Microgravity: living on the International Space Station

About this free course

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http://www.open.edu/openlearn/science-maths-technology/microgravity-living-on-the-international-space-station/content-section-0

There you'll also be able to track your progress via your activity record, which you can use to demonstrate your learning.

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Introduction and guidance

Introduction and guidance

Welcome to this free course, *Microgravity: living on the International Space Station*. The course lasts eight weeks, with approximately three hours of study each week. You can work through the course at your own pace, so if you have more time one week there is no problem with pushing on to complete another week's study.

You will be able to test your understanding of the course through the weekly interactive quizzes, of which Weeks 4 and 8 will provide you with an opportunity to earn a badge to demonstrate your new skills. You can read more on how to study the course and about badges in the next sections.

After completing this course, you will be able to:

- understand what microgravity is and the difference between mass and weight
- explain the types of scientific research that can benefit from microgravity environments, focusing on ageing
- explain the types of scientific research that can benefit from microgravity environments, focusing on bacterial resistance and planet formation
- understand some key concepts and principles that underpin scientific knowledge and why it is important to continue to ask moral questions about scientific research.

Moving around the course

In the 'Summary' at the end of each week, you can find a link to the next week. If at any time you want to return to the start of the course, click on 'Course content'. From here you can navigate to any part of the course. Alternatively, use the week links at the top of every page of the course.

It's also good practice, if you access a link from within a course page (including links to the quizzes), to open it in a new window or tab. That way you can easily return to where you've come from without having to use the back button on your browser.

The Open University would really appreciate a few minutes of your time to tell us about yourself and your expectations for the course before you begin, in our optional start-of-course survey. Participation will be completely confidential and we will not pass on your details to others.

What is a badged course?

While studying *Microgravity: living on the International Space Station* you have the option to work towards gaining a digital badge.

Badged courses are a key part of The Open University's mission *to promote the educational well-being of the community*. The courses also provide another way of helping you to progress from informal to formal learning.

To complete a course you need to be able to find about 24 hours of study time, over a period of about 8 weeks. However, it is possible to study them at any time, and at a pace to suit you.

Badged courses are all available on The Open University's OpenLearn website and do not cost anything to study. They differ from Open University courses because you do not receive support from a tutor. But you do get useful feedback from the interactive quizzes.

What is a badge?

Digital badges are a new way of demonstrating online that you have gained a skill. Schools, colleges and universities are working with employers and other organisations to develop open badges that help learners gain recognition for their skills, and support employers to identify the right candidate for a job.

Badges demonstrate your work and achievement on the course. You can share your achievement with friends, family and employers, and on social media. Badges are a great motivation, helping you to reach the end of the course. Gaining a badge often boosts confidence in the skills and abilities that underpin successful study. So, completing this course should encourage you to think about taking other courses.

How to get a badge

Getting a badge is straightforward! Here's what you have to do:

- read each week of the course
- score 50% or more in the two badge quizzes in Week 4 and Week 8.

For all the quizzes, you can have three attempts at most of the questions (for true or false type questions you usually only get one attempt). If you get the answer right first time you will get more marks than for a correct answer the second or third time. Therefore, please be aware that for the two badge quizzes it is possible to get all the questions right but not score 50% and be eligible for the badge on that attempt. If one of your answers is incorrect you will often receive helpful feedback and suggestions about how to work out the correct answer.

For the badge quizzes, if you're not successful in getting 50% the first time, after 24 hours you can attempt the whole quiz, and come back as many times as you like.

We hope that as many people as possible will gain an Open University badge – so you should see getting a badge as an opportunity to reflect on what you have learned rather than as a test.

If you need more guidance on getting a badge and what you can do with it, take a look at the OpenLearn FAQs. When you gain your badge you will receive an email to notify you and you will be able to view and manage all your badges in My OpenLearn within 24 hours of completing the criteria to gain a badge.

Get started with Week 1.

Week 1 Microgravity and the International Space Station

Introduction

In this first week you will look at weightlessness, zero gravity and microgravity in the context of a parabolic flight. You will study the physics of the International Space Station (ISS), its altitude and speed. You will consider the various rockets used to send Astronauts into space over the decades and you will use a software simulation to launch your own rocket. You will consider units of measurement for forces, mass and acceleration. Finally, you will carry out a practical experiment using a cup of rice to model circular motion similar to the ISS orbiting the Earth.

By the end of this week, you should be able to:

- understand what microgravity is and the difference between mass and weight
- understand equations of motion, forces and fields
- substitute numbers into an equation and understand what the answer means in context
- compare numerical values and understand their scientific significance
- interpret an online interactive diagram and extract information from it.

1 Microgravity and the 'vomit comet'

There are several ways of describing the apparent absence of gravity. You may have heard of 'weightlessness' where there seems to be no weight, or a 'zero *g*' environment where gravity (*g*) doesn't seem to be acting. What about 'microgravity' though? Do these terms mean the same thing?

Watch Video 1 which introduces 'microgravity' environments. Then complete Activity 1.

Video content is not available in this format.

Video 1 What is microgravity?

Activity 1 What is microgravity?

Allow approximately 15 minutes

Complete the following statements, based on what you learned in Video 1.

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Now watch Video 2, which discusses parabolic flights and how they can create a microgravity environment. This video also discusses how it is thought planets are formed. Then complete Activity 2.

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Video 2 The 'vomit comet'

Activity 2 Microgravity environments

Allow approximately 15 minutes

Study Figure 1, which shows the parabolic flight pattern in more detail. Then select the answer to the questions below, based on this figure and Video 2.

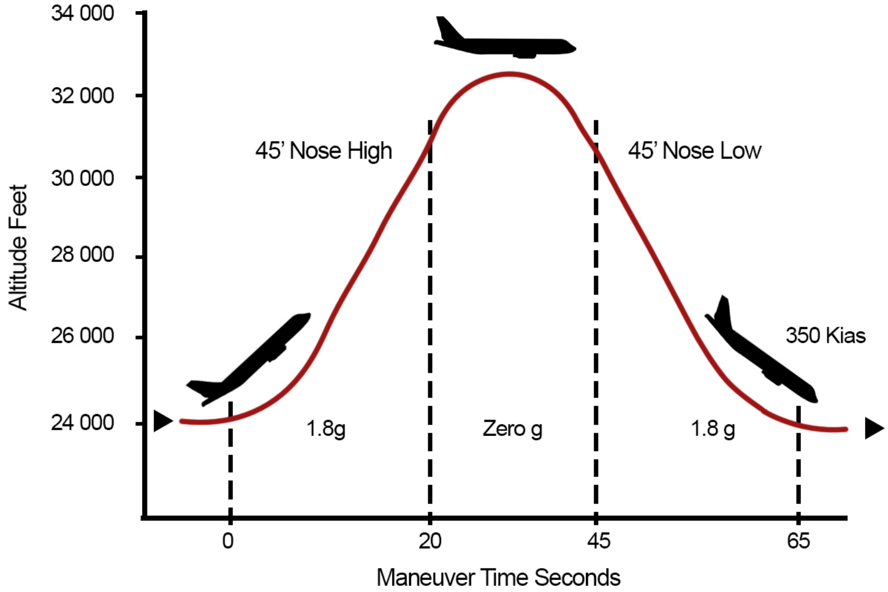

Figure 1 Parabolic flight of an aircraft.

1. What height does the aircraft need to achieve to start the experiment? (Hint: look at the top of the curve in Figure 1 and draw a line from this to the vertical axis.)

- ○ 32 000 feet
- ○ 24 000 feet
- ○ 34 000 feet
- ○ 28 000 feet
- ○ 26 000 feet

2. Roughly how long does the microgravity environment last?

- ○ 22 seconds
- ○ 0 seconds
- ○ 45 seconds
- ○ 10 seconds
- ○ 65 seconds

3. Which part of the parabolic flight curve can create a microgravity environment?

- ○ In the top portion of the curve
- ○ On the way up.
- ○ On the way down.
- ○ On the bottom portion of the curve.
- ○ Nowhere.

4. How are planets formed? (Hint: this was discussed in Video 2.)

- ○ Tiny ice and dust particles collide gently and stick together in space.
- ○ Large ice and dust particles collide hard and bounce off each other in space.

- ○ Tiny ice and dust particles collide hard and stick together in space.
- ○ Large ice and dust particles collide gently and stick together in space.
- ○ Tiny ice and dust particles collide gently and bounce off each other in space.

Moving on from parabolic motion and planetary formation, next you will consider the physics behind the orbit of the International Space Station (ISS).

2 The International Space Station

How high is the International Space Station (ISS) and how fast is it travelling?

Currently, the ISS is in orbit around the Earth at an altitude of about 400 kilometres (km). It travels at a speed of about 28 000 kilometres per hour (km/h). The ISS's orbit around the Earth is very similar to the Moon's orbit of the Earth. Both the ISS and the Moon are technically falling towards the Earth. However, they are falling at exactly the right rate to remain in orbit. Unlike the parabolic flight described in Section 1, there is no need to keep boosting the ISS back up to create another 20-second period of microgravity.

Figure 2 The ISS, photographed on 5 March 2008 from the Atlanta Space Shuttle.

To find out where the ISS currently is, you can 'spot the station' (Figure 3) here: https://spotthestation.nasa.gov/. This website gives you lots of opportunities to track the ISS from your computer.

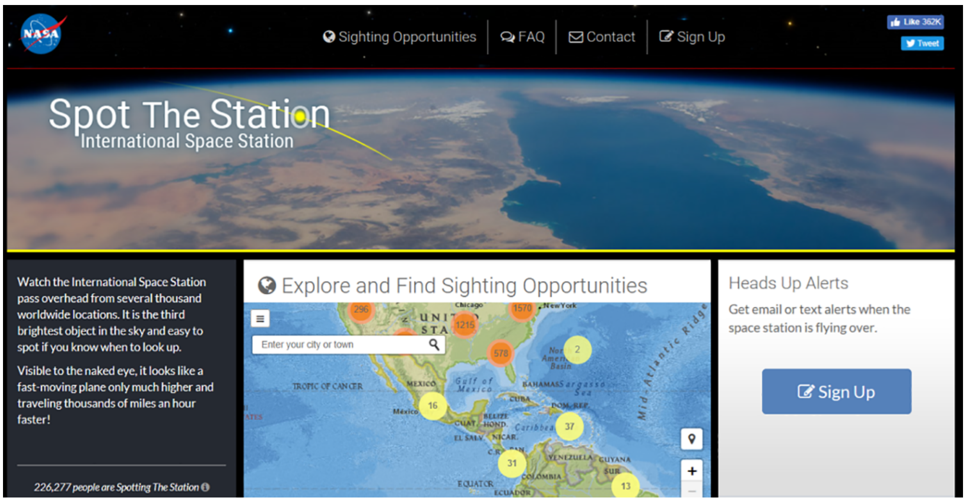

Figure 3 Spot the Station website.

You can also track the ISS's position 'in real time' (Figure 4) using another website called www.isstracker.com/. Go to this website and find out some facts about the ISS's flight path.

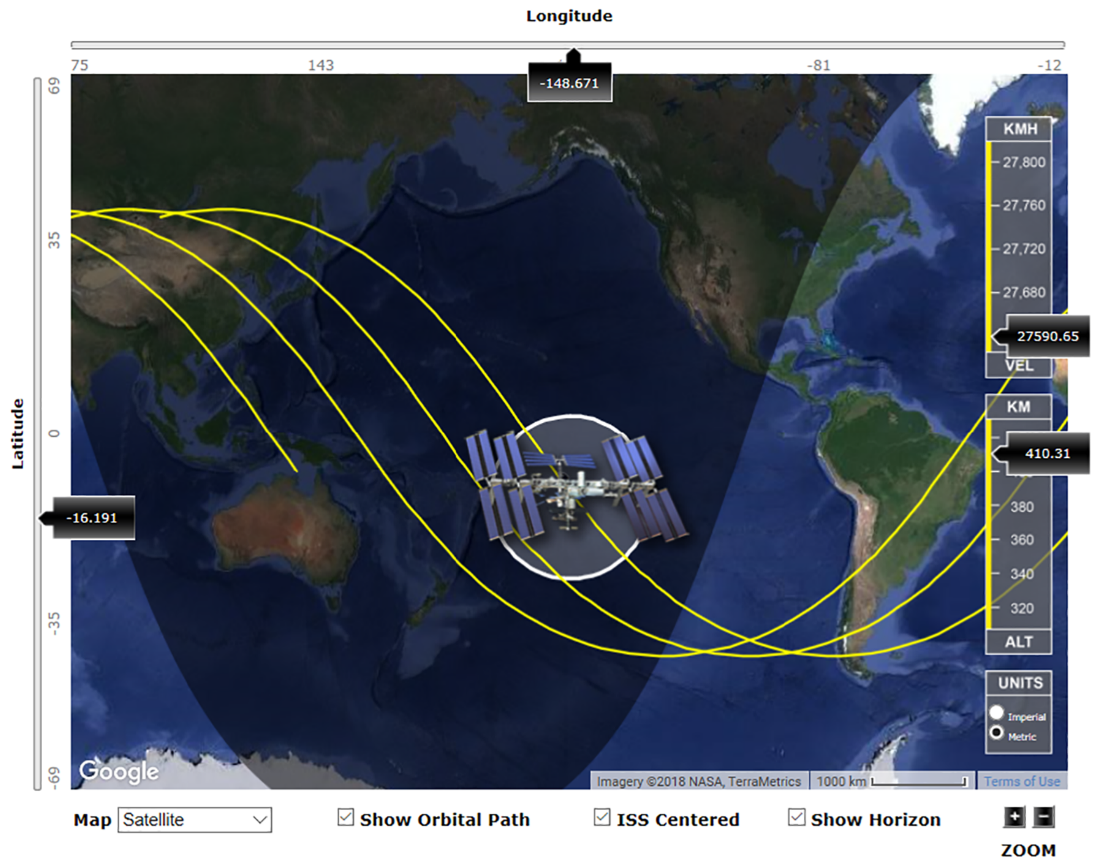

Figure 4 A screenshot from the ISS tracker website.

Did you discover that the three yellow lines show three orbital paths of the ISS directly over the Earth's surface? The longitude of the ISS is shown on the top horizontal axis and its latitude is shown on the left vertical axis. You can see that these trajectories cover roughly between +50 degrees latitude in the Northern Hemisphere to –50 degrees latitude in the Southern Hemisphere. This means that the ISS covers roughly 80% of the Earth.

The top box on the right of the screen – 'VEL' for 'velocity' – shows values of KMH. This is the speed of the ISS in km/h. The middle box on the right – 'ALT' for 'altitude' – shows values of KM. This is the altitude of the ISS in km. The bottom box on the right – 'UNITS' – gives the two options of units, in either imperial or metric. There are additional functions on the bottom bar. 'Map' gives the options of 'Satellite', 'Terrain' or 'Hybrid'. 'Show Orbital Path' provides the three orbital paths in yellow (Figure 4).

You can also click on and move the ISS. Pressing 'ISS centred' returns the ISS image to the centre of the screen. 'Show horizon' then provides the circle around the ISS, indicating the horizon view of the Earth's surface from the ISS. Finally, using the 'zoom' buttons on the bottom left changes the scale of the image from 10 km to 1000 km.

Activity 3 Exploring the ISS

Allow approximately 5 minutes

Now select the correct option to complete the following statements.

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There are also numerous apps about the ISS which can be downloaded to your mobile device. For example, there is a free app called ISS HD Live (Figure 5). You can even use this app to record video footage of the view of the Earth from the ISS!

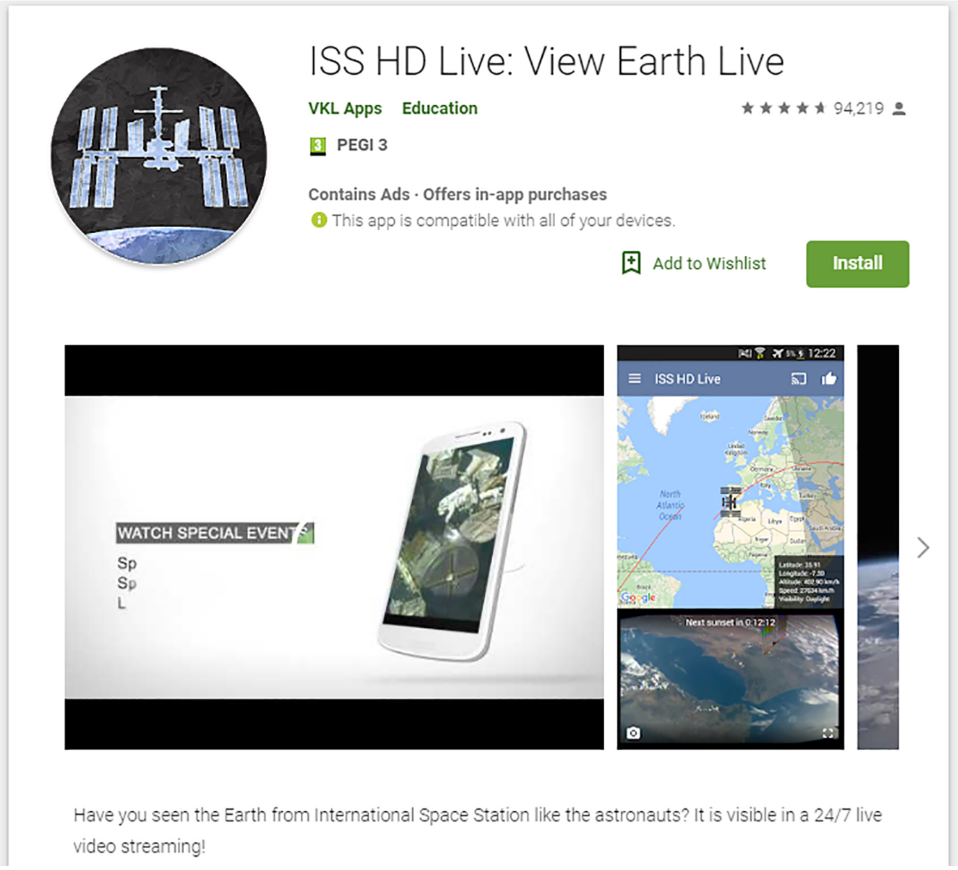

Figure 5 ISS HD Live app for Android devices.

You've now seen how to observe the Earth from the ISS. But how do Astronauts travel from the Earth to the ISS?

3 How astronauts get up there

Astronauts first need to get into space – but how? Obviously, a powerful rocket is needed. In the 1960s, the rocket that sent men to the Moon – Saturn V (Five) – was the most powerful machine ever built (Figure 6).

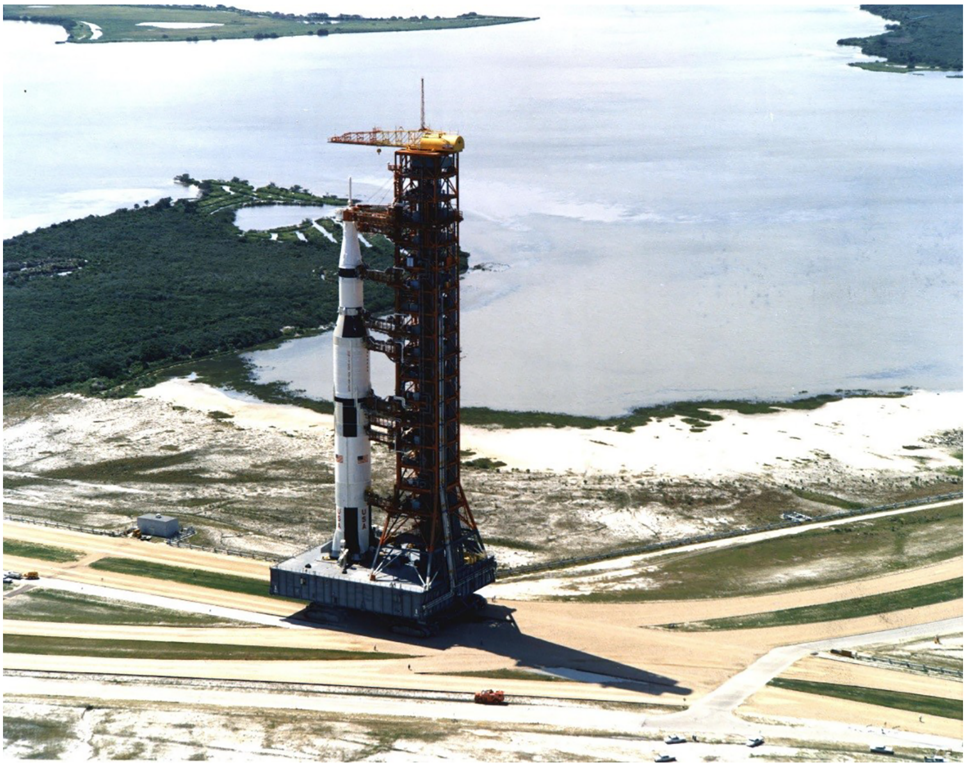

Figure 6 The Saturn V rocket and Apollo 11, Kennedy Space Center, Florida, USA, in 1969.

Between 1981 and 2011, NASA then sent astronauts to space using the Space Shuttle Program (Space Transportation System) (Figure 7).

Figure 7 The last flight of the Space Shuttle *Atlantis*, 8 July 2011.

The Space Shuttle was invaluable in building the ISS and the Hubble Space Telescope. It flew for 135 missions and was launched from the Kennedy Space Center in Florida, USA. Space Shuttles docked with the Russian Space Station, Mir, nine times and visited the ISS 37 times. A total of 355 people representing 16 countries flew on the Shuttle. Unfortunately, *Challenger* and *Columbia* had catastrophic accidents, leading to the deaths of 14 astronauts. Take a look at this full list of Space Shuttle missions.

Figure 8 shows the Space Shuttle launch profile as it lifts off and the external fuel tanks separate, returning to Earth. You will consider how recent developments have changed this 'launch profile' later in Week 8.

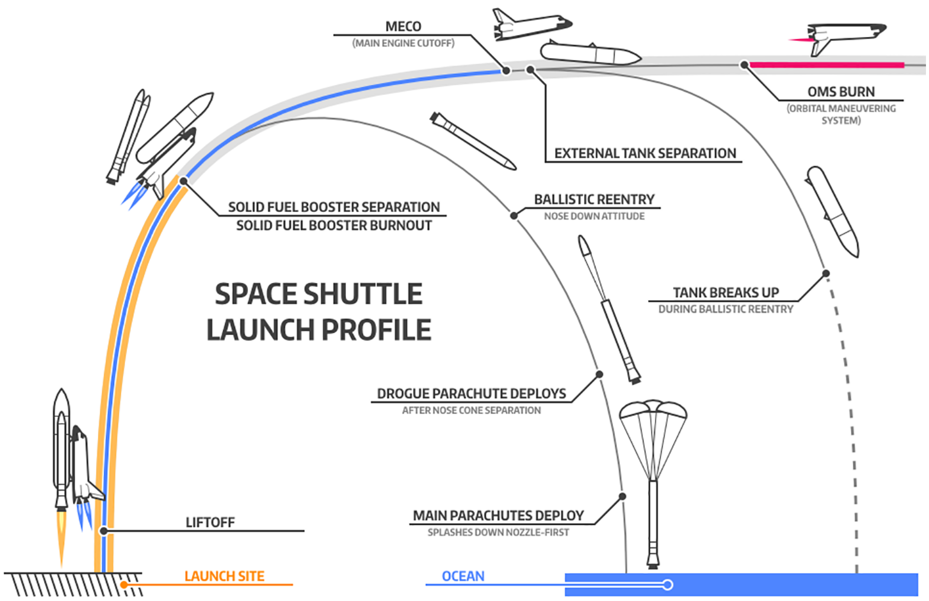

Figure 8 Space Shuttle launch profile.

Since the Space Shuttle was retired in 2011, the only way to get to the ISS now is on the Soyuz rocket from the Russian Mission Control Centre in Kazakhstan (Figure 9).

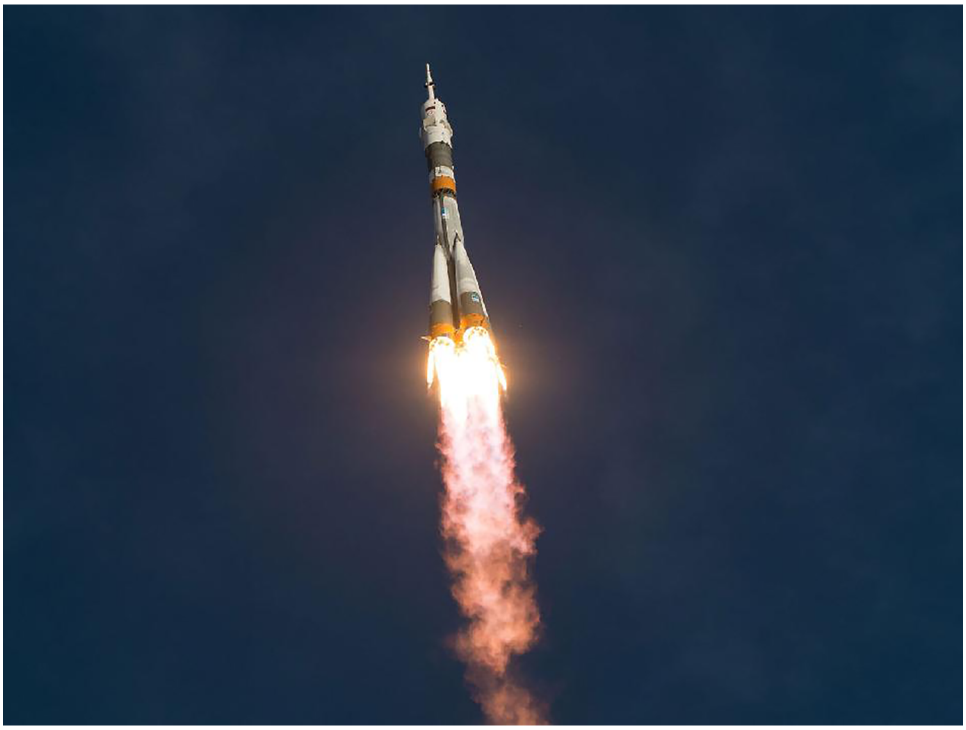

Figure 9 Expedition 33 Soyuz launch, 23 October 2012.

How do all these rockets compare by size? You can see from Figure 10 that the Saturn V rocket is still the tallest.

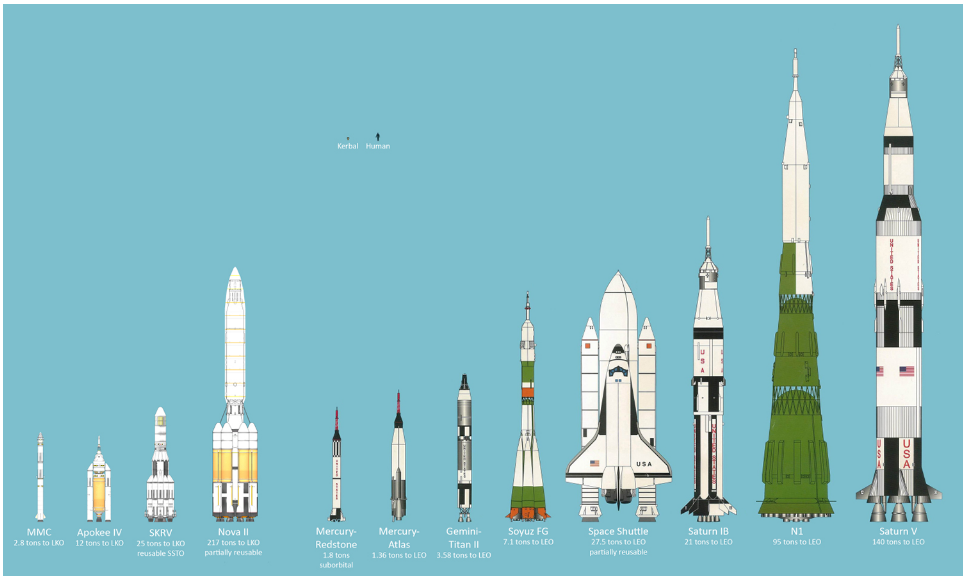

Figure 10 A comparison of the size of rockets to date.

3.1 How to launch a rocket

How can you launch a rocket into space? Obviously, you need something to push it upwards, so providing a force. This force is often called a ‘thrust’, which is measured in newtons (N). Burning rocket fuel to provide this force is one obvious solution. Opposing this motion, in addition to gravity, is air resistance. This is often called ‘drag’ and is also measured in N.

You then need to consider the mass of the rocket – measured in kilograms (kg) – and how long the fuel burns – measured in seconds (s). As the fuel is gradually exhausted, there is a reduction in the overall mass of the whole rocket. This is because the mass of fuel is reduced as time increases. This change of mass in time is given in kg/s.

Now complete Activity 4.

Activity 4 Launching your own rocket

Allow approximately 25 minutes

Using the link below to simulate a rocket launch, try to overcome the gravitational ‘pull’ of the Earth – the Earth’s gravitational field. In the following simulation you can change the mass, thrust, thrust time, drag and mass change.
See how far you can launch a rocket into space. Now record what happens when you change the parameters as follows.

Task 1

- Mass change = ‘off’
- Drag forces = ‘on’
- Time = 5 s
- Thrust = 400 N
- Mass = 1 kg

Answer

Your rocket exploded because the thrust was too high for the size of rocket you selected. Try again by selecting a smaller thrust or a larger mass for your rocket.

Now try Task 2 where the mass has been increased but all the other variables have been kept constant.

Task 2

- Mass = 20 kg
- Thrust = 400 N
- Time = 5 s
- Drag forces = ‘on’
- Mass change = ‘off’

Answer

You should have made a successful launch. Did your rocket also reach a maximum height of 267 m?

The ‘extra challenge’ is to switch off drag and mass change to see how the flight of the rocket would be different. Try this now in Task 3. Again, we have only changed one variable, keeping the others constant.

Task 3

- Mass = 20 kg
- Thrust = 400 N
- Time = 5 s
- Drag forces = 'off'
- Mass change = 'off'

Answer

Again, you should have made another successful launch. This time the rocket reached a maximum of 270 m, only 3 m more than the last one.

Task 4

Now see if you can beat our best result of a maximum height of 14 769 m (14.769 km) and a maximum speed of 517 metres per second (m/s).

Discussion

To do this, you need to use the following parameters.

- Mass = 5 kg
- Thrust = 400 N
- Thrust time = 5 s
- Drag forces = 'off'
- Mass change = 'on'

There are many other online rocket simulations. Here are a few to explore if you have time.

- Circular Orbit Simulation (NASA)
- Google Apps Orbit Designer
- Online Space Orbit Simulator

So now, when people say 'It's not rocket science', you can reply by saying that it is!

3.2 Location of launch sites

You should now appreciate how difficult it is to send a rocket into space. But what about the location of the launch site on Earth? Take a look at Figure 11 and then complete Activity 5.

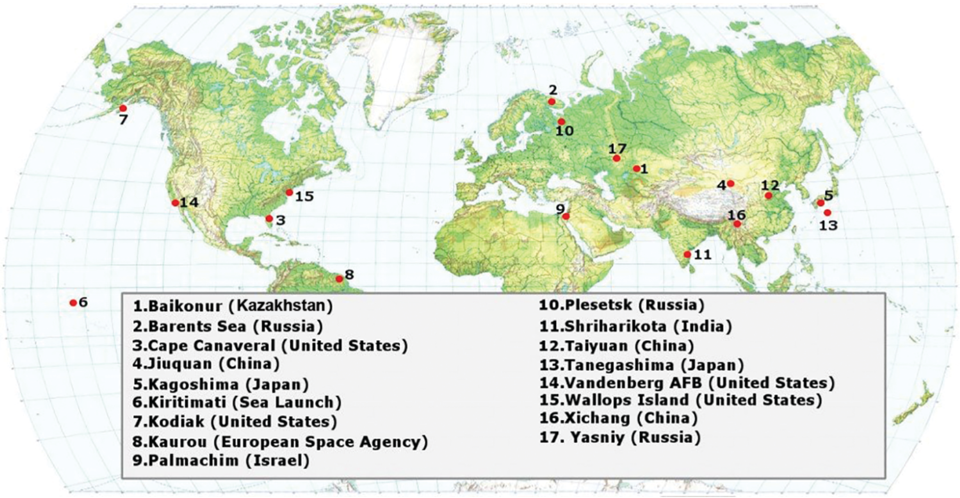

Figure 11 Worldwide rocket launch sites.

Activity 5 Launching a rocket

Allow approximately 15 minutes

Using the information in Figure 11, answer the following questions.

1. Where do you think the best places on Earth to launch a rocket from are? Choose the one correct option below.

- ○ Equator
- ○ North Pole
- ○ Atlantic Ocean
- ○ Pacific Ocean
- ○ South Pole

Discussion

At the Equator, Earth is rotating at nearly 1700 kilometres per hour (km/h). If the rocket is launched half-way between the Equator and the North or South Pole, the speed is reduced by nearly 500 km/h. This makes it harder for the rocket to escape Earth's gravity.

Now choose the correct options to complete the following statements.

2. The largest number of launch sites are in

- ○ Russia and the USA
- ○ India and China
- ○ Japan and the European Space Agency

Answer

The largest number of launch sites are in Russia and the USA.

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How can you calculate the acceleration of a rocket from the launch pad to the edge of the Earth's atmosphere? To do this, you need to use one of Newton's Laws. Here, you need the Second Law which relates force (*F*), mass (*m*) and acceleration (*a*) as shown in Equation 1.

Equation 1

You need to change the mass of the rocket – in this case, say 40 tonnes – into kg. So, the mass $m = 40 \times 1000$ kg = 40 000 kg = 4×10^4 kg.

Question 4 in Activity 5 provided an approximate value of the thrust of such a rocket, that is, $F = 800\,000$ N = 8×10^5 N.

Now, if you rearrange Equation 1 and substitute in these values, you get Equation 2.

Equation 2

Here you can see that the derived units of newtons (N) have been broken down into the fundamental units of kilograms (kg), m and s. The numerical value in Equation 2 is just over twice the value of the acceleration due to gravity (*g*) near the surface of the Earth, which is 9.81 m/s^2 (or m s^{-2}). It means that, for every second you fall under Earth's gravity, you travel another 9.81 m/s faster.

Now you've calculated how to get to the ISS. But how does it stay up in Earth's orbit?

4 How the ISS stays up there

The ISS is just a satellite in orbit. It wasn't launched in one go. It is a combination of many smaller satellites launched over several years and joined together. It is obviously a massive satellite when compared with the others. It does occupy a very low orbit though, mainly to avoid all of the other satellites and especially space debris. This was shown graphically in the film *Gravity* (2013)!

However, because of this relatively low orbit on the edge of the Earth's atmosphere, the ISS must be reboosted occasionally. The Earth's atmosphere slows it down, resulting in the ISS falling slowly back to Earth.

You can now test your knowledge in the next activity.

Activity 6 A test on the ISS

Allow approximately 15 minutes

1. How high is the ISS from Earth? Choose the correct answer from the options below.

- ○ 400 km
- ○ 10 km
- ○ 1000 km
- ○ Near the orbit of the Moon
- ○ 100 000 km

2. Using the correct answer from Question 1, what is the approximate percentage of the distance from the ISS to the Earth's surface compared with the radius of the Earth? (Hint: divide the distance in Question 1 by the radius of the Earth (about 6000 km) and then multiply by 100. This is your answer in %.)

- ○ 7%
- ○ 70%
- ○ 0.07%

Answer

This is about 7%.

3. The ISS's speed is approximately:

- ○ 28 000 km/h
- ○ 100 km/h
- ○ 1000 km/h

Answer

The ISS's speed is approximately 28 000 km/h.

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Interactive content is not available in this format.

But what keeps the ISS in orbit around the Earth? Your first (and correct) answer is probably ‘gravity’. This ‘force’ of gravity’ gives the feeling of weight. But people often mix up scientific terms in everyday speech. For example, how often do you hear people saying that they need to lose weight? Mass and weight are not the same. Mass is a measure of the amount of ‘stuff’ you have and is measured in kg, whereas weight is a force, due to gravity, which is measured in N.

This force of gravity helps the ISS to orbit the Earth in a similar way to the Moon orbiting the Earth. The speed of the ISS and the Moon around the Earth are just enough to keep them orbiting.

You know that the Moon is a natural satellite of the Earth (that is, not manufactured), but what types of satellite are launched by humans into orbit? Two particularly distinct orbit trajectories are:

- geostationary – staying above the same part of the Earth (for example, Sky TV)
- polar orbiting (for example, monitoring weather systems).

These are shown in Figure 12.

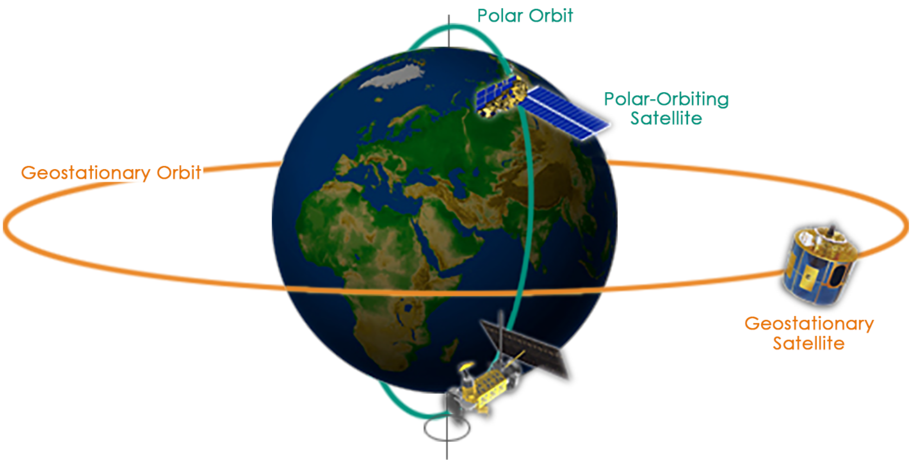

Figure 12 Geostationary and polar orbiting satellites.

Various global positioning and communication satellites are placed in orbits that are somewhere between geostationary and polar.

But how else other than gravity does the ISS stay in motion around the Earth? The answer to this is circular motion. Watch Video 3 which demonstrates circular motion with water in a bucket. Pay attention to what happens to the water when the swinging motion is stopped.

Video content is not available in this format.
Video 3 Circular motion of water.

In the next video, circular motion is demonstrated using a bicycle. Watch this video before moving onto the first practical experiment in this course.

Video content is not available in this format.
Video 4 Circular motion of a bicycle.

4.1 Practical experiment 1

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Video 5 Demonstration of Practical Experiment.

Practical experiment 1: Modelling how the ISS stays in motion around the Earth with the cup-of-rice experiment

To do this experiment, you need to be in a place with lots of space, ideally in a garden or a field. You will need a plastic cup, a piece of string and some rice. Cut two holes in the plastic cup opposite each other, thread the string through and tie it off. Half-fill the cup with rice. Taking care to avoid hitting anyone, swing this briskly around in a vertical circle.

To keep the cup moving, you need to exert a force (in the string, called tension). To increase the force on the cup, you need to increase the speed. If you put more rice into the cup, the mass has increased, so it will move slower. These are all factors which will change the motion of the cup. These variables are included in Equation 3 where F = force (N), m = mass (kg), v = velocity (speed) and r = radius (m).

Equation 3

If the mass m increases, the force F increases (when r and v are constant).

If v increases, F increases (when r and m are constant).

However, if r increases, F**decreases** (when v and m are constant).

If m = 5 kg, and you swing it on a string where r = 1 m and v = 4 m/s, then, using Equation 3, you have a resultant force with a numerical value, as shown in Equation 4.

Equation 4

Note that, while the forces are balanced in the rice cup experiment, the rice itself is in freefall while in motion, so that it doesn't fall out of the cup. You know from Equation 3 that the units for force in Equation 4 should be N. This is the same as kg m/s^2.

In terms of the orbit of the ISS, obviously there is no string connecting it to Earth! There must be some other kind of force acting on it. The gravitational pull of Earth is the force F acting here. However, if you then add the effects of friction from the atmosphere, the ISS slows down. It is no longer able to maintain the same gravitational orbit and you would have to either increase v or push it out to a higher orbit.

5 Is there any gravity on the ISS?

'Weightlessness' is where you don't experience the force of contact, for example when on a fairground ride or skydiving. It occurs when the forces are balanced. This feeling doesn't mean that there are no forces, however. For example, parachutists reach what is known as terminal velocity when the force of gravity is equal to the air resistance. These forces are balanced, although the speed of the parachutist is high and too dangerous to land! When a parachute is opened, it increases the drag forces to the point where a lower terminal velocity is achieved, and the forces are balanced again (see Week 6).

Most people are familiar with the term 'g-force' which tells you how many times heavier you feel compared with the everyday experience of 1 g. Astronauts frequently train in 'high g-force centrifuge' environments to prepare them for space travel. But what is 'zero-g'? The gravitational force has not disappeared but there is a feeling of weightlessness.

The correct term is *microgravity*. It happens whenever an object is in freefall. You now know that the ISS orbits the Earth at a distance of 400 km and travels at a speed of 28 000 km/h. Remember that the astronauts are travelling at the same speed as the ISS. Both the astronauts and the ISS are in orbit **around** (or about) the Earth, which also means they are in a continual state of freefall **towards** the Earth.

But how does gravity itself relate to masses and weights? Equation 5 shows how the weight W of an object can be calculated when you know its mass m and the acceleration due to gravity g.

Equation 5

If you have an object with a mass of 50 kg then, using Equation 5, you can calculate its weight (Equation 6).

Equation 6

Clearly, the units of weight are N, so weight is a force.

Now try the next activity, where you can calculate the weight of the same object on different planets.

Activity 7 Calculating weights on different planets

Allow approximately 15 minutes

Use Equation 6 to calculate the answers to the following questions. The numerical value of acceleration due to gravity g on each planet is given.

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Now you can compare the gravitational field on Earth (g_{Earth}) with that on the ISS (g_{ISS}), to see whether there is gravity on the ISS. You will need to use Equation 7 and several physical values precise to 3 significant figures to calculate g_{Earth}.

Equation 7

First, you need the value of the Earth's mass (M_{Earth}): this is 5.97×10^{24} kg.

Then you need the value of the Earth's radius, r_{Earth}: this is 6.37×10^{6} m.

Finally, you need the gravitational constant G: this is 6.67×10^{-11} N m^2/kg^2.

With these values you can find out the gravitational field on Earth, g_{Earth}, using Equation 7 to get a numerical value in Equation 8.

Equation 8

This answer is the same numerical value as the acceleration due to gravity on the Earth's surface, which is 9.81 m/s^2. Remember that the units m/s^2 are the units of acceleration. In the case of Equation 8, the units are N/kg which are the units of a gravitational field.

What about the gravitational field on the ISS? To work this out you just need to add in the extra distance from the Earth's surface to the ISS ($r_{Earth+ISS}$), remembering that this is 400 km. You should now convert this to metres as follows.

400 km = 400 000 metres = 4×10^{5} m.

So, $r_{Earth+ISS} = (6.37 \times 10^{6}\ m) + (4 \times 10^{5}\ m) = 6.77 \times 10^{6}$ m.

Equation 7 is now adapted to Equation 9 to take this extra distance into account and Equation 10 is the calculation of this gravitational field on the ISS, g_{ISS}.

Equation 9

Equation 10

Surprisingly there is not a lot of difference between the gravitational field on the ISS and the gravitational field on Earth.! On the ISS therefore, the acceleration due to gravity is not zero - and nor is the gravitational field. Therefore the term 'zero gravity' is a misleading one. In fact the gravitational field astronauts are 'exposed' to inside the ISS is almost as large as that they are exposed to on the Earth.

How does the gravitational field on the ISS compare with that on the Earth's surface? Look at Equation 11.

Equation 11

The gravitational field on the ISS is approximately 89% of that on the Earth's surface. Of course, irrespective of these facts, the astronauts on board the ISS (and even the ISS itself) feel 'weightless' . It is an issue of perception within the frame of reference (or place) we are in at the time. The microgravity environment on board the ISS describes the condition in which things, like the astronauts, experiments and objects all appear to be weightless. The perception that objects are weightless arises due to the orbital motion of the ISS, and the 'balance' between the two key forces acting on the objects - the gravitation force (pulling them 'down to earth') and the centrifugal force (pushing them 'out' in the circular motion - like the examples in the experiments above). We often use the terms 'zero gravity' 'weightlessness' and 'microgravity' to describe the conditions the objects perceive to be experiencing - but in reality the Physics tells us there is still a large gravitational field, so the objects actually have mass, and weight. Soemtimes the philosphy of science is harder than the equations!

Now complete the end-of-week quiz.

6 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 1 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

7 Summary

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You now understand what ‘microgravity’ is and the difference between mass and weight.
- By completing Practical experiment 1 and Activities 1 to 7, you have worked out the distance travelled by the ISS and used Newton’s Second Law of force, mass and acceleration.
- You have seen how to directly compare the distance from the ISS to Earth with the Earth’s radius and the distance travelled by the ISS in one day compared with the Moon’s orbit.
- You have compared the gravitational field on Earth with that on the ISS.
- You have also interpreted a diagram and extracted information from it in Activity 2.

Next week you will look at the research into the effects of ageing both on Earth and in space.

You can now go to Week 2.

Week 2 Ageing and microgravity environments

Introduction

Week 1 introduced microgravity in the context of the ISS, physics and orbits. This week, you will look at how microgravity environments can lead to research into the ageing process.

There are many challenges as a result of the ageing population in western countries. First, there are the medical implications. Then, there are the economic challenges of health care. What about pensions? Finally, there is quality of life. So, what research is now being done that will benefit everyone in their later years?

It turns out that the ageing process can be researched in a microgravity environment. Here the context of 'bed rest' is used. But how can resting in a bed simulate ageing? And does space travel make astronauts age?

This week, you will discover how microgravity environments are used to model the ageing process. You will learn how current research is helping both elderly people here on Earth and astronauts. You will also consider how exercise can reduce the effects of ageing. You will then have the opportunity to do another practical experiment. This time, you will measure your heart rate and respiration as you carry out a range of activities.

By the end of this week, you should be able to:

- explain the types of scientific research that can benefit from microgravity environments, focusing on ageing
- carry out a home practical experiment to measure your heart rate and respiration
- calculate speed using distance and time data
- interpret data from a pie chart and a logarithmic–linear graph.

1 An introduction to ageing

Human beings are complex life systems. As you get older, you experience the effects of ageing. But what is the ageing experience?

There are certain ‘hallmarks of ageing’. Figure 1 is based on research into the ageing process using insects as models, but the process equally applies to human beings.

Figure 1 The hallmarks of ageing.

There are many complicated processes going on here, but you don’t need to know the details. The most apparent hallmark of ageing is ‘genomic instability’. Here, the effect of unstable genomes could reduce life expectancy. All of the ‘hallmarks of ageing’ indicate a reduction in life expectancy. So how does this affect human beings in the 21st century?

You probably know that the population of the world is increasing and that older people are living longer. This is reported in the news almost every day. There are constant worries in western society about how to support our ageing populations, from providing care homes and long-term medical care (which can be very expensive) to state pensions. As a direct result of statistical analysis, most people are well aware of these financial implications; from reduced life insurance premiums to an increase in retirement age.

Figure 2 indicates how the population of the world changed between 1950 and 2000, and how it is anticipated to increase by 2050. This chart was produced by the Population Division of the Department of Economic and Social Affairs of the United Nations in 2005, so it is already out of date.

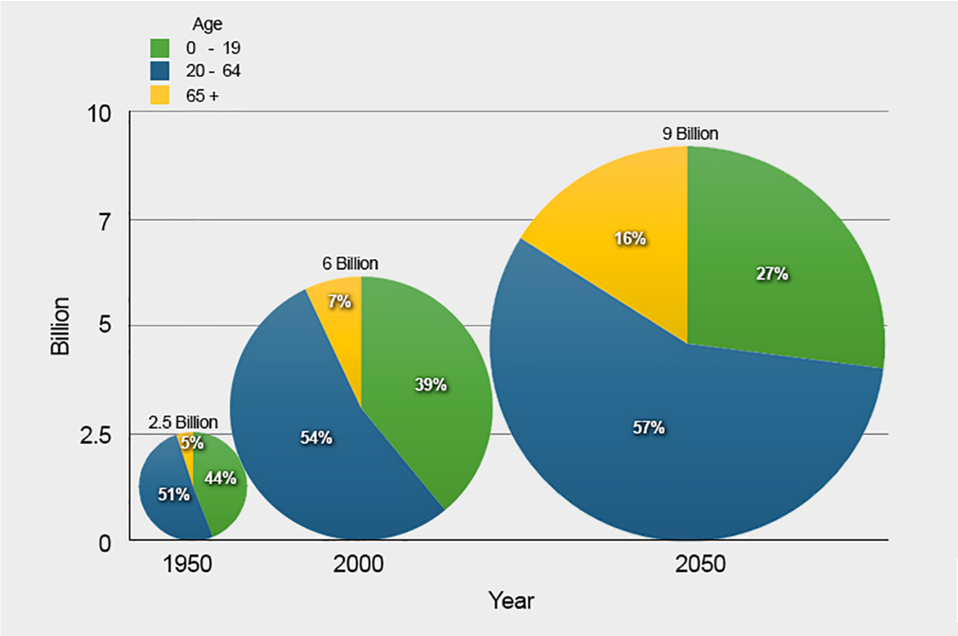

Figure 2 Changes in world population by age group from 1950 to 2050.

Now, using the data in Figure 2, complete Activity 1.

Activity 1 The ageing population from 1950 to 2050

Allow approximately 20 minutes

Answer the following questions by choosing the one correct option for each.

1. Between 1950 and 2000, how has the population of the 0 to 19-year-old group changed? (Hint: compare the green shaded regions of the first two circles.)

- It has increased from 44% to 39%.
- It has decreased from 44% to 39%.
- It has stayed the same.
- It has increased from 44% to 57%.
- It has decreased from 44% to 27%.

2. What is the expected proportion of this same age group by 2050? (Hint: look at the green shaded region of the third circle.)

- 7%
- 15%
- 16%
- 27%
- 39%

3. How does the population of the 20 to 64-year-old group change between 1950 and 2050? (Hint: compare the blue shaded regions of the first and third circles.)

- It is set to increase from 51% to 57%.
- It will decrease from 57% to 51%.
- It is predicted to stay the same.
- It is set to increase from 51% to 54%.
- It will decrease from 54% to 51%.

4. What is expected to happen to the 65+-year-old group from 1950 to 2050? (Hint: Compare the yellow shaded regions of the first and third circles.)

- ○ It will increase from 5% to 7%.
- ○ It will decrease from 7% to 5%.
- ○ It will stay the same.
- ○ It will increase from 5% to 16%.
- ○ It will decrease from 16% to 5%.

5. As a proportion of the world's population, which age group changes the most between 1950 and 2050? (Hint: compare the changes of the age ranges. Which group has the largest change?)

- ○ 0–19
- ○ 20–64
- ○ 65+
- ○ None

You can now appreciate not only how the world's population has changed between 1950 and 2000, but also how it is anticipated to change by 2050. The following statistics are given relative to the world's population for the year concerned.

- Between 1950 and 2000, the age group 0–19 *decreased* from 44% to 39%. By 2050, it is anticipated that this age group will *decrease further* to 27%.
- Between 1950 and 2000, the age group 20–64 *increased* from 51% to 54%. By 2050, it is anticipated that this age group will *increase further* to 57%.
- Between 1950 and 2000, the age group 65+ *increased* from 5% to 7% and is anticipated to *increase further* to 16% by 2050.

You have looked at how the world's population is expected to change between 1950 and 2050. Next, you will look at these changes as they impact on individual countries.

2 Ageing forecasts by country

The United Nations produced a world chart showing the percentage of the populations of individual countries aged 60 years or older for 2012. They then provided a forecast for the year 2050 (Figures 3a and 3b).

(a)

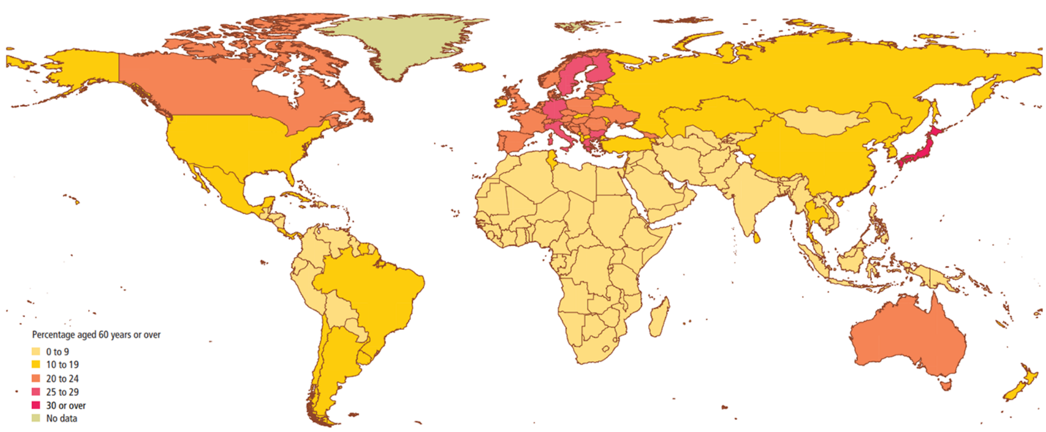

Figure 3a Percentage of the population aged 60 years or over in 2012.

(b)

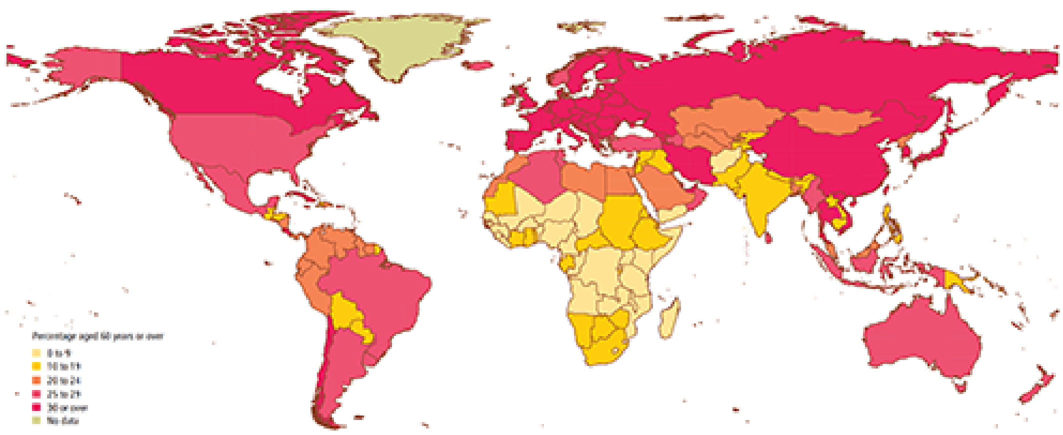

Figure 3b Forecast of the percentage of the population aged 60 years or over in 2050.

Activity 2 Ageing statistics for individual countries

Allow approximately 10 minutes

Using Figures 3a and 3b, answer the following questions by choosing the one correct option for each.

1. In 2012, what was the percentage of the population aged 60 years or over in the UK?

○ 0–9%

- ○ 10–19%
- ○ 20–24%
- ○ 25–29%
- ○ No data

2. In 2050, what percentage is the over-60 population expected to reach in the UK?

- ○ 0–9%
- ○ 10–19%
- ○ 20–24%
- ○ 30% or over
- ○ No data

3. In 2012, what was the percentage of the population aged 60 years or over in Africa, the Middle East and India?

- ○ 0–9%
- ○ 10–19%
- ○ 20–24%
- ○ 30% or over
- ○ No data

4. By 2050, which regions are anticipated to have an ageing population of more than 30%?

- ○ Africa and the Middle East
- ○ Australia and Indonesia
- ○ India and the Middle East
- ○ North and South America
- ○ Russia, China and Europe

Here you have seen that the projected figures indicate that the populations of the developed world may rise by 30% or more. The proportions of the ageing populations in these countries are also expected to rise. So, what research is being carried out on the effects of ageing?

3 Bed rest and ageing

It turns out that if you spend a lot of time in bed (even more than a teenager!), your body ages faster than usual. Is this because of inactivity or the act of lying down? Standing up and walking around obviously makes the human body work against gravity, which puts the joints, muscles and bones under stress. Lying down clearly doesn't put the same parts of the human body under stress.

You can simulate the effects of being in a microgravity environment by using the 'bed rest' model, as shown in Video 1. Watch the video and then complete Activity 3.

Video content is not available in this format.

Video 1 The 'bed rest' model.

Activity 3 Bed rest in a microgravity environment

Allow approximately 15 minutes

Choose the one correct answer to each of the following questions, based on Video 1.

1. In a microgravity environment, what happens to the blood pressure of an astronaut? Does it:

○ drop
○ increase
○ stay the same
○ disappear
○ accelerate

2. In a microgravity environment, does an astronaut's heart work:

○ poorly
○ not as hard
○ harder
○ faster and faster
○ unchanged

3. In a microgravity environment, an astronaut's vision could be:

○ temporarily affected
○ more short-sighted
○ more long-sighted
○ permanently damaged
○ unchanged

In the case of the ISS, remember that the astronauts circle the Earth travelling at 28 000 km/h. This means that they will circle the Earth once every 90 minutes and will see up to 16 sunrises and sunsets during a 24-hour period. Also, there is no 'up' or 'down'. So, can you imagine trying to sleep on the ISS (Figure 4)?

Figure 4 'Sleeping' in a microgravity environment.

Obviously, on Earth you are used to seeing one sunrise and one sunset in a 24-hour period. This means that astronauts have significant changes in their sleep patterns. Their so-called 'body clocks' are seriously disturbed.

This disturbance to a sleep pattern also happens to ageing patients. If you don't get enough sleep, you are less alert during the day. It becomes a vicious circle of tiredness and disturbed sleep patterns, which can seriously affect your overall health. Researchers have found that using a very bright light can reset the 'body clock' by copying the effects of sunrise. This approach was originally developed to help ageing people on Earth but has since been adapted to help astronauts preparing for living in space.

As astronauts may have to travel huge distances in future space travel, this will affect their ageing process. Scientists, and writers of science fiction, have often considered how to offset these effects. One option is to place the astronauts into a long sleep whilst they are travelling and then wake them up at their destination. If they had stayed awake the whole journey then they could have aged more when compared with a fellow astronaut placed into a hypersleep state.

Video 1 also mentions long-distance space travel. You might have seen science fiction films which use the concept of 'hypersleep' to deal with travelling astronomical distances. In fact, back in 1968 the famous film director Stanley Kubrick (1928–1999) introduced 'hypersleep' into popular culture, as well as reinforcing the importance of exercise. This was even more amazing, and showed incredible foresight, when you consider that his film was finished a year before Apollo 11 landed on the Moon in 1969.

All this just shows how an astronaut's health is affected by living in a microgravity environment. You will now look at other impacts on an astronaut's general health while in space.

4 Reducing the effects of ageing in a microgravity environment

You've seen how living in a microgravity environment affects the blood pressure, heart and vision of an astronaut. But how does this environment affect the other senses? Watch Video 2 to see.

Video content is not available in this format.
Video 2 Hearing in space.

How else does living in a microgravity environment affect the health of an astronaut? Bones and muscles are then weakened further by the reduced effects of Earth's gravity in a microgravity environment. However, the 'flip side' is that prolonged stays in microgravity environments also affect astronauts' balance, posture and coordination.

Can hormones, drugs and surgical intervention prevent bone loss or encourage bone formation? In the 1940s, Russian scientists developed a surgical technique for promoting bone growth. They found that inserting screws into the bones and gradually forcing the bones apart promotes bone growth (Figure 5).

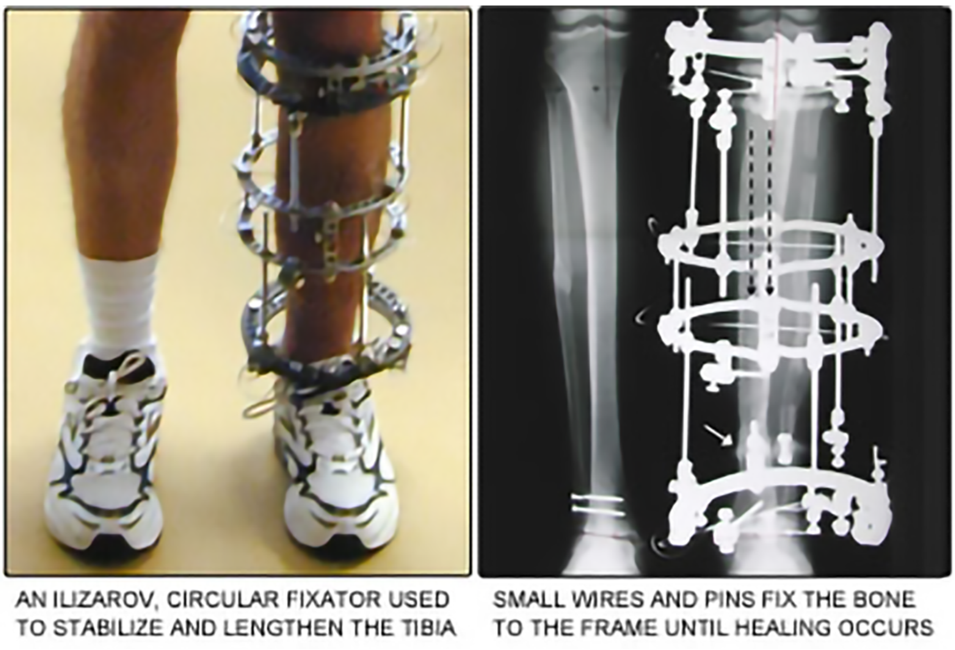

Figure 5 External limb-lengthening surgery.

Such a procedure is a bit extreme for astronauts on board the ISS though! Instead, astronauts need to follow a strict physical regime, devoting at least two hours per day to excercise.

What kind of exercises would help to reduce bone and muscle loss? Due to the effects of microgravity, some activities are much easier on the ISS than on Earth: for example, weightlifting. This means that exercise equipment has to be designed specifically to be

used in space. You can discover more on this website:
www.nasa.gov/audience/foreducators/stem-on-station/ditl_exercising

Figure 6 shows NASA astronaut Karen Nyberg using the rather exotically named Advanced Resistive Exercise Device (ARED) (weightlifting equipment) on board the ISS. How do you think this has been adapted for use in space?

Figure 6 Astronaut Karen Nyberg exercising on the ISS in 2015.

Weightlifting is not the only exercise that astronauts can do. They can even run marathons on the ISS. The main adaptation for space use is a harness which attaches the runner to the treadmill (see Figure 7). Here, in 2007, NASA astronaut Sunita Williams completed the first marathon in orbit around the Earth. She ran as an entrant in the Boston Marathon in a respectable time of 4 hours and 24 minutes.

Figure 7 NASA astronaut Sunita Williams running on a treadmill on the ISS in 2007.

Now complete Activity 4 which focuses on marathon distances, times and speeds.

Note: some values will need to be rounded to the appropriate number of significant figures. The 'trick' here is to look carefully at the number given by your calculation, for example 123 552. If you needed to round this to 2 significant figures, look at the second digit in this number. Here it is 2. The digit immediately after this is 3. As this digit is 4 or less, you leave it alone. If it is between 5 and 9, you round up the previous digit. In the case of 123 552, to 2 significant figures, this would be rounded down to 120 000.

If the value was 7777.77, to 2 significant figures and because the third digit is 7, it would be rounded up to 7800.

Activity 4 Running a marathon

Allow approximately 15 minutes

Answer the following questions by choosing the one correct option for each.

1. How far is 42 kilometres in metres?

(Hint: multiply 42 by 1000 to obtain the correct answer in metres.)

- ○ 42 metres
- ○ 420 metres
- ○ 4200 metres
- ○ 42 000 metres
- ○ 420 000 metres

2. How long is 4 hours and 24 minutes in seconds?

(Hint: first, change 4 hours and 24 minutes into minutes. Multiply 4 by 60 and then add 24. Then multiply your answer by 60 to obtain the correct answer in seconds.)

- ○ 26.4 seconds
- ○ 264 seconds
- ○ 1584 seconds
- ○ 2640 seconds
- ○ 15 840 seconds

3. As the ISS travels at 28 000 km/h, how fast is this in terms of m/s?

(Hint: first, convert 28 000 km to m by multiplying by 1000. Then divide your answer by 3600 to convert hours to seconds. Then round your final answer to 2 significant figures.)

- ○ 0.78 m/s
- ○ 7.8 m/s
- ○ 78 m/s
- ○ 7800 m/s
- ○ 780 000 m/s

4. Using the correct value of the speed of the ISS in m/s from Question 3, and the time in seconds in Question 2, how far in km did Sunita and the ISS travel in orbit around the Earth while she was running the marathon?

(Hint: distance is speed times time. Multiply the value from Question 3 by the value in Question 2. Then divide by 1000 to change from m to km. Then round your answer to 2 significant figures.)

- ○ 0.12 km
- ○ 12 km
- ○ 120 km
- ○ 1200 km
- ○ 120 000 km

You will now look at how NASA used an innovative approach to consider how the ageing process affected their astronauts.

5 Research on astronauts and the ageing process

In the 1980s, NASA and the National Institute on Aging (NIA) held a conference to discuss the effects of microgravity on ageing. They looked at microgravity environments and how astronauts would readapt to Earth's gravity after space flight. Would space travel affect them for the rest of their lives?

Using the scientific method of keeping one variable constant to measure changes to another variable, NASA researchers used a unique situation. They studied Scott and Mark Kelly, who are the only twins to have both worked as NASA astronauts (Figure 8).

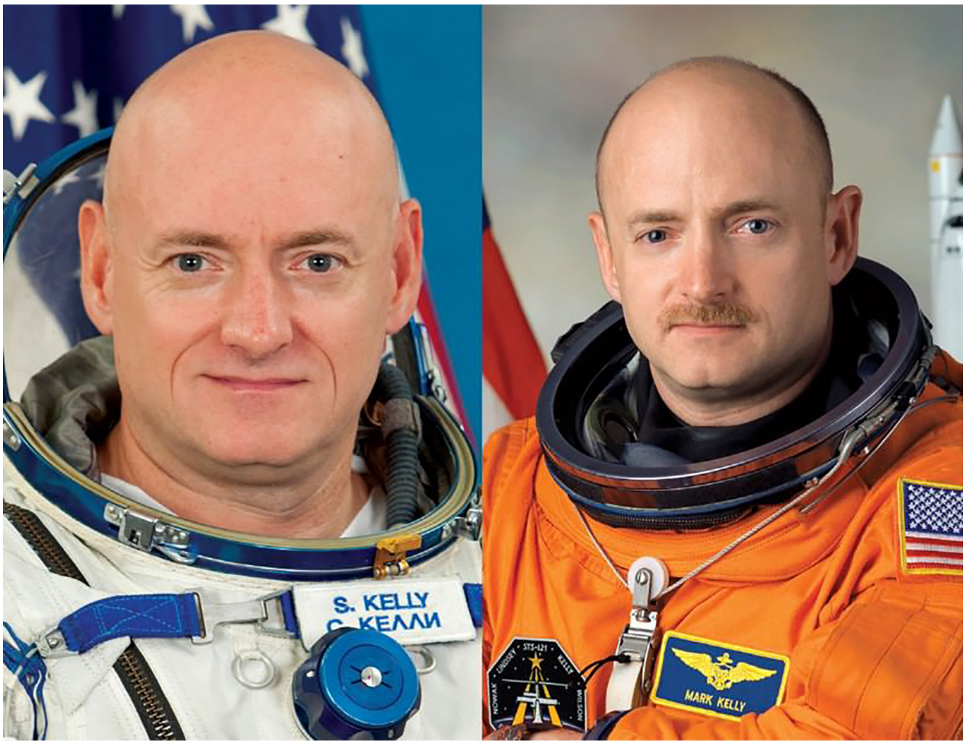

Figure 8 NASA's twin astronauts Scott and Mark Kelly.

Scott Kelly went more frequently into space than his twin brother and it was expected that, because of the dangerous nature of living in space, his DNA would be damaged more than Mark's DNA. However, the opposite happened, and it looked like Scott's DNA may actually have adapted to the environment in space!

Returning astronauts give medical scientists great opportunities to study all the effects of microgravity.

Now it's time to measure your own general health in your second practical experiment.

6 Measuring your heart and respiration rates

Could you be an astronaut? By now, you should appreciate that there is much involved in astronaut training and health. You should also realise that your heart rate and respiration is a good indication of how healthy you are.

You can explore this now in the second practical experiment of this course.

6.1 Practical experiment 2

Practical experiment 2: Measuring your heart rate and respiration

For this experiment, you are going to take some measurements of your heart rate and respiration after three activities: sitting down, lying down and after some moderate exercise. You will only need a timer (on a smartphone for example), a chair and somewhere to lie down comfortably. It would be great if you could use an inclined bed like that used in Video 1.

If taking part in these activities is difficult for you, please watch the following videos and then use the alternative data provided in Table 4a and 4b below.

First, watch Video 3 which introduces this experiment and demonstrates the first activity..

Video content is not available in this format.
Video 3 Introduction to Practical experiment 2

Remember that you will need to find your pulse to measure your heart rate. If you place two fingers (not your thumb!) on the pulse point in your neck, you should feel your pulse.

Measuring your respiration is just counting the number of breaths you take in (inhale). It is easier if you find someone else who can count this while you are counting your heart rate.

Now complete Activity 5.

Activity 5 Counting heart rate and respiration when lying down

Allow approximately 20 minutes

Use the tables below to record your results when lying down.

Table 1a

Heart rate	Reading 1	Reading 2	Reading 3	Average
lying down				

Table 1b

Respiration	Reading 1	Reading 2	Reading 3	Average

lying down				

Now watch Video 4 which shows how to measure your heart rate in a sitting position. Then complete Activity 6.

Video content is not available in this format.
Video 4 Measuring your heart rate and respiration when sitting

Activity 6 Counting heart rate and respiration when sitting

Allow approximately 15 minutes

Give yourself a few moments to relax and then count the number of times your heart beats in one minute (60 seconds). You will also need to record the number of breaths you take in 60 seconds (respiration).

Table 2a

Heart rate	Reading 1	Reading 2	Reading 3	Average
sitting				

Table 2b

Respiration	Reading 1	Reading 2	Reading 3	Average
sitting				

Now watch Video 5 which shows how to measure your heart rate after doing some moderate exercise, for example jogging on the spot, or walking up and down stairs. Then complete Activity 7.

Video content is not available in this format.
Video 5 Measuring your heart rate and respiration after moderate exercise

Activity 7 Counting heart rate and respiration after moderate exercise

Allow approximately 15 minutes

Measure your heart rate and the number of breaths you take in 60 seconds whilst doing some form of moderate exercise.

Table 3a

Heart rate	Reading 1	Reading 2	Reading 3	Average

moderate exercise				

Table 3b

Respiration	Reading 1	Reading 2	Reading 3	Average
moderate exercise				

Now watch Video 6, which discusses recording your results and calculating the averages.

Video content is not available in this format.
Video 6 Recording your results and calculating averages.

Now calculate your averages by using Equation 1. Please note that you should round your final average answer to 2 significant figures.

Equation 1

What were your results? Don't worry if you weren't able to complete the activities. The results for Tom's activities are provided in Table 4a and 4b.

Table 4a Tom's results for Practical experiment 2

Heart rate				
Activity	**Reading 1**	**Reading 2**	**Reading 3**	**Average**
lying down	56	53	55	55
sitting	66	67	64	66
moderate exercise	97	95	102	98

Table 4b Tom's results for Practical experiment 2

Respiration				
Activity	**Reading 1**	**Reading 2**	**Reading 3**	**Average**
lying down	11	13	10	11
sitting	30	29	32	30
moderate exercise	34	32	35	34

You can now compare your results with Figure 9. The two charts are for men and women, divided into age ranges. You won't be surprised to know that, to be an astronaut, you would probably have to meet the 'athlete' criteria! Resting heart rate is in the sitting position.

MEN (Beats per Minutes)							
Age	Athlete	Excellent	Great	Good	Average	Below Average	Poor
18 - 25	49 - 55	56 - 61	62 - 65	66 - 69	70 - 73	74 - 81	82+
26 - 35	49 - 54	55 - 61	62 - 65	66 - 70	71 - 74	75 - 81	82+
36 - 45	50 - 56	57 - 62	63 - 66	67 - 70	71 - 75	76 - 82	83+
46 - 55	50 - 57	58 - 63	64 - 67	68 - 71	72 - 76	77 - 83	84+
56 - 65	51 - 56	57 - 61	62 - 67	68 - 71	72 - 75	79 - 81	82+
65+	50 - 55	56 - 61	62 - 65	66 - 69	70 - 73	74 - 79	80+

WOMEN (Beats per Minutes)							
Age	Athlete	Excellent	Great	Good	Average	Below Average	Poor
18 - 25	54 - 60	61 - 65	66 - 69	70 - 73	74 - 78	79 - 84	85+
26 - 35	54 - 59	60 - 64	65 - 68	69 - 72	73 - 76	77 - 82	83+
36 - 45	54 - 59	60 - 64	65 - 69	70 - 73	74 - 78	79 - 84	85+
46 - 55	54 - 60	61 - 65	66 - 69	70 - 73	74 - 77	78 - 83	84+
56 - 65	54 - 59	60 - 64	65 - 68	69 - 73	74 - 77	78 - 83	84+
65+	54 - 59	60 - 64	65 - 68	69 - 72	73 - 76	77 - 84	84+

Figure 9 Resting heart rates for men and women.

When you experience stress or take exercise, your heart rate increases. Look at Figure 10 which shows the heartbeat of astronaut Neil Armstrong (1930–2012) as he landed Apollo 11 on the surface of the Moon in 1969.

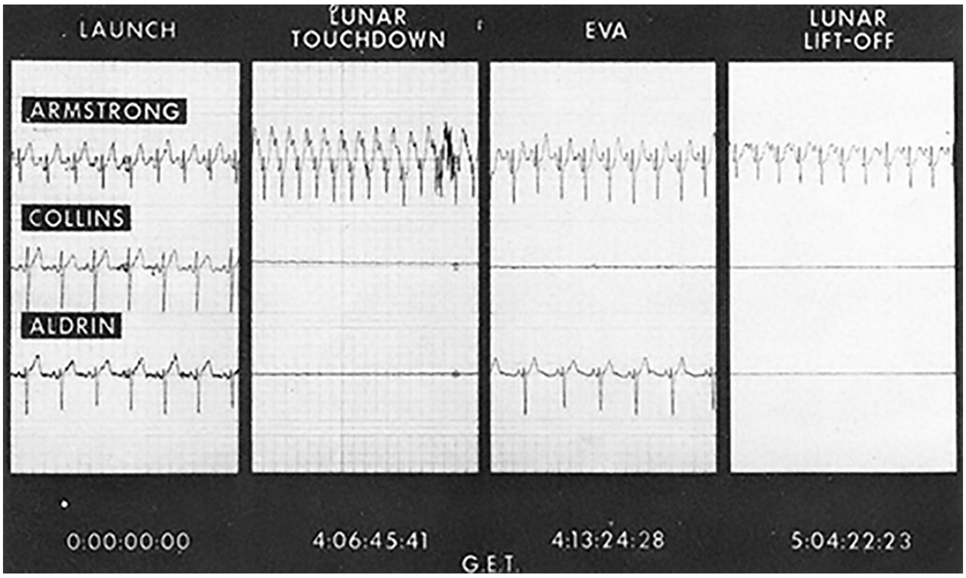

Figure 10 Recordings of the heartbeats of the Apollo 11 crew.

Neil Armstrong and ‘Buzz’ Aldrin were in the lunar module while Mike Collins was in orbit around the Moon. You can see that Armstrong’s heart rate increased substantially at the ‘lunar touchdown’. There might have been issues with measuring the heart rates of Collins and Aldrin at key points, judging by the ‘flat line’ traces, but they were clearly still alive! Armstrong’s heart rate then reduced during the ‘extra-vehicle activity’ (EVA) when he walked on the Moon’s surface. Finally, his heart rate reduced more on lunar lift-off.

Now you will look at the heart rates of human beings compared with other animals.

7 Comparing the heart rates of animals and human beings

Is a person's life expectancy greater or less than an animal's life expectancy? In Figure 11 you can see that a human's life expectancy is longer. This graph is a 'logarithmic–linear' scale, so you need to be careful when you read values from the scales. On the heart rate scale (the vertical one on the left), the values go up in tens from 20 to 50 and then in hundreds from 100 to 1000. This helps to fit the data on a more manageable graph. The life expectancy scale increases linearly, from 0 to 90 in equal increments of 10.

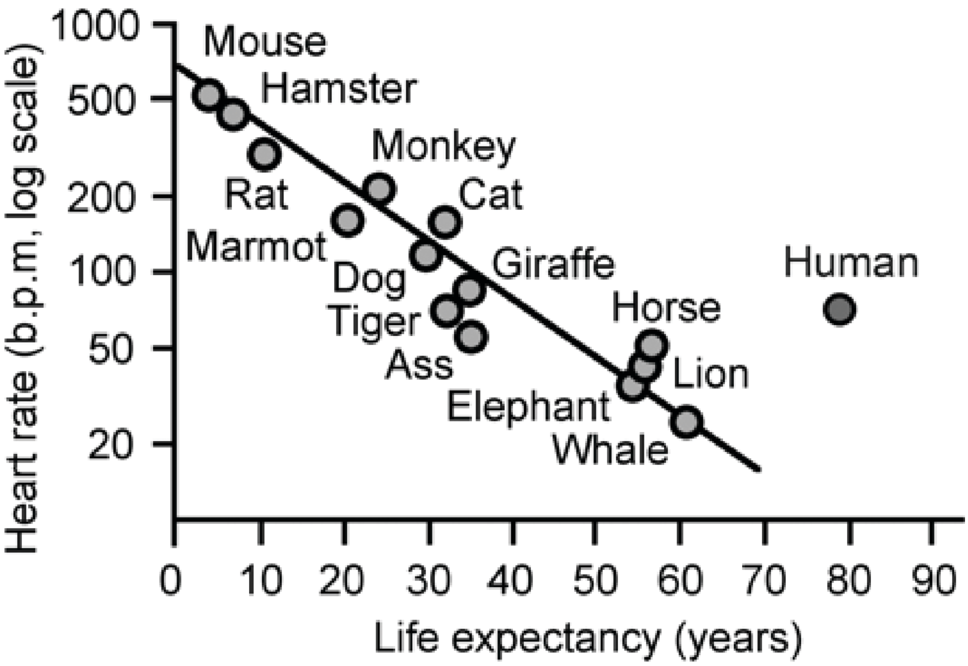

Figure 11 Heart rate (beats per minute, bpm) and life expectancy (years) of animals and humans.

Activity 8 Life expectancies and heart rates

Allow approximately 15 minutes

Using the data in Figure 11, answer the following questions, choosing one correct option for each.

1. What is the life expectancy and heart rate (beats per minute, bpm) of a human?

- ○ 20 years and 100 bpm
- ○ 60 years and 20 bpm
- ○ 80 years and 80 bpm
- ○ 90 years and 20 bpm
- ○ 100 years and 80 bpm

2. What is the life expectancy and heart rate of an elephant?

- ○ 20 years and 100 bpm
- ○ 55 years and 40 bpm

- ○ 60 years and 20 bpm
- ○ 80 years and 100 bpm
- ○ 100 years and 80 bpm

3. Choose the correct options provided to complete the following conclusions.

Interactive content is not available in this format.

4. Choose the correct options provided to complete the following conclusions.

Interactive content is not available in this format.

Human beings are incredibly adaptable. For example, free-divers can slow down their heart rates substantially and can dive to incredible depths (Figure 12). Every 10 metres down in the water adds another atmospheric pressure (about 100 000 newtons per square metre). So, the pressure at great depths quickly becomes very dangerous. This contrasts with the pressure when you are at an increased height. This pressure reduces, which you experience when your ears ‘pop’ and you need to swallow to equalise the pressure.

Figure 12 Free-divers in the Caribbean.

Everyone is aware of the dangers of heart attacks. You may have seen a defibrillator (Figure 13). This life-saving device can help to save human lives by stopping and then restarting a heart that is fibrillating or in cardiac arrest. There are portable versions, which can be used by paramedics, and community ones are also now available in public places such as shopping centres and airports.

You have seen how your heart rate can be compared with an astronaut's; clearly your heart is a measure of your overall health. When placing astronauts into physically challenging situations, their hearts are working incredibly hard. Indeed many of us will experience heart racing situations; it's reassuring to know that defibrillators are more available now in the event of an emergency!

Figure 13 A portable defibrillator used to treat heart attacks.

You will now move on to your next practical activity, growing mold on bread.

8 Preparing for the bread mold experiment

You now need to prepare for the 'space bugs' bread mold experimentin Week 5. Here you will grow mold on bread to simulate 'bugs'. You need at least four slices of bread, preferably two white and two wholemeal. You also need some sealable plastic bags. Place one slice in each bag as shown in Figure 14.

Figure 14 Preparing samples for the 'space bugs' experiment.

Then choose two locations for the bags. One should be in direct sunlight and airy (for example, on a window ledge), and the other in a dark, warm environment (for example, under the stairs). Monitor the bags at least once a day, ideally photographing each one, starting about a week after you have set this up. Then record your observations. Please be patient; this experiment depends on the weather. If it is cold then it may take a long time!

Table 5

Sample	Day 7	Day 8	Day 9	Day 10	D
white bread in sunlight	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	
brown bread in sunlight	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	
white bread in dark	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	
brown bread in dark	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	*Provide your answer...*	

Health and safety note: please handle the bread with care as mold will start to grow on it.

Now complete the end-of-week quiz.

9 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 2 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

10 Summary

Now is a good time to revisit the learning outcomes for this week. Below is a summary of what you have covered.

- This week you have learned about the types of scientific research that can benefit from microgravity environments, focusing on ageing. Activity 1 showed that, as a proportion of the world's total population, the younger population is anticipated to decrease. This would lead to lower contributions to the world's economies and, as a 'double whammy', the older retired generation is anticipated to increase substantially.
- You have extrapolated data from a pie chart (Figure 2, and Activity 1). You have also interpreted data on a logarithmic–linear graph (Figure 11 and Activity 8).
- You have calculated speed using distance and time data (Activity 4).
- You have also carried out or watched Practical experiment 2 in which you measured your heart rate and respiration rate in a seated position, when lying down and after moderate exercise .

Next week you will start by looking at the very small. After Weeks 1 and 2 of learning about the ISS and the impact of microgravity on humans, you will look at the other scale of size by diving into the quantum world.

You can now go to Week 3.

Week 3 The quantum world

Introduction

In Week 1, you looked at the large physical values involving the ISS, Earth and the Moon. In Week 2, you looked at the effects of microgravity and ageing in the context of 'bed rest'. This week, you will look at very small physical values – the quantum world. You will also see how quantum experiments are used in the context of the ISS.

First, watch Video 1 which introduces what this week will cover.

Video content is not available in this format.
Video 1 Introduction to Week 3

By the end of this week, you should be able to:

- consider how quantum science experiments are being conducted on the ISS
- understand logarithmic powers (powers of ten) and how they describe the whole Universe
- explain the types of scientific research that can benefit from microgravity environments
- consider powers of ten and the difference between positive and negative values.

1 Research areas and orders of magnitude

The scientific word for discrete, as opposed to continuous, values is ‘quantum’. This is often portrayed as the world of the very small, but what comes to mind when you think of this word? If you do a Google search, you will find over 12 million matches (Figure 1).

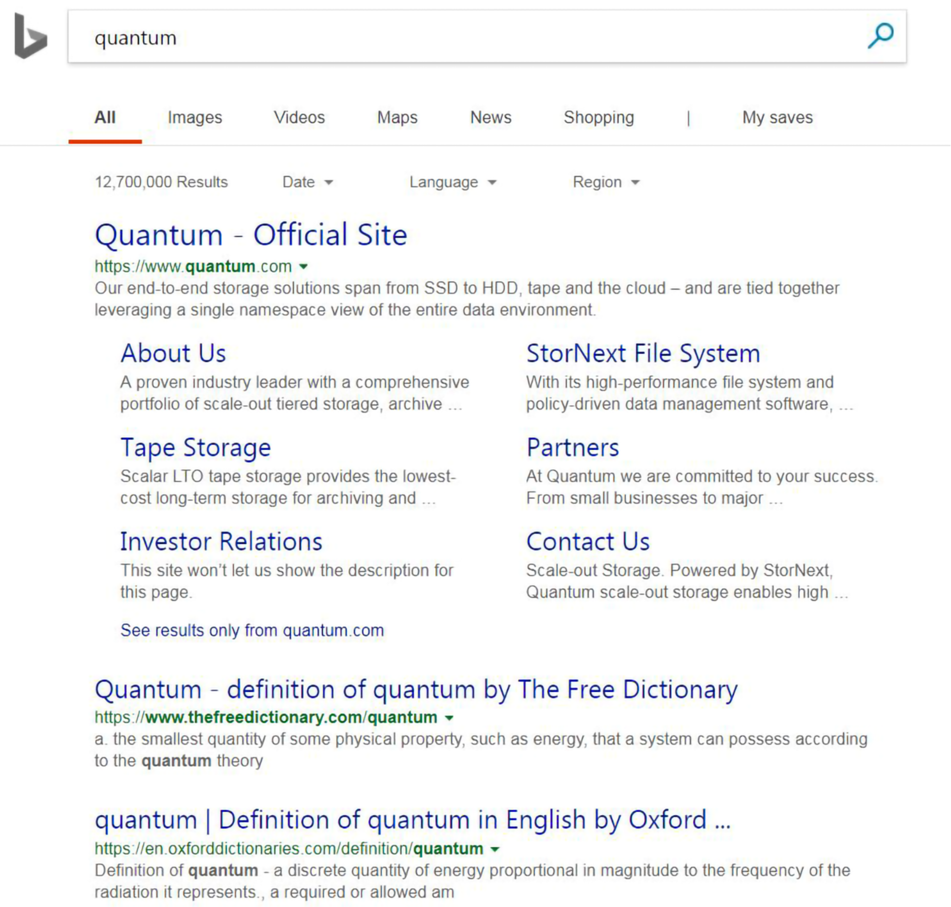

Figure 1 A Google search on the word ‘quantum’.

It may surprise you that quantum experiments are being done on the ISS. However, it is ideally suited as a platform to look out to the rest of the Universe and look down at Earth.

You already know about some of the scientific research taking place on the ISS. But did you know that it offers the unique environment of being humanity’s only permanent microgravity laboratory? For example, colloids (tiny particles in liquids) can be studied on the ISS where their structures are controlled by ‘quantum forces’ in a microgravity environment. These effects were predicted over 30 years ago and were first observed in 2008.

You first need to appreciate the change in size scales and the best way to do this is by using a logarithmic scale. Remember in Week 2 you were introduced to a similar scale in the context of heart rates and life expectancy.

Powers of ten are used to quantify these sizes from the very large to the very small. These powers are interpreted on a logarithmic scale and they give a feeling for the ‘order of magnitude’.

If you need to refresh what these powers of ten mean, look again at Section 5 in Week 1.

Figure 2 illustrates the vast changes in scale from the sizes of clusters of galaxies (10^{22} m) through to humans and down to subatomic particles and beyond (10^{-15} m). This is a huge range! In 'real numbers' it goes from ten thousand million million million metres down to 0.000 000 000 000 001 m.

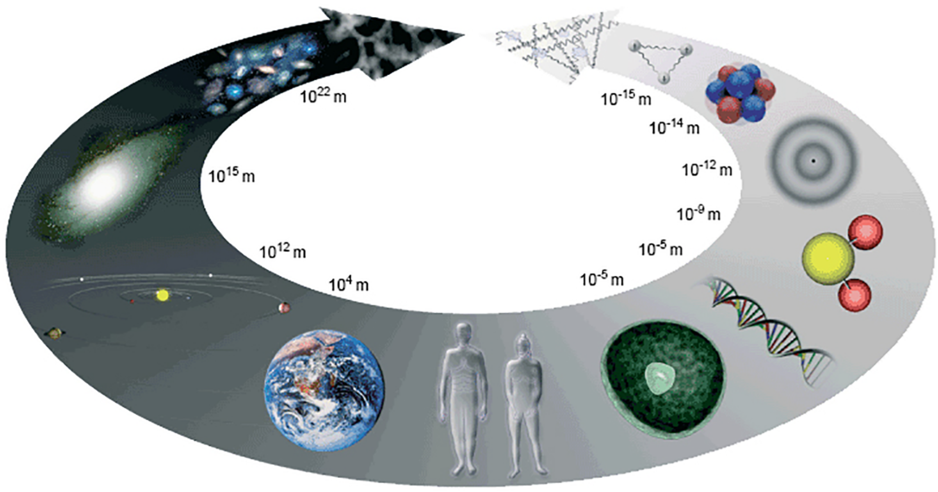

Figure 2 A logarithmic scale from clusters of galaxies to subatomic particles.

Now use Figure 2 to help you complete Activity 1.

Activity 1 Size scales

Allow approximately 5 minutes

Choose the one correct option for each of the following.

1. The rough size of a DNA helix is:

○ 10^{-6} m
○ 10^{60} m
○ 10^{-600} m

Answer

The rough size of a DNA helix is 10^{-6}m.

2. What is the rough size of the nucleus of an atom?

○ 10^{14} m
○ 10^{140} m
○ 10^{-140} m
○ 10^{-1} m
○ 10^{-14} m

Answer

The rough size of the nucleus of an atom is 10^{-14}m.

3. The smallest object is 10^{-15} and the largest object is:

○ 10^{15}
○ 10^{12}
○ 10^{22}

○ 10^{18}

Answer

The smallest object is 10^{-15}m and the largest object is 10^{22}m.

You will now look at quantum science in general.

2 An introduction to quantum science

Traditionally, science has been broken down into the disciplines of biology, chemistry, Earth sciences, physics and astronomy, which are usually linked to the scales in Figure 2:

- Biology and Earth Sciences, from animals, including humans, down to DNA
- chemistry on the scales of atoms and molecules
- astronomy for large-scale planets and stars
- physics for the rest.

Nearly 50 years ago, Richard Feynman (Figure 3) gave a lecture on the subject 'There's plenty of room at the bottom'. In it he said: '[based on] the problem of manipulating and controlling things on a small scale … it is a staggeringly small world that is below.' (RSC, n.d.).

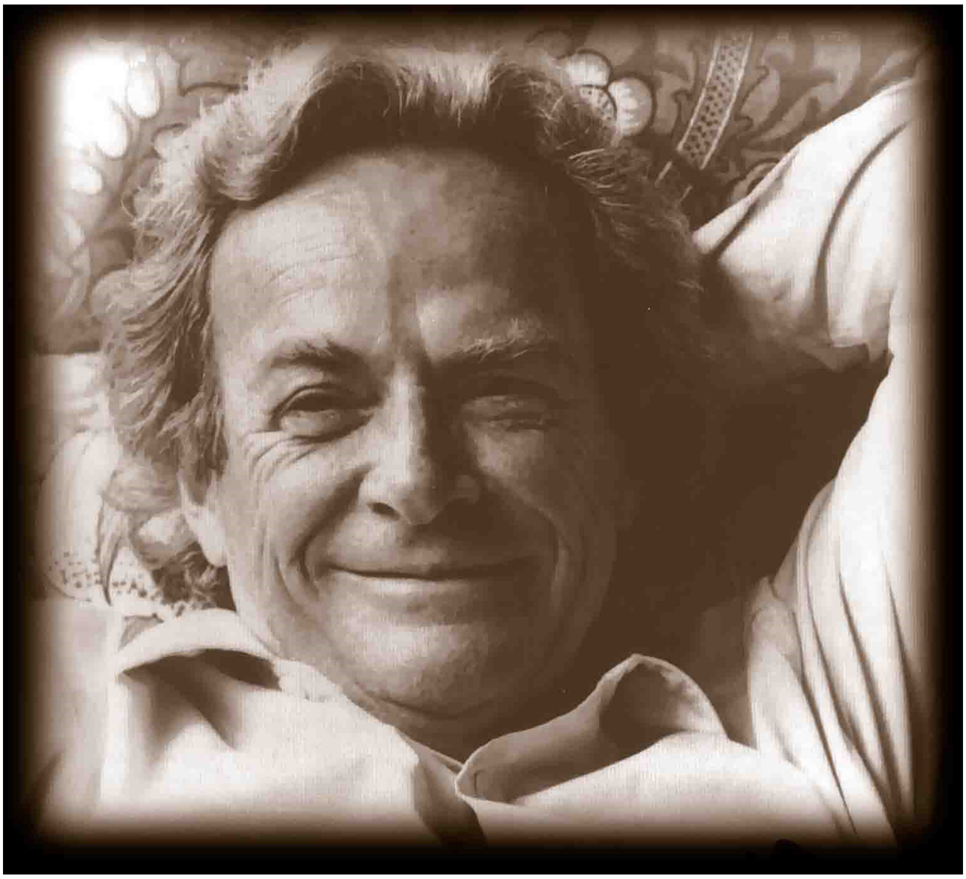

Figure 3 Richard Feynman (1918–1988), the American theoretical physicist.

But below what? Well, the quantum world is on the scale of atoms and smaller. From Figure 2, you can see that these scales are less than 0.000 000 000 000 01 m (10^{-14} m). Do you think there any devices in your household that work on this small scale?

Well, in most households there are CDs, DVDs and blu-rays. How are these read though? These discs are read using LASERs (Light Amplification by Stimulated Emission of Radiation), which use quantum effects. You will learn more about LASERs later on this week. Then, if you have a PC or laptop with a solid-state drive (SSD), this relies on solid state physics, which also relies on quantum effects. Modern digital televisions have plasma screens. Several years ago, TV screens were effectively particle accelerators with huge screens!

You will now look at properties of waves, starting with diffraction.

3 Diffraction of waves

Before you journey into the quantum world, you need to consider some physical effects that can be seen in your everyday life. Diffraction of waves is one of them. For example, when the entrance to a harbour is of the right size, water waves diffract, or spread out, as they move into the harbour (Figure 4).

Figure 4 Water wave diffraction in a harbour.

If you click here, it will take you to an online animation where you can change the gap size for single slit and ripple tank simulations. Note carefully what happens to the waves, then try Activity 2.

Activity 2 Exploring diffraction

Allow approximately 15 minutes

Choose the one correct option to complete the following statements based on the animation.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

You can also see diffraction effects using LASER light. Watch Video 2 where this effect is demonstrated using LASER pens and diffraction gratings. Then complete Activity 3.

Video content is not available in this format.

Video 2 LASER pen diffraction experiment.

Here, the concept of light behaving as a particle and a wave is introduced. Later on, you will see how electrons, as small particles of matter, can also behave as particles and waves.

Activity 3 The LASER diffraction experiment

Allow approximately 15 minutes

Choose the one correct answer from the options given to complete the following statements.

1. Moving out from the centre of the board, the order of the colours was as follows.

- ○ red and green
- ○ blue, green and red
- ○ yellow and red
- ○ green and blue
- ○ green, red, blue and yellow

2. The diffraction gratings used, in terms of lines per millimetre (mm), were:

- ○ 300
- ○ 1200
- ○ 600 and 1200
- ○ 300 and 600
- ○ 300

3. As the number of lines per mm on the diffraction gratings decreased, the spots on the board:

- ○ moved closer
- ○ moved further away
- ○ were unchanged

As the number of lines per millimetre on the diffraction grating decreases, the distance *d* between the lines increases. When this happens, the angle θ increases which affects the distances between the spots in Question 3 above. But how are these terms related to each other? Video 2 introduced Equation 1 which can now be explained in more detail.

Equation 1

n is an integer (whole number) as you count the dots from the centre outwards; the central dot is labelled $n = 0$.

λ is the wavelength of the LASER and is measured in m.

d is the separation between adjacent lines on the diffraction grating, again measured in m.

θ is the angle of diffraction from the LASER pen to the individual dots.

sin(θ) is the sine of the angle θ; this can be calculated by using the ‘sin’ button on your calculator.

You will now look at sodium D-lines and the simplest atom of all, hydrogen.

4 Sodium D-lines and the hydrogen atom

Energy levels are demonstrated in the context of a sodium lamp in Video 3. Watch it now and then do Activity 4.

Video content is not available in this format.
Video 3 Sodium D-lines.

Activity 4 Energy levels

Allow approximately 15 minutes

For each question, choose the one correct answer from the options given below.

1. The sodium lamp has the following number of lines:

- zero
- 1
- 2
- 5
- 10

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Interactive content is not available in this format.

Video 3 introduced the concept of energy levels. These can be thought of as the rungs on a ladder (Figure 5).

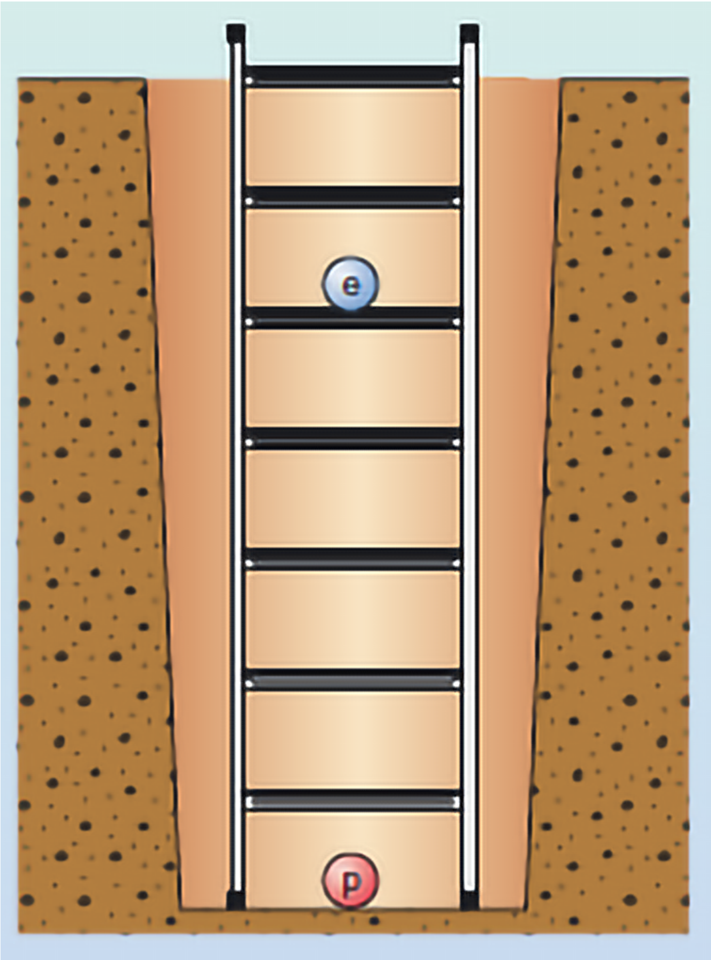

Figure 5 The analogy of rungs on a ladder for energy levels.

Figure 5 represents the simplest atom, hydrogen. This atom has one electron 'in orbit' around the nucleus (labelled as the blue circle with the letter 'e'). The nucleus of a hydrogen atom contains just one proton (labelled as the red circle with the letter 'p'). The rungs on the ladder represent discrete and separate energy levels. In the 'ground state', the electron would be on the first rung of the ladder. This state is given the value n = 1. (Please note that this is not the same 'n' as in the diffraction equation). If you give the electron exactly the right amount of energy, it will then move up to the next rung of the ladder. Here it would be the second rung where n = 2. You can test your understanding of this in the next activity.

Activity 5 Energy levels in a hydrogen atom (ladder analogy)

Allow approximately 15 minutes

Choose the correct answer from the options to complete the following statements.

1. The energy state of the electron in Figure 5 is:

- ○ n = 5
- ○ n = 4
- ○ n = 3
- ○ n = 2
- ○ n = 1

2. The highest energy state of the electron in Figure 5 would be:

- n = 3
- n = 4
- n = 5
- n = 6
- n = 7

Of course, the real picture is more complicated than a simple ladder! In Figure 6, the ground state of energy is labelled E_1. As you move up the energy levels, they bunch closer together. The electrons can transition, or move, between each energy level. Indeed, there are numerous permutations.

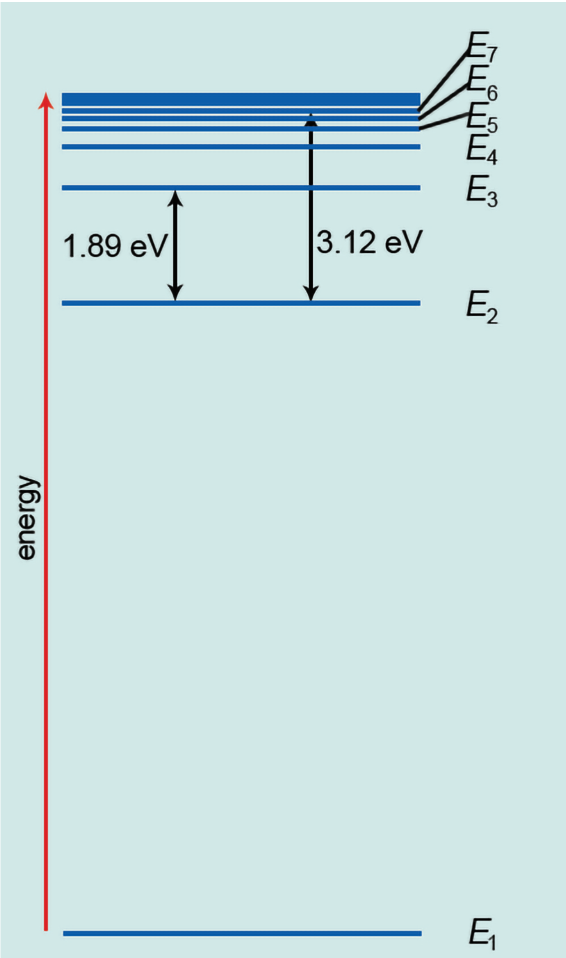

Figure 6 Energy levels of a hydrogen atom.

You can see that the energy units of eV, or electronvolts, are used here. At this size in the quantum world, the usual unit of energy, the joule, is much too big.

Now complete this section on energy levels by doing Activity 6.

Activity 6 Energy levels in a hydrogen atom

Allow approximately 10 minutes

For each question, choose the one correct answer from the options given.

1. How many energy levels are shown in Figure 5?

- 7
- 6
- 5
- 3
- 4

2. The 1.89 eV transition is between the following energy levels.

- E_1 and E_2
- E_1 and E_3
- E_2 and E_3
- E_3 and E_4
- E_4 and E_5

3. The 3.12 eV transition is between the following energy levels.

- E_1 and E_7
- E_2 and E_7
- E_3 and E_7
- E_4 and E_7
- E_5 and E_7

You will now look at quantum energy levels.

5 Quantum energy levels

You probably won't be surprised to know that there is an equation for energy levels! Equation 2 is used to calculate the energy of a certain level (E_n) when you know the energy level (n). This n can take any integer value, that is 1, 2, etc.

Equation 2

You should note the minus sign. It means that the electron is bound to an atom. You need to give it this amount of energy to release it. You can practise calculating energy levels in Activity 7.

Activity 7 Calculating energy values

Allow approximately 15 minutes

1. Using your calculator and Equation 2, calculate the energy value when n = 1. Then choose the correct option below.

- ○ –1.51 eV
- ○ –3.4 eV
- ○ –13.6 eV
- ○ –27.2 eV
- ○ 13.6 eV

2. Using your calculator and Equation 2, calculate the value of energy when n = 2. Then choose the correct option below.

- ○ –1.51 eV
- ○ –3.4 eV
- ○ –13.6 eV
- ○ –27.2 eV
- ○ 13.6 eV

3. Using your calculator and Equation 2, calculate the value of energy when n = 3. Then choose the correct option below.

- ○ –1.51 eV
- ○ –3.4 eV
- ○ –13.6 eV
- ○ –27.2 eV
- ○ 13.6 eV

You will now look at probably the most famous experiment in physics: the double slit experiment.

6 The double-slit experiment

The weirdness of quantum behaviour is discussed by 'Dr Quantum' in the next video. The double-slit experiment has been voted as the most important experiment in physics, but it is also the most baffling! Watch Video 4 now and then do Activity 8.

View at: youtube:DfPeprQ7oGc

Video 4 Dr Quantum and the double-slit experiment

Activity 8 The double-slit particle or wave?

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

You will now look at how these quantum effects are used on Earth and on the ISS.

7 LASER cooling: researching quantum effects

You have now experienced some fascinating quantum effects. Next, watch Video 5 which is an interview taking place in the Open University's Quantum Physics Laboratory. Here these quantum effects are discussed in more detail as they are applied on Earth. Their current and future applications on the ISS are also discussed. After watching the video, complete Activity 9.

Video content is not available in this format.

Video 5 Interview in the LASER cooling laboratory.

Activity 9 LASER cooling and 'cold atoms'

Allow approximately 15 minutes

Choose the correct option to complete the following statements.

Interactive content is not available in this format.

2. The cooled atoms move at speeds of about:

- ○ 100 m/s
- ○ 300 m/s
- ○ 1 cm/s
- ○ 1000 m/s
- ○ 50 m/s

Interactive content is not available in this format.

You will now look at other physical measurements that are taking place on the ISS.

8 Gravity, timing and metrology

In the previous section you encountered timing research on the ISS. This research also includes 'metrology' which is the application of physical units. To summarise this research in context, Figure 7 shows the components of technology driving the modules of research into the development of systems.

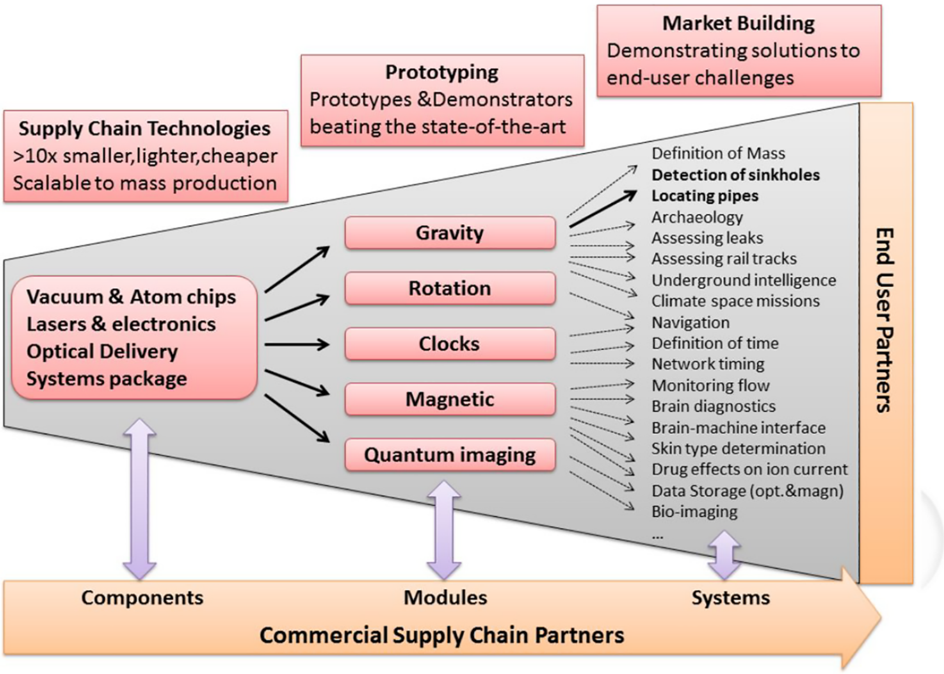

Figure 7 Metrology research by the University of Birmingham.

The precision of timing instruments is very important, but what type of clocks do we use? In Figure 7 you can see that some components, for example LASERs, can drive prototypes of clocks for navigation, defining time and for network timing. How important are these systems? Obviously, navigation systems are very important for applications in global positioning systems (GPS) and banking transactions also rely heavily on precise timing, so how are these systems made more accurate?

Read the following article: http://newsfeed.time.com/2013/07/11/new-optical-atomic-clock-poised-to-redefine-time-keeping/, which introduces a new optical clock to improve timing precisions. Then complete Activity 10.

Activity 10 A new optical atomic clock

Allow approximately 15 minutes

Choose the correct option to complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

You will now look at communication and security using the ISS as a platform.

9 Communication and security

The security of communications is extremely important. The effectiveness of encrypting a message will determine whether anyone unauthorised can read it. Similarly, decrypting a message can give the advantage to an eavesdropper. The film *The Imitation Game* (2014), starring Benedict Cumberbatch as Alan Turing, provides a good background to the decrypting or 'cracking' of the German Enigma machine during the Second World War (Figure 8).

Figure 8 Publicity poster for *The Imitation Game* (2014).

The outcome of this cutting-edge research was the first electromechanical computer (called a Bombe), developed by Gordon Welchman, and the electronic Colossus, developed by Tommy Flowers.

Governments around the world have vested interests in maintaining communications security of their own systems as well as cracking the codes of other countries' systems.

As light can be viewed as a wave or a particle (see Section 3), quanta of light called photons are used for secure communications. How relevant is this to the ISS? Well, in 2012, NBC News published an article (Hsu, 2012) on the subject of quantum key distribution. In it discusses a potential quantum entanglement for space experiments (QUEST) experiment to test quantum communication to and from the ISS. If you have some spare time this week, give this optional article a read.

What other types of quantum technology are under investigation? Figure 9 lists the possible space applications of quantum devices from quantum key distribution (QKD) to quantum communication complexity (QCC). It also summarises the quantum research introduced in Video 5.

Applications	Benefits	Space application
Quantum key distribution (QKD) using single and entangled photons	Unconditional security = detection of eavesdropper	• Secure access to a satellite • Secure communications between gateways / ground stations • Secure satellite-to-satellite communication
Quantum state teleportation (QT)	Transfer of quantum information without disturbing the quantum information, but speed of light limit for classical information	• Quantum telecomputation for deep space missions • Global distribution of quantum entanglement and global quantum networks
Quantum dense coding (QDC)	Higher channel capacity	• Satellite telecommunications • Deep space missions
Quantum communication complexity (QCC)	Higher efficiency	• Deep space missions

Figure 9 Application and benefits of quantum technologies.

Next you will complete the end-of-week quiz.

10 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 3 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

11 Summary

Video content is not available in this format.
Video 6 Conclusion of Week 3.

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have revisited logarithmic graphs (Section 1) and looked at how powers of ten can be used to give an order of magnitude from the very large (clusters of galaxies) down to the very small (atoms and below).
- You have also looked at quantum science, quantum biology, LASERs, metrology, clocks, and communication and security, as well as the double-slit experiment and diffraction effects.
- You have interpreted Figure 2 (a logarithmic picture) and extracted key information in Activity 3.
- You have read an online article in Section 8.

Next week you will read three online articles and use the PROMPT strategy to verify their authenticity. Next week is also the Week 4 compulsory badge quiz!

Now go to Week 4.

Week 4 Researching online sources

Introduction

You are nearly halfway through this course and should be proud of what you have achieved. This week is mostly dedicated to the mid-course quiz which covers what you have learned so far. There are 15 questions to complete.

Before completing the quiz you will first consider the question: how reliable online sources are. How can you check them? This week you will use the PROMPT approach to ascertain how much you can trust online sources.

Before you start this though, you will continue on from last week's focus on the quantum world by looking at how quantum effects occur in nature given the thought-provoking title of 'do weird physics effects also occur in Nature? Then PROMPT activity above, followed by 'you will look at how viable future travels to our nearest neighbour Mars are'.

By the end of this week, you should be able to:

- enhance your digital literacy skills, by locating information and studying online
- read a published article on quantum effects and consider how nature uses quantum mechanics
- apply the PROMPT approach to assessing the reliability of online sources
- successfully complete the Week 4 compulsory badge quiz.

1 Do weird physics effects also occur in nature?

In January 2013, the BBC reported on quantum biology. Read this article on the topic, then complete Activity 1.

Activity 1 Quantum biology

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

1. The article discusses the potential for quantum research to help in the development of:

- ○ new drugs
- ○ computers
- ○ perfumes
- ○ cancer
- ○ all of these areas

Interactive content is not available in this format.

Interactive content is not available in this format.

Next you will look at the impact of microgravity research.

2 Microgravity research and its impact

Have you ever watched the television programme *The Big Bang Theory*? In this series, there are humorous conflicts between the theoretical physicist, Sheldon Cooper, and everyone else. He takes a rather dismissive view towards the other sciences, particularly against his friends who portray a LASER physicist (Leonard Hofstadter), an aerospace engineer (Harold Wolowitz), a neurobiologist (Amy Fowler), a microbiologist (Bernadette Rostenkowski-Wolowitz), and an astrophysicist (Raj Koothrappali). These tensions are drawn out in some humorous situations.

Figure 1 Some of the characters from *The Big Bang Theory*.

On occasion, the writers imply that there are intellectual differences between Theoretical Physics, Engineering and Biology, although often at the expense of Sheldon, the Theoretical Physicist. In Week 3 you saw how science at the quantum level is investigated across these traditional disciplines; you should bear in mind that in reality scientists rarely work alone in their own field of research. Indeed, in the context of the ISS, scientists from various different disciplines work together to solve problems and present scientific investigations.

2.1 Disciplines in space research

Because so many scientists work across so many fields, this gives us the opportunity to bring together scientific research and look at the whole picture. Now see Activity 2 where you are asked to search by topics paying particular attention to interdisciplinary scientific research.

Activity 2 Topics search

Allow approximately 45 minutes

Search the web for the following topics.

1. How space is dangerous to humans.
2. Important discoveries on the ISS.
3. The future of the ISS.

Once you find a video and/or article, write comments about the following questions in the boxes provided. You can use Table 1 as a checklist for all of your online searches and decide for yourself how reliable your internet sources are.

Table 1 PROMPT criteria for checking your online sources

PROMPT criterion
Presentation
Is the information presented and communicated clearly?
Consider the language, layout and structure.
Relevance
Is the resource relevant to the topic you are researching?
Look at the introduction or overview to find out what it is mainly about.
Objectivity
Is the resource biased, or motivated by a particular agenda?
Is the language emotive?
Are there hidden, vested interests?
Method: for research reports
Is it clear how the data was collected?
Were the methods appropriate and can you trust the data?
Provenance
Is it clear where the information has come from?
Can you identify the author(s) or organisation(s), and are they trustworthy?
Are there references or citations that lead to further reading, and are they trustworthy sources?
Timeliness
How up-to-date is the material?
Is it clear when it was written?

Does the date of the writing meet your requirements, or is it obsolete?

1. How space is dangerous to humans.

Provide your answer...

Discussion

The course team found the following using the same search criteria.

View at: youtube:p_MVpZuDrog

Video 1 'Four ways space is trying to kill you'.

2. Important discoveries on the ISS.

Provide your answer...

Discussion

The course team found the following using the same search criteria.

View at: youtube:t5ceKXK6Kdk

Video 2 'Three big discoveries on the ISS'.

3. The future of the ISS.

Provide your answer...

Discussion

The course team found the following using the same search criteria.

Video content is not available in this format.

Video 3 'Ten more years'.

The next section has the course team's approach to using the PROMPT criteria for this content.

2.2 PROMPT criteria

Table 2 is the course team's approach to using the PROMPT category for Videos 1, 2 and 3 in Activity 1. How does this compare with your findings?

Table 2 PROMPT criteria applied to Videos 1, 2 and 3.

PROMPT criterion	Resource 1 ‘Four ways space is trying to kill you’	Resource 2 ‘Three big discoveries on the ISS’	Resource 3 ‘Ten more years’
Presentation Is the information presented and communicated clearly? Consider the language, layout and structure.	Not clearly presented. Video is 3 minutes and 3 seconds long.	Quite clearly presented. Video is 4 minutes and 1 second long.	Clearly presented. Video is 4 minutes and 40 seconds long.
Relevance Is the resource relevant to the topic you are researching? Look at the introduction or overview to find out what it is mainly about.	How space is dangerous to humans. Yes, this is relevant as it discusses extremely low pressure, vision problems, wasting effects and cell damage from radiation.	Important discoveries on the ISS. Yes, it discusses the Alpha Magnetic Spectrometer (AMS), long-term effects of living in space and cancer research.	The future of the ISS. Yes, it introduces the precision robotic arm, research into antimatter particles, long duration space travel, the Cold Atoms lab (CAL), quantum matter, Earth science and commercial space ventures.
Objectivity Is the resource biased, or motivated by a particular agenda? Is the language emotive? Are there hidden, vested interests?	No evident bias. Quite excited and rapid delivery.	No evident bias. Excited and rapid delivery.	No evident bias. Calm and measured delivery.
Method: for research reports Is it clear how the data was collected? Were the methods appropriate and can you trust it?	No external evidence of statements for less than 90 seconds in a low-pressure environment, 60% of NASA astronauts having reduced vision, 2% per month less bone material, 253 days to travel to Mars, and a 3-foot-thick metal wall on ISS to replicate the Earth’s protective atmosphere (which is equivalent to whole body CT scan every 5 to 6 days).	No external evidence of statements that the ISS cost US$140–160 billion, it took 13 years to build with the input from 16 nations, the inference of dark matter in the 1930s (accounting for 23% of the Universe) and the detection of billions of gamma-ray particles by the AMS.	No external evidence of statements that the ISS was extended until 2024, that the research on board the ISS has mitigated 21 out of 32 known human health risks with long-distance space travel, the AMS programme, and CAL established in 2016.
Provenance	‘What the stuff?’ No references provided.	Scishow No references provided.	Science @ NASA No references provided.

Is it clear where the information has come from? Can you identify the author(s) or organisation(s), and are they trustworthy? Are there references or citations that lead to further reading, and are they trustworthy sources?			
Timeliness	16 March 2015	6 September 2013	13 February 2014
How up-to-date is the material? Is it clear when it was written? Does the date of writing meet your requirements, or is it obsolete?	16 000+ views Still valid	472 000+ views Still valid	44 000+ views Still valid

3 Travelling to Mars

Now you've researched the dangers of space, the discoveries on the ISS and the future of space travel, you'll look at travelling to Mars in more detail. Remember that an astronaut's journey to Mars is expected to take 253 days? Well there are plans for a human settlement on Mars called 'MarsOne'. Have a look at the 'Mission roadmap'and answer the following questions by choosing the correct option.

Activity 3 Mission roadmap

1. The start of crew training is expected to take place in:

- 2018
- 2022
- 2030

Answer

The start of crew training is expected to take place in 2018.

2. In 2022, the lander payload is expected to include something to provide energy to maintain and grow the settlement. What is that something?

- solar panels
- water
- batteries

Answer

In 2022, the lander payload is expected to include **solar panels** to provide energy to maintain and grow the settlement.

Interactive content is not available in this format.

You have now reached the end of this Week. Some of this content forms part of the Week 4 compulsory badge quiz which you should complete next.

4 This week's quiz

Now it's time to complete the Week 4 compulsory badge quiz. It is similar to previous quizzes, but this time instead of answering 5 questions there will be 15.

Week 4 compulsory badge quiz

Remember, this quiz counts towards your badge. If you're not successful the first time, you can attempt the quiz again in 24 hours.

Open the quiz in a new window or tab, then return here when you have done it.

5 Summary

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have seen how scientists in different fields actually work together, as opposed to the hilarious sitcom *The Big Bang Theory*.
- You have researched the internet for online videos related to the dangers of space, important discoveries and the future of the ISS.
- You have used the PROMPT strategy to assess the reliability of your online sources.
- You have then compared your approach to the PROMPT assessment of three videos provided by the course team.

Next week you will look at bacteria and fungi, and will revisit your bread mold experiment which you started in Week 2.

You are now half way through the course. The Open University would really appreciate your feedback and suggestions for future improvement in our optional end-of-course survey, which you will also have an opportunity to complete at the end of Week 8. Participation will be completely confidential and we will not pass on your details to others.

Now go to Week 5.

Week 5 Bacteria and fungi

Introduction

Welcome to the second half of the course. First, watch Video 1 which introduces what is covered this week.

Video content is not available in this format.
Video 1 Introduction to Week 5.

This week you will look at bacteria and fungi, and your results from your bread mold experiment which you started in Week 2 will also be discussed.

By the end of this week, you should be able to:

- understand the key differences between bacteria and fungi
- explain the types of scientific research that can benefit from microgravity environments, focusing on bacterial resistance
- calculate gravitational acceleration on different planets from data obtained by a random positioning machine (RPM)
- reflect on a home-based practical experiment and compare results.

1 Microbes, bacteria and fungi

This week, you will look at microbes, bacteria and fungi. What are they? And are they the same thing?

The term ‘microbes’ describes microorganisms. These exist either as *single* cells (unicellular) or as a *colony* of cells (multicellular), as shown in Figure 1.

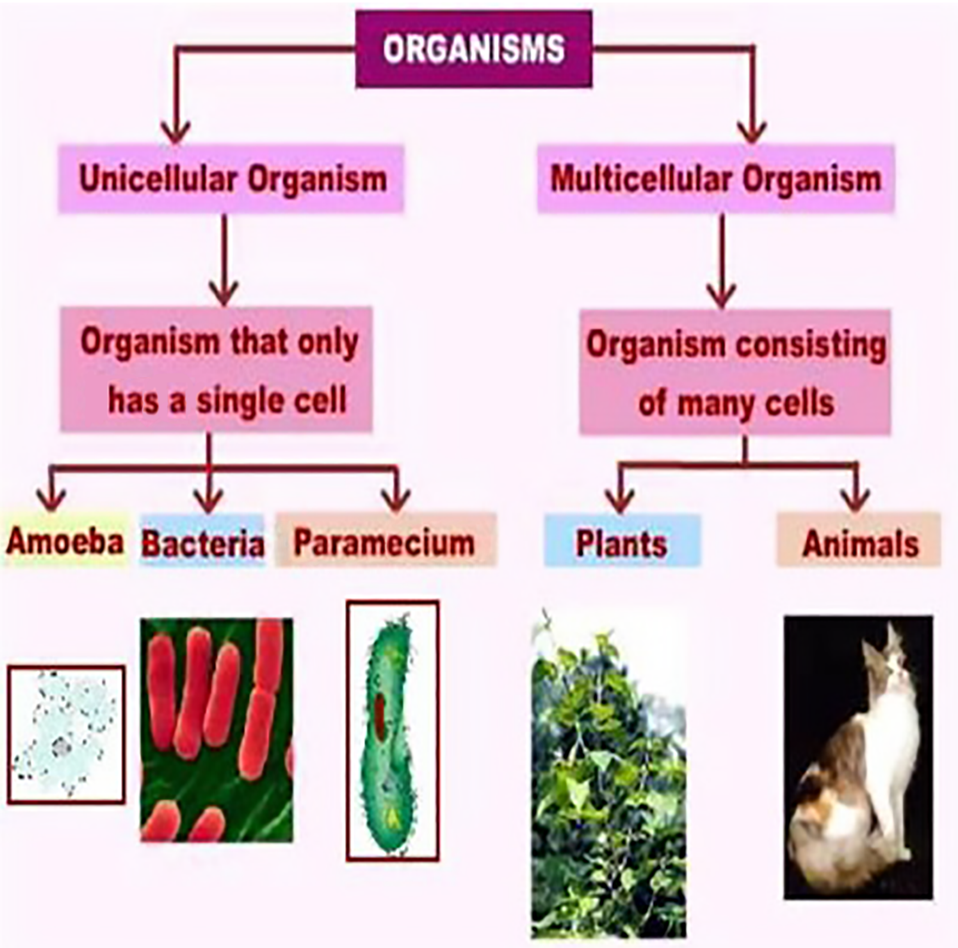

Figure 1 A comparison of unicellular and multicellular organisms.

Using Figure 1, now complete Activity 1.

Activity 1 Unicellular and multicellular organisms

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

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You have now looked at bacteria, but what about fungi? The first difference to consider is that fungi are eukaryotes while bacteria are prokaryotes (Figures 2 a and b respectively).

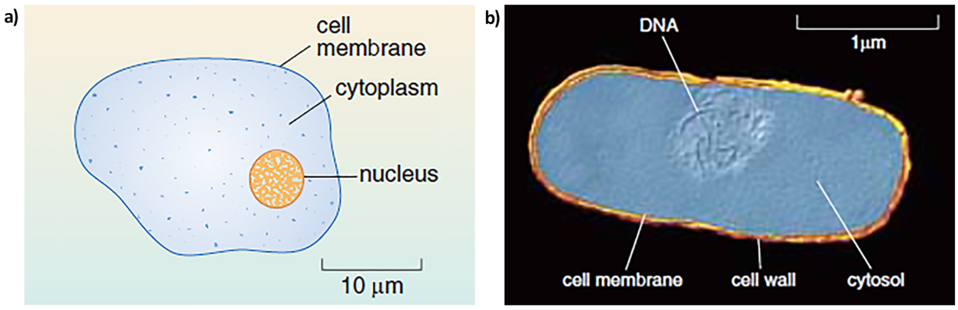

Figure 2 (a) A eukaryotic cell where the scale is 10 micrometres (10×10^{-6} m) and (b) a prokaryotic cell where the scale is 1 micrometre (1.0×10^{-6} m).

Using Figure 2, now complete Activity 2.

Activity 2 Eukaryotic and prokaryotic cells

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

5. What is the scale of the sketch of a yeast fungus in Figure 3?

(Hint: this scale includes the Greek lower-case letter mu, µ. This means multiply the distance by 0.000001.)

Figure 3 A budding yeast cell-shaped fungus.

- ○ 50×10^{-6} m
- ○ 5×10^{-5} m
- ○ 5×10^{-6} m
- ○ 50 cm
- ○ 5 m

In summary, fungi:

- are unicellular eukaryotes
- are about 10 micrometres big
- contain a cell membrane, cytoplasm and a nucleus.

and bacteria:

- are unicellular prokaryotes
- are about 2 micrometres big
- contain a cell wall, cell membrane, cytosol and DNA.

You will now revisit your bread mold experiment to see how you got on.

2 Your bread mold experiment and yeast

How did you get on with your bread experiment from Week 2? Did you take some photographs over the days which showed the growth of mold?

In case you were unable to do it, we also carried out this experiment. Watch Video 2, which shows how a loaf of bread changes over several days.

Video content is not available in this format.
Video 2 Time-lapse video of mold growing on bread.

You can see that, as the mold starts to grow and spread, bubbles of gas and liquid form in the plastic bag containing the bread. This plastic bag then starts to collapse in on the loaf of bread.

In Section 1, you met the term fungi (singular: fungus). Fungi are carried in the air as **spores**. When these spores land on bread, they germinate and start to grow as a fungus.

- What does this fungus need to grow?
- It needs a food source (the bread) and an environment containing moisture. Humidity is the amount of water vapour in the air, so it's now definitely worth watching the weather forecasts!

- What happened to your bread? Why does it change? Would you have believed that the environments you chose had moisture in the air? But why does the bread change?
- It goes through a chemical change. The mold 'eats' the sugar, water and minerals in the bread. At the same time, another chemical change takes place: the bread is decomposing. As a result of both of these changes, gases are emitted and heat is produced.

In Week 2, you saw how research in a microgravity environment is key to establishing how space can affect astronauts' health. Are you wondering how your bread experiment and fungi are relevant to a microgravity environment? Well, in your experiment, you saw how mold is gradually created over a period of time. In space, it has been found that yeast cells, from bread, grow much more quickly than on Earth. But why is yeast a good organism for research in a microgravity environment? Read this article on microscopic astronauts (NASA, 2007) to find out and then complete Activity 3.

Activity 3 Yeast in a microgravity environment

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

2. The genome of yeast has been:

- ○ withheld

- partially mapped

deleted

- completely mapped
- unmapped

Interactive content is not available in this format.

4. Yeast also has some genes in common with

- humans
- bacteria
- microbes
- dogs
- monkeys

You will now look at ‘space bugs’.

3 ‘Space bugs’

As well as wondering what space travel does to a human body, it is also worth asking what does space travel do to microbes? Microgravity environments can alter their genetics, commanding the microbes to do things differently.

There are billions of microbes in the gut of one astronaut on the ISS. Many of them are very beneficial. For example, some produce vitamin K to help blood to clot; others help to digest food. It has been found, though, that in a microgravity environment the ability of *Salmonella* to cause disease is *increased*. Other bacteria, however, produce more helpful antibiotics in space than on Earth.

Now watch Video 3, which introduces ‘space bugs’, and then complete Activity 4.

Video content is not available in this format.
Video 3 Sixty-second adventures in microgravity: space bugs.

Activity 4 Bacteria in a microgravity environment

Allow approximately 15 minutes

Choose the correct option to answer the following questions.

1. What did scientists discover about bacteria in space, compared with those on Earth? They are:

- ○ less virulent
- ○ unchanged
- ○ more virulent
- ○ eliminated
- ○ unimportant

2. What type of chamber do scientists use to recreate a microgravity environment on Earth when experimenting with bacteria?

- ○ Dropping
- ○ Horizontally moving
- ○ Rotating
- ○ Stationary
- ○ None at all

3. What effect does this chamber have on the bacteria?

- ○ They can breed and multiply, and know the difference between up and down.
- ○ They can breed and multiply, but don’t know the difference between up and down.
- ○ They can’t breed and multiply, and don’t know the difference between up and down.
- ○ They can breed but they can’t multiply.
- ○ They can’t breed but they can multiply.

You will now look at how random positioning machines are used in experiments.

4 Random positioning machines

Random positioning machines or RPMs (Figure 4) are used for research into:

- cell biology
- microbiology
- regenerative medicine
- tissue engineering and stem cells
- experimenting with bacteria in a microgravity environment.

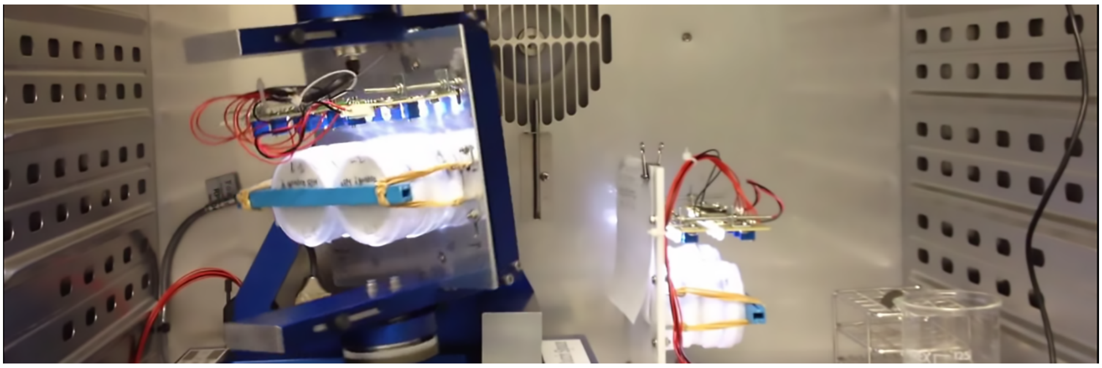

Figure 4 A random positioning machine (RPM).

An RPM simulates microgravity by rotating with random speeds in all directions. This makes the sample experience gravity from every direction. Over a period of time, the average acceleration due to gravity is zero. The RPM can also provide a different value of gravity where organisms or cells can change.

An RPM can simulate the numerical values of gravity different from Earth's gravity *g* (9.81 m/s^2). In the case of Mars, this is equivalent to 0.38 *g*. In the case of the Moon, this is equivalent to 0.18 *g*.

Now, using these values, complete Activity 5.

Activity 5 RPM and values of gravity

Allow approximately 15 minutes

Answer the following questions by choosing one correct option.

1. What is the numerical value of the acceleration due to gravity on the Moon?

○ 3.54 m/s^2

○ 2.77 m/s^2

○ 0.77 m/s^2

○ 1.77 m/s^2

○ 177 m/s^2

2. What is the numerical value of the acceleration due to gravity on Mars?

○ 3.73 m/s^2

○ 7.46 m/s^2

○ 37.3 m/s^2

○ 373 m/s^2

- ○ 0.373 m/s^2

3. In Week 1, you calculated the weight of an object with the same mass on different planets. Which unit for gravitational field strength did you use?

- ○ N
- ○ kg
- ○ N/kg
- ○ m/s
- ○ m

You will now look at the survivability of microbes in extreme physical conditions on Earth and elsewhere in the Universe.

5 Can microbes survive elsewhere in the Universe?

As well as thinking about life in the Universe, you may wonder how well microbes can survive in very hostile conditions on Earth. The Open University has carried out some research on this in low Earth orbit and in extreme physical conditions on Earth.

Watch Video 4, which is an interview with a microbiologist discussing this research, then complete Activity 6.

Video content is not available in this format.
Video 4 Interview with a microbiologist.

Activity 6 Survivability of microbes

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

2. The name of the mission to investigate Devonian rocks on the ISS was:

- Devon1
- TP
- OU-20
- TP20
- Beare1

Interactive content is not available in this format.

In Video 4, the survivability of microbes on the outside of the ISS was discussed. In the ISS experiment ‘Biopan-6’, a group of tardigrades (water bears) – multicellular organisms, roughly the size of a grain of salt (Figure 5) – hold the record for the longest-lived animals in open space. Read this BBC News report about the experiment and watch the video within it.

Figure 5 A tardigrade, or water bear, which is approximately 0.2 mm long.

Amazingly, tardigrades can effectively hibernate for weeks and can 'come back to life' after it comes into contact with water. This is called **dessication**. Watch Video 5 which shows this happening.

Video content is not available in this format.
Video 5 Anhydrobiosis in tardigrades.

Which other organisms do you think could survive in an extreme environment? Watch Video 6 and then complete Activity 7 (which also draws on the discussion in Video 4).

Video content is not available in this format.
Video 6 The life of extremophiles.

Activity 7 What conditions make it difficult for life?

'Allow approximately 15 minutes'

Based on Videos 4 and 6, complete the following statements.

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Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

You will now look at the habitability of other planets.

6 The habitability of planets

There is continuous research into finding exoplanets outside the Solar System with environments similar to Earth's. But how is this done?

A range of techniques are used. For example, the measurements of planets can be plotted on a graph similar to Figure 6. Here, the orbital radius is measured in terms of astronomical units (AU). This is the distance from the Earth to the Sun (150 million km). The planet's mass is measured relative to the mass of the Earth (M_E) (6×10^{24} kg).

Using Figure 6, now complete Activity 8.

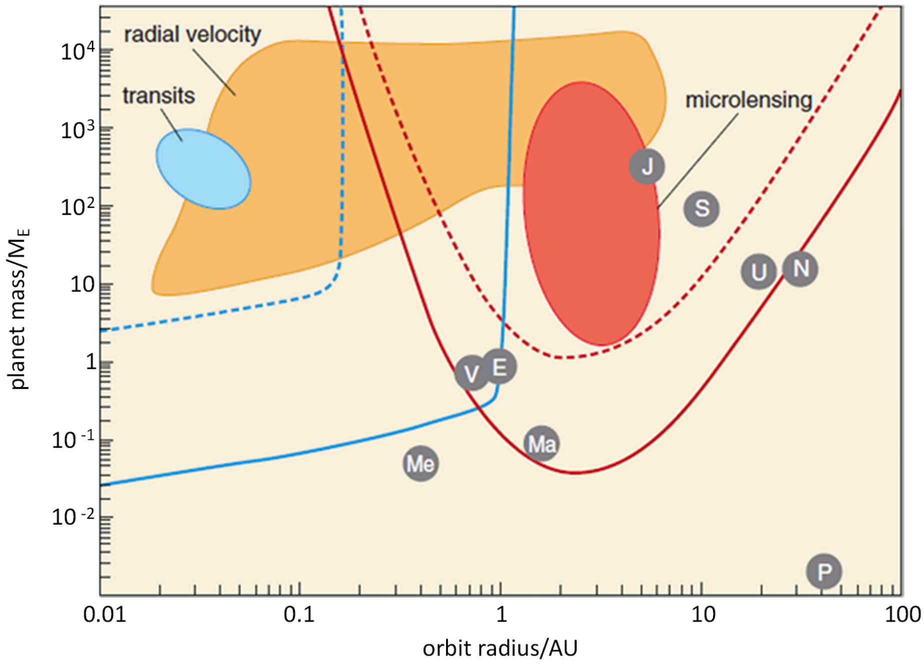

Figure 6 A graph used to plot other planets.

Activity 8 Exploring the habitability of other planets

Allow approximately 15 minutes

Choose the correct answer to the following questions.

1. Which values are plotted on the horizontal axis?

- ○ Orbit
- ○ Orbit radius
- ○ Planet mass
- ○ Orbit radius/AU
- ○ Planet mass/M_E

2. Which values are plotted on the vertical axis?

- ○ Orbit
- ○ Orbit radius
- ○ Planet mass

- Orbit radius/AU
- Planet mass/M_E

3. Where would you expect to find Earth? (Hint: Earth is at a distance of 1 AU from the Sun and has a relative mass of 1 M_E.

- J
- S
- E
- V
- N

4. The planets labelled V, E, J, S and N are in our Solar System. Which one has the largest relative mass?

- J
- S
- E
- V
- N

5. Which planet has the smallest orbital radius?

- J
- M_e
- E
- V
- M_a

What makes planets habitable for humans?

You might have heard of the 'Goldilocks zone'. This is the zone occupied by the Earth in its orbit about the Sun. This zone is neither too close to the Sun – that is, too hot – nor too far away from the Sun – that is, too cold. So, Earth is located where the conditions are just right for life to exist.

In trying to find other planets which are suitable for humans, the Planetary Habitability Laboratory (PHL) aims to map the habitable Universe. It holds the Habitable Exoplanets Catalogue (HEC) which lists and compares potentially habitable exoplanets (Figure 7). Using this information in Figure 7, now complete Activity 9.

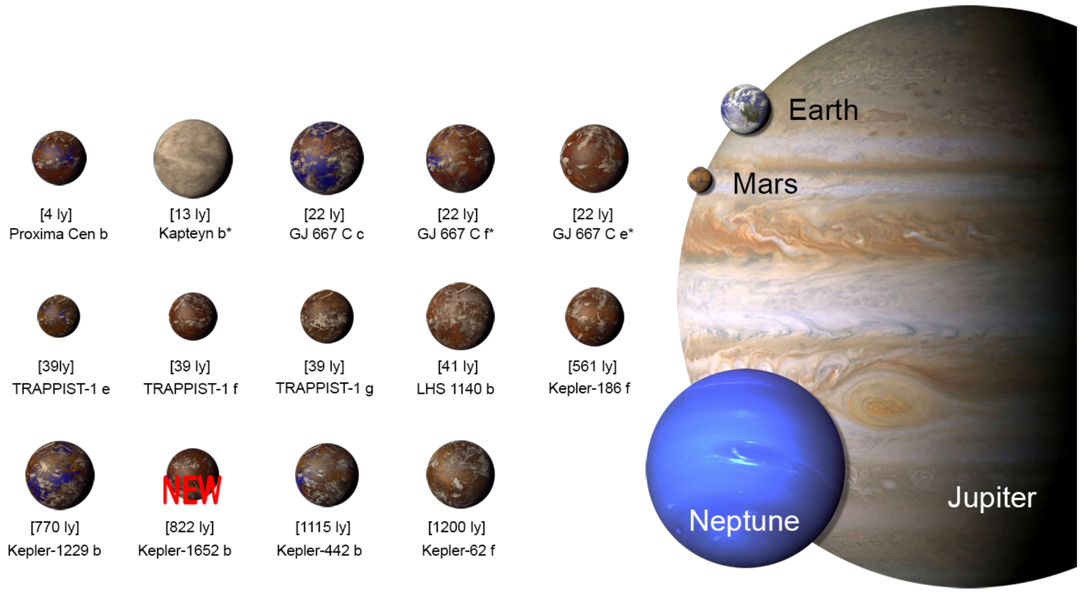

Figure 7 Potentially habitable exoplanets ranked by distance from Earth in light years (ly). Kapteyn b, GJ 667 C e and GJ 667 C f are planet candidates.

Activity 9 Potentially habitable exoplanets

Allow approximately 15 minutes

Answer the following questions, choosing one option for each.

1. Which planet is closest to Earth?

- ○ Trappist-1 f
- ○ Kepler-62 f
- ○ GJ 667 C c
- ○ Proxima Cen b
- ○ Kepler-1229 b

2. According to Figure 7 only, what is the greatest distance of an exoplanet from Earth?

- ○ 1200 ly
- ○ 770 ly
- ○ 1115 ly
- ○ 2000 ly
- ○ 39 ly

3. Which one of the following is a ‘planet candidate’?

- ○ Trappist-1 f
- ○ Kepler-62 f
- ○ GJ 667 C c
- ○ Proxima Cen b
- ○ Kepler-1229 b

Next you will complete the end-of-week quiz.

7 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 5 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

8 Summary

Video content is not available in this format.
Video 7 Conclusion of Week 5.

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have encountered the differences between bacteria and fungi.
- You have compared your experiment of growing mold on bread with the course team's results.
- You have seen how research into 'space bugs' is being carried out on the ISS.
- You have looked at how random positioning machines can be used to alter the values of gravitational acceleration.
- Finally, you have looked at the survivability of microbes elsewhere in the Universe, and the habitability of other planets.

Next week you will see how microgravity environments are recreated on Earth and the processes involved in forming planets.

You can now go to Week 6.

Week 6 Microgravity environments on Earth

Introduction

This week you will look at how microgravity environments can be achieved on Earth and how planets are formed.

From Week 1, you know that the Earth's gravity pulls objects and the ISS towards the Earth’s surface. This week, you will see how drop towers and parabolic flights can also simulate microgravity environments.

Finally, you will look at how the formation of planets can be modelled.

By the end of this week, you should be able to:

- understand terminal velocity in the context of a microgravity environment
- explain the types of scientific research benefiting from microgravity environments, focusing on planet formation
- calculate speed, given distance and time data
- interpret diagrams and extract information from them.

1 Felix Baumgartner's record freefall jump

Watch Video 1, which shows Felix Baumgartner achieving the freefall record during his successful attempt at the jump world record on 14 October 2012.

Video content is not available in this format.
Video 1 Felix Baumgartner's world record jump.

- Figure 1 gives 833.9 mph which is 1342 km/h. How would you convert this to m/s? What would his maximum speed be in m/s?
- First, multiply 1357.6 by 1000 to change km to m. Your intermediate answer is then 1.3576×10^6m. Then divide this answer by (60 × 60) to change hours to seconds. Your final answer should be 377.11 m/s.

  The speed of sound in air at about 20 000 m is around 300 m/s. So, at this maximum speed of 377 m/s, Felix was travelling faster than the speed of sound, which is measured on the Mach scale. This was the first time the sound barrier had been broken by a human outside an aircraft!

  Note that these values are given precision up to 5 significant figures. This precision is retained throughout this section.

Figure 1 shows the jump in more detail. Using the details from Figure 1 and Video 1, complete Activity 1.

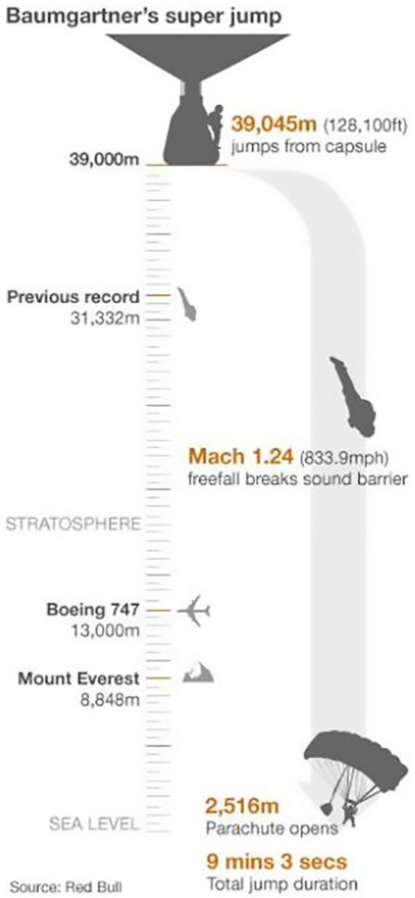

Figure 1 Felix Baumgartner's world record jump.

Activity 1 Felix Baumgartner's record jump

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Baumgartner's maximum speed in freefall was also his **terminal velocity**. This means he was no longer accelerating as the forces acting on were balanced. There were two main forces acting on him – Earth's gravity and air resistance, each acting in opposite directions (Figure 2).

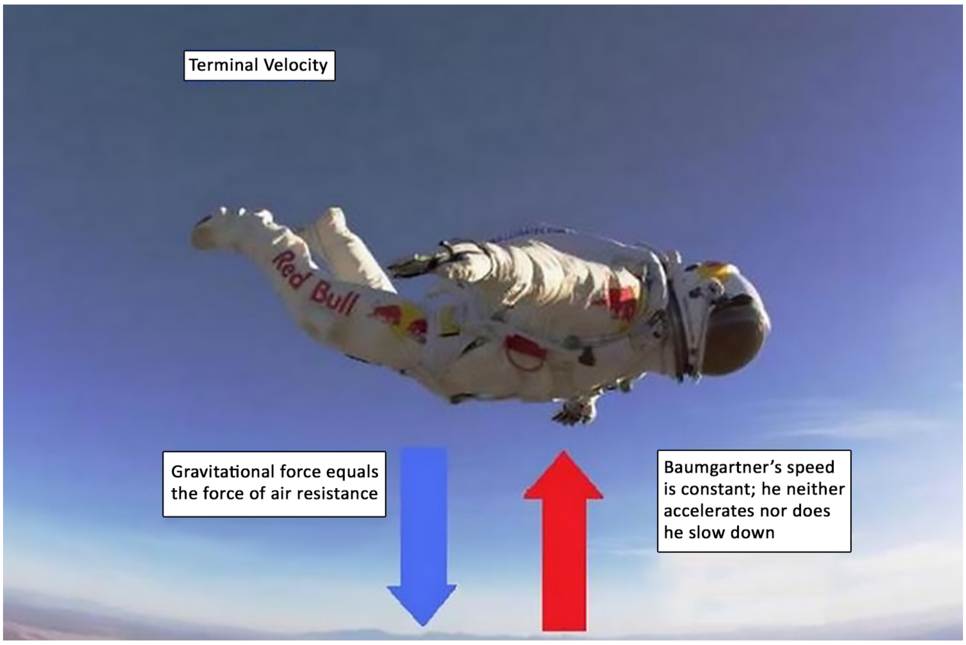

Figure 2 Balanced vertical forces on Felix Baumgartner at terminal *vertical* velocity.

Obviously, it would be too dangerous to land at his maximum speed! Therefore, a parachute was deployed at 2516 m. This increased the air resistance. The forces then became unbalanced. Baumgartner's speed then reduced until the forces were balanced again. At this stage, a lower (and much safer!) terminal velocity was reached (Figure 3). Remember the end of Video 1 where he appears to step calmly onto Earth?

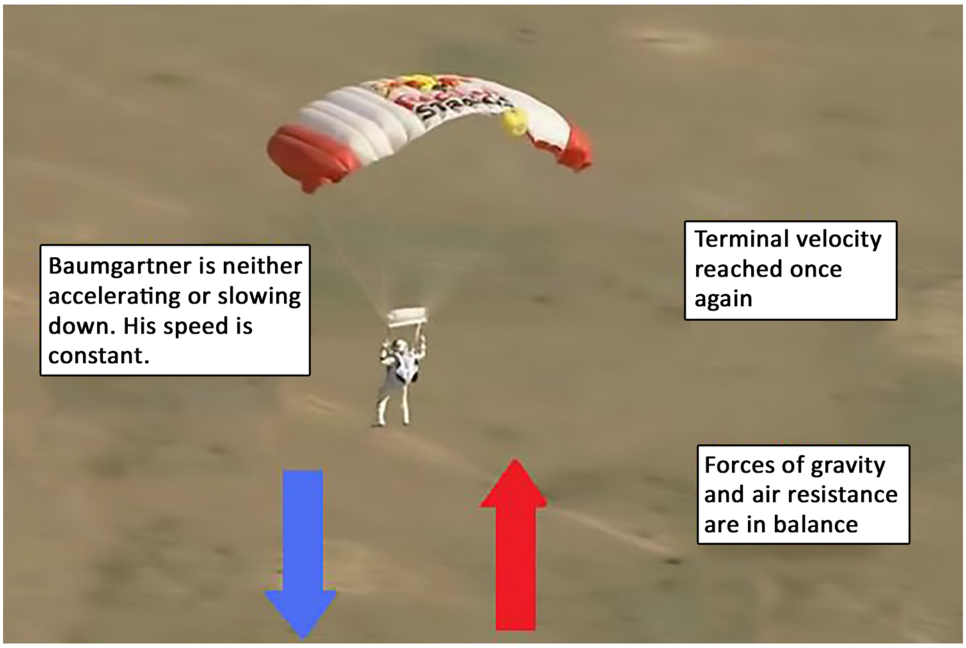

Figure 3 Balanced vertical forces on Felix Baumgartner after his parachute opened - terminal *vertical* velocity again reached.

During his freefall, Baumgartner was effectively in a microgravity environment. He was falling to Earth in the same way that the ISS and the Moon fall to Earth. Clearly, this is too dangerous (and expensive) to replicate for reliable scientific research, so instead drop towers are used, as you will see next.

2 Using drop towers to simulate microgravity

When objects are dropped from the top of drop towers, they achieve freefall as they drop. This briefly creates a microgravity environment (Figure 4).

Figure 4 The 140-metre drop tower in Bremen, Germany.

Listen to Audio 1 which describes drop towers and rollercoasters. A transcript is also provided if you would prefer to read it.

Audio content is not available in this format.
Audio 1 drop towers and rollercoasters

According to this *New Scientist* article (Cross, 1990), up to 10 seconds of a microgravity environment can be replicated in the Japan Microgravity Centre (JAMIC) (Figure 5).

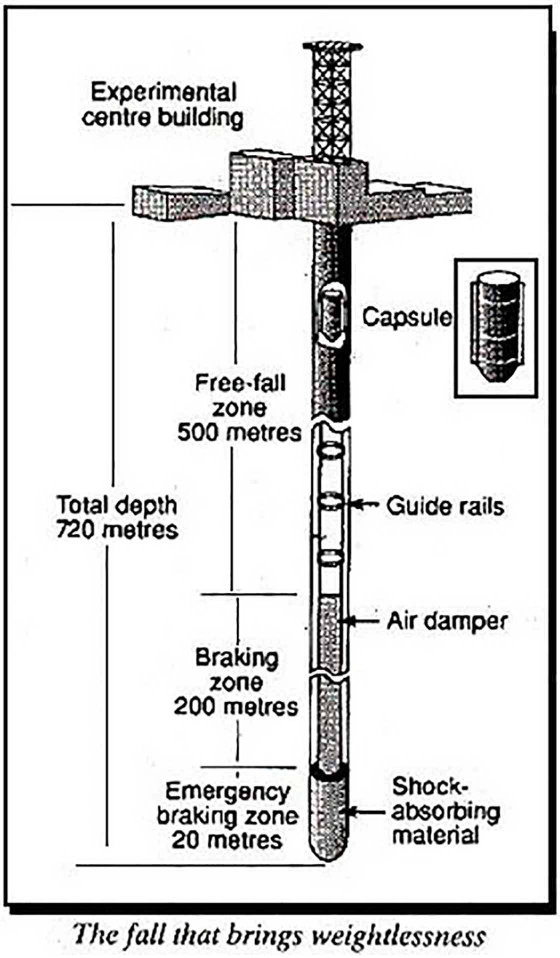

Figure 5 The Japan Microgravity Centre or JAMIC (Cross, 1990).

To test your understanding of freefall and drop towers you should now complete Activity 2.

Activity 2 Drop towers and freefall

Allow approximately 15 minutes

Choose the correct answers to the following questions.

1. The Bremen drop tower is 140 metres high and objects freefalls from top to bottom in 4.6 seconds. What is the average speed achieved by objects in this drop tower? (Hint: divide distance by time. Then round your final answer to 2 significant figures.)

- ○ 3.0 m/s
- ○ 300 m/s
- ○ 30 m/s
- ○ 0.30 m/s
- ○ 3000 m/s

Answer

Actually, because it just gets faster and faster, thinking of this as an average speed is not particularly helpful.

Interactive content is not available in this format.

3. JAMIC's 700-metre drop tower provides a 500-metre freefall distance in about 10 seconds. What is the average speed of an item when dropped into the JAMIC? (Hint: divide distance by time.)

- ○ 500 m/s
- ○ 7 m/s
- ○ 5 m/s
- ○ 50 m/s
- ○ 70 m/s

4. As Felix Baumgartner achieved about 370 m/s during his freefall, he was about ___ times faster in freefall than the average speed achieved by an item dropped in the Bremen drop tower (Question 1).

(Hint: divide Felix's rounded speed by the rounded speed achieved in the drop tower. Then round your answer to 2 significant figures.)

- ○ 25
- ○ 250
- ○ 2.5
- ○ 0.25
- ○ 0

Next, you will carry out your own experiment to calculate the acceleration of gravity on Earth.

3 Practical experiment 3

Practical experiment 3: Investigating gravity

Here you will time objects that fall under gravity to calculate the acceleration of gravity on Earth. This is often called 'little g' or *g*. This terminology is used to distinguish it from Newton's gravitational constant *G*, which, unsurprisingly, is called 'big G'. You met these terms in Section 5 of Week 1. First, watch Video 2.

Video content is not available in this format.
Video 2 Calculating gravity.

Now complete Table 1 using the following guidelines.

- Collect as many objects as you can with different sizes and masses (for example, balls)
- Measure the vertical distance *s* (in metres, m) from where you are going to drop your object to the ground
- Time the drop *t* (in seconds, s). Do this for all of your objects.
- Calculate the vertical distance doubled ($2 \times s$).
- Square the time (t^2).
- Finally, record your value of the doubled distance ($2 \times s$).

Take care. In the mathematics of motion it is quite common to use the letter *s* to denote distance. Watch out for also using the same letter as an abbreviation for seconds. When it is used for the unit of time, then it should be an upright symbol, s, if it means distance in an equation it will look like *s*. That means you have to be especially careful in handwriting!

Table 1 Results of Practical experiment 3

Object	Distance *s* / m	2 *s*	Time *t* / *s*	t^2

Table 2 shows the results taken from Video 2.

Table 2 The course team's results for Practical experiment 3

Ball	Distance *s* / m	2 *s*	Time *t* / s	t^2	$g = 2s / t^2$
1	0.50	1.0	0.32	0.10	9.8
2	0.50	1.0	0.32	0.10	9.8

The calculations from the results in Table 2 provide a final answer of 9.8 m/s^2 for 'little g'. You met the acceleration due to gravity in Week 1 where the value given was 9.81 m/s^2. So this experimental result is quite accurate!

Note that the two values taken from Video 2 are the same (to 2 significant figures). But what if the size of the balls was different? What about their masses? Do these factors affect the final calculations? What if you dropped a feather instead?

To help answer these questions, watch Video 3 which shows a hammer and a feather being dropped at the same time on the Moon's surface, then complete Activity 3.

Video content is not available in this format.
Video 3 Apollo 15 mission experiment on the Moon.

Activity 3 Effect of air resistance

Allow approximately 15 minutes

Choose the correct answers to the following questions.

1. If you drop a hammer and a feather together at the same time on Earth, what would you expect to happen?

- ○ The hammer and feather arrive on the ground at the same time.
- ○ The hammer arrives first.
- ○ The feather arrives first.
- ○ The hammer's speed is reduced more than the speed of the feather.
- ○ The feather's speed is greater than the hammer's speed.

2. What happens when a hammer and a feather are dropped together at the same time on the Moon?

- ○ The hammer and feather arrive on the ground at the same time.
- ○ The feather arrives first.

The hammer arrives first.

- ○ The hammer's speed is reduced more than the feather's speed.
- ○ The feather's speed is greater than the hammer's speed.

3. How do the conditions on the Moon differ from those on Earth?

- ○ They are the same.
- ○ There is no atmosphere on Earth.
- ○ The gravity on the Moon is stronger than the Earth's gravity.
- ○ The Earth's gravity is weaker than the Moon's gravity.
- ○ There is no atmosphere on the Moon.

You will now look at how planets are formed.

4 Forming planets: an introduction

Earlier this week you looked at drop towers on Earth. And in Section 1 of Week 1, you looked at parabolic flights in the 'vomit comet'.

It might surprise you to know that microgravity environments can also be used to model the formation of planets.

Knowing this and based on what you have learned previously you should now complete Activity 4.

Activity 4 How planets are formed

Allow approximately 15 minutes

Choose one answer for each of the following questions.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

When it comes to forming planets, our best guess is that smaller particles collide with each other. They then stick together and grow bigger and bigger.

Watch Video 4, a high-speed, high-resolution video, which shows some icy particles in a microgravity parabolic flight experiment. They are only a few millimetres in diameter and collide at low velocities. Then complete Activity 5.

Video content is not available in this format.

Video 4 Icy particles in a microgravity environment. The scale bar is about 0.1 mm. The image features one pair of particles projected towards each other from a pair of facing launch tubes a centimetre or so apart, seen from 2 angles simultaneously by careful positioning of a mirror. So it looks like we have an upper pair and a lower pair of tubes, but we are just seeing the same thing from two sides. From these images, the three-dimensional motion of the particles can be deduced.

Activity 5 Observing icy particles in microgravity

Allow approximately 15 minutes

Choose the correct options to complete the following statements.

Interactive content is not available in this format.

Answer

Don't forget that we have also got a mirror showing the same event from a different angle

2. What happens to the particles in the video?

- ○ They collide and merge on one occasion.
- ○ They collide and bounce off each other.
- ○ They completely miss each other.
- ○ Nothing.
- ○ They collide and merge on all of the occasions.

Video 4 shows that even small particles of a very small size (cm to mm) at low velocities don't easily stick together. This video became the subject of an OU paper published in 2014 called 'Collisions of small ice particles under microgravity conditions' (Hill, Heißelmann et al., 2014).

The following text is a summary of this paper. After you have read it, complete Activity 6.

> Planetesimals are thought to be formed from the solid material of a protoplanetary disk by a process of dust aggregation. It is not known how growth proceeds to kilometre sizes, but it has been proposed that water ice beyond the snowline might affect this process. To better understand collisional processes in protoplanetary discs leading to planet formation, the individual low-velocity collisions of small ice particles were investigated. The particles were collided under microgravity conditions on a parabolic flight campaign using a purpose-built, cryogenically cooled experimental set-up. The set-up was capable of colliding pairs of small ice particles (between 4.7 and 10.8 mm in diameter) together at relative collision velocities of between 0.27 m/s and 0.51 m/s at temperatures between 131 K and 160 K. Two types of ice particle were used: ice spheres and irregularly shaped ice fragments.
>
> Bouncing was observed in the majority of cases with a few cases of fragmentation. Coefficients of restitution were evenly spread between 0.08 and 0.65 with an average value of 0.36, leading to a minimum of 58% of translational energy being lost in the collision. The range of coefficients of restitution is attributed to the surface roughness of the particles used in the study. Analysis of particle rotation shows that up to 17% of the energy of the particles before the collision was converted into rotational energy. Temperature did not affect the coefficients of restitution over the range studied.
>
> (Hill et al., 2014)

Activity 6 Collisions of small ice particles in microgravity

Allow approximately 15 minutes

Based on the summary of the paper on the 'Collisions of small ice particles under microgravity conditions', complete the following statements.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Next, you will look at how models can be used to change parameters (or variables) in conjunction with experimental data.

5 Forming planets: using models

In the previous section, you met the 'coefficient of restitution', 'translational energy' (or kinetic energy) and 'rotational energy'.

The 'coefficient of restitution' can take values between 0 and 1 where:

- **0** means a **perfectly inelastic** collision where the particles have no relative velocity after the collision and they stick together
- **1** means a **perfectly elastic** collision, where the particles move away from each other after the collision as fast as they were moving towards each other before it.

Equation 1 shows the ratio of final relative velocity to initial relative velocity as the coefficient of restitution.

Equation 1

In this case, highly **inelastic** collisions are key to understanding planet formation. As you saw in Video 4, these collisions show that the particles behave more like crashing cars than snooker balls!

Now look at Table 3 which lists the data obtained from a collision experiment (precise to up to 6 significant figures).

Table 3 Data obtained from a collision experiment

Velocity before collision			Coefficient of restitution		
0.394340	+/-	0.005249	0.312340	+/-	0.007026
0.404975	+/-	0.005254	0.430552	+/-	0.008426
0.417616	+/-	0.005249	0.472011	+/-	0.010388
0.418179	+/-	0.006828	0.527789	+/-	0.013723
0.335328	+/-	0.004141	0.354709	+/-	0.006535
0.418685	+/-	0.004471	0.870707	+/-	0.012637

You can see that, to 2 significant figures, the velocities before the collisions range between 0.34 m/s and 0.42 m/s.

The final velocities achieved in the experiment gave the results for the coefficients of restitution by using Equation 1 and the data in the experiment. The coefficients of restitution have therefore been calculated from the values of the final velocities and, to 2 significant figures, they range between 0.31 and 0.87. Figure 6 shows the data from Table 3 as a graph.

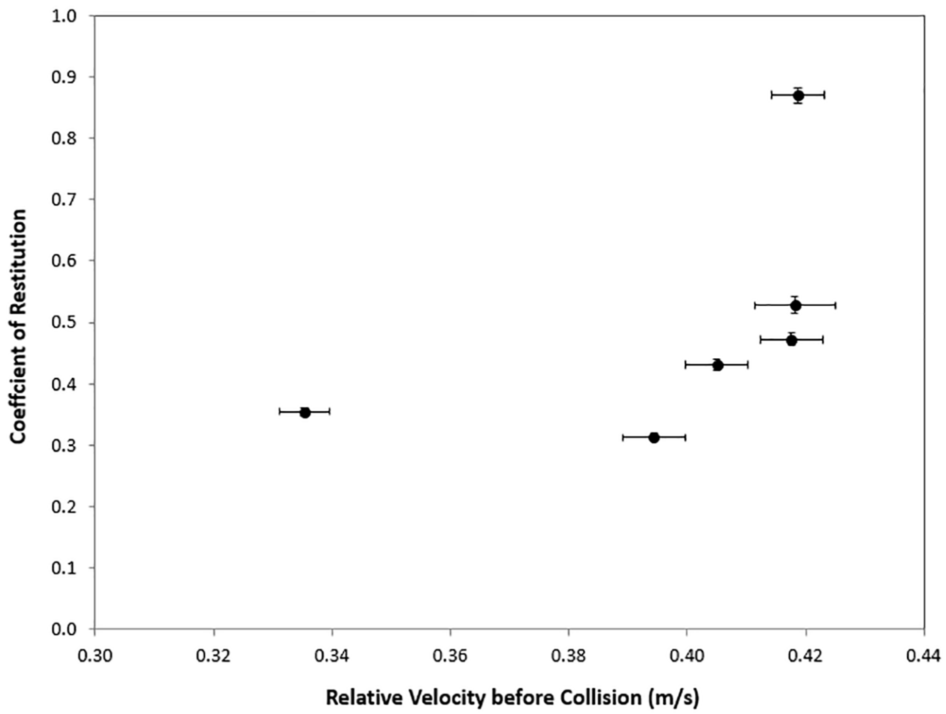

Figure 6 Graph of the coefficient of restitution against the relative velocity before collision.

Note that the horizontal lines are the 'error bars'. These correspond to the +/- values in Table 3.

- Can you deduce a relationship between the relative velocity before collision and the coefficient of restitution from the graph?
- It seems that, for lower values of relative velocity greater than the collision (0.34 m/s), the coefficient of restitution also takes lower values (0.3).

  This may be constant for values of relative velocity between the collision between 0.34 m/s and 0.40 m/s.

  However, as the relative velocity values after the collision increase beyond 0.40 m/s, the values of the coefficient of restitution increase quickly up to 0.90.

Now complete Activity 7.

Activity 7 Calculating the final velocities of the particles

Allow approximately 10 minutes

Calculate the values of the final velocities to 3 significant figures in the table below. (Hint: look at Equation 1 and rearrange it in terms of the final velocity.)

Table 4 Final velocities

Initial velocity (m/s)	Coefficient of restitution	Final velocity (m/s)
0.394	0.312	*Provide your answer...*
0.405	0.431	*Provide your answer...*

0.418	0.472	*Provide your answer...*
0.418	0.528	*Provide your answer...*
0.335	0.355	*Provide your answer...*
0.419	0.871	*Provide your answer...*

Answer

Table 4 Final velocities completed

Initial velocity (m/s)	Coefficient of restitution	Final velocity (m/s)
0.394	0.312	0.123
0.405	0.431	0.174
0.418	0.472	0.197
0.418	0.528	0.221
0.335	0.355	0.119
0.419	0.871	0.365

You will have found that the final velocity of the colliding objects is less than the initial velocity. The coefficient of restitution is also greater than zero which means that these particles don't stick together.

Next you will complete the end-of-week quiz.

6 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 6 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

7 Summary

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have looked at terminal velocity in the context of a microgravity environment with particular emphasis on Felix Baumgartner's skyfall and drop towers.
- You have considered how scientific research is being carried out on the model of planet formations using the coefficient of restitution.
- You have calculated values of speed, given distance and time data.

Next week you will look at the arguments for and against space exploration. Specifically you will look at its benefits and disadvantages and then consider whether there is such a thing as 'bad science'.

You can now go to Week 7.

Week 7 Space exploration and science

Introduction

Do we need space exploration? And have your views on this changed since starting this course?

You are probably already aware that space exploration costs a lot of money. But how much does the ISS cost? And how much does research in space cost? There have to be justifications, with arguments for and against this cost, so that informed decisions can be made.

This week, you will consider the following questions about space exploration.

- How do the costs compare with national budgets?
- Can you trust a reliable estimate of how much it costs per person on Earth?
- What does such research do for you personally?
- Does space research help or hinder social issues and problems?

You will then consider whether science can be divided into ‘good’ and ‘bad’ science. Can the scientific method be compromised or manipulated for a hidden agenda?

By the end of this week, you should be able to:

- compare the true cost of space research with other expenditure
- understand why it is important to continue to ask moral questions about scientific research
- ask questions that can be answered to support or refute a hypothesis and identify ‘good’ and ‘bad’ science.

1 How much does the ISS cost?

Recall Video 2 in Week 4 which stated that the ISS alone had cost between US$140 and 160 billion!

Figure 1 shows the cost history of the ISS for the period between the financial years (FY) 1995 and 2002. Note that 2002 has two cost elements – 'assembly complete' and 'core complete'. Please ignore the last column for 'core complete' as these values are taken forward into 2004 and 2006.

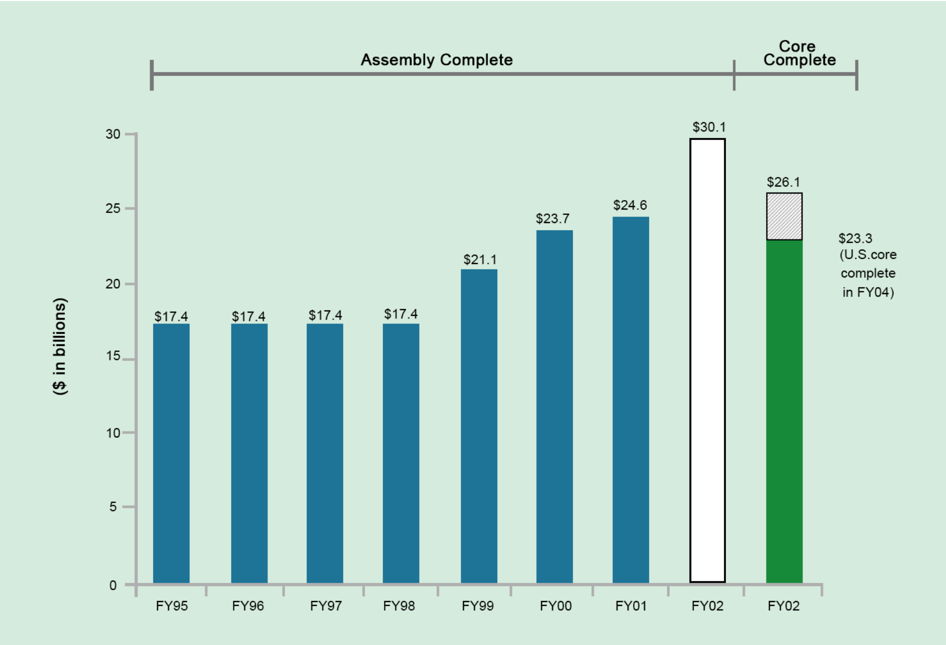

Figure 1 Cost history of the ISS.

Now use Figure 1 to complete Activity 1.

Activity 1 The cost history of the ISS

Allow approximately 10 minutes

Choose the correct answer to each of the following questions.

1. Which year was the most expensive?

- ○ 1995
- ○ 1999
- ○ 2000
- ○ 2001
- ○ 2002

2. What was the total cost in billion dollars between 1995 and 2002?

- ○ US$145.2 billion
- ○ US$169.1 billion
- ○ US$185.2 billion
- ○ US$205.2 billion
- ○ US$295.2 billion

3. What was the average cost between 1995 and 2002? (Hint: divide the total cost in question 2 by the number of years.)

- ○ US$19.14 billion per year
- ○ US$20.14 billion per year
- ○ US$21.14 billion per year
- ○ US$22.14 billion per year
- ○ US$23.14 billion per year

Now you will consider how much space exploration costs individual space companies, notably NASA.

2 How much does space exploration cost NASA?

Obviously, there is more to spending in space than the ISS. Figure 2 shows the costs to NASA of spending on space exploration for each year from the financial year (FY) 2004 up to the financial year (FY) 2020, known as 'Obama's NASA dilemma' for the period 2009 and beyond.

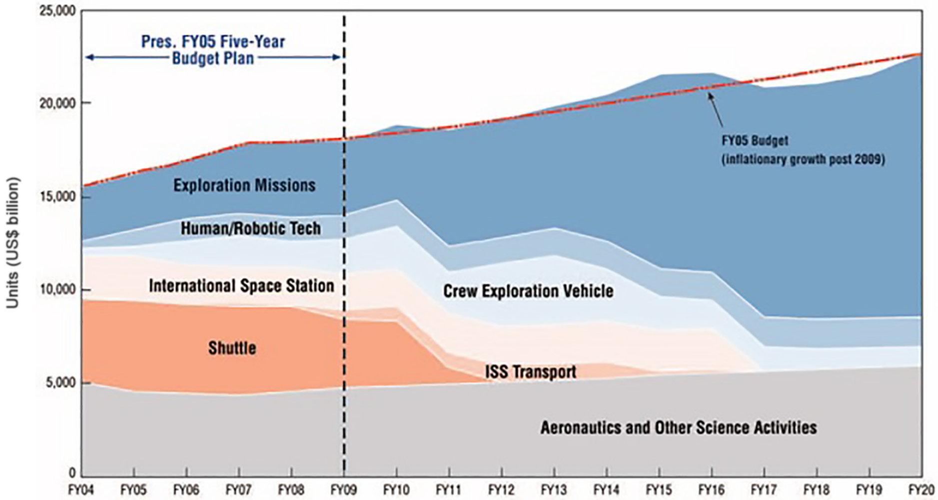

Figure 2 The cost of space exploration

Now use Figure 2 to complete Activity 2.

Activity 2 The cost of space exploration to NASA

Allow approximately 10 minutes

Choose the correct answer to each of the following questions.

1. By 2020, which aspect is likely to reach zero cost?

○ aeronautics and other science activities
○ exploration missions
○ crew exploration vehicle
○ human/robotic technology
○ shuttle

2. By 2020, which aspect is likely to achieve the greatest investment?

○ aeronautics and other science activities
○ exploration missions
○ crew exploration vehicle
○ human/robotic technology
○ shuttle

3. By which year was spending on the ISS anticipated to be almost zero?

○ 2009

- ○ 2012
- ○ 2015
- ○ 2017
- ○ 2020

You will now look at the cost of space exploration for a country, in this case the USA.

3 How much does space exploration cost the USA?

According to the website ‘National Priorities’, in 2015, the US President proposed the spending plan shown in Figure 3.

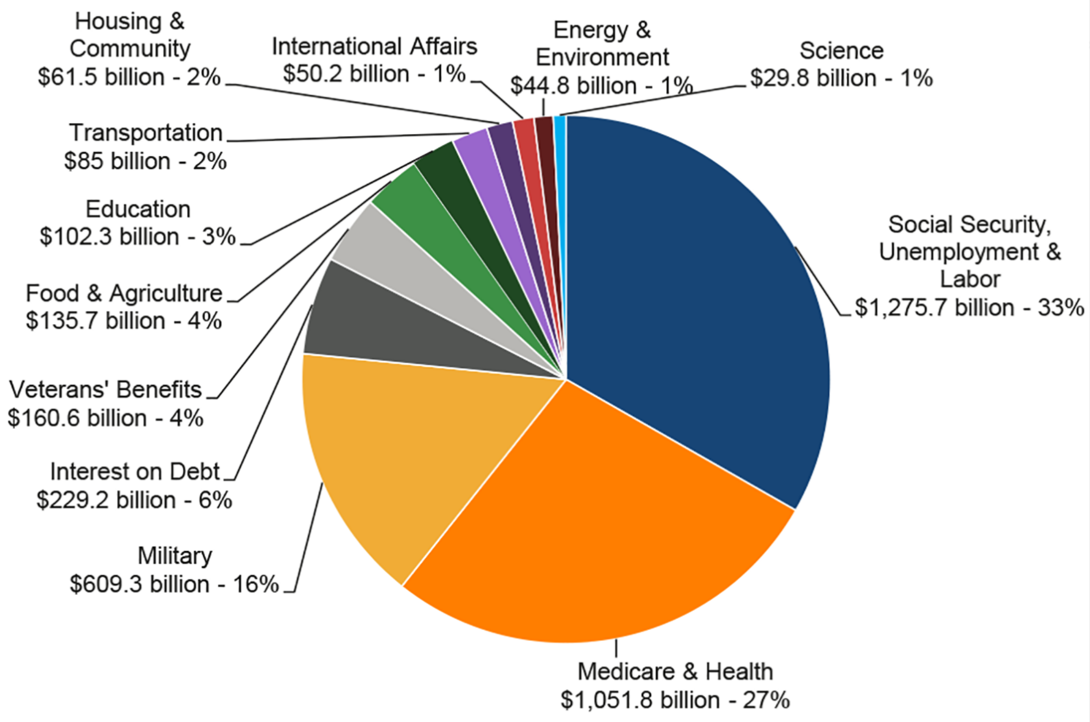

Figure 3 Pie chart of the distribution of US expenditure in 2015.

Using the data shown in Figure 3, complete Activity 3.

Activity 3 US national spending in 2015

Allow approximately 10 minutes

Choose the correct answer to each of the following questions.

1. Which department has the largest allocation of funds?

○ interest on debt

○ science

○ social security, unemployment and labour

○ military

○ medicare and health

2. What proportion of the budget is allocated to science?

○ 1%

○ 2%

○ 3%

- ○ 4%
- ○ 6%

3. How much money in total is allocated to energy and environment, and science?

- ○ US$15 billion
- ○ US$29.8 billion
- ○ US$44.8 billion
- ○ US$74.6 billion
- ○ US$78.6 billion

The exact figures are unavailable, but this gives an approximate order of magnitude. You will now look at how much space exploration costs the whole world!

4 How much do space missions cost the world?

How much do the space missions cost?

In Figure 4, the missions from *Voyager 1* to *Dawn* are compared with the historical deployment of US troops in Iraq. This is the global cost of space missions after all so these global costs can be compared with the US deployment to Iraq as a direct comparison. Use this information to complete Activity 4.

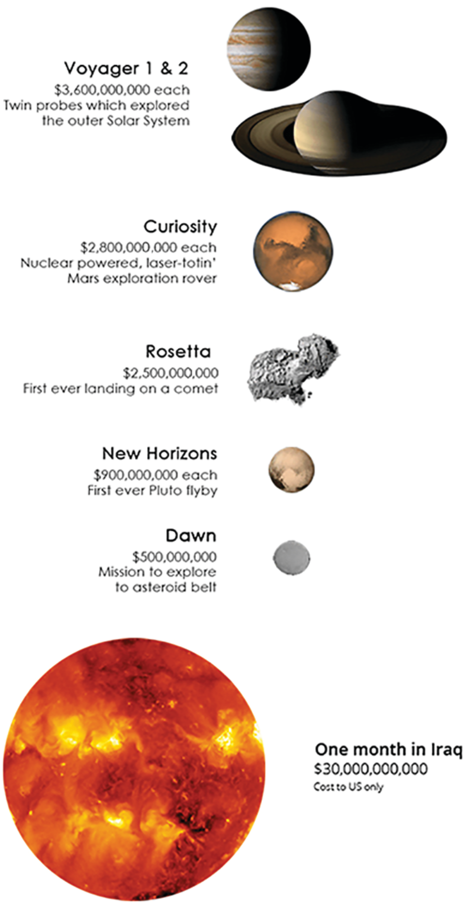

Figure 4 Relative costs per space mission.

Activity 4 The cost of space missions

Allow approximately 10 minutes

Choose the correct answer to the following questions.

1. What is the total cost of all of the space missions shown in Figure 4?

- US$10.3 billion
- US$900 billion
- US$2500 billion

- US$3600 billion
- US$10 300 billion

2. Given that there are about 8 billion people on Earth, how much would this cost each person? (Hint: round your final answer to 2 significant figures.)

- US$1.30
- US$1.40
- US$13.0
- US$14.0
- US$130

3. As a proportion of one month's deployment of US troops to Iraq, how much did the Rosetta mission cost?

- 0.08%
- 8%
- 18%
- 28%
- 80%

You've seen how much the Rosetta mission cost. The Open University was heavily involved in this mission which provided a significant amount of scientific data. Now watch Video 1 which briefly describes the Rosetta mission to the comet 67p.

Video content is not available in this format.

Video 1 The Rosetta mission.

You will now look at the potential impact of space research on social issues.

5 Space research and its impact on social issues and problems

Does space research help or hinder social issues and problems? Table 1 shows the advantages and disadvantages.

Table 1 Advantages and disadvantages of space exploration

Advantages	Disadvantages
Scientific discoveries	Research and development costs
Positive life changes to humankind	Not reducing poverty in underdeveloped countries
Finding essential minerals in space	Space travelling costs
Finding other living species in space	Risk to astronauts
Challenge of adventure	

(APECS, 2014)

What does space research do for you back on Earth? Recall Week 3 where you looked at the quantum devices in your household and the importance of atomic clocks and internet security (encryption). Can you imagine a life without your smartphone, Smart TV, Blu-ray player, CDs and DVDs, GPS (SatNav) in your car, and secure banking transactions? These are all as a result of space research, And all for the cost of a few dollars per person on Earth! The cost of space exploration could therefore be considered as reasonable in comparison.

You will now look at whether science can be separated into ‘good science’ and ‘bad science’.

6 Is there a difference between ‘good science’ and ‘bad science’?

To answer this question, you first need to consider the scientific method. This approach is shown in Figure 5. You start at number one by defining the question. Then you go through options two to seven clockwise. If your observations don’t support your hypothesis then you leave at stage six and return to the experimental stage. Even if your hypothesis is supported by your observations, a good scientist will continue to seek further opportunities to disprove the hypothesis.

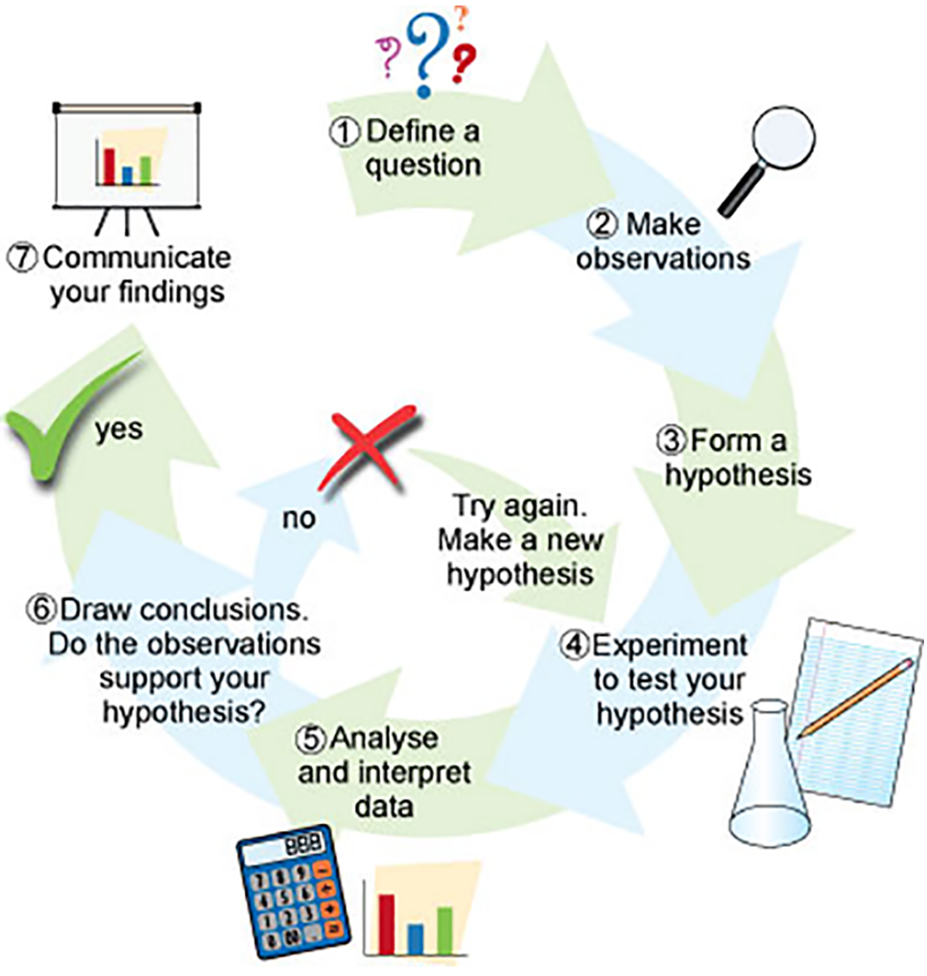

Figure 5 The scientific method.

Table 2 summarises what qualifies as ‘good science’ and ‘bad science’.

Table 2 Good and bad science

Good science	Bad science
Asking the right questions	Asking the wrong kind of question
	Too narrow a question
	Too broad a question
	Vague terminology

	Only looking where you predict you will see something
	Influencing the results of an experiment
Clarifying risks	
Complying with ethical standards	Ignoring ethical guidelines
Complying with moral standards	Uninformed consent
Using volunteers for clinical trials	Not allowing participants to withdraw from a clinical trial

So ‘good science’ contrasts to ‘bad science’ by approaching a problem with an open mind and ensuring that established standards are complied with. You should now complete the end-of-week quiz.

7 This week's quiz

Check what you've learned this week by taking the end-of-week quiz.

Week 7 practice quiz

Open the quiz in a new window or tab (by holding ctrl [or cmd on a Mac] when you click the link), then return here when you have done it.

8 Summary

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have considered the cost of space research for NASA, the US and the world.
- You have compared these costs with other expenditures.
- You have considered ‘good’ and ‘bad’ science approaches.

Next week, you will look at the opportunities for microgravity research in the future, as well as the opportunities for you to study so that you can be part of the space-enabled future. You will also see if you have what it takes to become an astronaut.

Week 8 is the final week of this course. At the end, you will have the opportunity to take the Week 8 compulsory badge quiz and, if you pass it, receive your well-earned badge!

You can now go to Week 8.

Week 8 To the ISS, Moon and Mars!

Introduction

This is the final week of the Microgravity badged open course! Well done for getting this far, you are now on the last lap. This week you will look at the future opportunities for microgravity research and perhaps your own path to be part of this future. You will also explore whether you could be an astronaut. Have you ever wondered what skills a potential astronaut needs and the training involved?

At the end of this week is the Week 8 compulsory badge quiz which, if you pass, will mean you can proudly display your well-earned course badge!

Video content is not available in this format.

Video 1 Introduction to Week 8

By the end of this week, you should be able to:

- consider the challenges in training to become an astronaut
- consider the future of space research
- understand current microgravity research and consider future areas of microgravity research
- successfully complete the end-of-course quiz.

1 The astronaut challenge

Can you see yourself as an astronaut? Do you think you have the skills?

First, are you a US citizen? If not, you can't apply to join NASA. However, if you are a European citizen, the European Space Agency (ESA) may be an option.

According to the NASA astronaut candidate programme, you need at least an undergraduate degree in engineering, biological sciences, physical sciences, computer sciences or mathematics, along with at least three years' experience.

You then need to pass the physical test set. You also need to meet the physical size requirements for wearing a space suit. If successful, you would then need to take part in a two-year long training and evaluation period at the Johnson Space Center in Houston, Texas. You would be expected to pass a swimming test and become SCUBA-qualified.

Finally, you would also need to pass the following training courses.

1. ISS systems
2. EVA skills
3. Robotics skills
4. Russian language
5. Aircraft flight readiness

(NASA, n.d.)

In order to replicate the effects of larger g-forces that astronauts experience, training is carried out on a **centrifuge** (Figure 1). This is described as a 'machine with a rapidly rotating container that applies centrifugal force to its contents' (Oxford dictionaries, 2018).

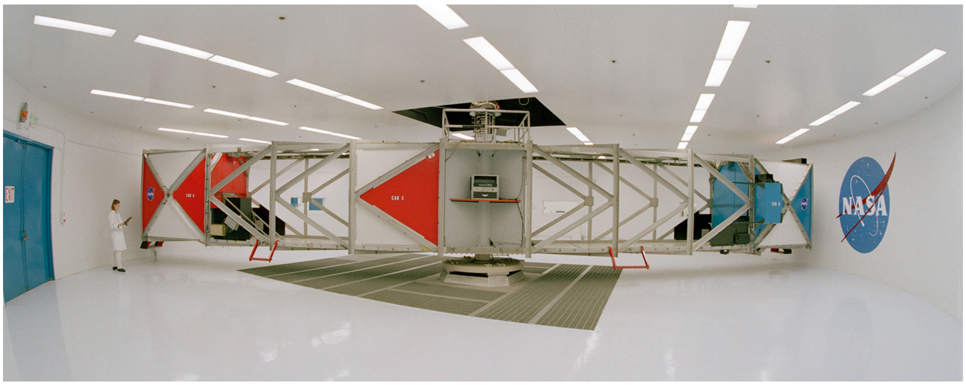

Figure 1 A NASA centrifuge used for training astronauts.

Now watch Video 2 which shows NASA g-force training where astronauts are rotated at increasing speeds (and increasing values of *g,* up to 7*g* – seven times normal gravity).

Video content is not available in this format.
Video 2 NASA astronauts in *g*-force training.

Next, you will see if you have what it takes to become an astronaut.

2 Astronauts: do you have what it takes?

You might also want to watch the six episodes of ‘Astronauts: do you have what it takes?’. There is more information on the BBC website. Read the synopsis of the TV programme available on the link above and then complete Activity 1.

Astronauts: Do You Have What It Takes?

Millions dream of being an astronaut, but how many of us have what it takes?

Astronaut and former Commander of the International Space Station, Chris Hadfield, former NASA medical researcher Dr Kevin Fong, and psychologist Dr Iya Whiteley, have chosen 12 exceptional applicants from thousands. From these 12, just one candidate will ultimately be selected as the winner. The person who impresses the most will receive the ultimate reference: Chris’s backing for their application when the space agencies next take on recruits.

Ep 1/6

Sunday 20 August
9.00pm-10.00pm
BBC TWO

NEW

Figure 2 Do you have what it takes?

Activity 1 What do you need to do for Astronaut selection?

Allow approximately 15 minutes

Based on the information given in the ‘Astronauts: do you have what it takes?’ synopsis, answer the following questions.

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Interactive content is not available in this format.

Interactive content is not available in this format.

Now take this online test, courtesy of the BBC's iWonder (Figure 3), to see whether you have what it takes to be an astronaut.

Figure 3 Do you have what it takes to be an astronaut?

How did you get on? Are you astronaut material? Beyond working as an astronaut on the Space Shuttle, there are lots of other opportunities to work with the ISS with a view to landing on Mars.

You will now look at the future of space research.

3 Human exploration

Do you remember in Week 4 that you met the concept of scientific research where scientists rarely work alone in their own fields of research. Video 3 looks at the future of human space exploration, and demonstrates this. After watching the video, complete Activity 2.

Watch Video 3, which is about the future of human space exploration and then complete Activity 2.

Video content is not available in this format.

Video 3 The space shuttle, ISS, NASA and Mars.

At the end of Video 3, the Commander of the last Space Shuttle mission in 2011 stated that 'We're not ending the journey today; we're completing a chapter of a journey that will never end' (Video 2).

Activity 2 The future of human space exploration

Allow approximately 15 minutes

Choose the correct option to complete the following statements.

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Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

As an example of private investment into low Earth-orbit rockets, first look at Figure 4 (this is Figure 8 from Week 1).

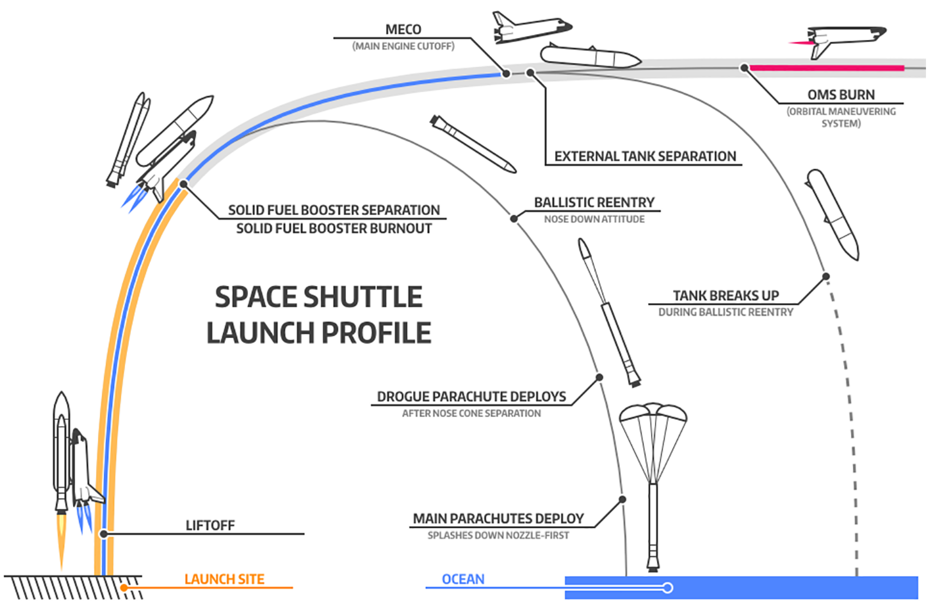

Figure 4 Space Shuttle launch profile.

Now look at Figure 5, which is the launch profile of the SpaceX Falcon 9. Having compared both figures, now complete Activity 3.

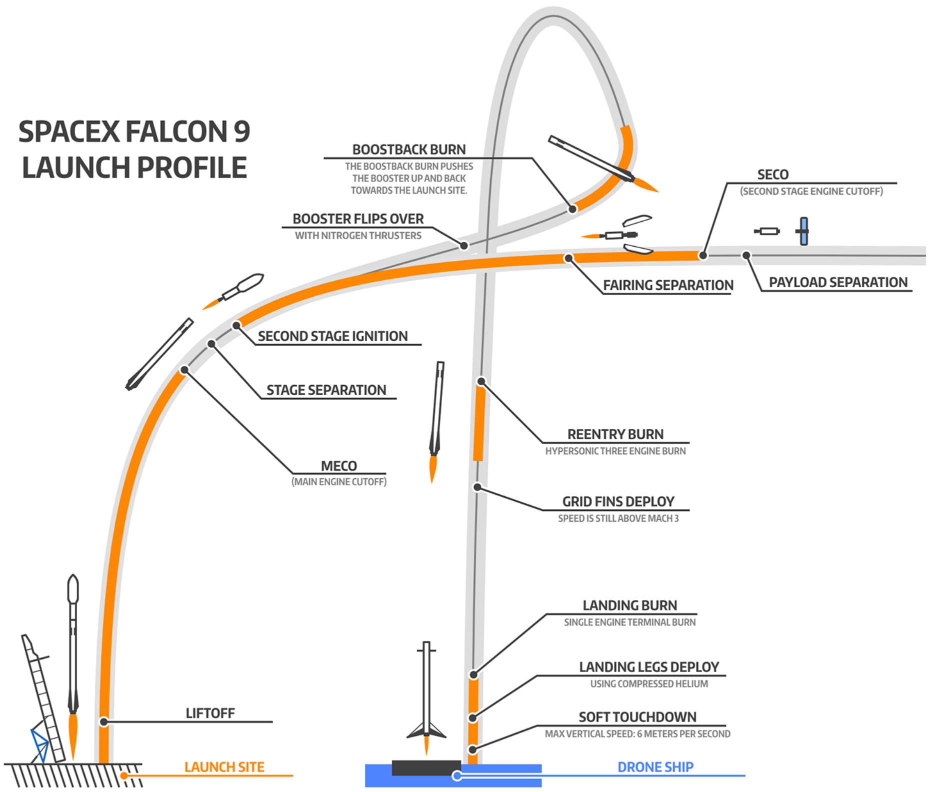

Figure 5 SpaceX Falcon 9 launch profile.

Activity 3 Comparing launch profiles of the Space Shuttle and SpaceX Falcon 9

Allow approximately 15 minutes

Choose the correct answer from the options given below for each of the following questions.

1. Which launch profile has the earlier main engine cut-off?

○ Space Shuttle

○ SpaceX Falcon 9

2. In which launch profile does one of the fuel tanks break up on re-entry?

○ Space Shuttle

○ SpaceX Falcon 9

3. In which launch profile does the booster land on a drone ship and not in the ocean?

○ Space Shuttle

○ SpaceX Falcon 9

Interactive content is not available in this format.

You will now look at how research in microgravity environments is currently being conducted, and how this is expected to progress in the future.

4 Current and future microgravity research

You should now watch Video 4, which is an interview with two research scientists at The Open University, both working in their respective fields in space engineering. After watching the video, complete Activity 4.

Video content is not available in this format.
Video 4 Interviews with two space research scientists.

Activity 4 The future of microgravity research

Allow approximately 15 minutes

Choose the correct option for the following questions and statements.

1. What does ISRU stand for?

- ○ Industrial Statistics Research Unit
- ○ International Science and Research University
- ○ Iranian Silk Road Ultramarathon
- ○ In situ resource utilisation
- ○ International Society of Reading University

2. What is both a primary resource to support humans and also a component of rocket fuel?

- ○ Carbon
- ○ Water
- ○ Oxygen
- ○ Hydrogen
- ○ Hydrocarbons

Interactive content is not available in this format.

Interactive content is not available in this format.

Interactive content is not available in this format.

Some of this content forms part of the Week 8 compulsory badge quiz which you should complete next.

5 This week's quiz

Now it's time to complete the Week 8 compulsory badge quiz. It is similar to previous quizzes, but this time instead of answering five questions there will be 15.

Week 8 compulsory badge quiz

Remember, this quiz counts towards your badge. If you're not successful the first time, you can attempt the quiz again in 24 hours.

Open the quiz in a new window or tab, then return here when you have done it.

6 Summary

As you can see, there are lots of exciting potential fields of future research in space!

Now is a good time to revisit the learning outcomes for this week. Here is a summary of what you have covered.

- You have considered the challenges in training to become an astronaut
- You have considered the future of space research
- You have looked at the current microgravity research and considered future areas of microgravity research.

Video content is not available in this format.
Video 5 Conclusion of Week 8

You also looked at the almost overwhelming criteria needed to become a NASA astronaut. This course, however, didn't cover all the other 'ground-based' careers which you could explore if you were interested in a career in space research, for example drop-tower experiments, research and development. If, after this course, you are interested in finding out more, and want to consider pursuing a degree in science, The Open University has a range of courses which can help you to achieve this.

- S111 *Question in Science*
- SM123 *Physics and Space*
- S217 *Physics from classical to quantum*
- S282 *Astronomy and Cosmology*
- S283 *Planetary science and the search for life*

Tell us what you think

Now you've come to the end of the course, we would appreciate a few minutes of your time to complete this short end-of-course survey (you may have already completed this survey at the end of Week 4). We'd like to find out a bit about your experience of studying the course and what you plan to do next. We will use this information to provide better online experiences for all our learners and to share our findings with others. Participation will be completely confidential and we will not pass on your details to others.

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