air around the Earth, and the amount an object is slowed down depends on its shape. So in real life, different objects do not all fall with the same acceleration.

The acceleration due to gravity is not the same everywhere. It decreases as you move away from the Earth. So when the force of gravity decreases, the acceleration also decreases. This means that if you travel away from the Earth, your weight will decrease. The table below shows how gravity and weight decrease with increasing distance from Earth for a 50 kg person.

Location of 50 kg person	Acceleration (m/s^2)	Weight (N)
On the Earth's surface	9.8	490
100 km above Earth	9.6	480
500 km above Earth	8.3	415
1000 km above Earth	6.8	340

The force of gravity also depends on the mass of the planet or moon. You can investigate the differences in the acceleration due to gravity on different planets in the activity below.



Activity

Suppose you are standing on the surface of planet X and you are curious to find out how the weights of various masses differ from those on Earth.

The table below shows the results for planet X.

Mass (kg)	Weight (N)
2	39.2
4	78.4
6	117.6
8	156.8

- Use the formula $W = mg$ to find the acceleration due to gravity on planet X.
- Suppose you took the four masses in the table back to Earth. Find the weights of the masses on the Earth's surface.
- The acceleration due to gravity on Jupiter is 25.5 m/s^2. Calculate the weights of the 2, 4, 6 and 8 kg masses in the table.
- Write a generalisation about the relationship between weight and gravity.
- If the force of gravity is directly proportional to the mass of the planet, work out which planet (X, Jupiter or Earth) has the smallest mass and which has the greatest.
- How much would you weigh on planet X? How much would you weigh on Jupiter?

Rocket science

The cartoon below illustrates Newton's third law of motion.

When the man fires the gun, the bullets go in one direction and the gun moves in the opposite direction. Newton's third law of motion states:

For every force there is an equal and opposite force.

The two forces in this law are often called the *action* force and the *reaction* force. You can investigate these forces in the activity below.

The action–reaction principle is used in rockets. Rockets shoot out hot exhaust gases from their engines. The force of the exhaust gases shooting out (the action) pushes the rocket forwards (the reaction). This is why rockets are sometimes called *reaction engines*. And the faster the hot exhaust shoots out, the faster the rocket moves in the opposite direction.

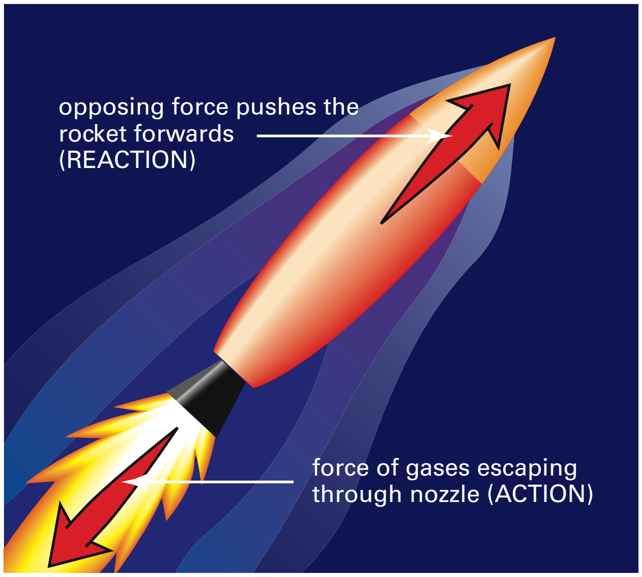


Fig 3 A rocket works on the principle of action and reaction.

All aircraft use the action–reaction principle. The blades on propeller-driven aircraft spin rapidly and push the air backwards (action), thus pushing the aircraft forwards (reaction). The engines on jet aircraft take in air at the front. This is mixed with jet fuel, ignited, and then the hot exhaust gases are forced out of the back of the engine. This pushes the aircraft forwards.

Activity

For this activity you need a heavy ball (medicine ball) and a skateboard or skates.

1 Stand on the skateboard facing the front and hold the medicine ball at chest level.

2 Throw the ball horizontally to another person without bending your legs or pushing the skateboard.
- Describe what happens.
- In what way is this similar to the gun cartoon above?
- Which is the action force and which is the reaction force?

3 Find out what happens when you throw the ball harder.
- Interpret your results.

Experiment 5 Model rockets

Planning and Safety Check

- Carefully read through Part A and Part B. Work in a small group to design the tests for both types of rockets.
- Make a list of the equipment you will need for each part of the experiment.
- Design and draw up data tables for your results.
- Discuss the safety precautions necessary in this experiment. Draw up a risk assessment sheet listing all the safety hazards and the precautions you will need to take.

PART A Balloon rockets

The task

Your task is to design an efficient balloon rocket that will be propelled along a length of nylon fishing line. The efficiency of the rocket will be tested in two ways:

- how far the rocket goes along the nylon fishing line
- how fast the rocket goes in the first 5 metres.

You are to use simple materials in your test—balloons, drinking straws, adhesive tape and nylon fishing line.

Discussion

1 Compile class results of the two tests.

2 Which design features are important in making a balloon rocket?

3 What caused the motion of the rocket?

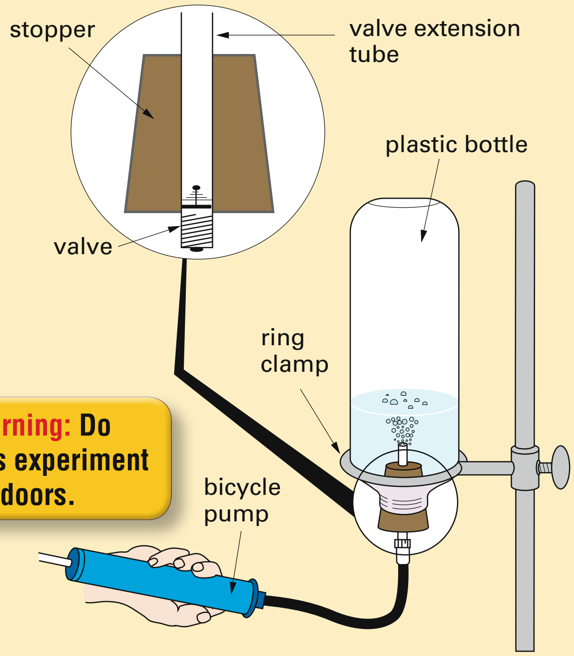
4 How well would your rocket go in space? Explain.

5 How would you design your rocket to test whether altering the size of the jet (where the air comes out of the balloon) has an effect on the speed of the rocket? Try it!

PART B Water rockets

In this part of the experiment, your task is to find out which variables affect the motion of a water rocket.

Use the diagram below to build a water rocket. Your teacher will help you fit a car valve extension tube through a rubber stopper. (You can also purchase commercial water rockets.)



Warning: Do this experiment outdoors.

Experiment with the water rocket to find out how the following variables affect its motion:

- the amount of water in the bottle
- the size and shape of the container.

Discussion

1 Write a report of your findings.

2 Explain in detail what caused the motion of the water rocket. In which ways is this similar to the motion of the balloon rocket? In which ways is it different?

3 Is water necessary for the operation of the water rocket? Test your prediction.

Rocket motion

In Part A of Experiment 5 the balloon rocket moved forwards (the reaction force) because air was forced out of the balloon in the opposite direction (the action force). The water rocket in Part B shot upwards (the reaction force) because the compressed air in the bottle forced water out of the mouth in the other direction (the action force).

In a space rocket, the fuel burns in a combustion chamber. The burning fuel produces hot gases, which are forced out of the nozzle at great speed. The force of the escaping gases produces an equal and opposite reaction, which pushes the rocket upwards. This force is called the **thrust**. Applying Newton's second law of motion (F = ma), the thrust of a rocket is equal to the mass of the escaping gases multiplied by the acceleration of the gases.

The net force accelerating the rocket from its launch pad is the thrust minus the weight of the rocket.

net force = thrust of engines − weight

For example, a 2 000 000 kg rocket has engines that develop a thrust of 69 600 000 N. What is the acceleration of the rocket at lift-off?

Weight of rocket = 2 000 000 kg × 9.8 m/s²
= 19 600 000 N

Thrust of engines = 69 600 000 N

Net force = thrust − weight of rocket
= 69 600 000 – 19 600 000 N
= 50 000 000 N

$$\text{acceleration} = \frac{\text{net force}}{\text{mass of rocket}} = \frac{50\,000\,000 \text{ N}}{2\,000\,000 \text{ kg}} = 25 \text{ m/s}^2$$

Space engineers design engines that develop as much thrust as possible, while at the same time they try to reduce the weight of the rocket.

Rocket engines

All rocket engines work on the same principle: they burn fuel to produce fast-moving exhaust gases that push the rocket forwards.

As well as the fuel, space rockets have to carry a source of oxygen because there is no air in space in which to burn the fuel. There are two types of rocket engine—the *solid-fuel engine* and the *liquid-fuel engine*.

The solid-fuel engine uses a solid fuel mixed with an *oxidiser* much like a fireworks skyrocket. A spark ignites the mixture and the explosive reaction produces gases that are forced out of the engine's nozzle. The solid-fuel engine is very simple in construction and very powerful for its weight, and is used mainly in booster rockets to lift heavy payloads into space. However, like the skyrocket, it suffers one major disadvantage—once ignited it cannot be extinguished until the fuel has been used up.

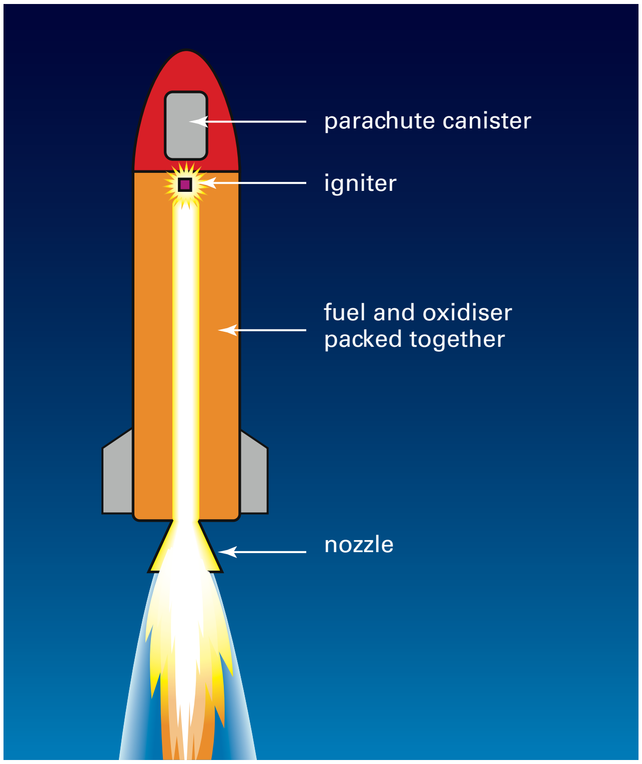


Fig 4 A solid-fuel rocket engine has solid fuel and oxidiser packed together. When ignited, the fuel burns, sending high-speed gases out through the nozzle. The parachute enables the rocket to be recovered for re-use.

The liquid-fuel engine needs complicated pipework and pumps to force the liquid hydrogen fuel and the oxidiser (liquid oxygen) into the combustion chamber. Here they are ignited and burn explosively. The advantage of this type of engine is that it can be throttled back, or turned on and off, to control the rocket's speed.

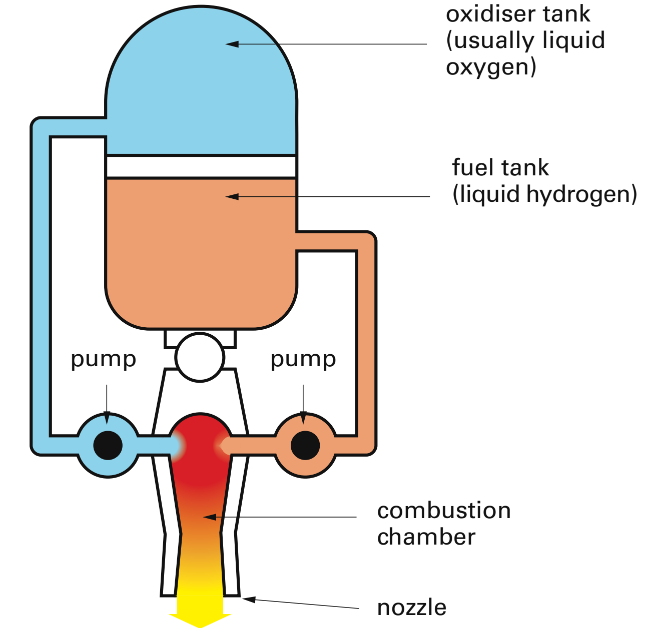


Fig 5 A liquid-fuel rocket engine. This engine is more complicated and expensive to build than the solid-fuel engine, but its thrust can be controlled.

Rocket designs

Since gravity is greatest at the Earth's surface, the most powerful engines in a rocket have to be used at lift-off. Space rockets usually use two to four solid-fuel booster engines alongside the main liquid-fuel engine. However, two minutes after lift-off the solid-fuel boosters have used up all their fuel. To reduce the mass of the rocket, engineers design parts of the rocket to fall away when they are no longer needed. Most rockets have this design and are called multistage rockets.

About 10 minutes after lift-off, the main rocket engines also run out of fuel. This first stage, which is the largest part, then detaches and burns up in the atmosphere as it falls to Earth. Engines in the second stage then ignite and carry the rocket further into space.

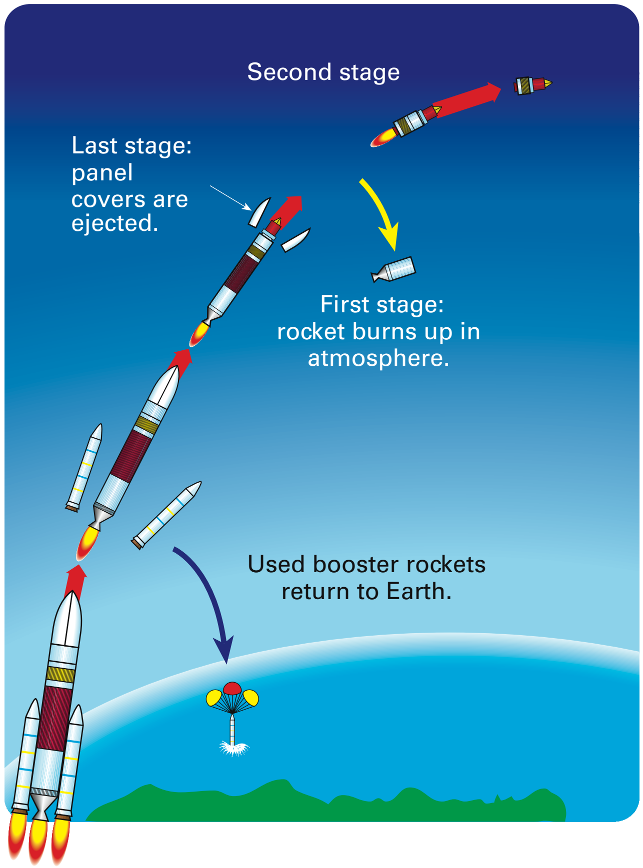


Fig 6 Sections of a multistage rocket detach and fall away after use. This helps to keep the mass of the rocket as small as possible while gaining maximum acceleration.

Check

1 a You simultaneously drop a 2 kg rock and a 10 kg rock from a high cliff. Why should they hit the ground at the same time?

  b You then drop a piece of paper and a small pebble from the cliff at the same time. Will they hit the ground at the same time? Explain.

2 How does Newton's third law of motion explain how a rocket moves?

3 A bag of sand is attached to a spring balance. The dial reads 147 N. What is the mass of the bag of sand?

4 Look at question 1 in the Getting started section.
   a What is the mass of the person?
   b How much does this person weigh?
   c Suggest why weighing scales are graduated in kilograms rather than newtons.
   d Why does the reading on the scales increase when the lift moves upwards?

5 Unlike jet aircraft, space rockets carry a source of oxygen as well as fuel. Explain why.

6 You tell a group of 8-year-old students that you lose weight when you go into space.
   a Suggest how the students might interpret this statement.
   b Write down your explanation of the statement.

7 Look at the photo of the helicopter.
   a Explain in terms of action–reaction how the helicopter can rise vertically from the ground.
   b How does the helicopter move forwards?

8 a Explain the difference between a solid-fuel rocket engine and a liquid-fuel engine.
   b The last stage of a multistage rocket contains a small liquid-fuel engine. Why is the engine small, and why does it use liquid fuel and not a solid fuel?

9 In this chapter and Chapter 2 you have learnt Newton's three laws of motion. In your own words write down these three laws. Check pages 44, 49 and 147.

Challenge

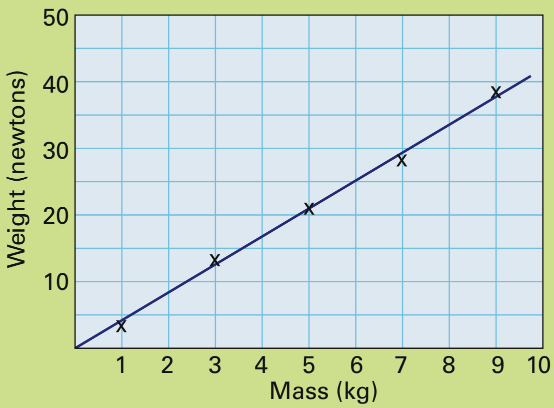
1 A man has a mass of 85 kg. Use the table on page 146 to calculate his weight:
   a on Earth
   b 1000 km above the Earth.

2 The rockets that carried the Apollo missions into space had a thrust-to-weight ratio of 12:1.
   a What does this statement mean?
   b Suggest what would happen to the acceleration of the rocket if the thrust-to-weight ratio was larger.

3 A lunar lander of mass 3000 kg lands on the moon's surface. When they are ready for lift-off, the astronauts fire the lander's rockets, which develop a thrust of 15 300 N. If $g = 1.6\ m/s^2$ on the moon, calculate the acceleration with which the lander leaves the moon's surface.

4 The space shuttle and the booster rockets pictured on page 144 have a combined mass of 2 200 000 kg. The acceleration on lift-off is maintained at 2.5 g for 50 seconds (g = acceleration due to gravity on Earth).
   a Calculate the net upwards force on the shuttle at lift-off.
   b Find the thrust developed by the engines.

5 The graph below shows a plot of weight versus mass for a number of objects. Use the graph to work out whether the readings were taken on the Moon ($g = 1.6\ m/s^2$), on Mercury ($g = 4.1\ m/s^2$) or on Saturn ($g = 10.8\ m/s^2$). Explain how you arrived at your answer.



6 Leon stands in a lift and hangs a 5 kg bag of potatoes on a spring balance. The dial reads 42.5 N. Describe the motion of the lift. As a challenge, calculate the acceleration of the lift.

6.2 Orbiting the Earth

If you look at the moon on successive nights, you will see that its position in the sky changes. This is because of the Earth's rotation, and also because the moon revolves around the Earth in its orbit. An **orbit** is a path taken by an object as it moves around another object.

Satellites

Objects that orbit planets are called **satellites**. The moon is Earth's natural satellite. The first artificial satellite to orbit the Earth, called *Sputnik 1*, was launched in October 1957 by the then Soviet Union. Since then, more than 4000 artificial satellites have been launched into orbit. Hundreds of communications satellites relay radio and television information between the continents on Earth 24 hours a day.

Fig 7 *Sputnik 1* was the Earth's first artificial satellite. It was relatively small with a mass of 84 kg and a diameter of 53 cm. Its four aerials beamed back information about the temperature and density of the upper atmosphere.

Investigation 9 Orbits

Aim

To use a model to show the forces acting on a body in orbit.

Materials

- 1.5 m length of nylon fishing line
- plastic tubing (about 15 cm long),
- rubber stopper with a hole in it
- brass hanger and some brass masses

Planning and Safety Check

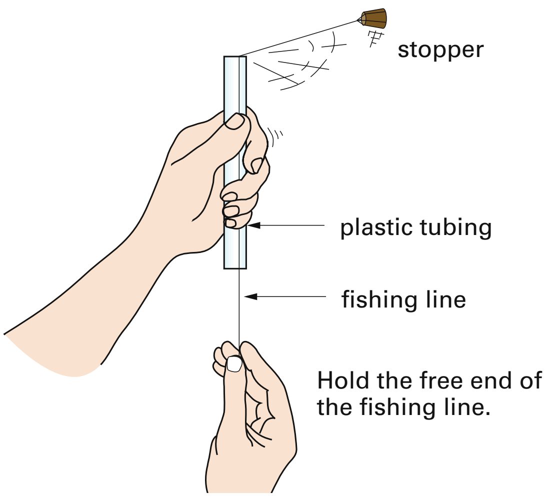
- Carefully read through the investigation. Then tell your partner what you have to do, what you have to record and what safety precautions you have to take.
- It is best to do this investigation outdoors.

Method

1 Tie the rubber stopper to the end of the fishing line. Thread the other end of the fishing line through the plastic tube.

2 Hold the end of the fishing line below the tube and whirl the stopper around in a circle as shown in the diagram below. Now let the fishing line go.

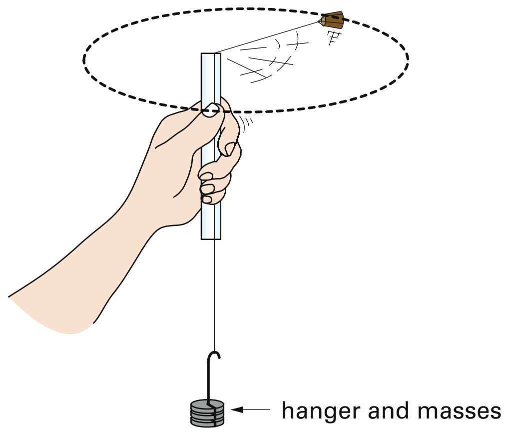
In which direction did the stopper travel? Draw a sketch to show this.



3 Thread the fishing line through the tubing again. Then tie the brass hanger to the free end.

4 Add some masses to the hanger and whirl the stopper so that it orbits at a constant distance and the masses do not move up or down. This may take a little practice.

Record the radius of the orbit.



5 Now speed up the orbiting stopper.

Record what happens to the masses.

6 Add masses to the hanger so that the stopper orbits at the same radius orbit as in Step 4.

7 What will happen if you decrease the speed of the orbiting stopper? Test your prediction.

Discussion

1 Why did the stopper fly off when you let the string go in Step 2?

2 What happens to the rotating stopper when its speed increases? How could you keep it rotating at the same radius of orbit?

3 What keeps a spacecraft in a circular path when it is in orbit?

In the investigation you just did, you should have concluded that the revolving stopper is being pulled towards the centre of the circle by the force along the fishing line. This force keeps changing the *direction* of the stopper's motion. And if this force disappears, the stopper flies off in a straight line. The stopper is not pulled in towards the tubing, because it has sufficient orbital speed (inertia) to keep it in 'orbit'.

In the same way, the gravitational force pulls an orbiting satellite towards the centre of the Earth. The satellite does not fall to Earth, because it has sufficient speed to stay in orbit.

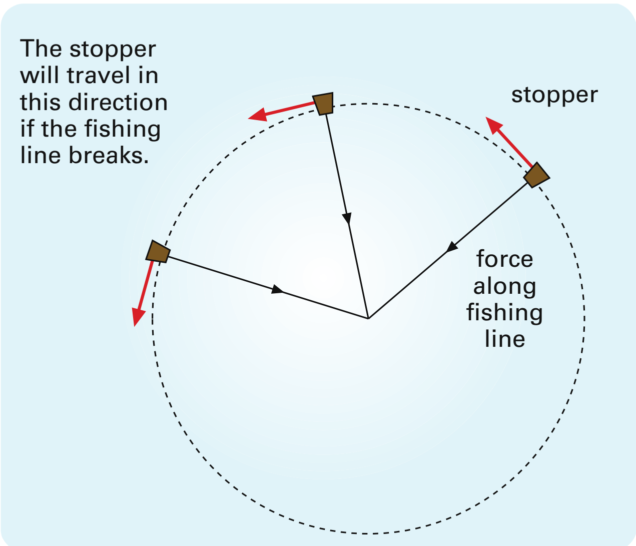


Fig 8 The inwards pulling force along the fishing line constantly changes the direction of the stopper's motion.

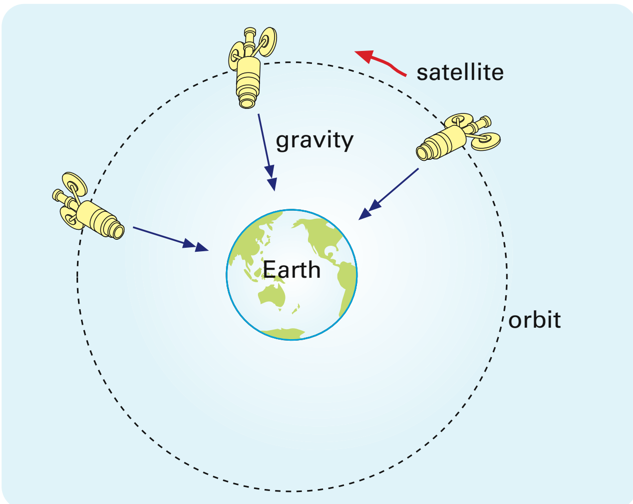


Fig 9 The satellite is being pulled towards Earth by the force of gravity, but its motion (inertia) keeps it in orbit.

Types of orbits

You found out earlier that the Earth's gravity is strongest at the surface and decreases with altitude. (In outer space gravity is zero.) This means that satellites in a low Earth orbit will experience a stronger gravitational pull than satellites in higher orbits. To overcome this problem, satellites in low Earth orbits have to have a greater orbital speed, otherwise they fall back to Earth. In general, the higher the altitude of the satellite, the slower its orbital speed.

Low Earth Orbits

Low Earth Orbits (called LEOs) are usually at altitudes of about 400 km. At this height, 99.9% of the Earth's atmosphere is beneath it, so satellites avoid the problem of friction with the Earth's atmosphere. LEO satellites move at high speeds of about 8000 m/s, and include the Earth-monitoring and 'spy' satellites. Because of their low altitude, LEO satellites can take very clear pictures of objects as small as 3 m across on the Earth's surface. They usually have a much shorter life than other satellites because even the tiny amounts of gases in the upper atmosphere gradually slow them down. As the satellite's speed decreases, it loses altitude and eventually falls to Earth where it burns up in the more dense atmosphere.

LEO satellites can be linked to form information networks in space. For example, 24 LEO satellites have been placed above the Earth to form the Global Positioning System (GPS). Sailors, airline pilots or even motorists driving along central Australian outback roads can find their position on the Earth's surface using a small portable receiver.

Even though LEO satellites have a much shorter life than high altitude ones, placing satellites in the lower orbit is much cheaper. This is because large, powerful and very expensive rockets are needed to launch the high altitude satellites. Sometimes the high altitude satellites are 'parked' in low orbit, before they are boosted into higher more useful altitudes.

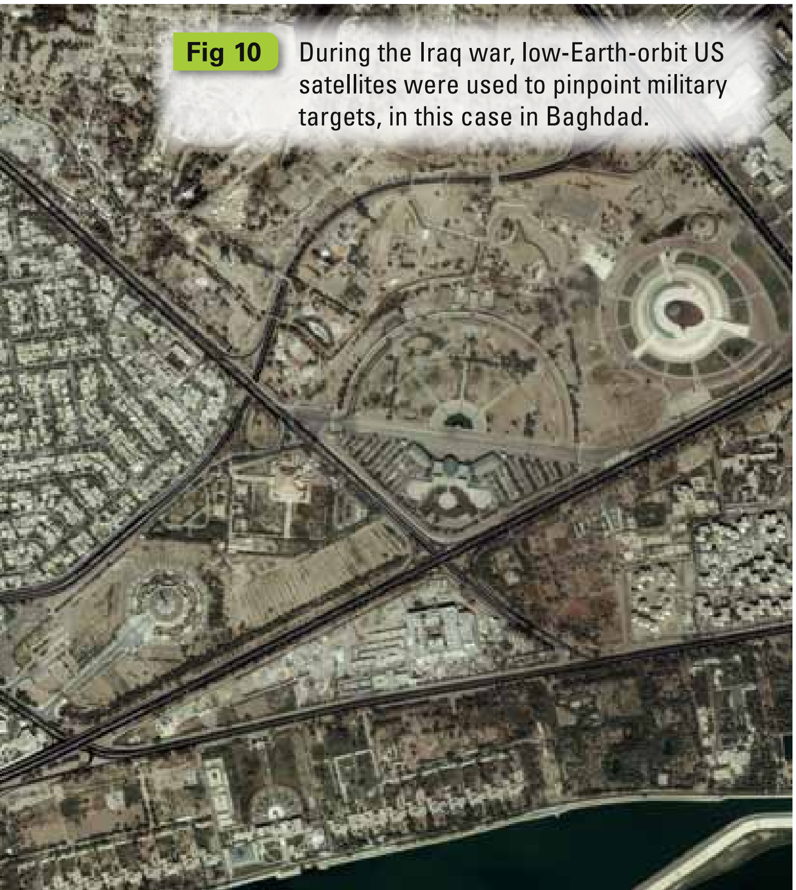


Fig 10 During the Iraq war, low-Earth-orbit US satellites were used to pinpoint military targets, in this case in Baghdad.

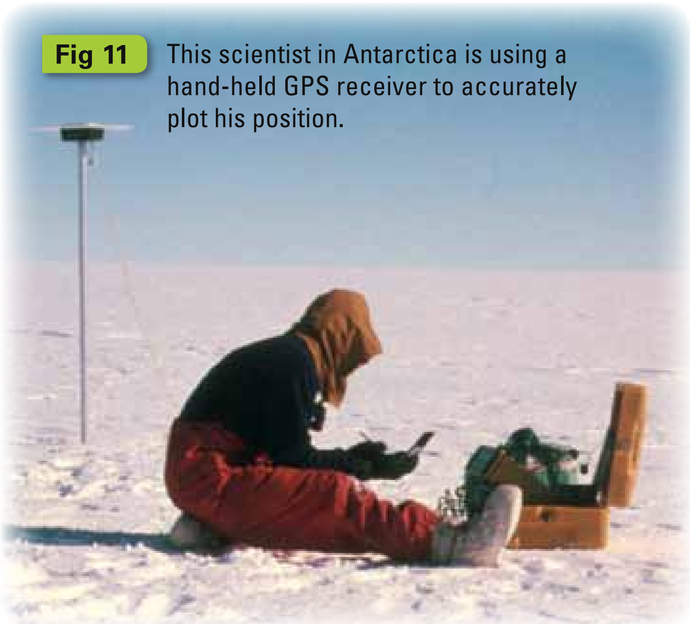


Fig 11 This scientist in Antarctica is using a hand-held GPS receiver to accurately plot his position.

Polar orbiting satellites

Polar orbits are special low Earth orbits that carry satellites in a circle over the North Pole and South Pole. These high-speed satellites complete about 14 revolutions of the planet every 24 hours. As the satellite revolves from pole to pole, the Earth rotates beneath it. In this way, the satellite 'sees' every part of the Earth's surface at relatively close range.

Geostationary orbits

A satellite placed in orbit 36 000 km above the Earth's equator takes exactly one day to complete an orbit. During this time, the Earth also turns once on its axis. This means that the satellite remains over the same point on the Earth's surface. Orbits at this altitude are called **geostationary orbits**, or sometimes geosynchronous orbits. Satellites in this orbit travel at about 3200 m/s, less than half the speed of the LEO satellites.

Geostationary satellites are used to beam everything from commercial radio and television broadcasts to navigational and weather information. However, there are so many satellites in this orbit that its use is now governed by international regulations.

Aussat and Intelsat satellites relay TV channels to subscribers all over Australia. To receive these broadcasts, subscribers have a satellite dish pointing towards a geostationary satellite above the equator.

Fig 12 A satellite dish on this school is used to receive TV channels from geostationary satellites.

The weather information that is continuously beamed down to Australian weather forecasters comes from one of five geostationary satellites that form a network around the equator. The MTSAT Japan satellite is positioned over the equator to the north of Papua New Guinea. This satellite sends information and pictures to forecasters who then send them on to radio and TV stations as well as newspapers.

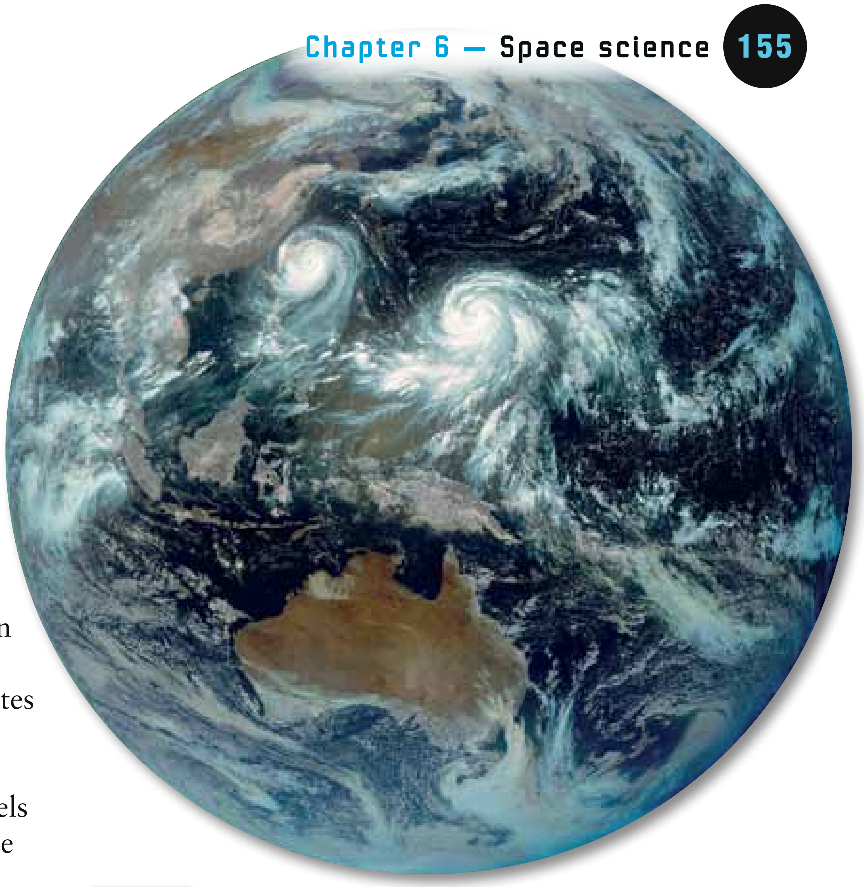


Fig 13 An image from the MTSAT Japan geostationary satellite positioned in orbit to the north of Australia

WEBwatch

1 Weather satellites

You might like to look at some images from weather satellites. Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Australian Region Satellite Images

The latest satellite images from the Bureau of Meteorology website

Observing the Earth

European Space Agency satellite images of various parts of the Earth's surface

2 Google Earth

Would you like to see a satellite's view of your neighbourhood, or even a close-up of your house? Go to **www.OneStopScience.com.au** and follow the links to **Google Earth**.

You can use this link to download the Google Earth application onto your computer. Then you can scan almost everywhere in the world and zoom in to see details of cities, mountains, lakes and oceans.

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Activity

In 2011 the ageing space shuttle was retired. So what will replace it, and how will astronauts get to the International Space Station and beyond? Apart from the existing Russian *Soyuz* spacecraft, there were three other spacecraft under development in 2011. Your task is to decide which of these three spacecraft, or an alternative, is most likely to replace the space shuttle. Space technology is changing rapidly so you will need to search the internet for the latest development.

1 *Orion*
The *Orion* spacecraft is being developed by Locheed Martin for NASA. It isn't a winged vehicle like the space shuttle, but is a much smaller capsule like the *Apollo* spacecraft. It has a service module for a crew of four, and uses parachutes to land in the sea. The drawing shows *Orion* approaching the International Space Station.

2 *Dream Chaser*
The *Dream Chaser* is being developed by the Sierra Nevada Corporation. It is similar to the space shuttle, but much smaller. It can carry seven astronauts. It is launched on top of an *Atlas V* rocket (see drawing) and can land on a normal runway.

3 *Skylon*
The *Skylon* is being developed by the British company Reaction Engines Limited. It is bigger than the space shuttle and can carry up to 30 astronauts or space tourists. It works like an ordinary jet engine, burning hydrogen or liquid oxygen. It is totally re-usable and can take off and land on a normal runway.


1


2

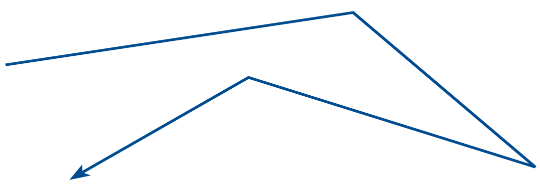

3

Check

1 Explain in your own words what the words *revolve* and *orbit* mean.

2 a A force can change the speed of an object. What is the other thing a force can do?

b Leon sketched the path taken by a ball rolling over a smooth horizontal surface. The ball started from rest and was struck four times during its movement. Copy the path in your notebook and show, using arrows, the direction of the forces acting on the ball.



3 Mariela whirls a tennis ball attached to a string around her head in a horizontal circle.
   a Explain in terms of force why the tennis ball moves in a circle.
   b What would happen to the ball if the string broke?

4 What is a geostationary satellite? How is it different from other types of satellites?

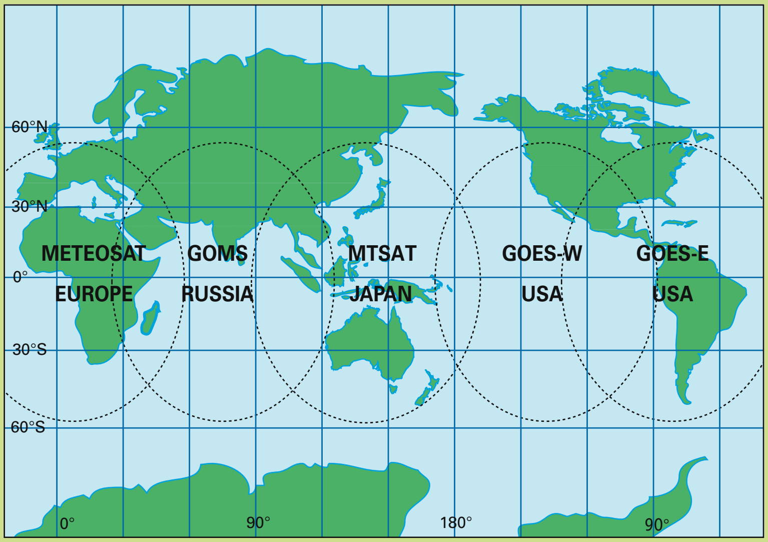
5 a A low Earth orbit (LEO) is usually about 400 km above the Earth's surface but very rarely below this altitude. Why?
   b Why do satellites in LEO have to have high orbital speeds?
   c What is the main advantage of placing a satellite in LEO?

6 How is a polar orbiting satellite different from a geostationary satellite? What are the advantages of placing satellites in polar orbits?

7 What was the purpose of building the space shuttle?

8 a What caused the temperature on the shuttle's surface to rise on re-entry?
   b Which parts of the space shuttle were re-usable, and which had to be replaced before the next launch?

Challenge



1 The map shows the five overlapping areas serviced by the geostationary weather satellites.
   a Which satellite's data would be used to determine the weather patterns for each of the following—Sydney, Perth, New York, Singapore and Hawaii?
   b What is the advantage of a geostationary satellite?
   c Why are these satellites unsuitable for obtaining weather data about Norway or Alaska? Suggest a way of obtaining data about these regions.
   d Geostationary satellites send weather data to Earth 24 hours a day. Suggest how they obtain weather data at night.

2 The tennis ball that Mariela is whirling around her head in Check 3 above does 10 revolutions in 8 seconds.
   a If the string is 2 metres long, how fast is the ball travelling in its circular path?
   b Calculate how long the ball will take to do 10 revolutions if it travels at the same speed but the string is 3 metres long.

3 It is cheaper to launch a satellite-carrying rocket in an easterly direction than in the opposite direction. Suggest why.

4 A satellite is moving with an orbital speed of 8000 m/s in a low Earth orbit at an altitude of 450 km. Assuming the Earth is circular with a radius of 6380 km:
   a calculate the time it takes for the satellite to orbit the Earth
   b find out how many times the satellite orbits the Earth in 24 hours.

5 *Columbia* was the first in NASA's fleet of space shuttles. It was launched on 9 April 1981 and landed again two days later. However, on 1 February 2003, it disintegrated on re-entry and all seven astronauts perished. Use your internet browser to research this space shuttle, and write a short story about its achievements.

6.3 Living in space

As the giant rocket blasts off from the launch pad, the astronauts aboard the space module feel the effects of the tremendous force of the rocket engines. One hour later the space module is in orbit 400 km above the equator. At this altitude the astronauts feel 'weightless'. Outside the space module, there is no air and no protection from the sun's radiation. Let's look at some of the problems of living in space.

Fig 14 An astronaut catches a weightless spoon during a snack on board the Space Shuttle *Atlantis*.

Weightlessness or microgravity

All objects on or near the Earth are attracted to it by the force of gravity. Your weight depends on your mass and the acceleration due to gravity. When an object is in outer space, there is no gravity; that is, the acceleration due to gravity is zero. Therefore objects in outer space are weightless. However, at an altitude of 400 km there is still some gravity. Why then do you feel weightless here?

At an altitude of 400 km the reduced gravity still pulls the spacecraft towards the Earth. However, the spacecraft is moving fast enough to keep it moving in a circular orbit. So the spacecraft and everything inside it is effectively in free fall. This is why astronauts feel weightless when in orbit.

Weightlessness is not really the correct word for this effect. Objects in orbit still have some weight, although very small. **Microgravity** is a more precise word that describes the lack of weight.

Advantages of microgravity

You can move in any direction with just a little push in the opposite direction. You can work upside down without the feeling of blood rushing to your head. And you can sleep horizontally or vertically, although you have to be strapped into your bed to avoid floating away when you move in your sleep.

Disadvantages of microgravity

Astronauts often get space sickness. This is related to the motion sickness some people feel in a rocking boat or when travelling in a car. Space sickness may also be caused by the effects of microgravity on the balancing organs inside the ear.

Eating and going to the toilet also have their problems in space. You have to drink all liquids through a straw from a closed container. In an open cup the liquids form drops and float around the compartment. Food is packed in individual serving pouches on trays that have magnets on them to hold them firmly on a table or wall or wherever you wish to eat.

In the shuttle toilet, air draws the faeces and urine into a bowl underneath the seat. Blades shred the solid wastes, which are then dried when exposed to the vacuum of space. Urine and other waste water is periodically dumped overboard where the material instantly vaporises in space.

Air and water

The air in the crew compartment of the spacecraft is similar to that on Earth. The air pressure is maintained at 1000 hectopascals (1000 hPa)—the same as at sea level.

The composition of the compartment's air is 79% nitrogen and 21% oxygen. Carbon dioxide, given off as a waste product of respiration, is monitored very closely. An excess of CO_2 in the air can make you drowsy and sleepy and this could be dangerous for the crew. Canisters filled with lithium hydroxide absorb the CO_2. The CO_2 reacts with the lithium hydroxide to form lithium carbonate and water vapour. Other canisters filled with activated charcoal absorb odours from the compartment.

Electrical power in the spacecraft is generated by fuel cells. In these devices, oxygen and hydrogen are chemically combined to produce electricity and about 3 litres of water per hour as a by-product. The water is stored and is used for drinking, for the toilet and for the air control system, which maintains the relative humidity at about 55%. Any excess water is dumped overboard where it vaporises and disperses into space.

Maintaining fitness

When you have been in space for a period of time, the microgravity affects your body in a number of ways.

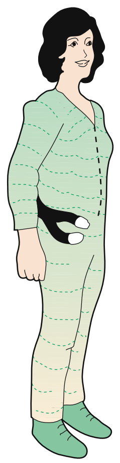
1 One of the most noticeable effects is that the liquids in your body redistribute themselves. The liquids in the upper part of your body increase, causing your face to puff up and some stuffiness in your sinuses.
2 Your posture alters with the low gravity. When you relax, your arms float away from your body, your knees bend and your toes point, making walking difficult. To overcome this, you can wear suction cups on your shoes.
3 The microgravity affects your heart in a similar way to being bedridden for a long period of time. Your heart and pulse rates decrease, as does your blood pressure. To overcome this problem, you have to exercise for at least 30 minutes each day on the treadmill or rowing machine.
4 The most serious problem for space travellers is the demineralisation of bones. Weightbearing bones lose calcium and phosphorus during long periods of microgravity, and this causes a weakening of the bones in the skeleton.
5 Long periods of microgravity also decrease muscle tissue. The Russian cosmonaut Yuri Romanenko lost 15% of the muscle tissue in his legs during an 11-month stay aboard the Mir space station.

Fig 15 Astronaut Shannon Walker exercising on a treadmill on the International Space Station. Why do you think she is wearing a bungee harness?

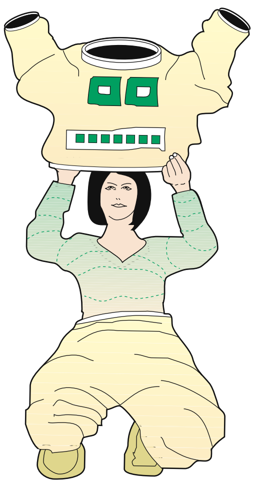
Heat and radiation

At an altitude of 400 km the temperature in space can be as high as 250°C in the sunlight and as low as –150°C in the shade. The crew compartment of the spacecraft is maintained at a constant temperature and pressure, but any space walks require special clothing. To overcome the extreme temperature changes in space, the undergarments of the spacesuits are equipped with water-cooling and ventilation.

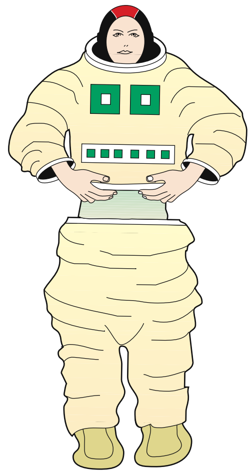
On Earth, the atmosphere absorbs much of the harmful high-energy radiation from the sun, but in space there is no such protection. This radiation can cause cancer and changes to the chromosomes in your sex cells. Spacesuits therefore have to be designed to reflect this dangerous radiation.



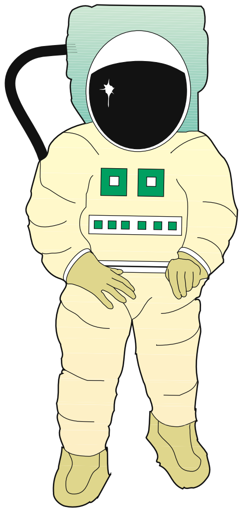
1 The spacesuit's undergarment is made from Spandex mesh with plastic tubing woven into it. The tubing circulates cool water from the life-support backpack.



2 The outer suit comes in two sections and can be put on in less than 5 minutes. The suit contains oxygen-filled pressure bladders that help to keep its shape.



3 When the torso section is put on, the cooling tubes from the undergarment are connected to the tubes that flow to the life-support backpack. The trousers are then joined to the torso section by a rigid aluminium ring.



4 The life-support backpack contains oxygen, water, batteries, and communication equipment. The spacesuit is designed to be re-used and should last 15 years.

Activity

Astronaut's diary

Use the information on pages 158–160 to write a 24-hour diary in the life of an astronaut orbiting the Earth in a space station. For this task, work in a group of three or four people. Use the following ideas in your diary.

- How many hours do you allocate for sleeping, exercising, working and relaxing?
- List the difficulties you face when doing everyday activities in microgravity; for example, washing, cleaning your teeth, eating and drinking, and using the toilet.
- What are the problems of working in a spacesuit and doing jobs in space?
- Describe the experiences at lift-off from Earth and in re-entry.

Space stations

In early 1971 the Russian spacecraft *Salyut 1* became the first space station to be put into Earth orbit. Since that time a number of improvements have been made to make them more liveable for the astronauts who spend an extended period of time in them.

The unmanned *Salyut 6* space station was sent into orbit in 1978. Two months later, two cosmonauts on board a Soyuz spacecraft docked with the Salyut space station and entered it via the docking bay. Three months later they were visited by two other cosmonauts in another Soyuz supply vehicle. This was the first time a space station had been supplied with fresh provisions, and unwanted materials removed.

In 1988 Musa Manarov and Vladimir Titov became the first people to spend more than a full year away from Earth on board the Mir space station. After nearly 15 years in space Mir crashed back to Earth in March 2001.

The International Space Station (ISS)

In 1998 a new space station was born. On 20 November, space scientists from 16 countries throughout the world watched as the Russian Proton rocket carried the first section of the International Space Station (ISS) to an orbit 400 km above the Earth. The ISS is the largest international space project in history.

The ISS is in orbit at an altitude of 360 km, and orbits the Earth every 92 minutes. By September 2011 it had completed over 73 000 orbits since its launch.

In 2006, additional solar panels were installed to increase electrical power, and further modules will be added until it is complete some time in 2012.

Fig 16 (*top*) The International Space Station in orbit 360 km above the Earth's surface
(*middle*) Astronauts in the Zvezda Service Module taking photos
(*bottom*) US astronaut flight engineer Susan Helms looking at Earth from a window in the ISS

Artificial gravity

The one factor that causes most problems for humans in space is the lack of gravity. Serious health problems such as the demineralisation of bones, weakening of the heart and loss of muscle tissue occur when people spend long periods of time in space. Many of the experiments on board the ISS are designed to look at these problems, but they may only be solved if artificial gravity can be created in space stations. How can space stations be designed to create artificial gravity? Try the activity below.

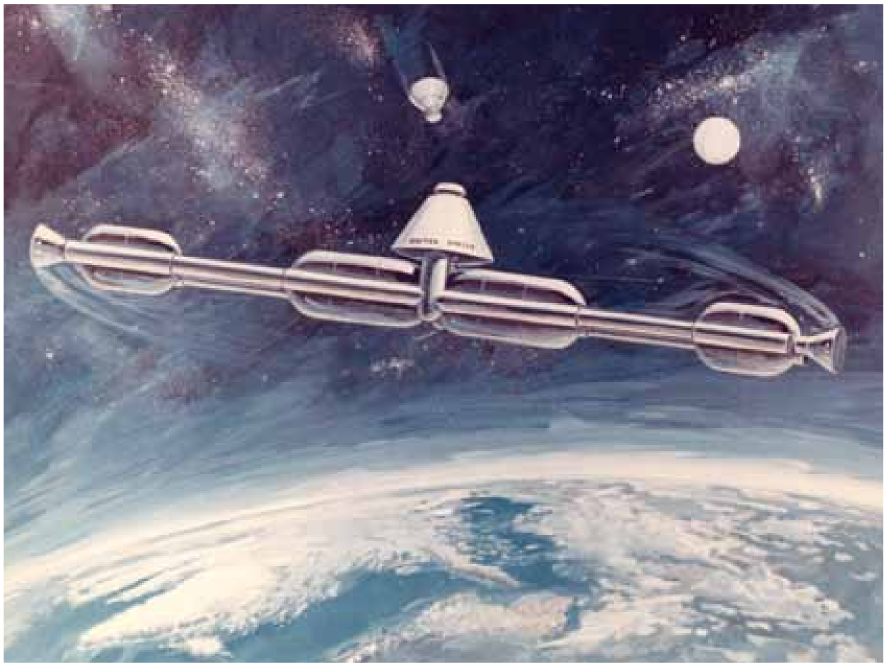


Fig 17 An artist's impression of a space station spinning around a central axis to create artificial gravity

Activity

Your task is to design a space station that will generate artificial gravity and will have facilities for an extended stay by the people on board. Use the internet, books and magazines to help you with this task.

Use the statements below as a guide in your design. As well as describing your design, write a report detailing the various features of the space station and how its inhabitants can survive in space.

- Describe the overall shape of the space station.
- Is it necessary to create artificial gravity in the space station? If not, how will the people on board overcome microgravity problems?
- How will light and electricity be provided for the occupants?
- How will the space station be built? Remember that the present-day shuttle can carry a maximum load of 20 tonnes.
- How will the space station be supplied with food, water, oxygen and fuel, and how will unwanted materials be removed?
- How will the space station be protected from radiation and from meteorites?

WEBwatch

Go to **www.OneStopScience.com.au** and follow the links to the websites below.

Inside the space station
A video of activities on the ISS

International Space Station (Wikipedia)

Space Station
Comprehensive information about the ISS

Life on the Space Station
YouTube video describing the ISS

International Space Station
NASA's space station site

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Science as a Human Endeavour

Andy Thomas: Australian astronaut

Andy Thomas is the only Australian to have orbited the Earth. He began his training with NASA in 1992 and flew his first flight into space on board the space shuttle *Endeavour* in May 1996.

In 1998 he spent 141 days and 2250 orbits of the Earth aboard the Mir space station and was the last US-trained astronaut to stay on Mir.

He blasted off into space again in 2001 on board the space shuttle *Discovery* along with three other crew, and headed towards the International Space Station. Three Space Station crew on board *Discovery* replaced three others who had been working on the ISS. Andy and fellow astronaut Paul Richards had to walk in space to attach a platform and pump to the outside of one of the modules on the ISS. In 2005 Andy visited the ISS again on board *Discovery*.

For more information about Andy Thomas, go to **www.OneStopScience.com.au** and follow the links to these websites:

Andrew S. W. Thomas
Mission Specialist Andy Thomas

Fig 18 Andy Thomas gathers equipment in the cargo bay of space shuttle *Discovery* at the end of his space walk in March 2001.

Check

1. What is meant by free fall? Where on the Earth's surface could you demonstrate free fall?
2. Explain the term *microgravity*. Are there any places in the solar system that would have zero gravity? Explain.
3. The photo on the right shows an astronaut getting a haircut on the ISS. Suggest reasons for the design of the hair clippers.
4. In which ways is the air in a spacecraft's crew compartment similar to the air on Earth? In which ways is it different?

Fig 19 Getting a haircut on the ISS

5 All items of equipment, including knives and forks, pens and scissors, that are used during a space mission have small velcro pads on them. What is the purpose of these pads?

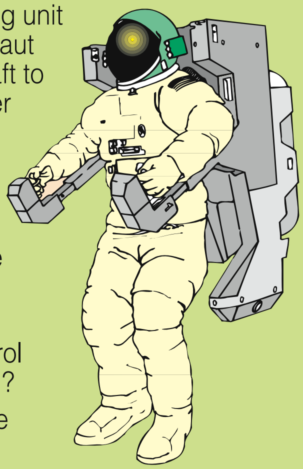
6 Why is the level of carbon dioxide in the air of the crew compartment monitored carefully?

7 The fuel cells in spacecraft produce electricity when hydrogen and oxygen combine. The two gases would take up a huge amount of space on the spacecraft. Suggest how space engineers have overcome this problem.

8 You have put on your spacesuit and are now ready to go outside into free space to begin repairs to a damaged satellite. Write a short story about how you would get out of the spacecraft, and what it might be like outside in space.

Challenge

1 The manned manoeuvring unit or MMU allows an astronaut to move from a spacecraft to other places, say, another orbiting satellite. The propellant is simply nitrogen gas.



a Suggest how this propellant might move you through space.

b How do you think you would be able to control the speed of the MMU?

2 a How is carbon dioxide removed from the air in a spacecraft?

b Write a word equation for the reaction that occurs when carbon dioxide is removed from the air in the spacecraft using lithium hydroxide.

3 Suggest why the outside temperature at an altitude of 400 km can be as high as 250°C in the sunlight and –150°C in the shade.

4 Electrical power for the space shuttle was produced in fuel cells. Each cell generated 1.2 volts DC and there were 24 cells in each battery. Each cell produced about 20 watts of electrical power.

a What was the total voltage produced by each battery?

b What power (in watts) was produced by each of the shuttle's batteries?

5 Suggest why water vaporises immediately it is released into space from a spacecraft.

6 The International Space Station has cost over $100 billion to build. The Human Genome Project cost $45 billion.

a Compare and contrast the benefits of these two science projects to humankind.

b What is your opinion about the statement that these projects are examples of 'scientists spending money on themselves and not on the people who really need it'?

7 Use the internet and other library resources to write a brief history of space stations. Find out how many space stations have been built and put into orbit, what functions they served, and what has happened to them.

8 Before humans went into space, small Rhesus monkeys were placed in orbit for various periods of time. Even recently monkeys have been used in a number of space experiments.

Discuss with others the pros and cons of using animals in space experiments. You might like to organise a debate on this subject.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

1 There are a number of problems to overcome when living in space: you need a supply of air and water, you need protection from ______ and extremes of temperature, and you have to deal with 'weightlessness' or ______.

2 The weight of an object is a ______ and it is found by multiplying its ______ by the acceleration due to gravity.

3 The acceleration due to ______ on the Earth's surface is 9.8 m/s^2, and it ______ as you move away from Earth.

4 The force or ______ developed by a rocket's engines is due to the exhaust gases moving backwards (the ______) and pushing the rocket forwards with an equal force (the ______).

5 The net force on a rocket at lift-off is equal to the thrust of the engines minus the ______ of the rocket.

6 Gravity pulls a satellite towards the Earth, but its ______ (motion) keeps it in orbit.

7 ______ in low Earth orbits, where the gravity is stronger, have much greater ______ than satellites in higher orbits.

action
decreases
force
gravity
inertia
mass
microgravity
orbital speeds
radiation
reaction
satellites
thrust
weight

Working with technology: **Try doing the Chapter 6 crossword at www.OneStopScience.com.au.** OneStopScience

REVIEW

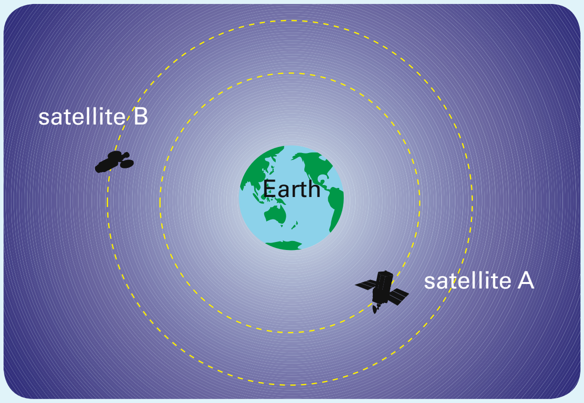
1 You are standing on some scales in a lift. The scales read 60 kg. The lift suddenly accelerates downwards. The reading on the scales will be:
- **A** 60 kg
- **B** less than 60 kg
- **C** more than 60 kg
- **D** 60 × 9.8 kg.

2 In 1975 *Apollo 15* astronaut Scott Irwin dropped a hammer and a feather while standing on the moon's surface.
- **a** Why did they both hit the ground at the same time on the moon but not on the Earth's surface?
- **b** Would the hammer fall faster or slower on the moon than on the Earth? Explain.

3 Jilly stands on ice wearing ice skates. She throws a heavy weight out in front of her.
- **a** In which direction does she move?
- **b** Explain what would have happened if Jilly had thrown the object with more force.

4 Which one of the statements is correct?
- **A** Liquid-fuel rockets are cheap to make and are very simple in construction.
- **B** Solid-fuel rockets have to carry a source of oxygen but liquid-fuel rockets do not.
- **C** Once ignited, solid-fuel rockets cannot be extinguished.
- **D** Most liquid-fuel rockets burn hydrogen and nitrogen gas in the combustion chamber.

5 Two satellites are in orbit around the Earth. Satellite A is at an altitude of 400 km while satellite B is at an altitude of 900 km. Explain why satellite A has to have a greater orbital speed than B.



6 You are in a spacecraft ready for lift-off. The engines that fire for lift-off are solid-fuel engines. The last stage is powered by liquid-fuel engines.

a Why do space rockets have to carry their own source of oxygen as well as the fuel?

b What is the advantage of using solid-fuel engines for lift-off?

c The engine in the spacecraft is a liquid- fuel type. Suggest why this engine is used.

7 Spending long periods of time in microgravity causes problems for the heart, weight-bearing bones and muscle tissues. Describe how microgravity affects these parts of the body.

8 Imagine you were a crew member of shuttle mission STS-120 to the International Space Station. You made the following observations.

a When the shuttle reached the ISS in orbit, you noticed that your face and neck became 'puffy' and you felt a fullness in your head.

b In the ISS crew compartment, you could drink liquids upside down as easily as right-side up.

c Inside the orbiting ISS, you sneezed and you crashed backwards into the compartment wall.

d During re-entry you noticed the tiles on the nose of the orbiter glowed red hot.

Write an inference for each observation.

9 The table gives the acceleration due to gravity for a number of bodies in our solar system.

Solar system body	Acceleration due to gravity (m/s^2)
Mars	4.1
Earth's moon	1.6
Saturn	10.8
Pluto	0.3
Ganymede (moon of Jupiter)	3.9
Uranus	8.9

a On which planet would your weight be about half of what it is on Earth?

b Astronaut Ziro's weight is 88 N on Earth's moon. What is his mass on Mars? What is his weight on Uranus?

c A rocket of mass 75 000 kg blasts off from Ganymede with an acceleration of 5 m/s^2. Calculate the thrust developed by the rocket's engines.

d Will the same rocket be able to lift off from the surface of Uranus? Explain.

10 An astronaut in a manned manoeuvring unit (MMU) or 'space scooter' has a total mass of 110 kg. Each of the 24 jet nozzles around the base of the MMU can produce a thrust of 9 newtons.

a What would the astronaut's weight in newtons be on Earth?

b The astronaut goes for a space walk and fires one jet nozzle. How fast would she accelerate?

c If the astronaut stood on the Earth's surface and fired all the jet nozzles downwards, would the MMU develop enough thrust to lift her off the ground?

d Would the astronaut lift off if she fired all the MMU's jets on the moon?

Check your answers on page 306.

Working with technology

Go to www.OneStopScience.com.au to access interactive activities to help you revise this chapter.

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Science Inquiry Skills

Space experiment

A major task for the crew of the International Space Station is to conduct experiments in space. School students are sometimes given the opportunity to participate in these experiments.

In 2003, eight Australian orb-weaving spiders were launched into space on board the space shuttle *Columbia*. They were part of an experiment designed by Year 9 students at Glen Waverley Secondary College in Melbourne. The aim of the experiment was to find out whether spiders can spin webs in microgravity. The spiders were in a special box that was kept at a constant temperature in the payload bay of the space shuttle. It contained fruit fly larvae to provide a food supply of flies for the spiders. The students controlled their space experiment by having a second spider habitat at school, identical to the one in space except for gravity. The spiders were monitored by video and data was available to everyone on Earth via an internet site. The spiders were able to spin webs in space, but they were not as neat as on Earth. Tragically, *Columbia* broke up as it re-entered Earth's atmosphere and all seven astronauts were killed. None of the spiders survived.

The researchers at RMIT University and Melbourne Zoo who supervised the 'Spiders in space' experiment are now working with NASA to take bees into space. If humans are to live on Mars, then they will need to cultivate crops in greenhouses. However, until now astronauts have had to pollinate plants by hand. Bees are excellent pollinators, but could they live in space? The 'Bees in space' project is developing an inflatable greenhouse to contain the plants and the bees. Project organisers are working with schools to develop experiments to find the bee species best suited to space. The 'Bees in space' project will include building a test greenhouse in the South Australian desert and a teleconference with astronauts aboard the International Space Station. Researchers think Australian stingless bees, for example the teddy bear bees in the photo, would be the best to use.

Activity

Design an experiment to be carried out on the International Space Station. First, think of something that would behave differently in the microgravity of space. Then devise a plan to carry out your experiment on the space station. The equipment you use must be compact and light, and the experiment needs to be simple and easily performed by the space station crew. You could search the internet under 'International Space Station experiments' for ideas.

Write a detailed outline of your experiment, with diagrams of the equipment needed. Include a paragraph predicting how the findings of your experiment using the space station technology could improve our knowledge of science and lead to benefits for people.