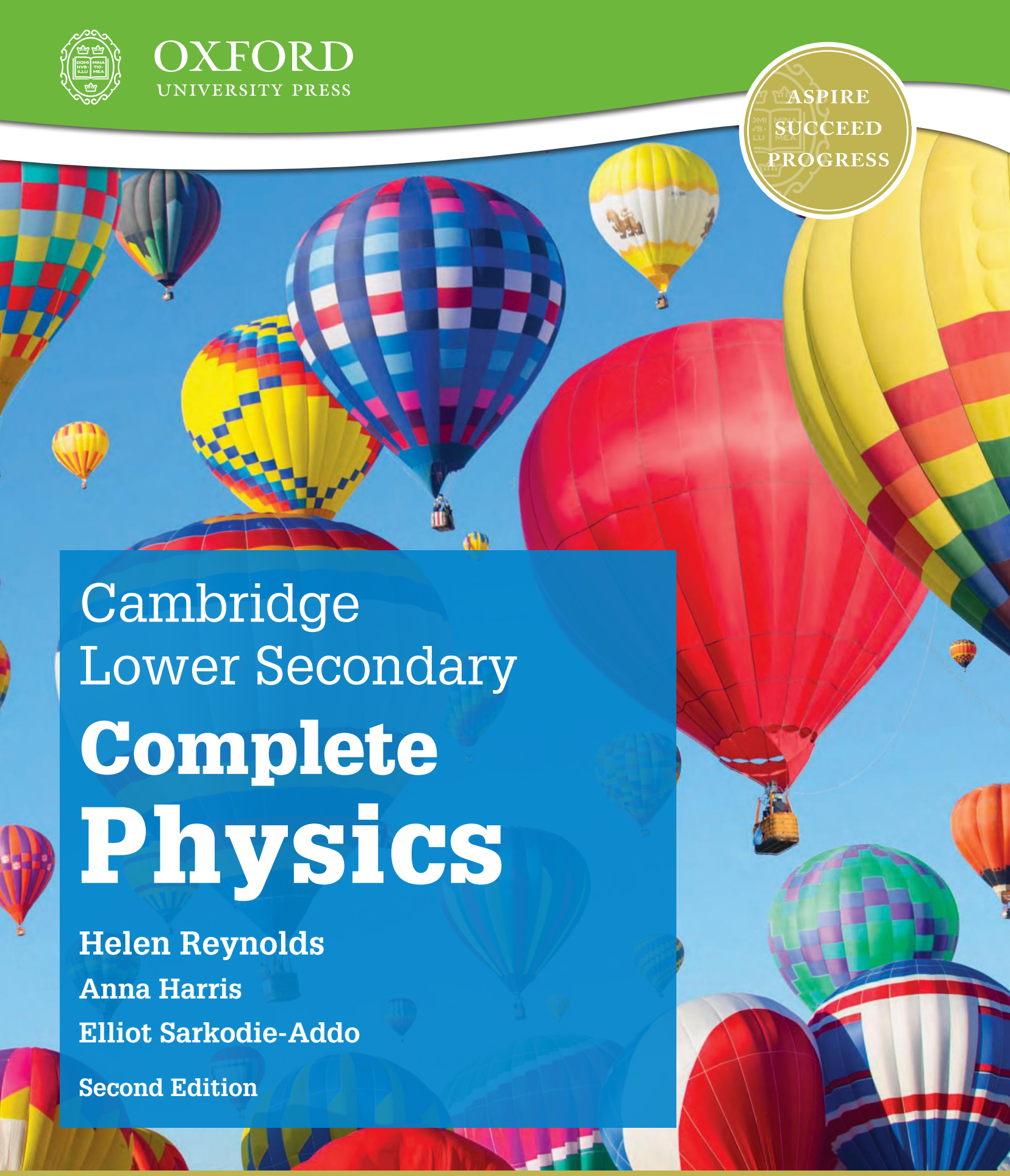


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Cambridge Lower Secondary

Complete Physics

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Second Edition

Oxford excellence for Cambridge Lower Secondary

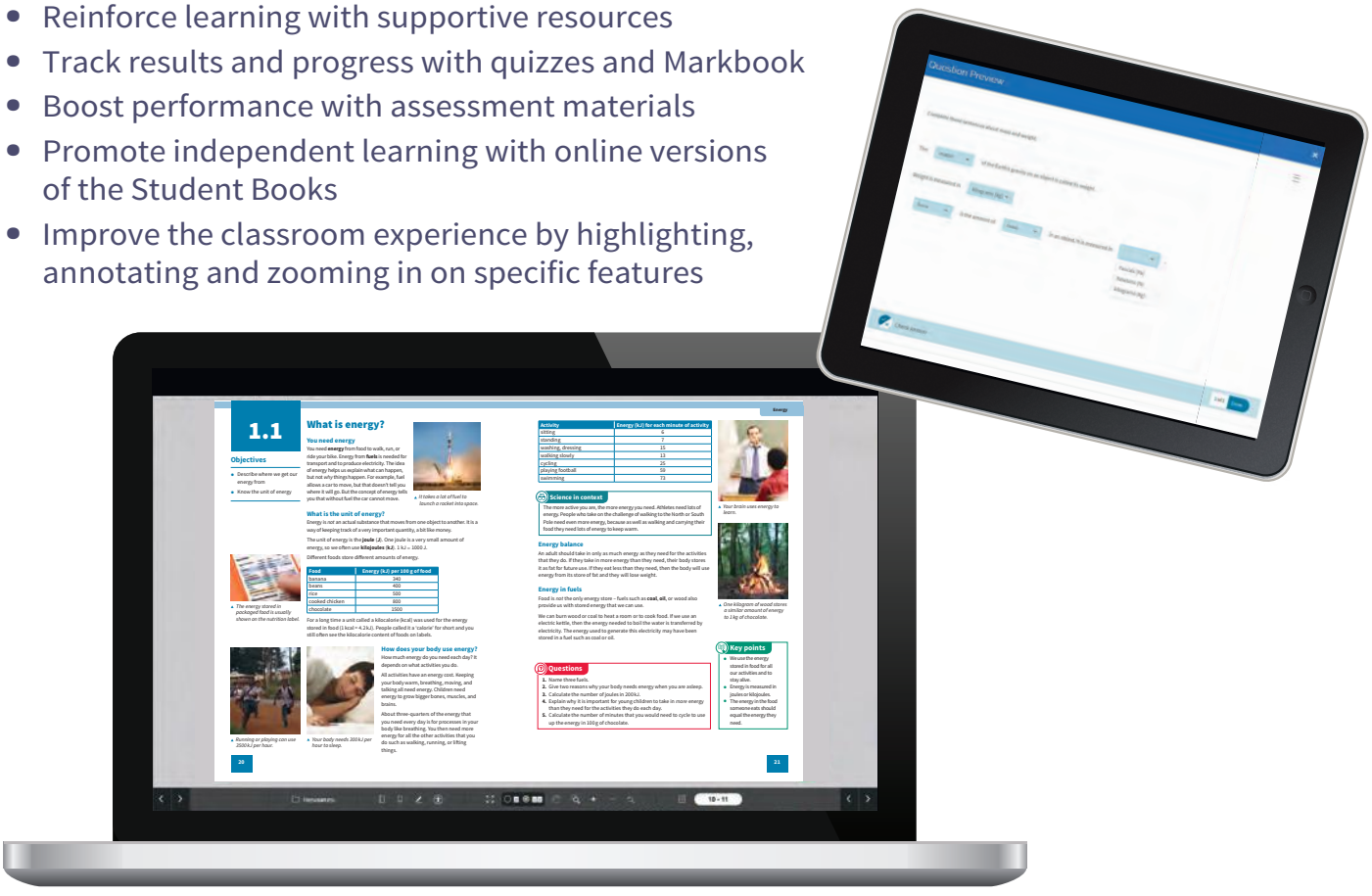
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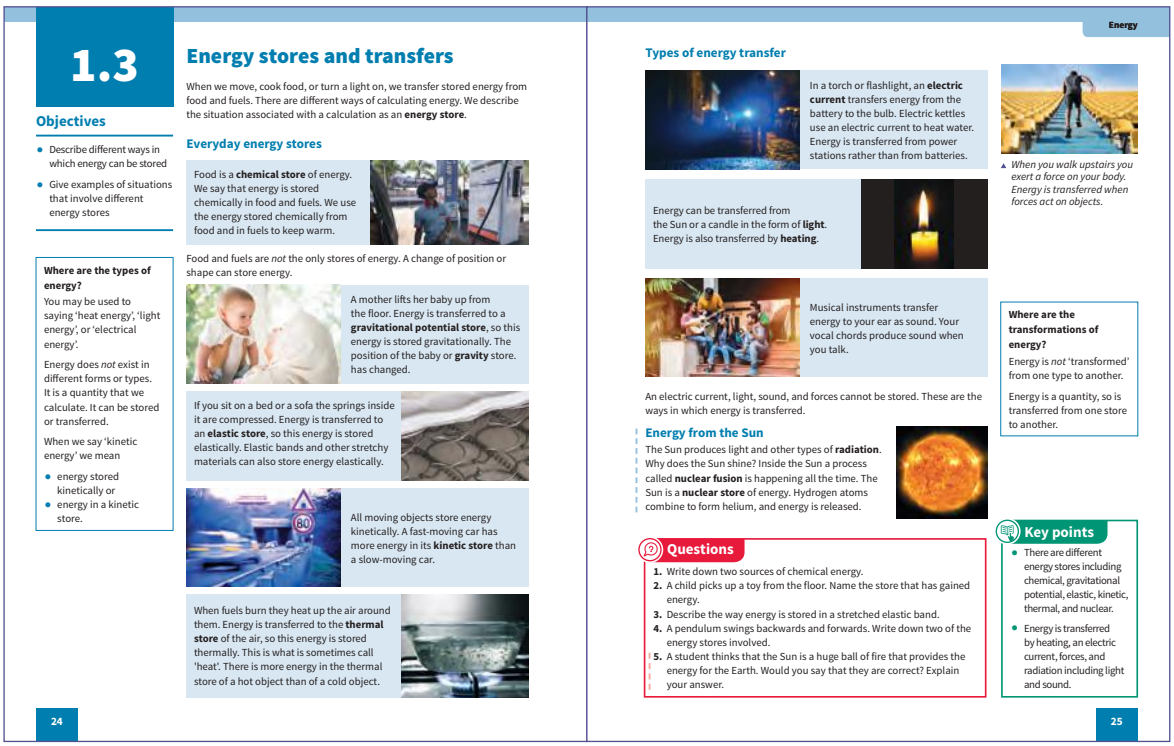
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Introduction

How to use your Student Book

Welcome to your Cambridge Lower Secondary Complete Physics Student Book. This book has been written to help you study Physics at all three stages of the Cambridge Lower Secondary Science curriculum framework.

Most of the units in this book work like this:



1.3

Energy stores and transfers

When we move, cook food, or turn a light on, we transfer stored energy from food and fuels. There are different ways of calculating energy. We describe the situation associated with a calculation as an **energy store**.

Objectives

- Describe different ways in which energy can be stored
- Give examples of situations that involve different energy stores

Everyday energy stores

Food is a **chemical store** of energy. We say that energy is stored chemically in food and fuels. We use the energy stored chemically from food and in fuels to keep warm.

Food and fuels are *not* the only stores of energy. A change of position or shape can store energy.

A mother lifts her baby up from the floor. Energy is transferred to a **gravitational potential store**, so this energy is stored gravitationally. The position of the baby or **gravity** store has changed.

If you sit on a bed or a sofa the springs inside it are compressed. Energy is transferred to an **elastic store**, so this energy is stored elastically. Elastic bands and other stretchy materials can also store energy elastically.

All moving objects store energy kinetically. A fast-moving car has more energy in its **kinetic store** than a slow-moving car.

When fuels burn they heat up the air around them. Energy is transferred to the **thermal store** of the air, so this energy is stored thermally. This is what is sometimes call 'heat'. There is more energy in the thermal store of a hot object than of a cold object.

Where are the types of energy?

You may be used to saying 'heat energy', 'light energy', or 'electrical energy'.

Energy does *not* exist in different forms or types. It is a quantity that we calculate. It can be stored or transferred.

When we say 'kinetic energy' we mean

- energy stored kinetically or
- energy in a kinetic store.

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Energy

Types of energy transfer

In a torch or flashlight, an **electric current** transfers energy from the battery to the bulb. Electric kettles use an electric current to heat water. Energy is transferred from power stations rather than from batteries.

Energy can be transferred from the Sun or a candle in the form of **light**. Energy is also transferred by **heating**.

Musical instruments transfer energy to your ear as sound. Your vocal chords produce sound when you talk.

An electric current, light, sound, and forces cannot be stored. These are the ways in which energy is transferred.

Energy from the Sun

The Sun produces light and other types of **radiation**. Why does the Sun shine? Inside the Sun a process called **nuclear fusion** is happening all the time. The Sun is a **nuclear store** of energy. Hydrogen atoms combine to form helium, and energy is released.

▲ *When you walk upstairs you exert a force on your body. Energy is transferred when forces act on objects.*

Where are the transformations of energy?

Energy is *not* 'transformed' from one type to another.

Energy is a quantity, so is transferred from one store to another.

Questions

1. Write down two sources of chemical energy.
2. A child picks up a toy from the floor. Name the store that has gained energy.
3. Describe the way energy is stored in a stretched elastic band.
4. A pendulum swings backwards and forwards. Write down two of the energy stores involved.
5. A student thinks that the Sun is a huge ball of fire that provides the energy for the Earth. Would you say that they are correct? Explain your answer.

Key points

- There are different energy stores including chemical, gravitational potential, elastic, kinetic, thermal, and nuclear.
- Energy is transferred by heating, an electric current, forces, and radiation including light and sound.

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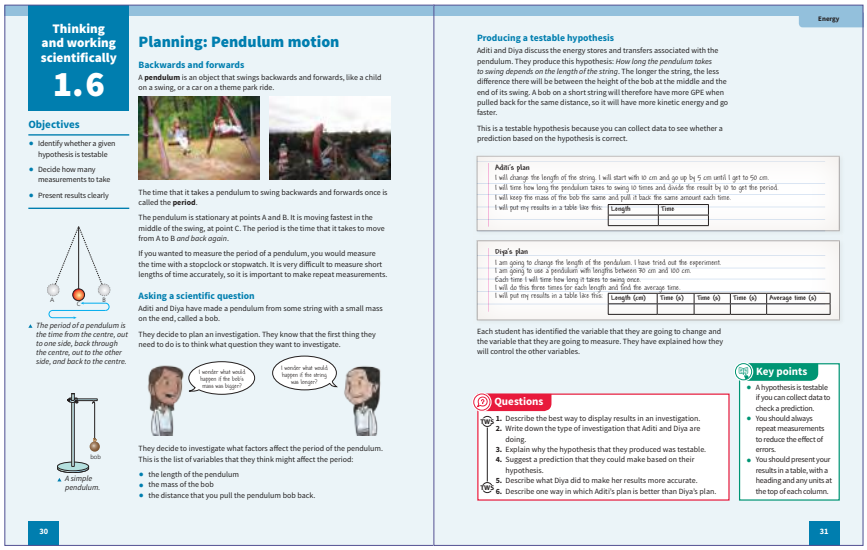
- Every page starts with the learning objectives for the unit. The learning objectives are linked to the Cambridge Lower Secondary Science curriculum framework.
- Key words are marked in **bold**. You can check the meaning of these words in the glossary at the back of the book.
- At the end of each unit there are questions to test that you understand what you have learned. The first question is straightforward and later questions are more challenging. The questions are written in the style of the Cambridge Checkpoint test, to help you prepare. Answers are available in the Teacher Handbook which is available in print and digitally via Kerboodle.
- The key points to remember from the unit are also summarised here.

These units cover the Physics topics in the Cambridge Lower Secondary Science curriculum framework.

In addition, many of the units help you think and work scientifically, put science in context, prepare for the next level, and test your knowledge.

Thinking and working scientifically

Thinking and working scientifically is an important component of the curriculum framework.



Thinking and working scientifically 1.6

Objectives
- Identify whether a given hypothesis is testable
- Decide how many measurements to take
- Present results clearly

Planning: Pendulum motion

Backwards and forwards

A **pendulum** is an object that swings backwards and forwards, like a child on a swing, or a car on a theme park ride.

The time that it takes a pendulum to swing backwards and forwards once is called the **period**.

The pendulum is stationary at points A and B. It is moving fastest in the middle of the swing, at point C. The period is the time that it takes to move from A to B *and back again*.

If you wanted to measure the period of a pendulum, you would measure the time with a stopclock or stopwatch. It is very difficult to measure short lengths of time accurately, so it is important to make repeat measurements.

The period of a pendulum is the time from the centre, out to one side, back through the centre, out to the other side, and back to the centre.

Asking a scientific question

Aditi and Diya have made a pendulum from some string with a small mass on the end, called a bob.

They decide to plan an investigation. They know that the first thing they need to do is to think what question they want to investigate.

A simple pendulum.

They decide to investigate what factors affect the period of the pendulum. This is the list of variables that they think might affect the period:
- the length of the pendulum
- the mass of the bob
- the distance that you pull the pendulum bob back.

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Energy

Producing a testable hypothesis

Aditi and Diya discuss the energy stores and transfers associated with the pendulum. They produce this hypothesis: *How long the pendulum takes to swing depends on the length of the string.* The longer the string, the less difference there will be between the height of the bob at the middle and the end of its swing. A bob on a short string will therefore have more GPE when pulled back for the same distance, so it will have more kinetic energy and go faster.

This is a testable hypothesis because you can collect data to see whether a prediction based on the hypothesis is correct.

Aditi's plan

I will change the length of the string. I will start with 10 cm and go up by 5 cm until I get to 50 cm.
I will time how long the pendulum takes to swing 10 times and divide the result by 10 to get the period.
I will keep the mass of the bob the same and pull it back the same amount each time.
I will put my results in a table like this:

Length	Time

Diya's plan

I am going to change the length of the pendulum. I have tried out the experiment.
I am going to use a pendulum with lengths between 90 cm and 100 cm.
Each time I will time how long it takes to swing once.
I will do this three times for each length and find the average time.
I will put my results in a table like this:

Length (cm)	Time (s)	Time (s)	Time (s)	Average time (s)

Each student has identified the variable that they are going to change and the variable that they are going to measure. They have explained how they will control the other variables.

Questions

TWS
1. Describe the best way to display results in an investigation.
2. Write down the type of investigation that Aditi and Diya are doing.
3. Explain why the hypothesis that they produced was testable.
4. Suggest a prediction that they could make based on their hypothesis.

TWS
5. Describe what Diya did to make her results more accurate.
6. Describe one way in which Aditi's plan is better than Diya's plan.

Key points
- A hypothesis is testable if you can collect data to check a prediction.
- You should always repeat measurements to reduce the effect of errors.
- You should present your results in a table, with a heading and any units at the top of each column.

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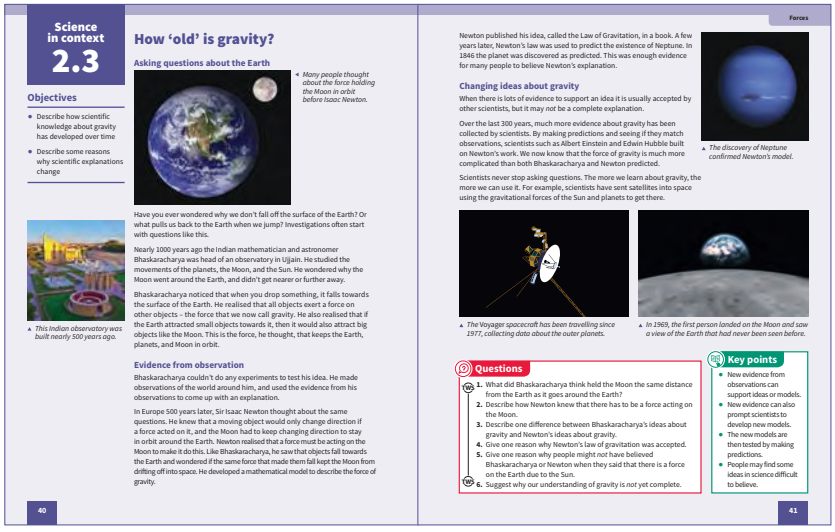
The Thinking and working scientifically units and features will help you learn:

- how to understand and apply models and representations
- the importance of asking scientific questions and planning how to answer them
- how to carry out enquiries such as fair test investigations and field work
- how to analyse data, draw conclusions, and evaluate your enquiry.

TWS Questions which test your Thinking and working scientifically skills and knowledge are marked with this icon.

On pages 8-19 you will find a dedicated Thinking and working scientifically chapter which introduces essential skills which will be useful throughout every stage of the curriculum framework.

Science in context



Science in context 2.3

Objectives
- Describe how scientific knowledge about gravity has developed over time
- Describe some reasons why scientific explanations change

How 'old' is gravity?

Asking questions about the Earth

Many people thought about the force holding the Moon in orbit before Isaac Newton.

This Indian observatory was built nearly 500 years ago.

Have you ever wondered why we don't fall off the surface of the Earth? Or what pulls us back to the Earth when we jump? Investigations often start with questions like this.

Nearly 1000 years ago the Indian mathematician and astronomer Bhaskaracharya was head of an observatory in Ujjain. He studied the movements of the planets, the Moon, and the Sun. He wondered why the Moon went around the Earth, and didn't get nearer or further away.

Bhaskaracharya noticed that when you drop something, it falls towards the surface of the Earth. He realised that all objects exert a force on other objects – the force that we now call gravity. He also realised that if the Earth attracted small objects towards it, then it would also attract big objects like the Moon. This is the force, he thought, that keeps the Earth, planets, and Moon in orbit.

Evidence from observation

Bhaskaracharya couldn't do any experiments to test his idea. He made observations of the world around him, and used the evidence from his observations to come up with an explanation.

In Europe 500 years later, Sir Isaac Newton thought about the same questions. He knew that a moving object would only change direction if a force acted on it, and the Moon had to keep changing direction to stay in orbit around the Earth. Newton realised that a force must be acting on the Moon to make it do this. Like Bhaskaracharya, he saw that objects fall towards the Earth and wondered if the same force that made them fall kept the Moon from drifting off into space. He developed a mathematical model to describe the force of gravity.

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Forces

Newton published his idea, called the Law of Gravitation, in a book. A few years later, Newton's law was used to predict the existence of Neptune. In 1846 the planet was discovered as predicted. This was enough evidence for many people to believe Newton's explanation.

The discovery of Neptune confirmed Newton's model.

Changing ideas about gravity

When there is lots of evidence to support an idea it is usually accepted by other scientists, but it may not be a complete explanation.

Over the last 300 years, much more evidence about gravity has been collected by scientists. By making predictions and seeing if they match observations, scientists such as Albert Einstein and Edwin Hubble built on Newton's work. We now know that the force of gravity is much more complicated than both Bhaskaracharya and Newton predicted.

Scientists never stop asking questions. The more we learn about gravity, the more we can use it. For example, scientists have sent satellites into space using the gravitational forces of the Sun and planets to get there.

The Voyager spacecraft has been travelling since 1977, collecting data about the outer planets.

In 1969, the first person landed on the Moon and saw a view of the Earth that had never been seen before.

Questions

TWS
1. What did Bhaskaracharya think held the Moon the same distance from the Earth as it goes around the Earth?
2. Describe how Newton knew that there has to be a force acting on the Moon.
3. Describe one difference between Bhaskaracharya's ideas about gravity and Newton's ideas about gravity.
4. Give one reason why Newton's law of gravitation was accepted.
5. Give one reason why people might *not* have believed Bhaskaracharya or Newton when they said that there is a force on the Earth due to the Sun.

TWS
6. Suggest why our understanding of gravity is *not* yet complete.

Key points
- New evidence from observations can support ideas or models.
- New evidence can also prompt scientists to develop new models.
- The new models are then tested by making predictions.
- People may find some ideas in science difficult to believe.

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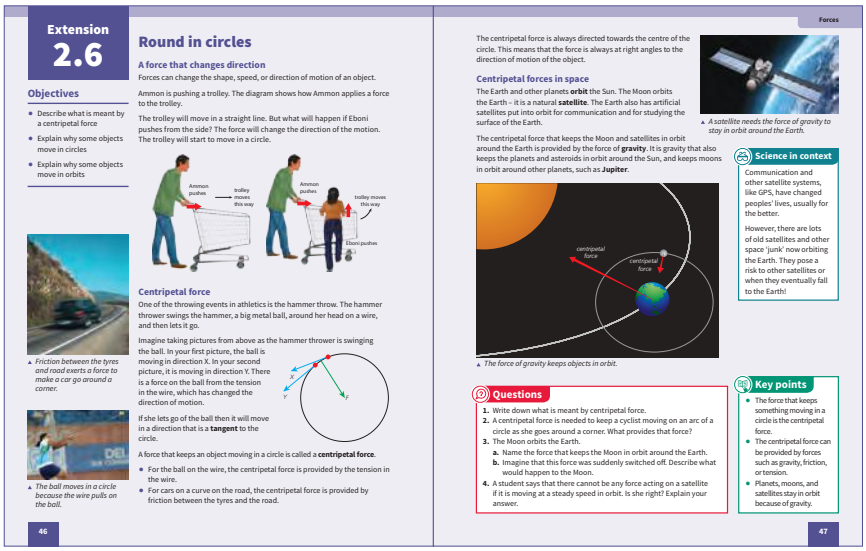
Science in context units will also help you learn:

- how scientists throughout history and from around the globe developed theories, carried out research, and drew conclusions about the world around them
- how science is applied in everyday life
- how issues involving physics are evaluated
- the global impact of the use of physics.

Extension

Throughout this book there are lots of opportunities to learn even more about physics, beyond the curriculum framework. These units are called Extension because they extend and develop your science skills further.

> You can tell when a question or part of a unit is Extension because it is marked with a dashed line, like the one on the left.



Extension 2.6

Round in circles

A force that changes direction

Forces can change the shape, speed, or direction of motion of an object.

Ammon is pushing a trolley. The diagram shows how Ammon applies a force to the trolley.

The trolley will move in a straight line. But what will happen if Eboni pushes from the side? The force will change the direction of the motion. The trolley will start to move in a circle.

Objectives

- Describe what is meant by a centripetal force
- Explain why some objects move in circles
- Explain why some objects move in orbits

Ammon pushes — trolley moves this way

Ammon pushes — trolley moves this way — Eboni pushes

Friction between the tyres and road exerts a force to make a car go around a corner.

The ball moves in a circle because the wire pulls on the ball.

Centripetal force

One of the throwing events in athletics is the hammer throw. The hammer thrower swings the hammer, a big metal ball, around her head on a wire, and then lets it go.

Imagine taking pictures from above as the hammer thrower is swinging the ball. In your first picture, the ball is moving in direction X. In your second picture, it is moving in direction Y. There is a force on the ball from the tension in the wire, which has changed the direction of motion.

If she lets go of the ball then it will move in a direction that is a **tangent** to the circle.

A force that keeps an object moving in a circle is called a **centripetal force**.

- For the ball on the wire, the centripetal force is provided by the tension in the wire.
- For cars on a curve on the road, the centripetal force is provided by friction between the tyres and the road.

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Forces

The centripetal force is always directed towards the centre of the circle. This means that the force is always at right angles to the direction of motion of the object.

Centripetal forces in space

The Earth and other planets **orbit** the Sun. The Moon orbits the Earth – it is a natural **satellite**. The Earth also has artificial satellites put into orbit for communication and for studying the surface of the Earth.

The centripetal force that keeps the Moon and satellites in orbit around the Earth is provided by the force of **gravity**. It is gravity that also keeps the planets and asteroids in orbit around the Sun, and keeps moons in orbit around other planets, such as **Jupiter**.

A satellite needs the force of gravity to stay in orbit around the Earth.

centripetal force — centripetal force

The force of gravity keeps objects in orbit.

Science in context

Communication and other satellite systems, like GPS, have changed peoples' lives, usually for the better.

However, there are lots of old satellites and other space 'junk' now orbiting the Earth. They pose a risk to other satellites or when they eventually fall to the Earth!

Questions

1. Write down what is meant by centripetal force.
2. A centripetal force is needed to keep a cyclist moving on an arc of a circle as she goes around a corner. What provides that force?
3. The Moon orbits the Earth.
   a. Name the force that keeps the Moon in orbit around the Earth.
   b. Imagine that this force was suddenly switched off. Describe what would happen to the Moon.
4. A student says that there cannot be any force acting on a satellite if it is moving at a steady speed in orbit. Is she right? Explain your answer.

Key points

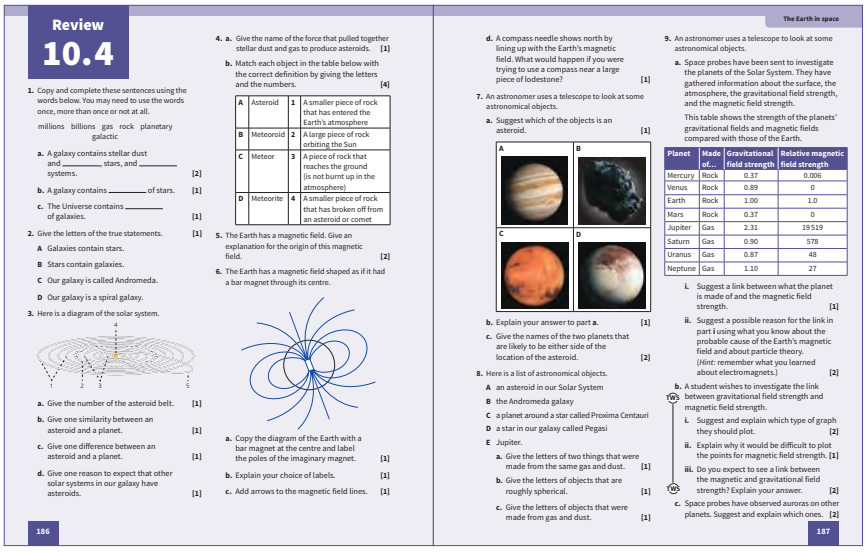
- The force that keeps something moving in a circle is the centripetal force.
- The centripetal force can be provided by forces such as gravity, friction, or tension.
- Planets, moons, and satellites stay in orbit because of gravity.

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Extension units will not be part of your assessment, but they will help you prepare for moving onto the next stage of the curriculum and eventually for Cambridge IGCSE Physics.

Review

At the end of every chapter and every stage there are review questions.



Review 10.4

1. Copy and complete these sentences using the words below. You may need to use the words once, more than once or not at all.

   millions billions gas rock planetary galactic

   a. A galaxy contains stellar dust and _____ stars, and _____ systems. [2]
   b. A galaxy contains _____ of stars. [1]
   c. The Universe contains _____ of galaxies. [1]

2. Give the letters of the true statements. [1]
   A Galaxies contain stars.
   B Stars contain galaxies.
   C Our galaxy is called Andromeda.
   D Our galaxy is a spiral galaxy.

3. Here is a diagram of the solar system.

   a. Give the number of the asteroid belt. [1]
   b. Give one similarity between an asteroid and a planet. [1]
   c. Give one difference between an asteroid and a planet. [1]
   d. Give one reason to expect that other solar systems in our galaxy have asteroids. [1]

4. a. Give the name of the force that pulled together stellar dust and gas to produce asteroids. [1]
   b. Match each object in the table below with the correct definition by giving the letters and the numbers. [4]

A	Asteroid	1	A smaller piece of rock that has entered the Earth's atmosphere
B	Meteoroid	2	A large piece of rock orbiting the Sun
C	Meteor	3	A piece of rock that reaches the ground (is not burnt up in the atmosphere)
D	Meteorite	4	A smaller piece of rock that has broken off from an asteroid or comet

5. The Earth has a magnetic field. Give an explanation for the origin of this magnetic field. [2]

6. The Earth has a magnetic field shaped as if it had a bar magnet through its centre.

   a. Copy the diagram of the Earth with a bar magnet at the centre and label the poles of the imaginary magnet. [1]
   b. Explain your choice of labels. [1]
   c. Add arrows to the magnetic field lines. [1]

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The Earth in space

   d. A compass needle shows north by lining up with the Earth's magnetic field. What would happen if you were trying to use a compass near a large piece of lodestone? [1]

7. An astronomer uses a telescope to look at some astronomical objects.

   a. Suggest which of the objects is an asteroid. [1]

A — B — C — D

   b. Explain your answer to part a. [1]
   c. Give the names of the two planets that are likely to be either side of the location of the asteroid. [2]

8. Here is a list of astronomical objects.
   A an asteroid in our Solar System
   B the Andromeda galaxy
   C a planet around a star called Proxima Centauri
   D a star in our galaxy called Pegasi
   E Jupiter.
   a. Give the letters of two things that were made from the same gas and dust. [1]
   b. Give the letters of objects that are roughly spherical. [1]
   c. Give the letters of objects that were made from gas and dust. [1]

9. An astronomer uses a telescope to look at some astronomical objects.

   a. Space probes have been sent to investigate the planets of the Solar System. They have gathered information about the surface, the atmosphere, the gravitational field strength, and the magnetic field strength.

   This table shows the strength of the planets' gravitational fields and magnetic fields compared with those of the Earth.

Planet	Made of...	Gravitational field strength	Relative magnetic field strength
Mercury	Rock	0.37	0.006
Venus	Rock	0.89	0
Earth	Rock	1.00	1.0
Mars	Rock	0.37	0
Jupiter	Gas	2.31	19 519
Saturn	Gas	0.90	578
Uranus	Gas	0.87	48
Neptune	Gas	1.10	27

   i. Suggest a link between what the planet is made of and the magnetic field strength. [1]
   ii. Suggest a possible reason for the link in part i using what you know about the probable cause of the Earth's magnetic field and about particle theory. (*Hint:* remember what you learned about electromagnets.) [2]

   b. A student wishes to investigate the link between gravitational field strength and magnetic field strength.
   i. Suggest and explain which type of graph they should plot. [2]
   ii. Explain why it would be difficult to plot the points for magnetic field strength. [1]
   iii. Do you expect to see a link between the magnetic and gravitational field strength? Explain your answer. [2]

   c. Space probes have observed auroras on other planets. Suggest and explain which ones. [2]

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These questions are written in the style of the Cambridge Checkpoint test. They are there to help you review what you have learned in that chapter or stage. Answers to these questions are available in the Teacher Handbook. The Teacher Handbook is available in print or digitally via Kerboodle.

Reference

At the back of this book, on pages 244-249, there are reference pages providing further information that will help you while you study.

Reference 3

Using ammeters and voltmeters

Measuring current and voltage

In your experiments with electrical circuits you will measure current and voltage using meters. There are two types of meter: analogue and digital.

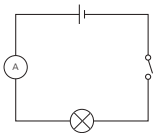
- Analogue meters have a needle that moves and shows the current on a scale.
- Digital meters have a display of numbers. A digital meter is usually a multimeter, which means that you can use it to measure current or voltage.

Using an analogue ammeter

An ammeter measures the current. You might want to find the current flowing through a component such as a lamp. To do this you place the ammeter *in series* with the lamp.



▲ *An analogue ammeter.*



▲ *An ammeter connected to a circuit with a cell or battery, a lamp, and a switch.*

For most components in a circuit it does not matter which way round you connect them. This is not true for an ammeter. It needs to be connected so that, if you follow the wires back to the battery or cell, the wire in the *black* terminal on the ammeter is connected to the *negative* terminal of the battery. The wire in the *red* terminal should be connected to the *positive* terminal of the battery.

This is how you connect the ammeter into a circuit with a cell or battery, a lamp, and a switch.

1. Disconnect the cell or open the switch.
2. Follow the wire from the negative terminal of the cell until you get to the lamp. Disconnect the lead from the lamp.
3. Plug that lead into the black terminal on your ammeter.
4. Use another lead to connect the lamp to the red terminal of the ammeter.

An analogue meter may have two different scales. Start by connecting it up using the red terminal labelled with the higher value of current. If the ammeter does not show a current in your circuit using that scale, then move the lead to the terminal with the lower value of current.

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Using an analogue voltmeter

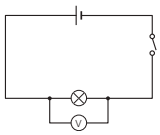
A voltmeter measures the voltage. You might want to find the voltage across a component such as a lamp. To do this you place the voltmeter *in parallel* with the lamp.

Like an ammeter, a voltmeter needs to be connected the right way round. This is how you connect the voltmeter into a circuit with a cell or battery, a lamp, and a switch.

1. Disconnect the cell or open the switch.
2. Follow the wire from the negative terminal of the cell until you get to the lamp. Do not disconnect the lamp but plug another lead into the terminal on that side of the lamp.
3. Connect the other end of this lead to the black terminal on your voltmeter.
4. Use another lead to connect the other side of the lamp to the red terminal of the voltmeter.



▲ *An analogue voltmeter.*



▲ *A voltmeter connected to a circuit with a cell or battery, a lamp, and a switch.*

Connecting meters

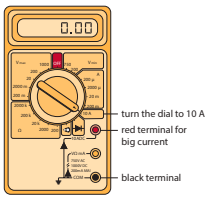
You connect an ammeter in series, and a voltmeter in parallel. It is important not to connect an ammeter in parallel with a component, or directly across a battery or cell. The resistance of the ammeter is very small so a very large current would flow that could damage the ammeter and drain the cell.

The resistance of a voltmeter is very, very high. If you connect it in series rather than in parallel no current will flow in the circuit.

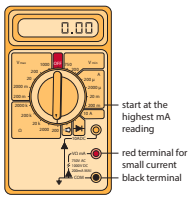
Using a multimeter

You can use a multimeter to measure current *or* voltage.

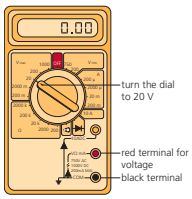
The multimeter has a dial that you turn to select current (A or mA) or voltage (V). You select whether you want to measure a large current (10 A) or a small current. Some examples of how to connect a multimeter are shown below.



▲ *Using a multimeter to measure a big current.*



▲ *Using a multimeter to measure a small current.*



▲ *Using a multimeter to measure voltage.*

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They include information on:

- how to choose suitable apparatus
- how to work accurately and safely
- how to use ammeters and voltmeters.

2.1

Introduction to forces

Objectives

- Describe how to represent forces on diagrams
- Describe the difference between contact and non-contact forces
- Describe how to measure forces



▲ *On a rollercoaster, forces change your speed and direction.*



▲ *A plastic comb attracts pieces of paper with an electrostatic force.*

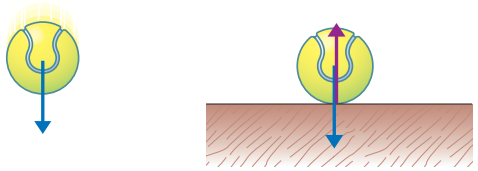
What is a force?

When a tennis ball hits the ground, a **force** changes its shape, speed, and direction. A force is a push or pull that can change the shape of an object, or change the way that it moves.

You cannot see forces but you can see what they do. If something starts to move, or speeds up, a force is acting on it. Forces can also slow things down or stop them moving. If an object is already moving, a force can also change the direction of motion.

Force arrows

You can show the force acting on an object by drawing an arrow. The length of the arrow shows the size of the force. The direction of the arrow shows the direction of the force. The arrow is drawn in contact with the object.



Different types of force

Non-contact forces

Some forces act when even when objects are *not* touching. They are **non-contact forces**.

- **Gravitational forces** act between any objects that have mass. On Earth, this force is called the object's **weight**. This force acts towards the centre of the Earth. It always pulls you 'down', wherever you are on the Earth. The force of gravity attracts you to the Earth. It also attracts the Earth to you!
- **Electrostatic forces** act between objects that are electrically charged. For example, rubbing plastic objects can charge them with static electricity. Once charged they can **attract** or **repel** other charged objects.
- **Magnetic forces** act between magnets, and between magnets and magnetic materials such as iron, steel, or nickel.



▲ *A magnetic force attracts iron filings to a magnet.*

Contact forces

Some forces , called **contact forces**, only act when objects are in contact (or touching).

- **Friction** acts when solid surfaces are in contact. The force of friction acts to stop objects moving.
- **Air resistance** and **water resistance** act on objects moving through air and water. They are types of **drag**. The moving object collides with the particles in the air or the water, and the collisions slow it down.
- **Thrust** pushes a car or plane forwards.
- **Upthrust** is the upward force on an object that is in contact with a fluid. It is the force pushing up on any **floating** object.
- **Tension** acts when objects are pulled, like the force in a rope that you pull.
- **Reaction** is the force that pushes you up in reaction to your weight pushing something downwards, for example when you sit on a chair. It is sometimes called the **normal** force.



▲ *A hot air balloon rises because of the upthrust from the air around it.*

Measuring forces

You can measure the size of a force. A device for measuring forces is called a **forcemeter**, such as a **spring balance**. Forces are measured in units called **newtons** (N), so force meters are also called **newtonmeters.**



Questions

1. **a.** Name three contact forces.
   b. Name three non-contact forces.
2. A magnet can exert a force of attraction or a force of repulsion on another magnet. Write down which of these forces is a push and which is a pull.
3. A car is travelling along a road. List three of the forces acting on it.
4. Explain why people on the other side of the Earth don't fall off.

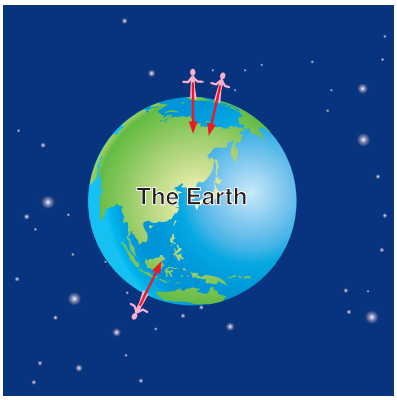
Key points

- Weight, electrostatic force, magnetic force, friction, air resistance, water resistance, thrust, upthrust, normal force, and tension are all types of force.
- Forces can change the direction of a moving object, speed it up, or slow it down.
- Forces are measured in newtons using a spring balance.

2.2

Objectives

- Describe the difference between weight and mass
- Describe how the force of gravity arises
- Describe the factors that affect the force of gravity between two objects



▲ *The force of gravity always acts towards the centre of the planet.*



▲ *This scale reads 300 g (mass) but should show a reading in newtons (weight).*

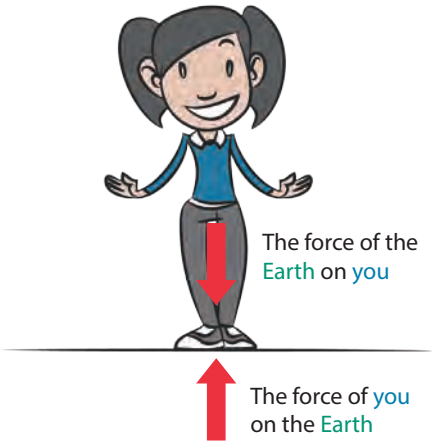
Gravity

The force of gravity

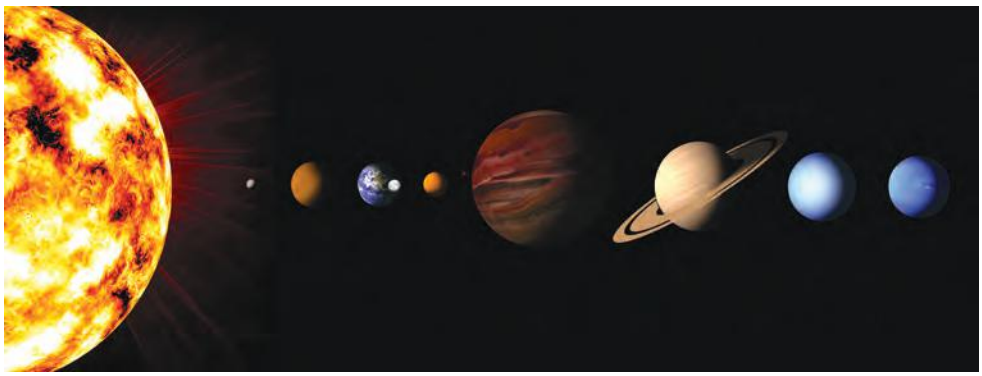
There is a force of attraction between all objects that have mass, called the force of **gravity**. This force is pulling you down towards the centre of the Earth. But forces come in pairs – you are also pulling the Earth with a force of gravity.

The size of the force of gravity between two objects depends on:

- the mass of the two objects
- how far apart they are.



▲ *There is a force of gravity between you and the Earth.*



▲ *Relative sizes of Jupiter and the Earth: a more massive planet exerts a bigger force on objects with the same mass.*

Weight and mass

The force of the Earth's gravity on an object is called its **weight**. When you use scales or a forcemeter you are measuring the force of gravity.

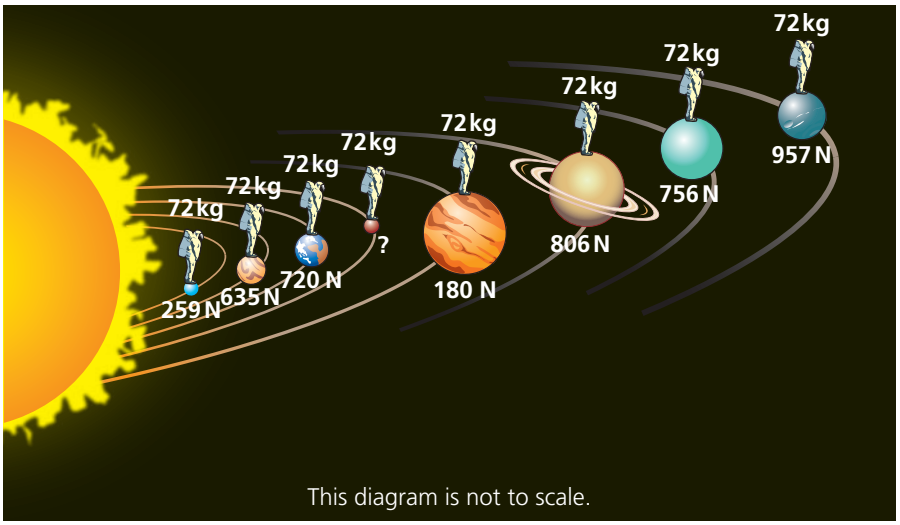
- Weight is a force.
- Weight is measured in **newtons** (N).
- **Mass** is the amount of **matter** in an object.
- Mass is measured in **kilograms** (kg).

Another way of thinking about mass is to do with motion. An object with a small mass will accelerate faster when you apply a force to it than something with a big mass.

It's easy to confuse weight and mass. Your weight is a force and should be measured in newtons, but often scales measure your 'weight' in kilograms! Scientifically this is wrong.

The force of gravity depends on the mass of the objects involved, so it is different on different planets. The more massive the planet, the larger the force of gravity.

On the Moon there is no atmosphere (air) and astronauts have to wear spacesuits to be able to breathe. Some people think this means there is no gravity there. This is *not* true. There is a force of gravity on the Moon, but it is about one-sixth as strong as on the Earth.



▲ *The weight of the astronaut changes, but his mass stays the same.*

Gravitational field strength

There is a **gravitational field** around all objects. This is a region where a mass experiences a force.

On the Earth the **gravitational field strength** is 10 newtons per kilogram (N/kg).

Weight (N) = mass (kg) × gravitational field strength (N/kg)

When people say that gravity is different on different planets, they mean that the gravitational field strength is different.

Gravitational field strength decreases as you move away from a planet.

In physics the idea of a 'field' is very important. Fields are linked to forces. There are other types of field, such as magnetic fields (see page 156).



▲ *The gravitational field strength on the Moon is 1.6 N/kg.*

Questions

1. **a.** Describe what is meant by 'the force of gravity'.
   b. Write down two things that affect the force of gravity.
2. **a.** Describe the difference between weight and mass.
   b. Is the mass of an astronaut on Mars bigger than, smaller than, or the same as their mass on Earth? Explain your answer.
3. A student says that objects get pulled down because the Earth is like a big magnet. Explain how a gravitational force is *and is not* like a magnetic force.
4. A baby has a mass of 4 kg. Calculate its weight on Earth.
5. An astronaut has a weight of 370 N on Mars where the gravitational field strength is 3.7 N/kg.
   a. Calculate the mass of the astronaut.
   b. Write down the mass of the astronaut on Earth.

Key points

- The force of gravity is an attractive force that acts between any objects with mass.
- The force of gravity acting on an object on Earth is called its weight.
- Weight is a force, and is measured in newtons.
- Mass is the amount of matter, and is measured in kilograms.
- The force of gravity is different on different planets or on the Moon.

Science in context

2.3

Objectives

- Describe how scientific knowledge about gravity has developed over time
- Describe some reasons why scientific explanations change

How 'old' is gravity?

Asking questions about the Earth



◀ *Many people thought about the force holding the Moon in orbit before Isaac Newton.*



▲ *This Indian observatory was built nearly 500 years ago.*

Have you ever wondered why we don't fall off the surface of the Earth? Or what pulls us back to the Earth when we jump? Investigations often start with questions like this.

Nearly 1000 years ago the Indian mathematician and astronomer Bhaskaracharya was head of an observatory in Ujjain. He studied the movements of the planets, the Moon, and the Sun. He wondered why the Moon went around the Earth, and didn't get nearer or further away.

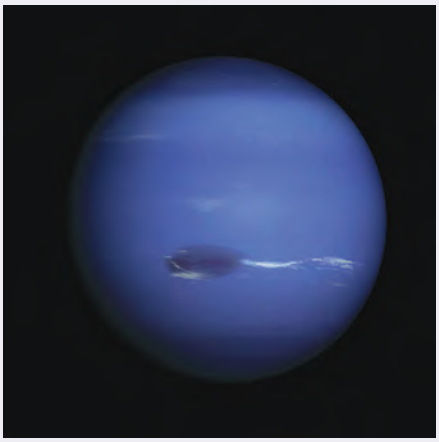
Bhaskaracharya noticed that when you drop something, it falls towards the surface of the Earth. He realised that all objects exert a force on other objects – the force that we now call gravity. He also realised that if the Earth attracted small objects towards it, then it would also attract big objects like the Moon. This is the force, he thought, that keeps the Earth, planets, and Moon in orbit.

Evidence from observation

Bhaskaracharya couldn't do any experiments to test his idea. He made observations of the world around him, and used the evidence from his observations to come up with an explanation.

In Europe 500 years later, Sir Isaac Newton thought about the same questions. He knew that a moving object would only change direction if a force acted on it, and the Moon had to keep changing direction to stay in orbit around the Earth. Newton realised that a force must be acting on the Moon to make it do this. Like Bhaskaracharya, he saw that objects fall towards the Earth and wondered if the same force that made them fall kept the Moon from drifting off into space. He developed a mathematical model to describe the force of gravity.

Newton published his idea, called the Law of Gravitation, in a book. A few years later, Newton's law was used to predict the existence of Neptune. In 1846 the planet was discovered as predicted. This was enough evidence for many people to believe Newton's explanation.



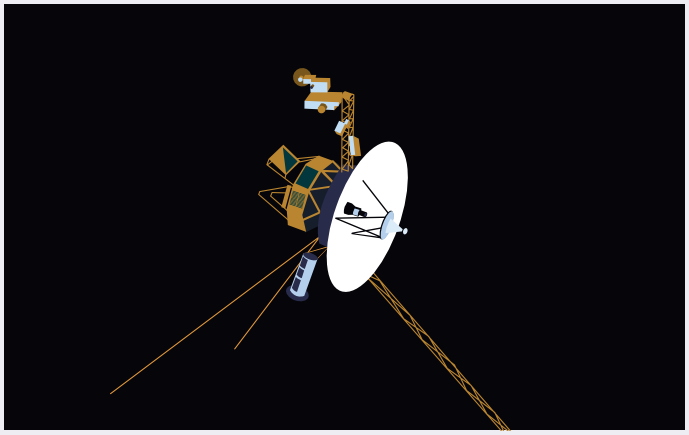
▲ *The discovery of Neptune confirmed Newton's model.*

Changing ideas about gravity

When there is lots of evidence to support an idea it is usually accepted by other scientists, but it may *not* be a complete explanation.

Over the last 300 years, much more evidence about gravity has been collected by scientists. By making predictions and seeing if they match observations, scientists such as Albert Einstein and Edwin Hubble built on Newton's work. We now know that the force of gravity is much more complicated than both Bhaskaracharya and Newton predicted.

Scientists never stop asking questions. The more we learn about gravity, the more we can use it. For example, scientists have sent satellites into space using the gravitational forces of the Sun and planets to get there.



▲ *The* Voyager *spacecraft has been travelling since 1977, collecting data about the outer planets.*



▲ *In 1969, the first person landed on the Moon and saw a view of the Earth that had never been seen before.*

Questions

TWS **1.** What did Bhaskaracharya think held the Moon the same distance from the Earth as it goes around the Earth?

2. Describe how Newton knew that there has to be a force acting on the Moon.

3. Describe one difference between Bhaskaracharya's ideas about gravity and Newton's ideas about gravity.

4. Give one reason why Newton's law of gravitation was accepted.

5. Give one reason why people might *not* have believed Bhaskaracharya or Newton when they said that there is a force on the Earth due to the Sun.

TWS **6.** Suggest why our understanding of gravity is *not* yet complete.

Key points

- New evidence from observations can support ideas or models.
- New evidence can also prompt scientists to develop new models.
- The new models are then tested by making predictions.
- People may find some ideas in science difficult to believe.

2.4

Air resistance

Objectives

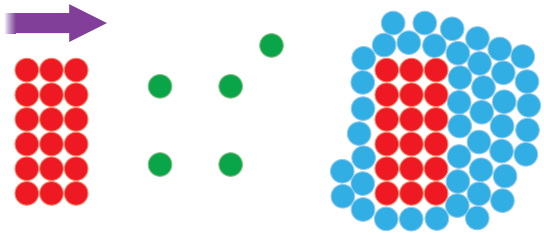
- Describe how air resistance is produced
- Describe where it causes a problem, and where it is useful
- Describe what happens in a vacuum

What is air resistance?



▲ *The air can produce a force that changes your face!*

When an object moves through air, there is a force on it called **air resistance**. Most of the time you don't really notice it. If the air is moving fast, for example if you are walking into a wind, or you are moving very fast through the air, for example if you are cycling fast or leaning out of a car window, then you notice the effect.



▲ *A solid moves through a gas*

▲ *A solid moves through a liquid*

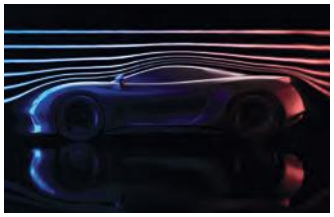
An object moving through the air collides with the particles in the air and is effectively pushing the air out of the way. These collisions with air particles provide the resistance. Air resistance is affected by the *speed* of the object moving through the air. Objects moving with a higher speed will push more air out of the way and experience more air resistance.

Reducing air resistance

Air resistance slows things down. Air resistance is less if the area in contact with the air is small. **Streamlining** reduces air resistance by changing the flow of air over a car or plane. Cyclists pull in their arms and crouch forward to reduce the area in contact with the air. They make themselves more streamlined by using special helmets.

Science in context

Scientists use wind tunnels to experiment and find the best shape for vehicles. Streamlined cars use less fuel.



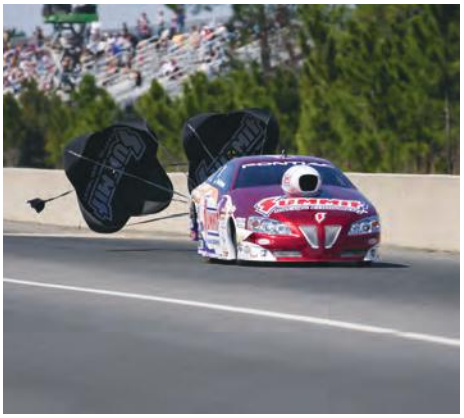
▲ *Smoke shows the path of air in a wind tunnel.*

Using air resistance

Air resistance can be very useful for slowing things down. A parachute increases the area that is in contact with the air, and therefore increases the air resistance. For example, rocket cars use parachutes to brake.

Air resistance depends on:

- the speed of the object
- the area of the object.



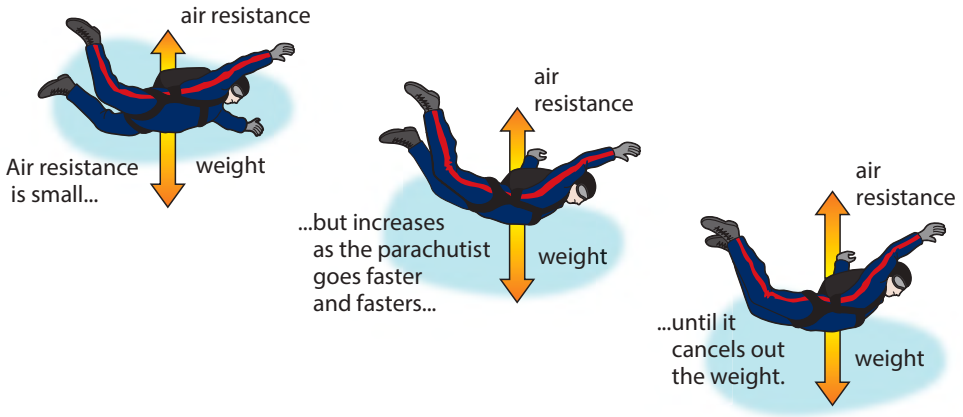
▲ *A parachute slows down a car.*

Science in context

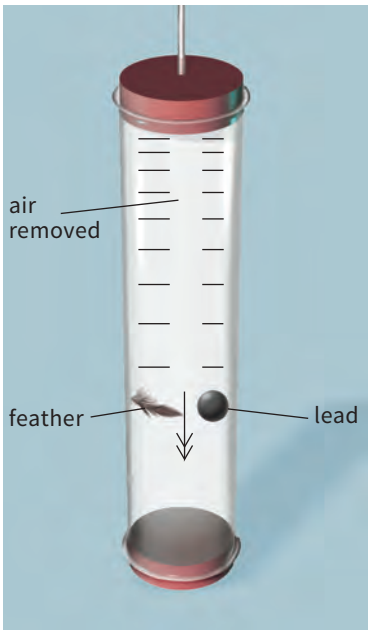
Aircraft have flaps that are spread to slow down the aircraft when it lands.

Aircraft designers think carefully about how to reduce air resistance in flight and use it on landing.





▲ *Without a parachute the parachutist will reach a high, steady speed.*



▲ *In a vacuum all objects fall at the same rate.*

Do heavier things fall faster?

When we see things fall on the Earth, like a feather or a hammer, the heavier object (the hammer) falls faster. This is because of air resistance. Air resistance affects the motion of the feather much more than the motion of the hammer.

If there is no air, there is a **vacuum**, so no air resistance. If there is no air resistance all objects fall at the same rate.

In 1971, an astronaut took a feather and a hammer to the moon, where there is no air, and dropped them together. The feather and the hammer hit the ground at the same time.

Questions

1. Car manufacturers put cars in wind tunnels to help them to design streamlined cars.
   - **a.** Explain what is meant by 'streamlined'.
   - **b.** Write down which object would experience more air resistance – a streamlined car travelling slowly or a lorry travelling fast. Explain your answer.
2. Explain why a tennis ball and a cricket ball dropped together will hit the ground at about the same time, even though the cricket ball is heavier. Assume that they are about the same size.

Key points

- Air resistance depends on the speed of the object and its area in contact with the air.
- The shape of streamlined objects reduces air or water resistance.
- Parachutes increase air resistance, so can slow down moving objects.
- If there is no air (in a vacuum), then there is no air resistance.
- In a vacuum, all objects fall towards the Earth at the same rate.

Thinking and working scientifically

2.5

Objectives

- Describe how to plan an investigation to test an idea in science
- Describe how to write a conclusion
- Describe how to write an evaluation

Planning fair tests: Streamlining

Asking questions



Kasini was watching a film about dolphins. The dolphins have to swim fast to catch fish. She wondered what affects how fast things can move through water.

Kasini decided to make different objects out of clay and drop them into a cylinder of water. She could time how long they took to hit the bottom.

Making a hypothesis and prediction

Kasini had learned that engineers design cars and aeroplanes to be as streamlined as possible to reduce drag. She used this information to make a prediction based on a hypothesis.

I have decided to investigate how the shape of the object affects how long it takes to fall through water.

Making a plan and choosing equipment

This is Kasini's plan.

I am going to investigate how long it takes different shapes of clay to reach the bottom of the cylinder of water. I will make different shapes from the same amount of clay. These are the shapes I have chosen: cone, cube, sphere, cylinder, cuboid.

I will time how long it takes for the shape to hit the bottom with a stopwatch.

I will write my results in a table.

This is a list of my equipment:

- a large measuring cylinder
- Modelling clay
- a stopwatch
- a balance
- a measuring jug



My indeoendent variables are:

- the shape of the clay
- the mass of clay
- the volume of water in the cylinder
- the temperature of the water

Writing a conclusion

Kasini completed her investigation and wrote down her results.

She concluded that the evidence did support her hypothesis, and that her prediction was correct.

However, Kasini worried that the data were not very good because it was hard to see when to start and stop the stopwatch.

She asked her friend Nadia. Nadia said that Kasini had not taken enough measurements, so she could not be sure that her measurements were correct. The measurement for the cone shape could be an anomalous result because of a mistake. Nadia also said that there should be a graph and evaluation.

Kasini wrote this for her evaluation:

> To improve this experiment I would find a better method of timing, like using a video camera. I would repeat the experiment several times for each shape. I would look for anomalous results and repeat them. Then I would find the mean. This would make my data more accurate.
>
> I would plot a bar chart of the results because my data are categoric.

It is important that an evaluation shows how to collect better data, *not* make the experiment quicker or easier. Repeating measurements enables you to identify anomalous results.



Shape	Time
cone	0.58
cube	0.65
sphere	0.61
cylinder	0.75
cuboid	0.68

▲ *Here is Kasini's results table.*

Questions

1. Copy and complete this table to explain why Kasini needed each piece of equipment.

Equipment	Why Kasini needs it
A large measuring cylinder	
Modelling clay	
A stopwatch	
A balance	
A measuring jug	

2. Name the independent, dependent, and control variables in this investigation. Use Kasini's list to help you.
3. What has Kasini missed out of her results table?
4. Explain why repeating the measurements will produce better data.

Key points

- A plan includes your hypothesis and prediction, equipment, and a method.
- A conclusion says what you have found out, whether it matches your prediction, and whether it supports your hypothesis.
- An evaluation includes what you would do to get better data next time.

Extension

2.6

Objectives

- Describe what is meant by a centripetal force
- Explain why some objects move in circles
- Explain why some objects move in orbits



▲ *Friction between the tyres and road exerts a force to make a car go around a corner.*



▲ *The ball moves in a circle because the wire pulls on the ball.*

Round in circles

A force that changes direction

Forces can change the shape, speed, or direction of motion of an object.

Ammon is pushing a trolley. The diagram shows how Ammon applies a force to the trolley.

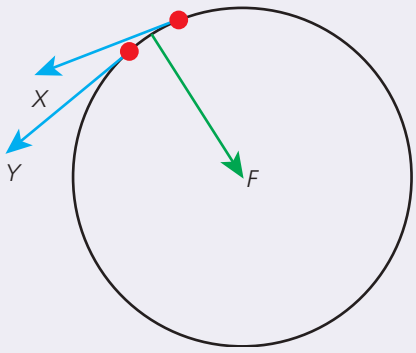
The trolley will move in a straight line. But what will happen if Eboni pushes from the side? The force will change the direction of the motion. The trolley will start to move in a circle.



Centripetal force

One of the throwing events in athletics is the hammer throw. The hammer thrower swings the hammer, a big metal ball, around her head on a wire, and then lets it go.

Imagine taking pictures from above as the hammer thrower is swinging the ball. In your first picture, the ball is moving in direction X. In your second picture, it is moving in direction Y. There is a force on the ball from the tension in the wire, which has changed the direction of motion.



If she lets go of the ball then it will move in a direction that is a **tangent** to the circle.

A force that keeps an object moving in a circle is called a **centripetal force**.

- For the ball on the wire, the centripetal force is provided by the tension in the wire.
- For cars on a curve on the road, the centripetal force is provided by friction between the tyres and the road.

The centripetal force is always directed towards the centre of the circle. This means that the force is always at right angles to the direction of motion of the object.

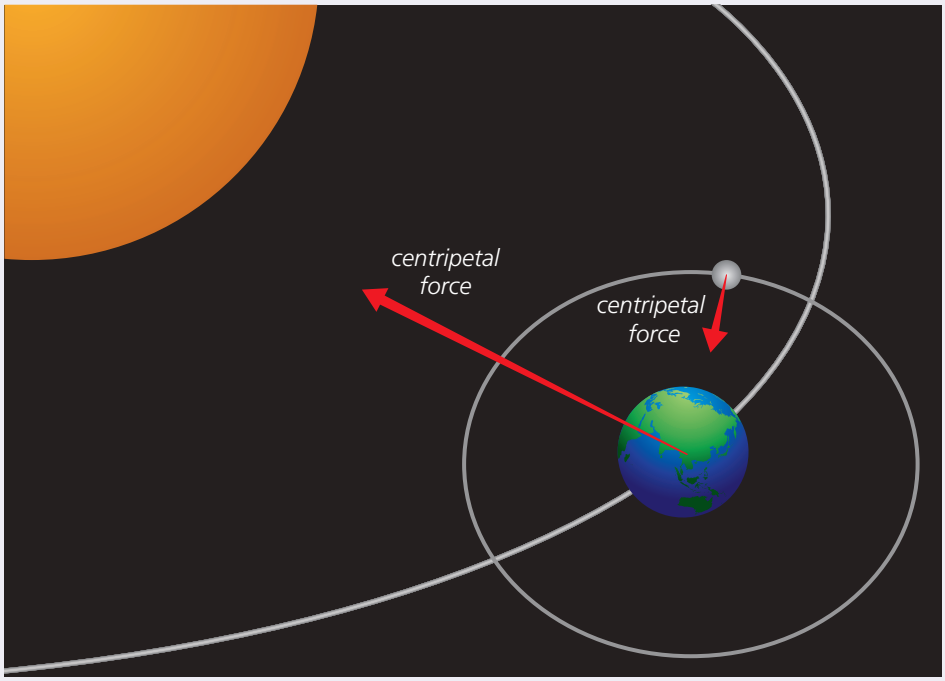


▲ *A satellite needs the force of gravity to stay in orbit around the Earth.*

Centripetal forces in space

The Earth and other planets **orbit** the Sun. The Moon orbits the Earth – it is a natural **satellite**. The Earth also has artificial satellites put into orbit for communication and for studying the surface of the Earth.

The centripetal force that keeps the Moon and satellites in orbit around the Earth is provided by the force of **gravity**. It is gravity that also keeps the planets and asteroids in orbit around the Sun, and keeps moons in orbit around other planets, such as **Jupiter**.



▲ *The force of gravity keeps objects in orbit.*

Science in context

Communication and other satellite systems, like GPS, have changed peoples' lives, usually for the better.

However, there are lots of old satellites and other space 'junk' now orbiting the Earth. They pose a risk to other satellites or when they eventually fall to the Earth!

Questions

1. Write down what is meant by centripetal force.
2. A centripetal force is needed to keep a cyclist moving on an arc of a circle as she goes around a corner. What provides that force?
3. The Moon orbits the Earth.
   a. Name the force that keeps the Moon in orbit around the Earth.
   b. Imagine that this force was suddenly switched off. Describe what would happen to the Moon.
4. A student says that there cannot be any force acting on a satellite if it is moving at a steady speed in orbit. Is she right? Explain your answer.

Key points

- The force that keeps something moving in a circle is the centripetal force.
- The centripetal force can be provided by forces such as gravity, friction, or tension.
- Planets, moons, and satellites stay in orbit because of gravity.

Review 2.7

1. Some forces need contact, and others act at a distance. **[2]**
Give the letters of the non-contact forces:

A friction

B gravity

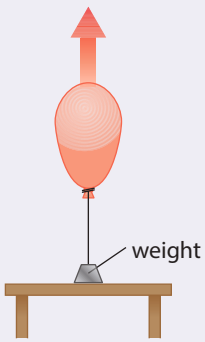
C air resistance

D magnetism

2. Match the words to the definitions. **[2]**

mass	force due to a planet or moon
weight	region in which an object experiences a force
field	amount of matter

3.



a. Write down the label on the upward arrow. **[1]**

b. Describe the other two force arrows that should be added to the diagram. **[1]**

c. Identify which of the three forces you have described are contact forces and which are non-contact forces. **[1]**

4. Which of these statements about mass and weight is or are correct? There may be more than one. **[1]**

A Weight is measured in kilograms.

B Mass is measured in kilograms.

C Weight is a force.

D Mass is measured in newtons.

5. On the Earth, a person with a mass of 70 kg has a weight of 700 N. Which of the following statements is or are correct? **[1]**

A If the person were on a more massive planet their weight will be larger.

B If their weight on a planet is 300 N, it means that the gravitational field there is stronger than on the Earth.

C A planet with a weaker gravitational field would make their weight smaller.

D A planet with a stronger gravitational field would make their mass bigger.

6. Alan Shepherd was the fifth person to walk on the Moon. He took a golf club and ball and hit the ball. The ball went a lot further than it would on the Earth. Give **two** reasons why. **[2]**

7. Scientists are planning a mission to take astronauts to Mars. Suppose an astronaut has a mass of 65 kg on the Earth. The gravitational field strength on Earth is 10 N/kg and on Mars is 3.7 N/kg.

a. Calculate the astronaut's weight on Earth. **[2]**

b. Describe and explain what will be the same and what will be different about their weight and mass when they go to Mars. **[2]**

8. a. Explain why ideas about gravity from hundreds of years ago were 'rediscovered' later. **[1]**

b. Explain why an idea in science might change. **[1]**

9. The table shows some information about Jupiter and one of its moons, Io.

An astronaut has a mass of 100 kg.
Compare their weight on Jupiter and Io. **[3]**

Object	Gravitational field strength (N/kg)
Jupiter	23
Io	1.8

10. A student investigates streamlining.

a. Define 'streamlined'. **[1]**

He makes three different shapes using modelling clay and times how long each shape takes to reach the bottom of a tank of water. Here are his results.

Shape	Time 1 (s)	Time 2 (s)	Time 3 (s)	Average time (s)
A	1.2	1.4.	1.3	1.3
B	1.8	0.1	2.0	
C	2.8	2.9	2.7	2.8

TWS **b.** Identify the anomalous result in his data. **[1]**

TWS **c.** Calculate the average time for shape **B**. **[1]**

d. List the shapes in order of most to least streamlined. Explain your answer. **[2]**

TWS **e.** Give two control variables in this investigation. **[2]**

f. Describe and explain the type of graph the student needs to plot. **[2]**

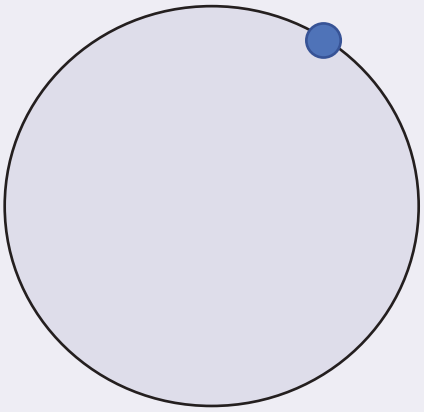
g. Another student says that they have made a shape that takes 4.6 seconds to reach the bottom of a tank.

Suggest why the first student might not be able to use this result. **[2]**

TWS

11. Explain why a streamlined car uses **less** fuel than if it were not streamlined. Use these words in your answer: thrust, air resistance, air particles, force. **[4]**

12. A boy connects a ball to a piece of string and whirls it in a vertical circle, as shown in the diagram below.



a. Copy the diagram and add an arrow to show the force keeping the ball moving in the circle. **[1]**

b. Describe what would happen to the ball if the string suddenly broke. **[1]**

Jupiter's moons move in a circle around Jupiter.

c. Name the force keeping them moving in a circle. **[1]**

d. Describe what would happen to the moons if the force was suddenly removed. **[1]**

13. Copy and complete these sentences about the force of air resistance using these words: vacuum force particles same **[4]**

When an object moves through the air, air _____ collide with it. This produces a _____ that slows down the object.

In a _____ there are no air particles, so all objects fall at the _____ rate.

14. Describe a situation in which air resistance is useful. **[2]**

15. When a diving bird is about to enter water, it folds its wings close to its body, so they are not injured when it hits the water. Explain the other effect this action has. **[3]**

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