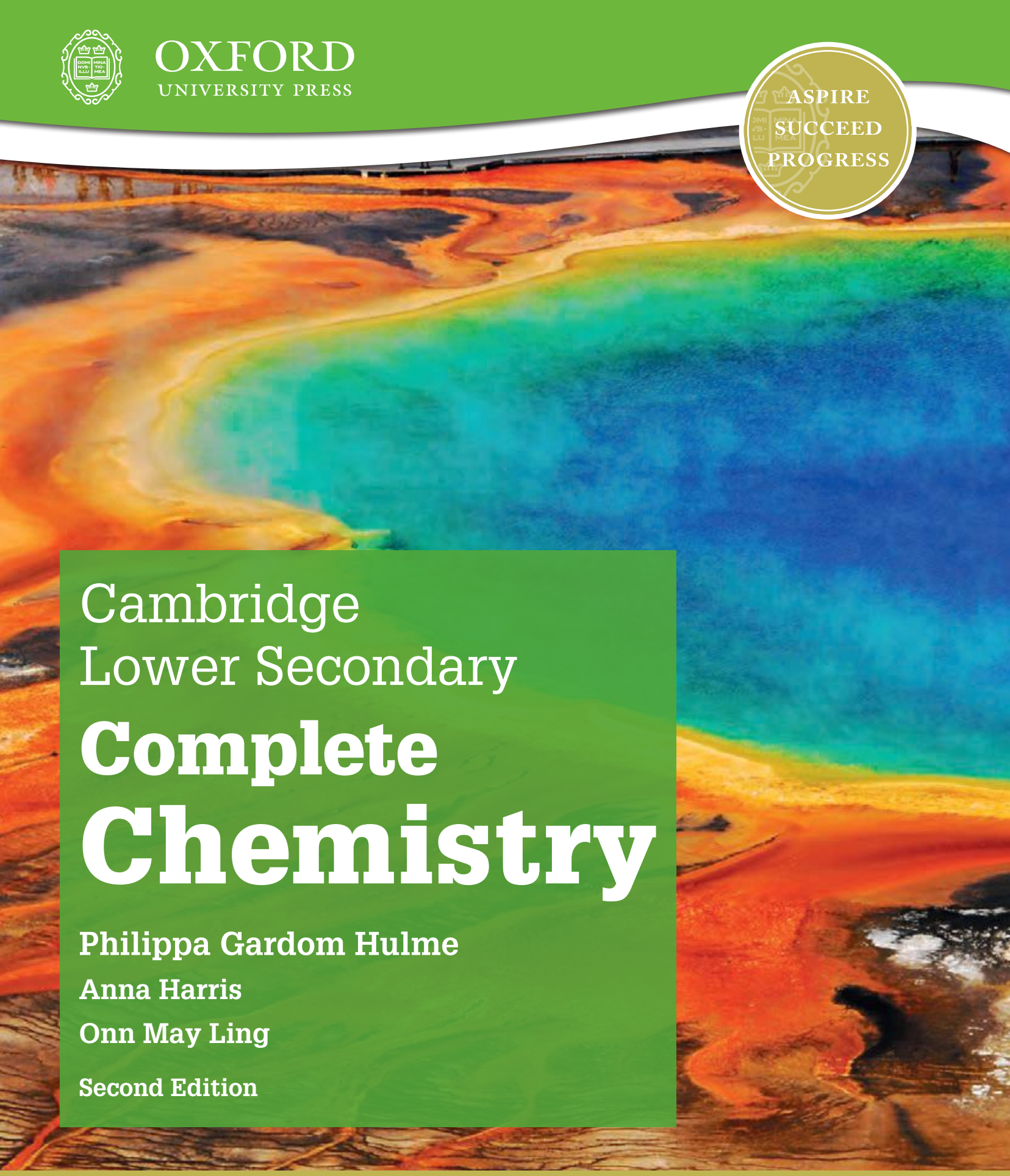


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Complete Chemistry

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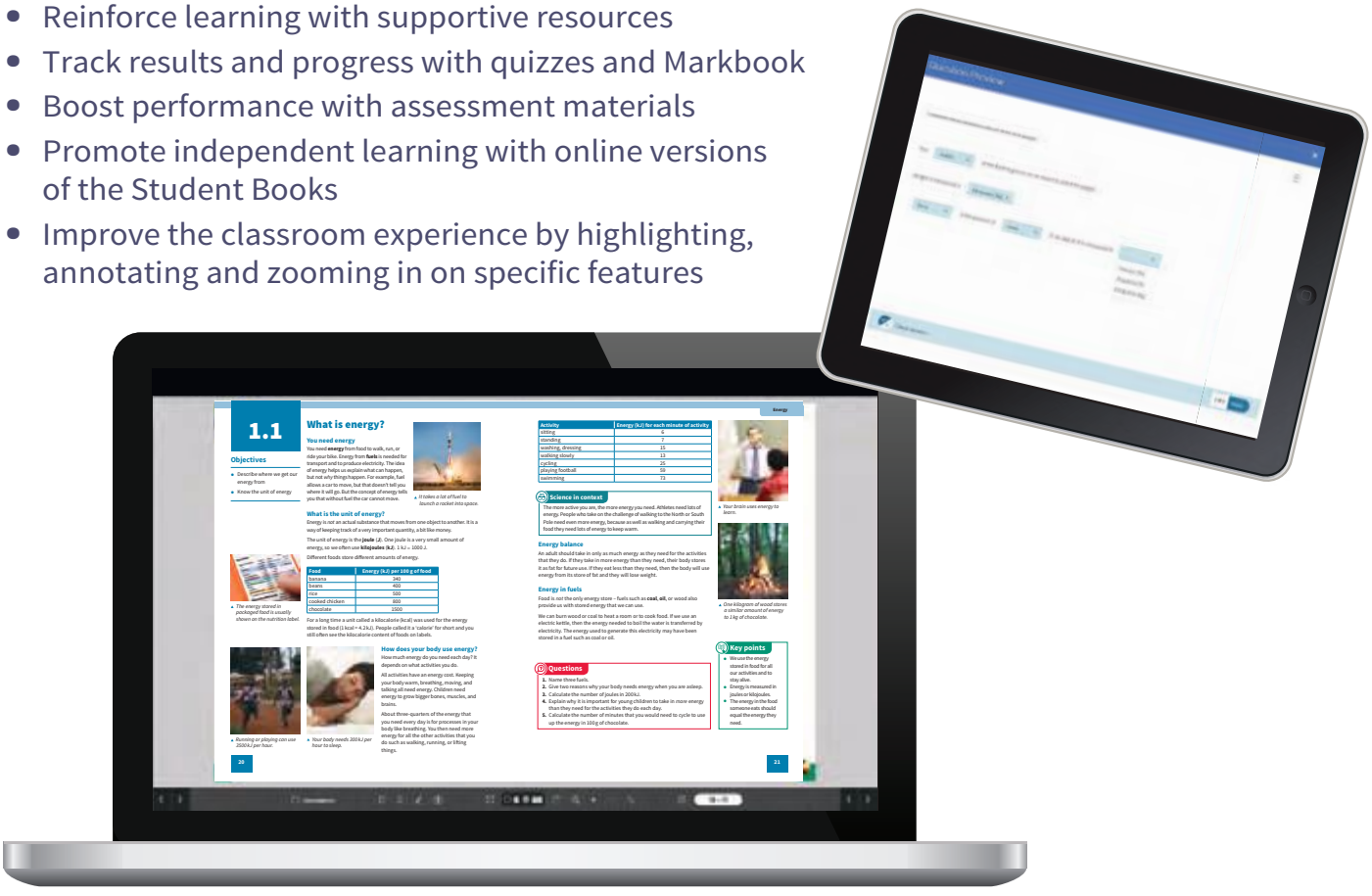
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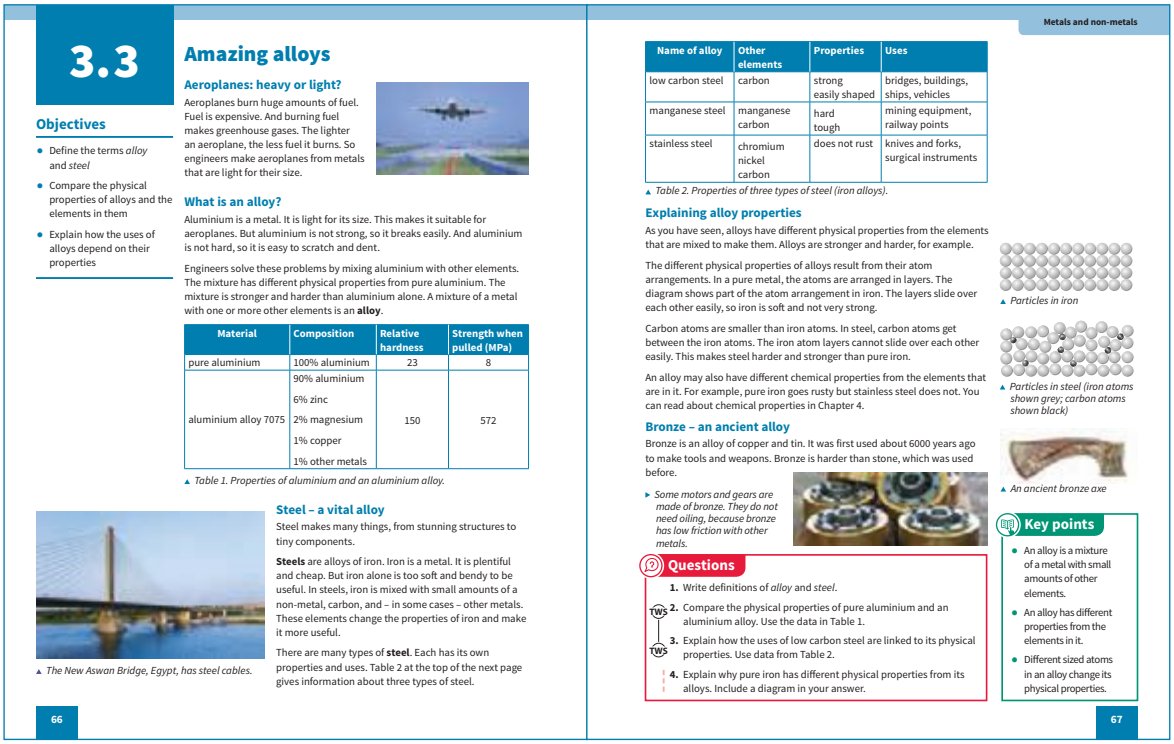
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Introduction

How to use your Student Book

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

Most of the units in this book work like this:



3.3

Amazing alloys

Objectives

- Define the terms *alloy* and *steel*
- Compare the physical properties of alloys and the elements in them
- Explain how the uses of alloys depend on their properties

Aeroplanes: heavy or light?

Aeroplanes burn huge amounts of fuel. Fuel is expensive. And burning fuel makes greenhouse gases. The lighter an aeroplane, the less fuel it burns. So engineers make aeroplanes from metals that are light for their size.

What is an alloy?

Aluminium is a metal. It is light for its size. This makes it suitable for aeroplanes. But aluminium is not strong, so it breaks easily. And aluminium is not hard, so it is easy to scratch and dent.

Engineers solve these problems by mixing aluminium with other elements. The mixture has different physical properties from pure aluminium. The mixture is stronger and harder than aluminium alone. A mixture of a metal with one or more other elements is an **alloy**.

Material	Composition	Relative hardness	Strength when pulled (MPa)
pure aluminium	100% aluminium	23	8
aluminium alloy 7075	90% aluminium 6% zinc 2% magnesium 1% copper 1% other metals	150	572

▲ *Table 1. Properties of aluminium and an aluminium alloy.*

▲ *The New Aswan Bridge, Egypt, has steel cables.*

Steel – a vital alloy

Steel makes many things, from stunning structures to tiny components.

Steels are alloys of iron. Iron is a metal. It is plentiful and cheap. But iron alone is too soft and bendy to be useful. In steels, iron is mixed with small amounts of a non-metal, carbon, and – in some cases – other metals. These elements change the properties of iron and make it more useful.

There are many types of **steel**. Each has its own properties and uses. Table 2 at the top of the next page gives information about three types of steel.

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Metals and non-metals

Name of alloy	Other elements	Properties	Uses
low carbon steel	carbon	strong easily shaped	bridges, buildings, ships, vehicles
manganese steel	manganese carbon	hard tough	mining equipment, railway points
stainless steel	chromium nickel carbon	does not rust	knives and forks, surgical instruments

▲ *Table 2. Properties of three types of steel (iron alloys).*

Explaining alloy properties

As you have seen, alloys have different physical properties from the elements that are mixed to make them. Alloys are stronger and harder, for example.

The different physical properties of alloys result from their atom arrangements. In a pure metal, the atoms are arranged in layers. The diagram shows part of the atom arrangement in iron. The layers slide over each other easily, so iron is soft and not very strong.

Carbon atoms are smaller than iron atoms. In steel, carbon atoms get between the iron atoms. The iron atom layers cannot slide over each other easily. This makes steel harder and stronger than pure iron.

An alloy may also have different chemical properties from the elements that are in it. For example, pure iron goes rusty but stainless steel does not. You can read about chemical properties in Chapter 4.

▲ *Particles in iron*

▲ *Particles in steel (iron atoms shown grey; carbon atoms shown black)*

Bronze – an ancient alloy

Bronze is an alloy of copper and tin. It was first used about 6000 years ago to make tools and weapons. Bronze is harder than stone, which was used before.

▲ *An ancient bronze axe*

▸ *Some motors and gears are made of bronze. They do not need oiling, because bronze has low friction with other metals.*

Questions

1. Write definitions of *alloy* and *steel*.
2. Compare the physical properties of pure aluminium and an aluminium alloy. Use the data in Table 1.
3. Explain how the uses of low carbon steel are linked to its physical properties. Use data from Table 2.
4. Explain why pure iron has different physical properties from its alloys. Include a diagram in your answer.

Key points

- An alloy is a mixture of a metal with small amounts of other elements.
- An alloy has different properties from the elements in it.
- Different sized atoms in an alloy change its physical properties.

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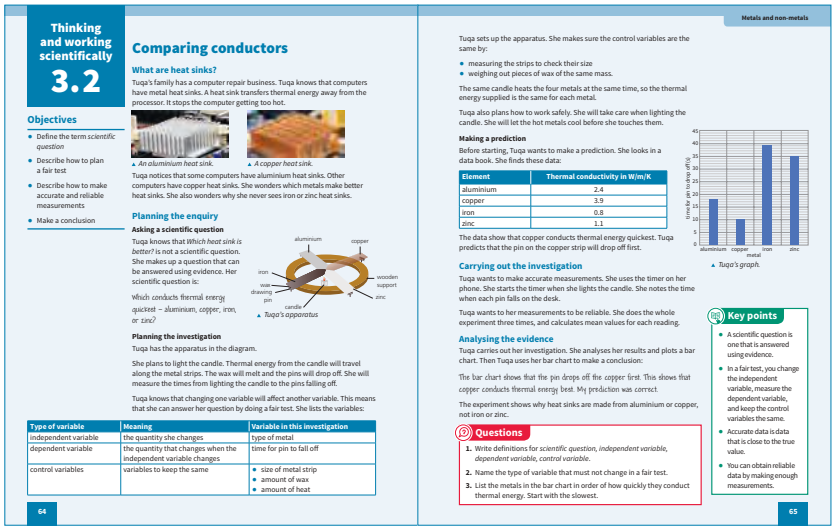
- Every page starts with the learning objectives for the unit. The learning objectives are linked to the Cambridge Lower Secondary Science curriculum framework.
- Key words are marked in **bold**. You can check the meaning of these words in the glossary at the back of the book.
- At the end of each unit 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 Chemistry 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 3.2

Comparing conductors

What are heat sinks?

Tuqa's family has a computer repair business. Tuqa knows that computers have metal heat sinks. A heat sink transfers thermal energy away from the processor. It stops the computer getting too hot.

Objectives

- Define the term *scientific question*
- Describe how to plan a fair test
- Describe how to make accurate and reliable measurements
- Make a conclusion

▲ *An aluminium heat sink.* ▲ *A copper heat sink.*

Tuqa notices that some computers have aluminium heat sinks. Other computers have copper heat sinks. She wonders which metals make better heat sinks. She also wonders why she never sees iron or zinc heat sinks.

Planning the enquiry

Asking a scientific question

Tuqa knows that *Which heat sink is better?* is not a scientific question. She makes up a question that can be answered using evidence. Her scientific question is:

Which conducts thermal energy quickest – aluminium, copper, iron, or zinc?

▲ *Tuqa's apparatus*

Planning the investigation

Tuqa has the apparatus in the diagram.

She plans to light the candle. Thermal energy from the candle will travel along the metal strips. The wax will melt and the pins will drop off. She will measure the times from lighting the candle to the pins falling off.

Tuqa knows that changing one variable will affect another variable. This means that she can answer her question by doing a fair test. She lists the variables:

Type of variable	Meaning	Variable in this investigation
independent variable	the quantity she changes	type of metal
dependent variable	the quantity that changes when the independent variable changes	time for pin to fall off
control variables	variables to keep the same	• size of metal strip • amount of wax • amount of heat

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Metals and non-metals

Tuqa sets up the apparatus. She makes sure the control variables are the same by:

- measuring the strips to check their size
- weighing out pieces of wax of the same mass.

The same candle heats the four metals at the same time, so the thermal energy supplied is the same for each metal.

Tuqa also plans how to work safely. She will take care when lighting the candle. She will let the hot metals cool before she touches them.

Making a prediction

Before starting, Tuqa wants to make a prediction. She looks in a data book. She finds these data:

Element	Thermal conductivity in W/m/K
aluminium	2.4
copper	3.9
iron	0.8
zinc	1.1

The data show that copper conducts thermal energy quickest. Tuqa predicts that the pin on the copper strip will drop off first.

▲ *Tuqa's graph.*

Carrying out the investigation

Tuqa wants to make accurate measurements. She uses the timer on her phone. She starts the timer when she lights the candle. She notes the time when each pin falls on the desk.

Tuqa wants to her measurements to be reliable. She does the whole experiment three times, and calculates mean values for each reading.

Analysing the evidence

Tuqa carries out her investigation. She analyses her results and plots a bar chart. Then Tuqa uses her bar chart to make a conclusion:

The bar chart shows that the pin drops off the copper first. This shows that copper conducts thermal energy best. My prediction was correct.

The experiment shows why heat sinks are made from aluminium or copper, not iron or zinc.

Questions

1. Write definitions for *scientific question*, *independent variable*, *dependent variable*, *control variable*.
2. Name the type of variable that must not change in a fair test.
3. List the metals in the bar chart in order of how quickly they conduct thermal energy. Start with the slowest.

Key points

- A scientific question is one that is answered using evidence.
- In a fair test, you change the independent variable, measure the dependent variable, and keep the control variables the same.
- Accurate data is data that is close to the true value.
- You can obtain reliable data by making enough measurements.

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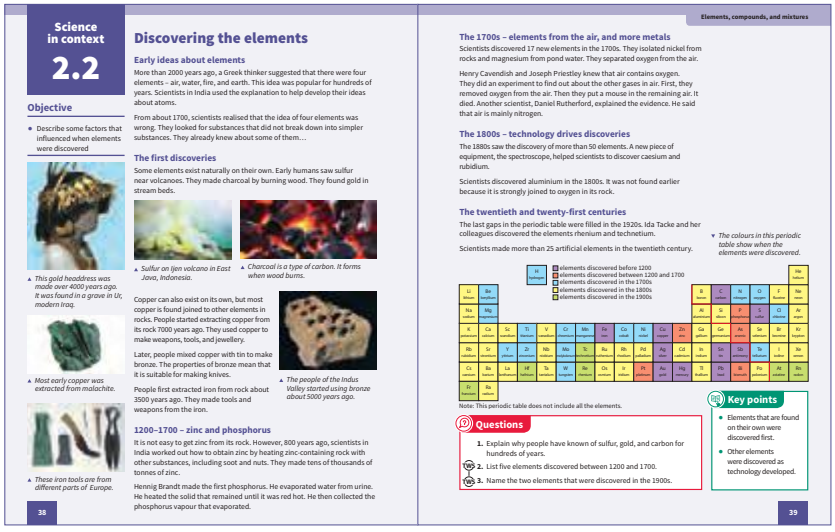
The Thinking and working scientifically units and features will help you learn:

- 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 2.2

Discovering the elements

Early ideas about elements

More than 2000 years ago, a Greek thinker suggested that there were four elements – air, water, fire, and earth. This idea was popular for hundreds of years. Scientists in India used the explanation to help develop their ideas about atoms.

Objective

- Describe some factors that influenced when elements were discovered

From about 1700, scientists realised that the idea of four elements was wrong. They looked for substances that did not break down into simpler substances. They already knew about some of them…

The first discoveries

Some elements exist naturally on their own. Early humans saw sulfur near volcanoes. They made charcoal by burning wood. They found gold in stream beds.

▲ *This gold headdress was made over 4000 years ago. It was found in a grave in Ur, modern Iraq.*

▲ *Sulfur on Ijen volcano in East Java, Indonesia.* ▲ *Charcoal is a type of carbon. It forms when wood burns.*

Copper can also exist on its own, but most copper is found joined to other elements in rocks. People started extracting copper from its rock 7000 years ago. They used copper to make weapons, tools, and jewellery.

▲ *Most early copper was extracted from malachite.*

Later, people mixed copper with tin to make bronze. The properties of bronze mean that it is suitable for making knives.

▲ *The people of the Indus Valley started using bronze about 5000 years ago.*

People first extracted iron from rock about 3500 years ago. They made tools and weapons from the iron.

▲ *These iron tools are from different parts of Europe.*

1200–1700 – zinc and phosphorus

It is not easy to get zinc from its rock. However, 800 years ago, scientists in India worked out how to obtain zinc by heating zinc-containing rock with other substances, including soot and nuts. They made tons of thousands of tonnes of zinc.

Hennig Brandt made the first phosphorus. He evaporated water from urine. He heated the solid that remained until it was red hot. He then collected the phosphorus vapour that evaporated.

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Elements, compounds, and mixtures

The 1700s – elements from the air, and more metals

Scientists discovered 17 new elements in the 1700s. They isolated nickel from rocks and magnesium from pond water. They separated oxygen from the air.

Henry Cavendish and Joseph Priestley knew that air contains oxygen. They did an experiment to find out about the other gases in air. First, they removed oxygen from the air. Then they put a mouse in the remaining air. It died. Another scientist, Daniel Rutherford, explained the evidence. He said that air is mainly nitrogen.

The 1800s – technology drives discoveries

The 1880s saw the discovery of more than 50 elements. A new piece of equipment, the spectroscope, helped scientists to discover caesium and rubidium.

Scientists discovered aluminium in the 1800s. It was not found earlier because it is strongly joined to oxygen in its rock.

The twentieth and twenty-first centuries

The last gaps in the periodic table were filled in the 1920s. Ida Tacke and her colleagues discovered the elements rhenium and technetium.

Scientists made more than 25 artificial elements in the twentieth century.

▼ *The colours in this periodic table show when the elements were discovered.*

Note: This periodic table does not include all the elements.

Questions

1. Explain why people have known of sulfur, gold, and carbon for hundreds of years.
2. List five elements discovered between 1200 and 1700.
3. Name the two elements that were discovered in the 1900s.

Key points

- Elements that are found on their own were discovered first.
- Other elements were discovered as technology developed.

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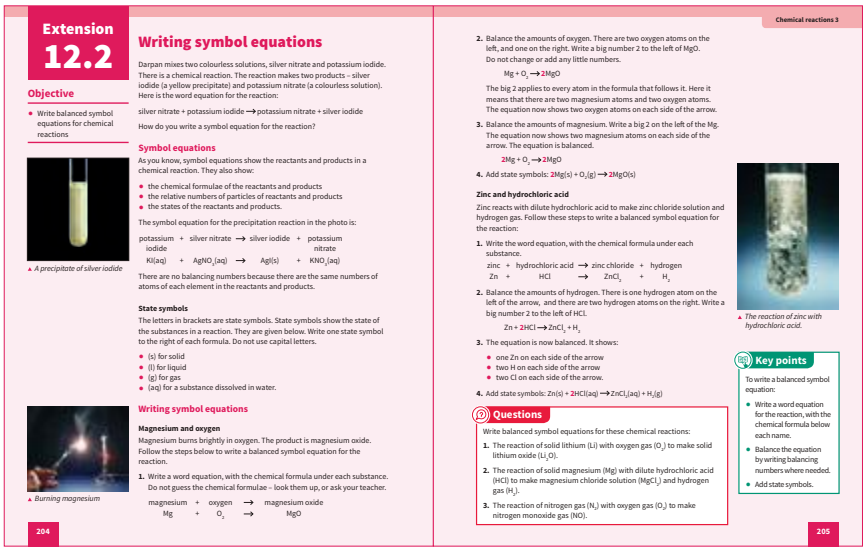
Science in context units will also help you learn:

- 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 chemistry are evaluated
- the global impact of the use of chemistry.

Extension

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

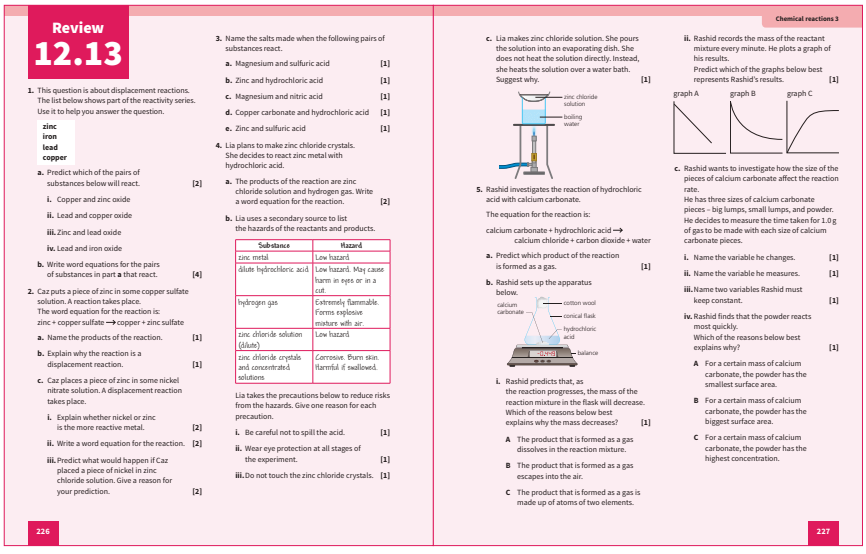
> You can tell when a question or part of a unit is Extension because it is marked with a dashed line, like the one on the left.



Extension 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 Chemistry.

Review

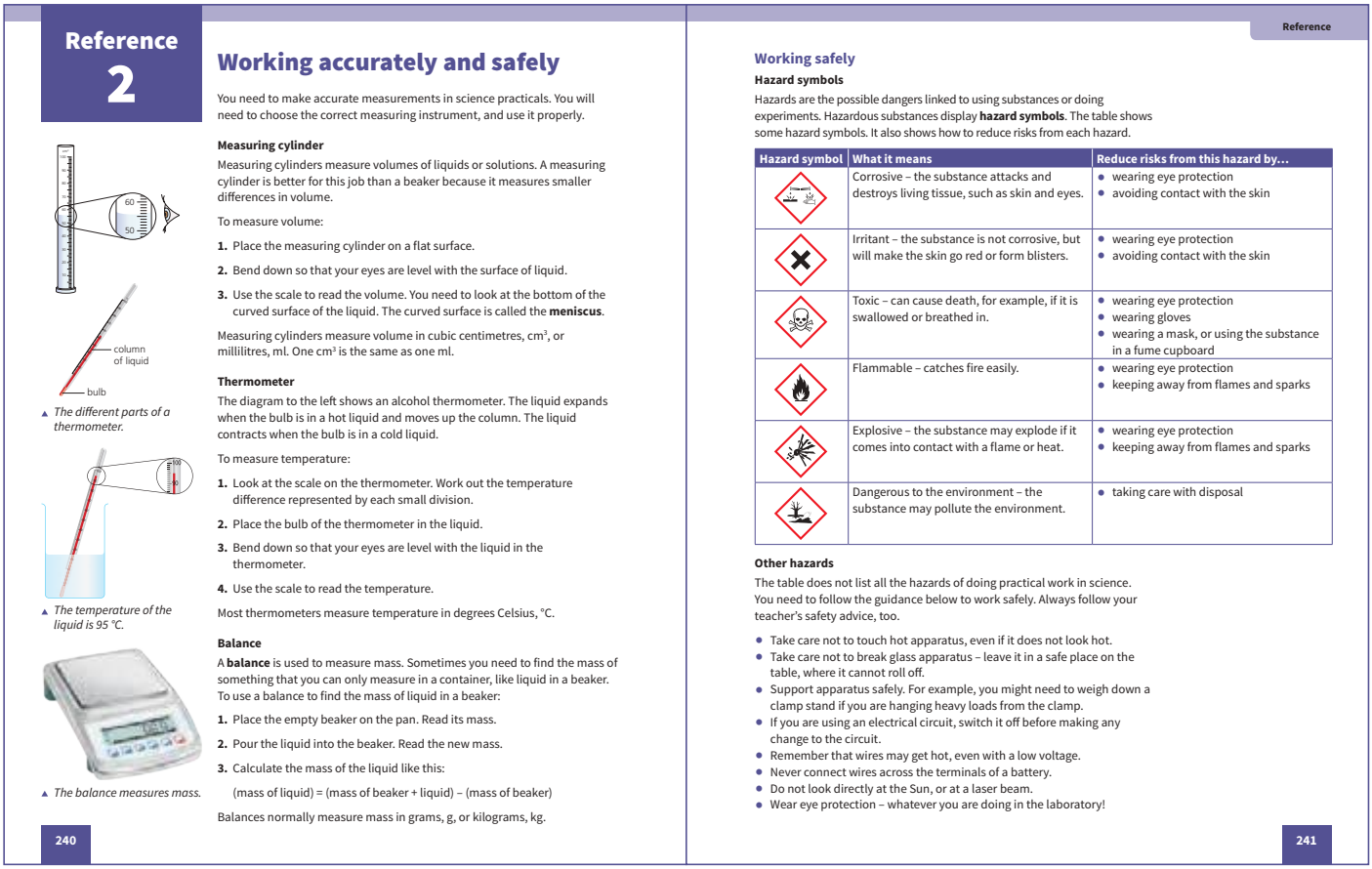
At the end of every chapter and every stage there are review questions.



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 238-241, there are reference pages providing further information that will help you while you study.



Reference 2

Working accurately and safely

You need to make accurate measurements in science practicals. You will need to choose the correct measuring instrument, and use it properly.

Measuring cylinder

Measuring cylinders measure volumes of liquids or solutions. A measuring cylinder is better for this job than a beaker because it measures smaller differences in volume.

To measure volume:

1. Place the measuring cylinder on a flat surface.
2. Bend down so that your eyes are level with the surface of liquid.
3. Use the scale to read the volume. You need to look at the bottom of the curved surface of the liquid. The curved surface is called the **meniscus**.

Measuring cylinders measure volume in cubic centimetres, cm^3, or millilitres, ml. One cm^3 is the same as one ml.

▲ *The different parts of a thermometer.*

Thermometer

The diagram to the left shows an alcohol thermometer. The liquid expands when the bulb is in a hot liquid and moves up the column. The liquid contracts when the bulb is in a cold liquid.

▲ *The temperature of the liquid is 95 °C.*

To measure temperature:

1. Look at the scale on the thermometer. Work out the temperature difference represented by each small division.
2. Place the bulb of the thermometer in the liquid.
3. Bend down so that your eyes are level with the liquid in the thermometer.
4. Use the scale to read the temperature.

Most thermometers measure temperature in degrees Celsius, °C.

Balance

A **balance** is used to measure mass. Sometimes you need to find the mass of something that you can only measure in a container, like liquid in a beaker. To use a balance to find the mass of liquid in a beaker:

▲ *The balance measures mass.*

1. Place the empty beaker on the pan. Read its mass.
2. Pour the liquid into the beaker. Read the new mass.
3. Calculate the mass of the liquid like this:

   (mass of liquid) = (mass of beaker + liquid) – (mass of beaker)

Balances normally measure mass in grams, g, or kilograms, kg.

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Reference

Working safely

Hazard symbols

Hazards are the possible dangers linked to using substances or doing experiments. Hazardous substances display **hazard symbols**. The table shows some hazard symbols. It also shows how to reduce risks from each hazard.

Hazard symbol	What it means	Reduce risks from this hazard by…
	Corrosive – the substance attacks and destroys living tissue, such as skin and eyes.	• wearing eye protection • avoiding contact with the skin
	Irritant – the substance is not corrosive, but will make the skin go red or form blisters.	• wearing eye protection • avoiding contact with the skin
	Toxic – can cause death, for example, if it is swallowed or breathed in.	• wearing eye protection • wearing gloves • wearing a mask, or using the substance in a fume cupboard
	Flammable – catches fire easily.	• wearing eye protection • keeping away from flames and sparks
	Explosive – the substance may explode if it comes into contact with a flame or heat.	• wearing eye protection • keeping away from flames and sparks
	Dangerous to the environment – the substance may pollute the environment.	• taking care with disposal

Other hazards

The table does not list all the hazards of doing practical work in science. You need to follow the guidance below to work safely. Always follow your teacher's safety advice, too.

- Take care not to touch hot apparatus, even if it does not look hot.
- Take care not to break glass apparatus – leave it in a safe place on the table, where it cannot roll off.
- Support apparatus safely. For example, you might need to weigh down a clamp stand if you are hanging heavy loads from the clamp.
- If you are using an electrical circuit, switch it off before making any change to the circuit.
- Remember that wires may get hot, even with a low voltage.
- Never connect wires across the terminals of a battery.
- Do not look directly at the Sun, or at a laser beam.
- Wear eye protection – whatever you are doing in the laboratory!

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They include information on:

- how to choose suitable apparatus
- how to work accurately and safely.

There is also a periodic table of the elements at the end of this book, which you can quickly refer to whenever you need to.

1.1

The particle model

Objectives

- Define the terms *material, substance, particle model, property*
- Describe the particle model
- List the factors that give a substance its properties

The picture shows a lake in Sikkim, India. Imagine visiting the lake and the mountains. What are they made from?



What is matter made from?

The different types of matter (stuff) that things are made from are **materials**. There are millions of materials. The water of the lake is a material. The rock of the mountains is a material. The gases of the air are materials, too.

All materials are made up of tiny **particles**. Particles are too small to see. One grain of sugar is made up of about 1 000 000 000 000 000 000 particles.

Substance or material?

Most materials are mixtures. Wood is a mixture. So is soil and most rock. But some materials are not mixtures. They have just one type of matter. A material that has one type of matter is called a **substance**. Substances include silver, sugar, and pure water.

All the particles in a substance are the same as each other. One water particle is the same as all other water particles. One silver particle is the same as all other silver particles.

But the particles of different substances are different. Water particles are different to silver particles. Silver particles are different to sugar particles. Every substance has its own type of particle.

What are properties?

Every substance has its own properties. The **properties** of a substance describe what it is like and what it does. The pictures show some of the properties of three substances at room temperature (20 °C).



▲ *Silver is shiny. Its shape stays the same unless you apply a force.*



▲ *Water has no colour. It flows.*



▲ *Sugar is white. It has a sweet taste.*

How does the particle model explain properties?

The **particle model** describes the arrangement and movement of the particles in a substance. You can use the particle model to explain properties. The properties of a substance depend on five factors:

- what its particles are like
- how its particles are arranged
- how its particles move
- how far apart the particles are (their separation)
- how strongly its particles hold together (their attraction for each other).

The pictures and captions show how the particle model explains some properties.



▲ *A gold particle is a similar size to a copper particle. But a gold particle is heavier than a copper particle. This explains why a gold coin is heavier than a copper coin of the same size.*



▲ *Liquid water and steam have the same particles. But the particles in steam are further apart than the particles in liquid water. So, one gram of steam takes up more space than one gram of liquid water.*



▲ *The particles in liquid water move around. The particles in solid rock are held in one place. This explains why liquid water flows but solid rock does not flow.*



▲ *The particles in silver hold together less strongly than the particles in diamond. This explains why silver is easier to scratch than diamond.*

Questions

1. Write definitions for *substance, material, property, particle model*.
2. Describe three properties of silver at room temperature.
3. Choose the one factor from the list that explains why ice is easier to scratch than silver.
   List of factors: what the particles are like, how the particles are arranged, how strongly the particles hold together.
4. A gold particle is the same size as a silver particle. Suggest why a gold ring is heavier than a silver ring of the same size.

Key points

- Matter is made up of particles.
- A substance has one type of particle.
- The properties of a substance describe what it is like and what it does.
- The particle model explains properties.

1.2

The states of matter

Objectives

- Define the term *physical property*
- List the three states of matter
- Describe differences in the physical properties of a substance in its three states
- Describe the arrangement, movement, separation, and attraction of the particles in the three states

What do the pictures have in common?







The pictures show water in its three states: solid, liquid, and gas. Most substances can exist as a solid, liquid, or gas. These are the three **states of matter**.

What are the properties of a substance in its three states?

Ritula has a jug of liquid water. She pours some water into a glass. The shape of the water changes.



▲ *Liquid water changes shape.*

Ritula also has some ice shapes. Ice is water in the solid state. If Ritula keeps the ice cold, the shapes do not change.



▲ *Solid water (ice) shapes do not change shape.*

Shape – and whether or not it can change – is one property that depends on the state of a substance. The table shows some other properties that depend on state.

State	In this state, does a substance flow?	In this state, can you compress (squash) a substance?	In this state, can the shape change?
solid	no	only a tiny bit	shape stays the same unless you apply a force
liquid	yes	only a tiny bit	takes the shape of the bottom of its container
gas	yes	yes, a lot	takes the shape of the whole container

The properties in the table are physical properties. **Physical properties** are properties that you can observe or measure without changing a material.

What do the particles do in the three states?

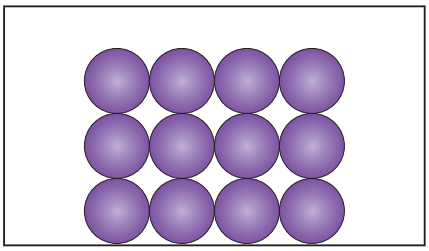
The particle model explains the physical properties of a substance in its three states. The particles themselves are the same in all three states. For example, a particle in ice is the same as a particle in liquid water and in steam.

But some factors are different for a substance in the three states:

- how its particles are arranged
- how its particles move
- how far apart the particles are (their separation)
- how strongly the particles hold together.

The solid state

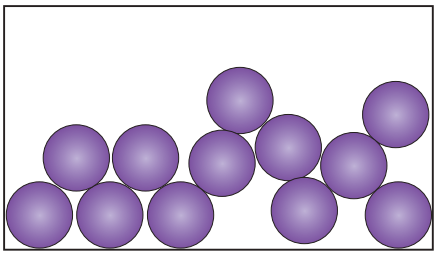
In the solid state, the particles touch each other. The particles are in fixed positions in a regular pattern. The particles vibrate on the spot. The particles hold together strongly.



▲ *Some particles of a substance in the solid state.*

The liquid state

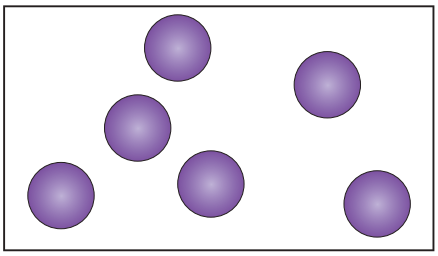
In the liquid state, the particles touch each other. They are not in a pattern. The particles move around randomly, sliding over each other. The particles hold together strongly.



▲ *Some particles of a substance in the liquid state.*

The gas state

In the gas state, the particles are far apart. They are not in a pattern. The particles move around very fast, in all directions. The particles do not hold together strongly.



▲ *Some particles of a substance in the gas state.*

The table summarises the arrangement and behaviour of the particles in the three states.

State	How close are the particles?	How are the particles arranged?	How do the particle move?	How strongly do the particles hold together?
solid	touching	in a pattern	vibrate on the spot	strongly
liquid	touching	randomly	move around randomly, sliding over each other	strongly
gas	far apart	randomly	move around randomly, in all directions	very weakly

Questions

1. List the three states of matter.
2. Describe two differences and one similarity between the physical properties of a substance in the solid and liquid states.
3. Describe the arrangement, movement, and separation of the particles in the liquid state.
4. Compare how strongly the particles hold together in the liquid and gas state.

Key points

- There are three states of matter: solid, liquid, and gas.
- Physical properties are those you can observe or measure without changing a material.
- A substance has different physical properties in its three states.
- The particles have different arrangements in the three states, and they move and are held together differently.

1.3

Objectives

- Use the particle model to explain the physical properties of substances in their three states
- Define the term *vacuum*
- Describe one application of science

Science in context

Keeping vaccines cold

Solid carbon dioxide is also called dry ice. Dry ice can keep vaccines very cold. It is packed into boxes around the vaccine bottles.



▲ *Dry ice keeps one COVID-19 vaccine colder than −70 °C.*

Using the particle model

The picture shows carbon dioxide in the solid state. The shape and size of each lump does not change, if it is kept cold. But in the gas state, carbon dioxide spreads out and mixes with the air, all around the Earth. Why is this property so different in the two states?



How does the particle model explain shape?

In solid carbon dioxide, the particles are arranged in fixed positions. They hold together strongly. This explains why the shape and size of each lump does not change.

In the gas state, the particles move around. They do not hold together strongly. This explains why carbon dioxide gas spreads out. It takes the shape of its container.



◀ *Pouring water*

This boy is playing with liquid water. He pours it from one jar to another. The shape of the water changes, because the particles move around.

How does the particle model explain other physical properties?

Different parts of the particle model explain different properties.

Flow

A substance can flow in its liquid and gas states. This is because the particles move around. But in the solid state, the particles are in fixed positions. They cannot move. This explains why, in the solid state, a substance cannot flow.



▲ *Liquid mercury flows, but solid mercury cannot flow.*



▲ *Carbon dioxide flows in the gas state. Solid carbon dioxide cannot flow.*

Compression

There is enough oxygen squashed into the firefighter's cylinder to support her for several hours. Normally, this amount of oxygen fills 1000 soda bottles.

You can **compress** (squash) all substances in the gas state. This is because the particles are far apart. They get closer together when the gas is compressed. The particles themselves stay the same – they do not change size.

In the solid and liquid states, a substance can be compressed only a very tiny bit. This is because the particles are already touching.



▲ *The firefighter's cylinder is full of oxygen.*

What is a vacuum?

A space that has no particles (and so no matter) is called a **vacuum**. Most of outer space is close to being a vacuum. But there are a few particles in outer space. They are very, very, very far apart.

Questions

1. Write the definition for a *vacuum.*
2. Choose the one factor from the list that can be used to explain why a gas can be compressed.
   List of factors: how the particles move, how the particles are separated, what the particles are like.
3. Use the particle model to explain why a lump of a solid does not change its shape.
4. Use the particle model to explain why the shape of liquid water can change.
5. Describe how a substance flows, or does not flow, in the solid, liquid, and gas states. Use the particle model to explain your answer.

Key points

- The particle model explains properties such as whether a substance flows or can be compressed.
- Different parts of the particle model explain different properties.
- A vacuum is a space that has no matter in it.

1.4

Objectives

- Define the terms *boiling, evaporating*, and *condensing*
- Describe how the arrangement, movement, and separation of the particles change when a substance boils, evaporates, or condenses
- Make conclusions from data

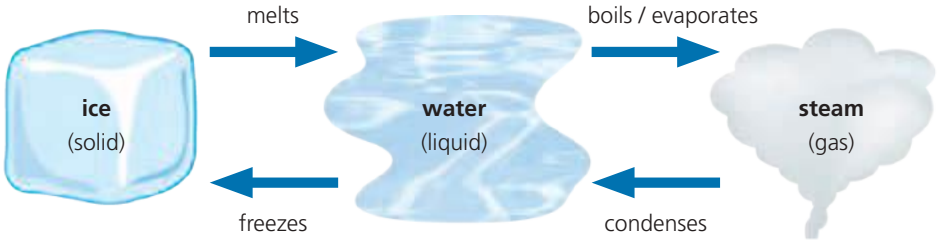
Changes of state – evaporating, boiling, and condensing



Chahaya lights a candle. Some of the solid wax melts, forming liquid wax. Some of the liquid wax evaporates, forming wax in the gas state. The wax gas burns.

What are changes of state?

Melting and evaporating are **changes of state**. The diagram gives the names for six changes of state. You may already know the names.



Most substances change state, not just water.

How does the particle model explain changes of state?

When a substance changes from one state to another, its particles stay the same. They do not change. The things that change are:

- how the particles are arranged
- how the particles move
- the separation of the particles.

Evaporating or **evaporation** is the change of state from liquid to gas that can happen at any temperature.

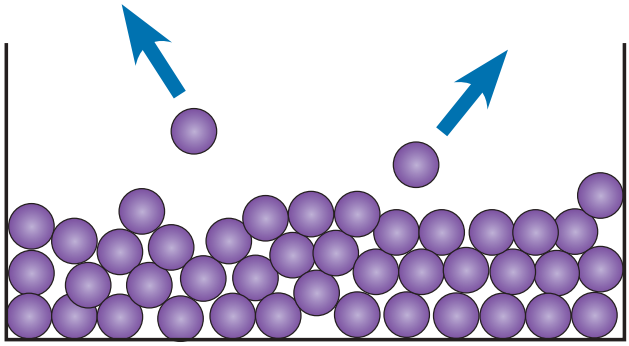
In the liquid state, particles touch each other. They move around, sliding over each other. Some particles move faster than others. The faster-moving particles leave the surface of liquid. They separate from each other, forming gas. This is evaporation.



▲ *Clothes dry when water evaporates from them.*



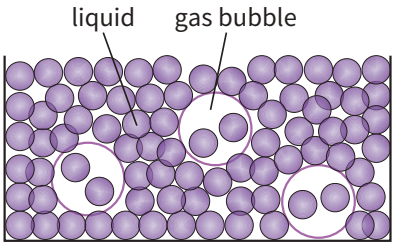
▲ *The eggs are cooking in boiling water.*



◀ *During evaporation, particles leave the liquid surface. Not to scale.*

Boiling is the change of state from liquid to gas. It only happens if the liquid is hot enough.

When you heat liquid water, bubbles of steam form everywhere in the liquid. In liquid water, the particles are touching each other. Inside the bubbles, the particles are spread out. The bubbles rise to the surface and escape. The water is boiling.



▲ *When a liquid is boiling, bubbles of gas form throughout. Not to scale.*

The temperature that a substance boils at is its **boiling point.** Different substances have different boiling points. A substance has a high boiling point if its particles hold together strongly. A substance has a low boiling point if its particles hold together weakly.

Process	Change of state	Temperature	How particles leave the liquid
evaporating	from liquid to gas	happens at any temperature	particles leave the liquid surface
boiling	from liquid to gas	happens at the boiling point	bubbles of the substance in the gas state form everywhere in the liquid; the bubbles rise to the surface and escape

▲ *Table 1: A comparison of evaporating and boiling.*

Thinking and working scientifically

Making conclusions from data

Table 2 shows the boiling points of six substances.

You can interpret the data in the table to make conclusions.

- First conclusion: Diamond has the highest boiling point. Its particles are held together most strongly.
- Second conclusion: The boiling point of nitrogen is lower than room temperature (20 °C). This means that nitrogen is in the gas state at room temperature.

Substance	Boiling point (°C)
nitrogen	−196
chlorine	−102
ethanol	78
water	100
mercury	357
copper	2595
diamond	5100

▲ *Table 2*

Condensing or **condensation** is the change of state from gas to liquid. A gas condenses at any temperature below its boiling point.

When a substance changes from the gas state to the liquid state, the particles in the gas move more slowly. They get closer until they are touching, forming liquid. The substance has condensed.

Questions

1. Name the change of state from gas to liquid.
2. Describe the movement and separation of the particles before and after a substance evaporates.
3. Compare evaporating and boiling. Use Table 1 to help you.

TWS 4. Look at the data in Table 2. Name one substance, other than nitrogen, that is in the gas state at 20 °C.

Key points

- A substance changes from liquid to gas by evaporating or boiling.
- A substance changes from gas to liquid by condensing.
- Every substance has its own boiling point.

Thinking and working scientifically

1.5

Objectives

- Describe how to collect evidence to test a hypothesis
- Draw a graph to present data
- Describe patterns in results and make conclusions

Investigating boiling points

Rabia is a school student. She lives in Mumbai, a city by the sea. She visits Leh, high in the mountains. She discovers that water boils at different temperatures in the two places. Rabia asks a scientific question:

Why does water boil at different temperatures in different places?





Planning the investigation

Making a hypothesis

Rabia makes a hypothesis. As you know, a hypothesis is a possible explanation that is based on evidence, and can be tested further.

My hypothesis – The boiling point of water depends on altitude (height above sea level). The higher the altitude, the lower the boiling point.

Rabia can collect evidence to find out if her hypothesis is correct. This means that the hypothesis is testable.

Carrying out the investigation

Rabia uses a thermometer to measure the boiling point of water in Mumbai. This is not enough evidence to test her hypothesis. She needs to collect more evidence. She asks her relatives to measure the boiling temperature of water in other places.

Some of her relatives send photos of the thermometers they use.



▲ *Different thermometers*

Rabia then uses the Internet to find the altitude of each place, and the boiling temperatures on two mountain summits. Rabia writes all the results in a table. This makes it easy to see all the data.

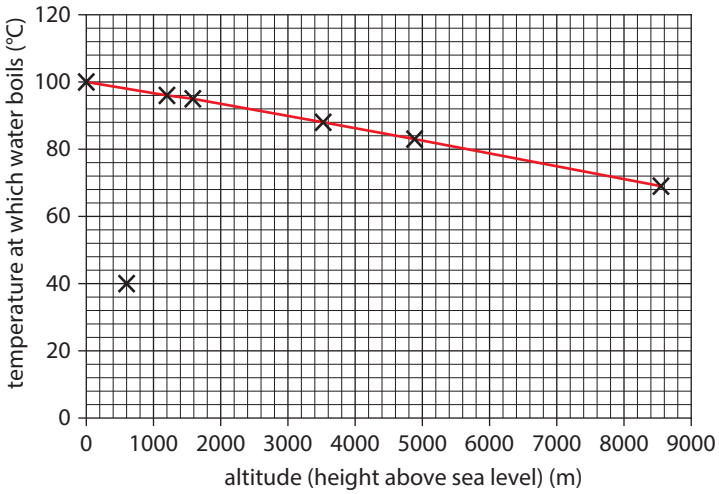
Place	Altitude (metres above sea level)	Boiling temperature of water (°C)
Chennai, India	0	100
Jos, Nigeria	1200	96
Leh, India	3524	88
Mumbai, India	0	100
Riyadh, Saudi Arabia	610	40
Srinagar, India	1585	95
Summit of Mount Everest, Nepal	8550	69
Summit of Puncak Jaya, Indonesia	4884	83

Analysing the evidence

Making a conclusion

Rabia uses the data in her table to draw a line graph. This will make it easier to spot a pattern.

Rabia notices that the boiling point for Riyadh does not fit the pattern. It is anomalous. She messages her relative there. He said that he made a mistake, and measured the air temperature, not the boiling temperature of water. Rabia decides to ignore this result.



Rabia writes a conclusion:

My conclusion – My results show that as altitude increases, boiling temperature decreases. This supports my hypothesis. A limitation of my investigation is that it does not explain **why** boiling temperatures are different at different altitudes.

Suggesting improvements

Rabia knows that her uncle in Srinagar boiled water in three different pots. He measured the boiling temperature in each pot. It was the same each time. Rabia knows that his data is precise. If she did the investigation again, she would ask everyone to repeat the experiment three times.

Questions

1. Write the definition for *hypothesis*.
2. Use the table to write down the boiling temperature of water at the summit of Mount Everest. Include units in your answer.
3. Describe the pattern shown by the graph.
4. The city of Addis Ababa, in Ethiopia, is at altitude 2400 m. Use the graph to predict the boiling temperature of water in Addis Ababa.
5. Look at the pictures of the thermometers. Suggest and explain an improvement that Rabia could make to the investigation, other than asking everyone to repeat the experiment three times.

Key points

- A hypothesis is a possible explanation that is based on evidence and can be tested further.
- An anomalous result is one that does not fit the pattern.
- In a conclusion, describe any patterns and explain any limitations.

1.6

Changes of state – melting and freezing

Objectives

- Define the terms *melting* and *freezing*
- Describe how the arrangement, movement, and separation of the particles change when a substance melts or freezes
- Make conclusions from data



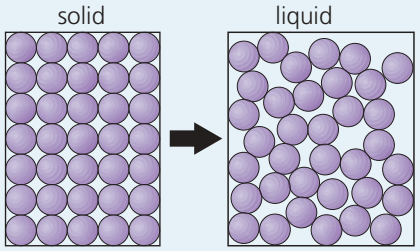
Arin puts some butter in a pan. He heats the pan. As he heats, the butter starts to become runny. It is changing from the solid state to the liquid state.

How does the particle model explain melting?

The change of state from solid to liquid is **melting**. When a solid begins to melt, its particles vibrate faster. The particles move out of their fixed positions. They move around, sliding over each other. Some of the substance is now in the liquid state.

If the substance continues to be heated, more of its particles start to move around. Eventually, all the substance has melted. In the liquid, the particle arrangement changes all the time.

But melting does not change the separation of the particles. The particles touch each other in both the solid and liquid states.



◀ *On melting, particles leave their fixed positions.*



▲ *Gallium melts on your hand. Its melting point is 30 °C.*



▲ *This photo shows ice forming from liquid water.*

Melting point

The temperature that a substance melts at is its **melting point**. Every substance has its own melting point. A substance has a high melting point if its particles are held together strongly.

Substance	Melting point (°C)
nitrogen	−210
water	0
gallium	30
paracetamol	169
gold	1063
copper	1083

Science in context

Identifying substances

Scientists use melting points to help identify substances. In a university laboratory, Gladys and Jamil follow instructions to make a painkiller, paracetamol. They end up with white crystals.

The students want to check that the crystals are definitely paracetamol. They put some crystals in a thin glass tube. They place the tube in the melting point apparatus. The substance melts at 169 °C. The melting point confirms that they have made paracetamol.



▲ *Using melting point apparatus.*

How does the particle model explain freezing?

The change of state from liquid to solid is **freezing**. A substance freezes at, or below, its melting point.

When a liquid freezes, its particles stop moving around from place to place. Over time, they arrange themselves in a pattern. Eventually, all the particles are in fixed positions. They vibrate on the spot. All of the substance is now frozen.

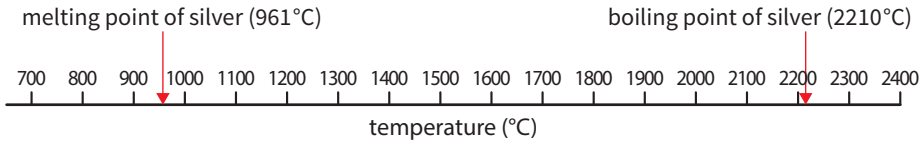
In melting and freezing, the particles themselves do not change. No particles are added or removed. This is true for all changes of state.

Thinking and working scientifically

Making conclusions from data: solid, liquid, or gas?

If you know the melting point and boiling point of a substance, you can predict its state at different temperatures:

- Below the melting point, it is in the solid state.
- Between its melting and boiling points, it is in the liquid state.
- Above its boiling point, it is in the gas state.



◀ *The diagram shows the melting point and boiling point of silver.*

Questions

1. Name the change of state from:

a. solid to liquid **b.** liquid to solid **c.** liquid to gas.

2. Describe the movement, arrangement, and separation of particles before and after freezing.

TWS TWS **3.** Look at the diagram of the melting point and boiling point of silver. Give the state of silver at these temperatures:
a. 700 °C **b.** 1400 °C **c.** 2400 °C **d.** 20 °C.

Key points

- Melting is the change of state from solid to liquid.
- Freezing is the change of state from liquid to solid.
- Every substance has its own melting point.

Thinking and working scientifically

1.7

Objectives

- Define the term *model* in science
- Consider strengths and limitations of the particle model

Models in science

Yana makes a model truck. How is the truck like a real truck? How is it different?



▲ *A model truck*

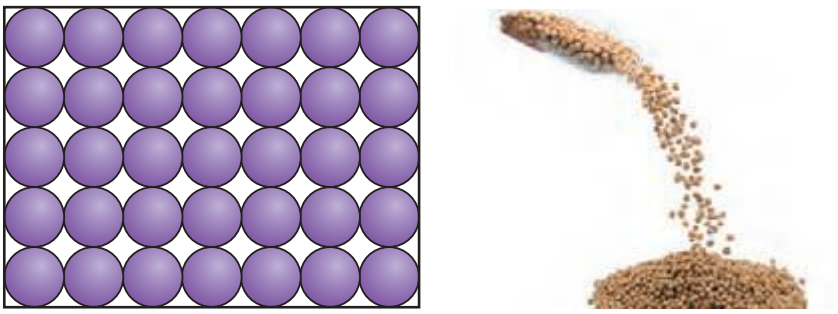


▲ *A real truck*

The model truck is the same colour as the real truck. It is a similar shape. But there are differences between the real truck and the model truck. The model truck is smaller. It cannot move by itself, or carry heavy loads.

What are models in science?

In science, a **model** is an idea that explains observations and helps in making predictions. The particle model is one model. You can imagine it in your head. You can draw it. Or you can use something else to represent the particles, like peas.



▲ *Two ways of representing the particle model – as a drawing, and with dried peas.*

There are many other models in science. Some models represent things that are very small, such as particles and cells. Some models represent things that are very big, such as the Solar System. You can read about other models later in the book.

What are the strengths and limitations of the particle model?

Strengths

Models help to explain things. The particle model explains why liquid water takes the shape of a cup, and why solid water does not. The particle model also explains changes of state, such as melting and freezing.

Models help in making predictions. If you know that the particles hold together strongly in solid gold, you can predict that gold has a high melting point.

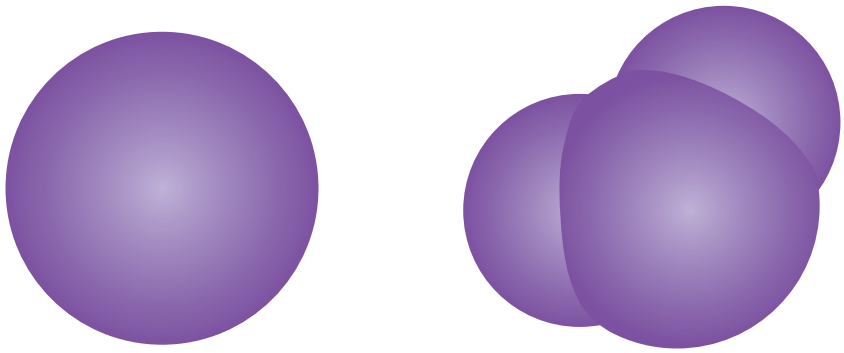


▲ *Gold has a high melting point.*

Limitations

Models are simpler than reality. This is what makes them useful. But because they are simpler, they are not exactly the same. A model can never be perfect. Every model has limitations.

In the particle model, every particle is a solid sphere. In reality, different particles are different shapes. And in reality, particles are not solid. As you will see in Chapter 7, particles are mostly empty space.



▲ *In the particle model, we imagine that all particles are spheres. But the shape of a water molecule is more like the shape on the right.*

The differences between the particle model and reality give the model some limitations, or weaknesses:

- The particle model does not explain all observations perfectly.
- Predictions made with the particle model are sometimes not accurate.

Even though the particle model has limitations, it is still useful.

Questions

1. Write the definition for a *model* in science.
2. Use the particle model to explain why you can pour a substance when it is liquid, but not solid.
3. Describe two ways that the particle model is different from reality.
4. Describe two limitations of the particle model.

Key points

- In science, a model is an idea that explains observations and helps in making predictions.
- Every model has strengths and limitations.

Review 1.8

1.



The picture shows water in two states.

a. Name the two states shown in the picture. **[2]**

b. Give the name of the state in which water takes the shape of the bottom of its container. **[1]**

c. Give the names of two states in which water can flow. **[1]**

2. Choose one word from the list below to answer each question part.

properties	**particle model**
substance	**physical properties**
vacuum	**evaporation**

a. These are properties that you can observe or measure without changing a material. **[1]**

b. A space with no particles in it. **[1]**

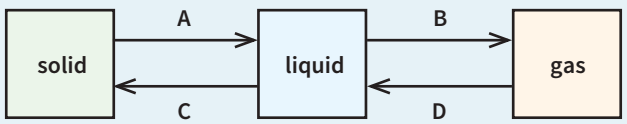
c. A material that has one type of matter. **[1]**

d. These describe what a substance is like and what it does. **[1]**

e. This describes the arrangement, separation, and movement of the particles in a substance. **[1]**

f. The change of state from liquid to gas that can happen at any temperature. **[1]**

3. In the diagram below, each arrow represents a change of state.



a. Give the letter of the arrow that shows freezing. **[1]**

b. Give the letter of the arrow that shows condensing. **[1]**

c. Give the name of the change of state represented by arrow A. **[1]**

d. Give the name of the change of state represented by arrow B. **[1]**

4. Use the words and phrases to copy and complete the sentences below. You may use each word or phrase once, more than once, or not at all.

a little	**close together**
far apart	**gas**
liquid	**much**
solid	**vibrate on the spot**

move around from place to place
move around and slide over each other

Copper exists in three states – solid, liquid, and _____. In the solid state, its particles _____. The particles are _____. When copper melts, it changes state from _____ to _____. Its particles start to _____. They get _____ further apart. If copper is heated to 1084 °C, it changes from the liquid to the _____ state. Its particles get _____ further apart and they start to _____. **[10]**

5. TWS The table gives the melting points and boiling points for five substances.

Substance	Melting point (°C)	Boiling point (°C)
bromine	−7	59
chlorine	−102	−34
iodine	114	184
osmium	3000	5000
tungsten	3422	5555

a. Name the substance in the table with the highest melting point. **[1]**

b. Name the substance in the table with the lowest boiling point. **[1]**

c. Name one substance in the table that is in the gas state at 20 °C. **[1]**

d. Name two substances in the table that are in the solid state at 20 °C. **[1]**

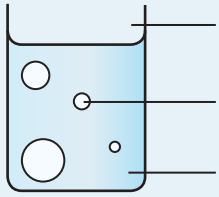
e. Give the state of bromine at 20 °C. **[1]**

f. Copy and complete the sentence using words from the list. You may use them once, more than once, or not at all.
solid **liquid** **gas**
When bromine is heated from 20 °C to 100 °C it changes from the _____ to the _____ state. **[2]**

g. Name the change of state that occurs when osmium is heated from 4000 °C to 6000 °C. **[1]**

TWS

6. Write the letter of each label next to the correct line on the diagram. **[3]**



A Water in the liquid state.
B Water in the gas state (steam or vapour).
C Mixture of air and steam.

7. Complete the sentences using words and phrases from the list. You may use each once, more than once, or not at all.
increases **decreases** **stays the same**

a. When liquid water boils, the separation of the particles _____ **[1]**

b. When steam condenses, the speed of movement of the particles _____ **[1]**

c. When steam condenses, the distance between the particles _____ **[1]**

8. Read the statements below about the particles in liquid water. All the statements are true.
X The particles are close together in the solid and liquid states.
Y The particles are not arranged in a regular pattern.
Z The particles move around, sliding over each other.

a. Write the letter of the one statement above that best explains why you can pour liquid water. **[1]**

b. Write the letter of the one statement above that best helps to explain why the volume of 1 g liquid water is similar to the volume of 1 g of solid water (ice). **[1]**

c. Write the letter of the one statement above that best explains why a liquid takes the shape of the bottom of its container. **[1]**

9. Oxygen is a gas at 20 °C.

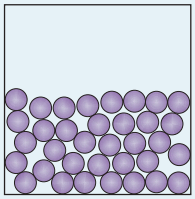
a. Describe the arrangement, separation, and movement of particles in the gas state. **[3]**

b. Use the particle model to explain why oxygen gas can be compressed. **[1]**

10. The diagram shows the particles of a substance in its liquid state.

a. Describe what you could do to make the particles in the liquid move more quickly. **[1]**

b. Draw a diagram to show the same particles after some of the liquid has evaporated. **[1]**



11. Copy these and draw lines to match each property with the best explanation. **[3]**

Property	Explanation
You cannot compress a solid.	The particles move around, sliding over each other.
If a gas is in a container with no lid, it escapes from the container.	There is no empty space between the particles.
A liquid takes the shape of the bottom of its container.	Its particles are in fixed positions.
You cannot pour a solid.	The particles move around in all directions.

Cambridge Lower Secondary

Complete Chemistry

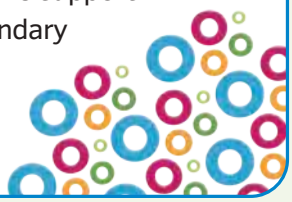
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