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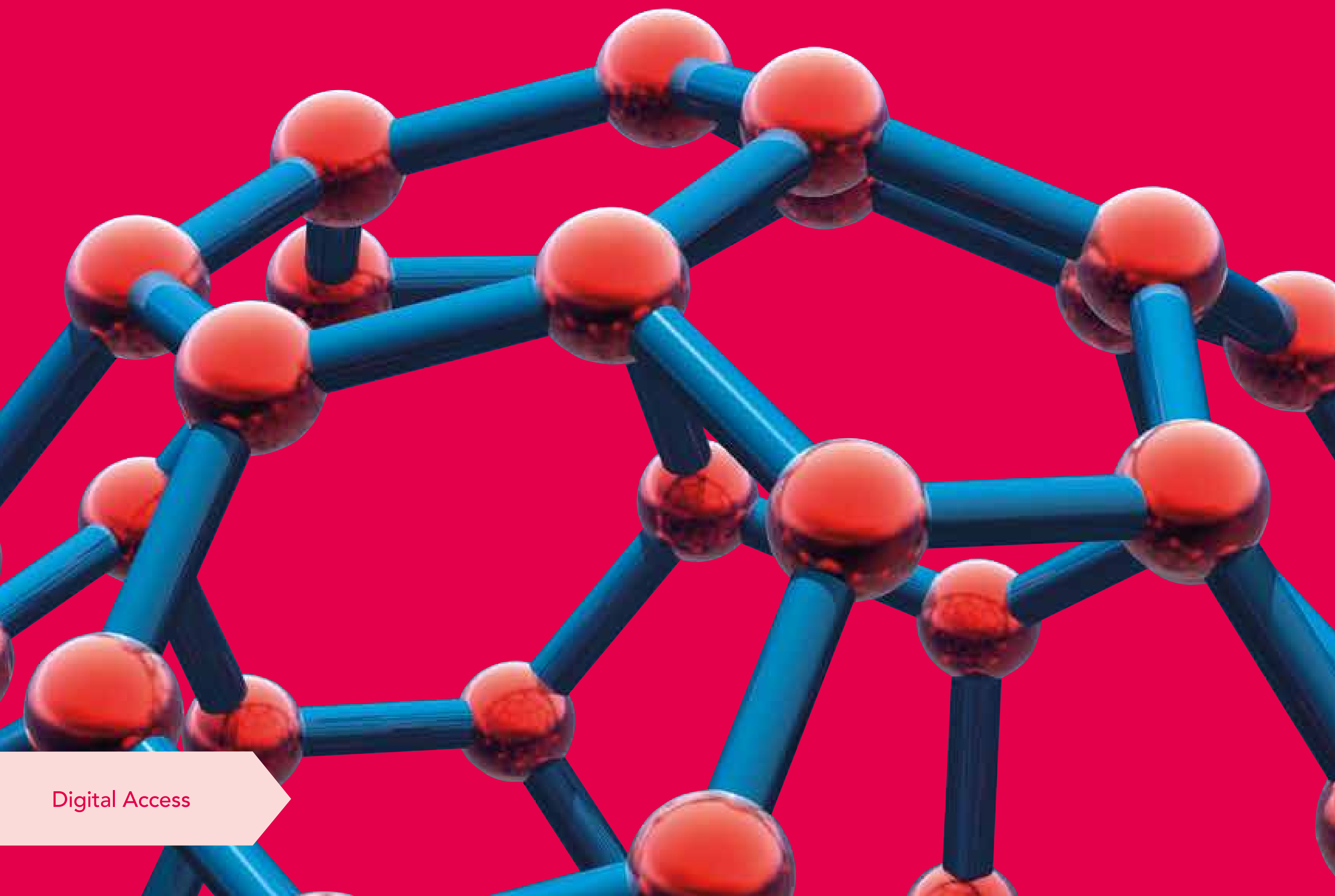
Executive Preview

Chemistry

for Cambridge IGCSE™

MULTI-COMPONENT SAMPLE



Digital Access

Dear Cambridge Teacher,

The new *Cambridge IGCSE™ Chemistry* series will publish in Spring 2021, updated for the revised Cambridge International syllabuses (0620/0971) for examination from 2023.

This Executive Preview contains sample content from the series, including:

- A guide explaining how to use the series
- A guide explaining how to use each resource
- The table of contents from each resource
- The first chapter from each resource, including the coursebook, workbook, practical workbook, English language skills workbook and maths skills workbook

This new series has been designed after extensive research interviews and lesson observations with teachers and students around the world. As well as targeted support in the coursebook, we have produced updated workbooks to address the key challenges we heard from teachers. A new workbook includes exercises for each topic, providing more practice opportunities to consolidate students' learning. The practical workbook includes practical activities to develop students' investigative skills, with extensive support notes and exemplar data provided in the teacher's resource.

A maths skills workbook and an English skills workbook develop students' maths skills (in relation to science) and linguistic skills, in the context of the Cambridge IGCSE Chemistry syllabus respectively. Both resources publish in 2022.

We have also updated the teacher's resource. With teaching activity, assessment and homework ideas, guidance on how to tackle common misconceptions in each topic and a new feature developing your own teaching skills, we hope this resource will inspire and support you and save you time.

Finally, as we develop new resources, we ensure that we are keeping up to date with best practice in pedagogy. For this new series we have added features to the coursebook, such as engaging projects to develop students' collaborative skills and 'getting started' questions and activities to help you evaluate students' learning starting points. We have developed our differentiated support in this new series, with three-tier exercises in the workbook progressing from 'focus', to 'practice', to 'challenge' and differentiated worksheets for each of the syllabus topics in the teacher's resource, supporting all your learners' different needs.

Visit our website to view the full series or speak to your local sales representative.

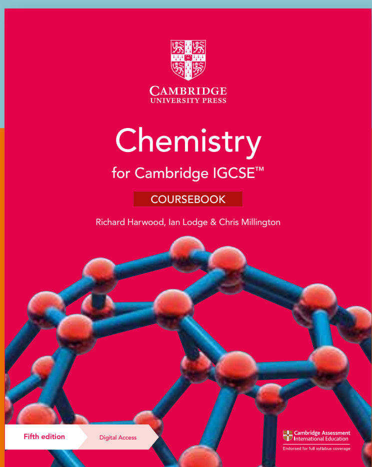
cambridge.org/education

Priyanka Comar and Gemma Coleman

Commissioning Editors for Cambridge IGCSE™ Sciences, Cambridge University Press

How to use this series

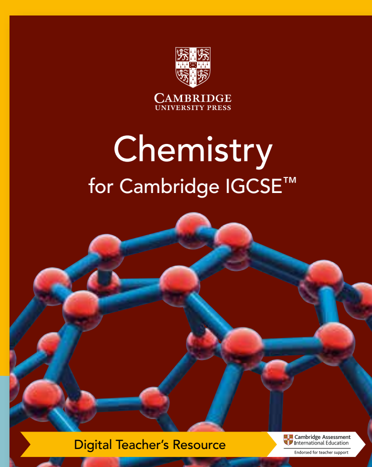
We offer a comprehensive, flexible array of resources for the Cambridge IGCSE™ Chemistry syllabus. We provide targeted support and practice for the specific challenges we've heard that students face: learning science with English as a second language; learners who find the mathematical content within science difficult; and developing practical skills.

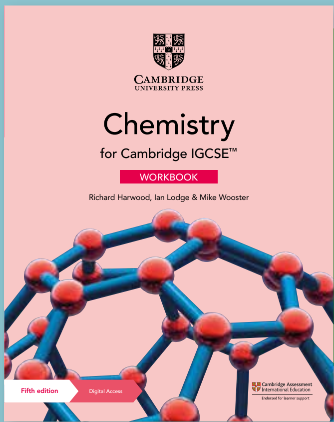


This coursebook provides coverage of the full Cambridge IGCSE Chemistry syllabus. Each chapter explains facts and concepts, and uses relevant real-world examples of scientific principles to bring the subject to life. Together with a focus on practical work and plenty of active learning opportunities, the coursebook prepares learners for all aspects of their scientific study. At the end of each chapter, examination-style questions offer practice opportunities for learners to apply their learning.

The digital teacher's resource contains detailed guidance for all topics of the syllabus, including common misconceptions identifying areas where learners might need extra support, as well as an engaging bank of lesson ideas for each syllabus topic. Differentiation is emphasised with advice for identification of different learner needs and suggestions of appropriate interventions to support and stretch learners. The teacher's resource also contains support for preparing and carrying out all the investigations in the practical workbook, including a set of sample results for when practicals aren't possible.

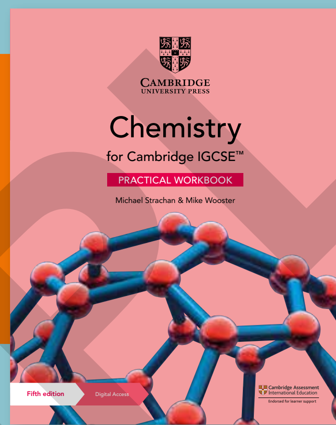
The teacher's resource also contains scaffolded worksheets and unit tests for each chapter. Answers for all components are accessible to teachers for free on the Cambridge GO platform.





The skills-focused workbook has been carefully constructed to help learners develop the skills that they need as they progress through their Cambridge IGCSE Chemistry course, providing further practice of all the topics in the coursebook. A three-tier, scaffolded approach to skills development enables students to gradually progress through ‘focus’, ‘practice’ and ‘challenge’ exercises, ensuring that every learner is supported. The workbook enables independent learning and is ideal for use in class or as homework.

The practical workbook provides learners with additional opportunities for hands-on practical work, giving them full guidance and support that will help them to develop their investigative skills. These skills include planning investigations, selecting and handling apparatus, creating hypotheses, recording and displaying results, and analysing and evaluating data.



Mathematics is an integral part of scientific study, and one that learners often find a barrier to progression in science. The Maths Skills for Cambridge IGCSE Chemistry write-in workbook has been written in collaboration with the Association for Science Education, with each chapter focusing on several maths skills that students need to succeed in their Chemistry course.

Our research shows that English language skills are the single biggest barrier to students accessing international science. This write-in English language skills workbook contains exercises set within the context of Cambridge IGCSE Chemistry topics to consolidate understanding and embed practice in aspects of language central to the subject. Activities range from practising using the passive form of verbs in the context of electrolysis to the naming of chemical substances using common prefixes.

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Chemistry

for Cambridge IGCSE™

COURSEBOOK

Richard Harwood, Ian Lodge & Chris Millington

Fifth edition

Digital Access

Cambridge Assessment International Education

Endorsed for full syllabus coverage

Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

LEARNING INTENTIONS

These set the scene for each chapter, help with navigation through the coursebook and indicate the important concepts in each topic.

In the learning intentions table, the summary table and the exam-style questions, Supplement content is indicated with a large arrow and a darker background, as in the example here.

GETTING STARTED

This contains questions and activities on subject knowledge you will need before starting this chapter.

SCIENCE IN CONTEXT

This feature presents real-world examples and applications of the content in a chapter, encouraging you to look further into topics that may go beyond the syllabus. There are discussion questions at the end, which look at some of the benefits and problems of these applications, and encourage you to look further into the topics.

EXPERIMENTAL SKILLS

This feature focuses on developing your practical skills. They include lists of equipment required and any safety issues, step-by-step instructions so you can carry out the experiment, and questions to help you think about what you have learnt.

KEY WORDS

Key vocabulary is highlighted in the text when it is first introduced, and definitions are given in boxes near the vocabulary. You will also find definitions of these words in the Glossary at the back of this book.

Questions

Appearing throughout the text, questions give you a chance to check that you have understood the topic you have just read about. The answers to these questions are accessible to teachers for free on the Cambridge GO site.

ACTIVITY

Activities give you an opportunity to check and develop your understanding throughout the text in a more active way, for example by creating presentations, posters or role plays. When activities have answers, teachers can find these for free on the Cambridge GO site.

COMMAND WORDS

Command words that appear in the syllabus and might be used in exams are highlighted in the exam-style questions. In the margin, you will find the Cambridge International definition. You will also find these definitions in the Glossary at the back of the book.

Supplement content: Where content is intended for students who are studying the Supplement content of the syllabus as well as the Core, this is indicated using the chevron, as on the left here. You may also see the teal text with just an arrow (and no bar), in boxed features such as the Key Words or the Getting Started.

WORKED EXAMPLE

Wherever you need to know how to use a formula to carry out a calculation, there are worked examples boxes to show you how to do this.

REFLECTION

These activities ask you to think about the approach that you take to your work, and how you might improve this in the future.

SELF/PEER ASSESSMENT

At the end of some activities and experimental skills boxes, you will find opportunities to help you assess your own work, or that of your classmates, and consider how you can improve the way you learn.

These boxes tell you where information in the book is extension content, and is not part of the syllabus.

SUMMARY

There is a summary of key points at the end of each chapter.

PROJECT

Projects allow you to apply your learning from the whole chapter to group activities such as making posters or presentations, or taking part in debates. They may give you the opportunity to extend your learning beyond the syllabus if you want to.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions, some of which may require use of knowledge from previous chapters. The answers to these questions are accessible to teachers for free on the Cambridge GO site.

SELF-EVALUATION CHECKLIST

The summary checklists are followed by 'I can' statements which relate to the Learning intentions at the beginning of the chapter. You might find it helpful to rate how confident you are for each of these statements when you are revising. You should revisit any topics that you rated 'Needs more work' or 'Almost there'.

I can	See Topic...	Needs more work	Almost there	Confident to move on
Core				
Supplement				

Chapter 1

States of matter

IN THIS CHAPTER YOU WILL:

- learn that matter can exist in three different states: solid, liquid or gas
- understand that substances can change state depending on the physical conditions
- understand that matter is made up of very small particles such as atoms or molecules
- see how changes in temperature produce changes of state by affecting the motion of the particles involved
- learn how to describe the structure of the physical states in terms of the arrangement and movement of particles
- describe how changes in temperature and pressure affect the volume of a gas
- explain diffusion in terms of the movement of particles

- think about how the movement of particles (kinetic particle theory) helps explain how changes of state happen
- understand the effects of changes in temperature and pressure on the volume of a gas
- learn how the molecular mass of particles in a gas affects the rate of diffusion.

GETTING STARTED

You will know about solids, liquids and gases from general life experience and your science courses. However, the ideas concerning the ways in which one state of matter changes into another are more complex.

Spray a small amount of air freshener at the front of a room. How does the smell spread around the room? Shake the can. Can you hear the liquid in it? Or try placing some liquid perfume in a dish in front of you and see how long it takes for someone to notice the scent some distance away. Discuss these observations in terms of changes of state and the movement of the molecules involved.

Look at the flowchart (Figure 1.1). Working in groups, can you add more detail to improve and extend the flowchart?

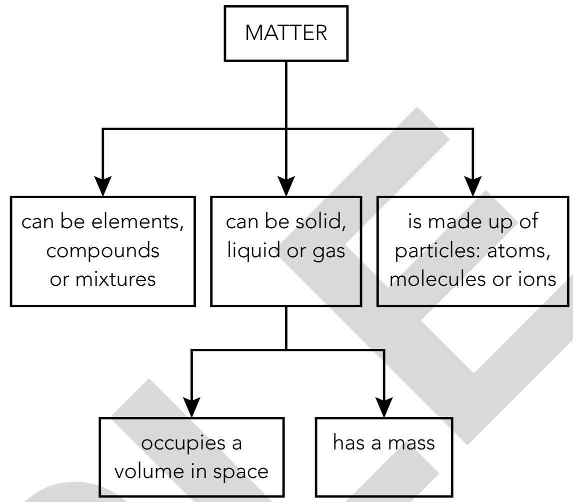


Figure 1.1: Flowchart of the nature of matter.

LORD OF THE RINGS

Saturn is perhaps the most beautiful of the planets of our solar system. Saturn has fascinated astronomers, even the famous Galileo, because of its mysterious rings. Galileo himself was confused by the rings thinking, at first, that the rings were planets. The *Pioneer*, *Voyager* and *Cassini-Huygens* space probes have sent back a lot of information to Earth about the structure of the moons and rings of Saturn. Figure 1.2 is an image captured by the Hubble Space Telescope. The photograph shows the rings at close to their maximum tilt (angle) to the Earth, which shows their magnificence.

Each ring around Saturn is made up of a stream of icy particles, following each other nose-to-tail, like cars in a traffic jam, around the planet. The particles can be of widely varying sizes. The rings resemble a snowstorm, in which tiny snowflakes are mixed with snowballs that can be as large as a house. The ice that surrounds one of the most spectacular planets of our solar system is made of water, which is the same substance (with the same chemical formula, H_2O) that covers so much of the Earth's surface.

Figure 1.2 also shows the pastel colours of the clouds of ammonia and methane in Saturn's atmosphere. However, the bulk of the planet is made of hydrogen and helium gases. Deep in the centre of these lightweight gases is a small rocky core, surrounded by a liquid layer of the gases. The hydrogen is liquid because of the high pressure in the inner regions of the planet nearest the core. The liquid hydrogen shows metallic properties, producing the planet's magnetic field. A study of Saturn's physical structure emphasises how substances that we know on Earth can exist in unusual physical states in different environments.

Discussion questions

1 Why are the planets Jupiter and Saturn called 'gas giants'? What progression do we see in the physical nature of the planets as we move away from the Sun?

2 Why does hydrogen only exist as a liquid under such extreme conditions of temperature and pressure?

Figure 1.2: Saturn and its rings. A photograph taken by the Hubble Space Telescope.

1.1 States of matter

There are many different kinds of **matter**. The word is used to cover all the substances and materials of which the universe is composed. Samples of all of these materials have two properties in common: they each occupy space (they have volume) and they have mass.

Chemistry is the study of how matter behaves, and of how one kind of substance can be changed into another. Whichever chemical substance we study, we find that the substance can exist in three different forms (or physical states) depending on the conditions. These three different **states of matter** are known as *solid*, *liquid* and *gas*. Changing the temperature and/or pressure can change the state in which a substance exists (Figure 1.3).

Each of the different physical states have certain general characteristics that are true whatever chemical substance is being considered. These are summarised in Table 1.1.

Table 1.1 highlights a major difference between solids and the other two physical states. Liquids and gases are able to flow, but a solid has a fixed shape and volume. Liquids and gases are **fluids**. This means that liquids and gases can be poured, or pumped, from one container to another. The three physical states also show differences in the way they respond to changes in temperature and pressure. All three show an increase in volume (an expansion) when the temperature is increased and a decrease in volume (a contraction) when the temperature is lowered. The effect is much bigger for a gas than for a solid or a liquid.

The volume of a gas at a fixed temperature can easily be reduced by increasing the pressure on the gas. Gases are easily compressed ('squashed'). Liquids are only slightly compressible, and the volume of a solid is unaffected by changing the pressure.

KEY WORDS

matter: anything that occupies space and has mass

states of matter: solid, liquid and gas are the three states of matter in which any substance can exist, depending on the conditions of temperature and pressure

fluid: a gas or a liquid; they are able to flow

Figure 1.3: Gallium metal melts with the warmth of the hand.

Physical state	Volume	Density	Shape	Fluidity
solid	has a fixed volume	high	has a definite shape	does not flow
liquid	has a fixed volume	moderate to high	no definite shape – takes the shape of the container	generally flows easily
gas	no fixed volume – expands to fill the container	low	no definite shape – takes the shape of the container	flows easily

Table 1.1: Differences in the properties of the three states of matter.

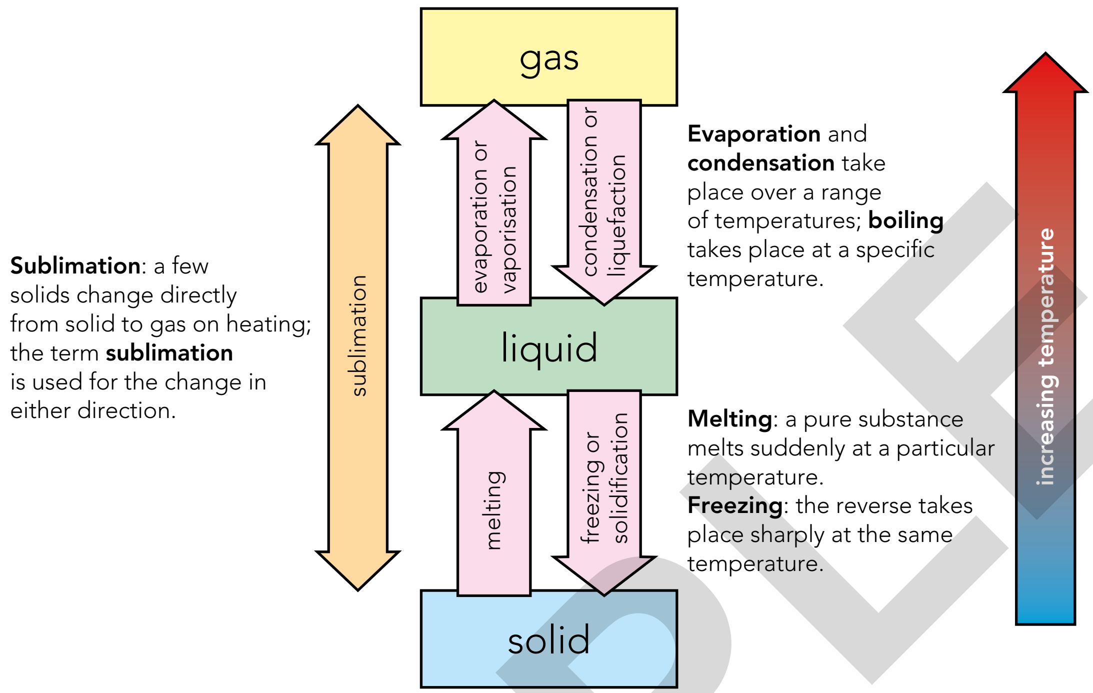


Figure 1.4: Changes of physical state and the effect of increasing temperature at atmospheric pressure.

Changes in state

Large increases, or decreases, in temperature and pressure can cause changes that are more dramatic than expansion or contraction. They can cause a substance to change its physical state. The changes between the three states of matter are shown in Figure 1.4. At atmospheric pressure, these changes can occur by raising or lowering the temperature of the substance.

Melting and freezing

The temperature at which a substance turns to a liquid is called the **melting point (m.p.)**. This always happens at one particular temperature for each substance (Figure 1.5). The process is reversed at precisely the same temperature if a liquid is cooled down. It is then called the *freezing point* (f.p.). The melting point and freezing point of any given substance are both the same temperature. For example, the melting and freezing of pure water take place at 0 °C.

> **KEY WORDS**
>
> **melting point (m.p):** the temperature at which a solid turns into a liquid – it has the same value as the freezing point; a pure substance has a sharp melting point

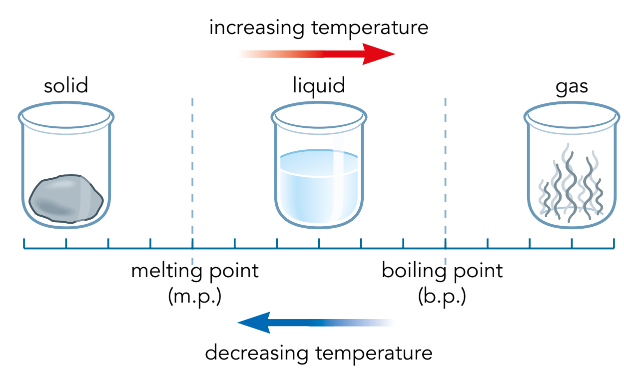


Figure 1.5: Relationship between the melting and boiling points of a substance.

Sublimation

A few solids, such as solid carbon dioxide, do not melt when they are heated at normal pressures. Instead, they turn directly into gas. Solid carbon dioxide is often called 'dry ice' because the surface of the block is dry (Figure 1.6). This is different to a normal ice cube, which has a thin film of liquid water on the surface.

This change of state is called sublimation: the solid *sublimes* (see Figure 1.3). Sublimation is a direct change of state from solid to gas, or gas to solid; the liquid phase is bypassed. As with melting, this also happens at one particular temperature for each pure solid.

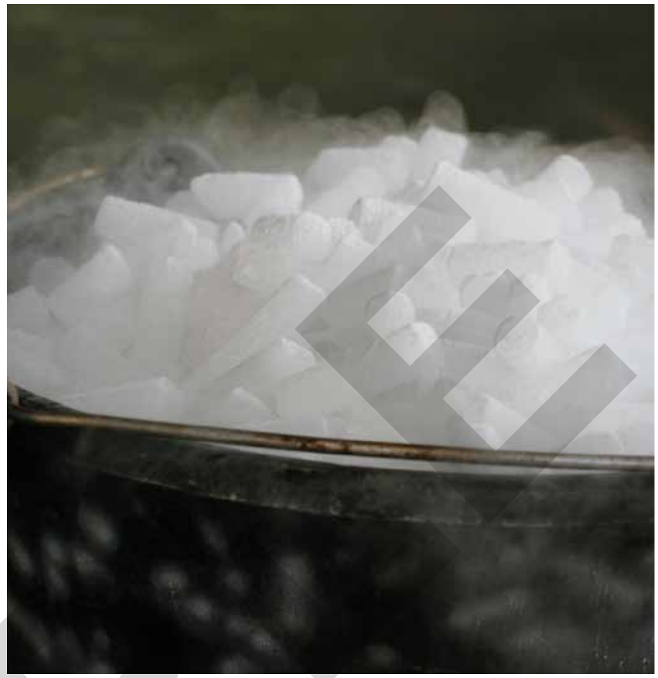


Figure 1.6: Solid carbon dioxide sublimes. The white smoke is composed of water droplets condensed from the air.

Evaporation, boiling and condensation

If a liquid is left with its surface exposed to the air, it evaporates. When liquids change into gases in this way, the process is called **evaporation**. Evaporation takes place from the surface of the liquid. The larger the surface area, the faster the liquid evaporates. The warmer the liquid is, the faster it evaporates. The hot climate around the Dead Sea means that water evaporates easily and the sea has a high salt concentration (Figure 1.6).

KEY WORD

evaporation: a process occurring at the surface of a liquid, involving the change of state from a liquid into a vapour at a temperature below the boiling point

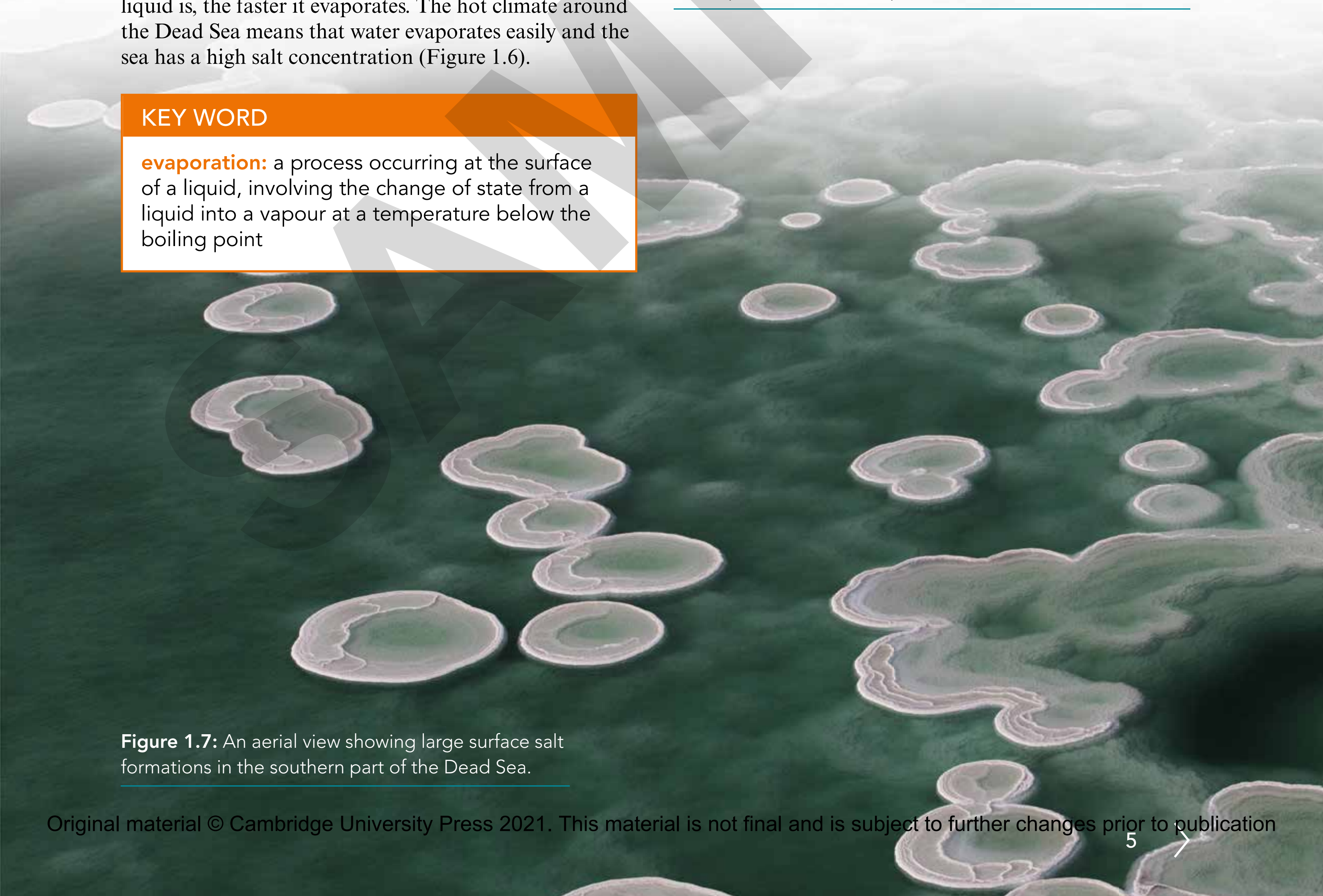


Figure 1.7: An aerial view showing large surface salt formations in the southern part of the Dead Sea.

Eventually, at a certain temperature, a liquid becomes hot enough for gas to form within the liquid and not just at the surface. Bubbles of gas appear inside the liquid (Figure 1.8a). This process is known as **boiling**. It takes place at a specific temperature, known as the **boiling point** for each pure liquid (Figure 1.5).

Water evaporates fairly easily and has a relatively low boiling point (100 °C). Water is quite a **volatile** liquid. Ethanol, with a boiling point of 78 °C, is more volatile than water. It has a higher **volatility** than water and evaporates more easily.

The reverse of evaporation is **condensation**. This is usually brought about by cooling. However, we saw earlier that the gas state is the one most affected by changes in pressure. It is possible, at normal temperatures, to condense a gas into a liquid by increasing the pressure, without cooling.

We can see these different processes in action if we look closely at a kettle as water boils (Figure 1.8b). Colourless, invisible water vapour escapes from the kettle. Water vapour is present in the clear region we can see at the mouth of the kettle. The visible cloud of steam is made up of droplets of liquid water formed by condensation as the vapour cools in the air.

KEY WORDS

boiling: a condition under which gas bubbles are able to form within a liquid – gas molecules escape from the body of a liquid, not just from its surface

boiling point: the temperature at which a liquid boils, when the pressure of the gas created above the liquid equals atmospheric pressure

volatile: term that describes a liquid that evaporates easily; it is a liquid with a low boiling point because there are only weak intermolecular forces between the molecules in the liquid

volatility: the property of how easily a liquid evaporates

condensation: the change of a vapour or a gas into a liquid; during this process heat is given out to the surroundings

Figure 1.8 a: Water boiling in a glass kettle; bubbles are formed throughout the liquid. **b:** A boiling kettle produces colourless, invisible water vapour that then condenses to produce a cloud of steam.

For a beaker of boiling water, the bubbles form when there are enough high-energy water molecules to give a pocket of gas with a pressure equal to atmospheric pressure. The boiling point of a liquid can change if the surrounding pressure changes. The value given for the boiling point is usually stated at the pressure of the atmosphere at sea level (*atmospheric pressure* or *standard pressure*). If the surrounding pressure falls, the boiling point falls. The boiling point of water at standard pressure is 100 °C. On a high mountain, the boiling point is lower than 100 °C. If the surrounding pressure is increased, the boiling point rises.

Pure substances

A **pure substance** consists of only one substance without any contaminating impurities. A pure substance melts and boils at definite temperatures. Table 1.2 shows the precise melting points and boiling points of some common substances at atmospheric pressure.

Substance	Physical state at room temperature (25 °C)	Melting point / °C	Boiling point / °C
oxygen	gas	−219	−183
nitrogen	gas	−210	−196
ethanol (alcohol)	liquid	−117	78
water	liquid	0	100
sulfur	solid	115	444
common salt (sodium chloride)	solid	801	1465
copper	solid	1083	2600
carbon dioxide	gas	−78[a]	

[a] *Sublimes at atmospheric pressure*

Table 1.2: Melting and boiling points of some common chemical substances.

KEY WORDS

pure substance: a single chemical element or compound – it melts and boils at definite precise temperatures

The values for the melting point and boiling point of a pure substance are precise and predictable. This means that we can use them to test the purity of a sample. These values can also be used to check the identity of an unknown substance. The melting point of a solid can be measured using an electrically heated melting-point apparatus or by the apparatus described later in Figure 1.9.

A substance's melting and boiling points in relation to room temperature (standard taken as 25 °C) determine whether it is usually seen as a solid, a liquid or a gas. For example, if the melting point is below 25 °C and the boiling point is above 25 °C, the substance will be a liquid at room temperature.

Effect of impurities

Seawater is impure water. This fact can be easily demonstrated if you put some seawater in a dish and heat it until all of the water evaporates. A solid residue of salt is left behind in the dish (you can see this effect in Figure 1.7, which shows solid salt formations on the surface of the Dead Sea).

Impurities often affect the value of the melting or boiling point of a substance. An impure substance sometimes melts or boils over a *range* of temperatures, not at the precise point of the pure substance.

Seawater freezes at a temperature below the freezing point of pure water (0 °C) and boils at a temperature above the boiling point of pure water (100 °C). Other substances that contain impurities show differences in their freezing and boiling points when compared with the known values for the pure substance.

Questions

1 State the names for the following physical changes:
   a liquid to solid
   b liquid to gas at a precise temperature
   c gas to liquid

2 The melting and boiling points of three pure substances are given in Table 1.3.

Substance	Melting point / °C	Boiling point / °C
ethanol	−117	78
methane	−182	−164
mercury	−30	357

Table 1.3: Melting and boiling points of ethanol, methane and mercury.

   a All three substances have negative values for their melting point. Which of them has the lowest melting point?
   b Which two substances are liquids at room temperature? Explain your answer.
   c What effect does the presence of an impurity have on the freezing point of a liquid?

3 **a** What do you understand by the word *volatile* when used in chemistry?

b Put these three liquids in order of volatility, with the most volatile first: water (b.p. 100 °C), ethanoic acid (b.p. 128 °C) and ethanol (b.p. 78 °C).

c Table 1.4 shows the melting and boiling points of four substances A–D. In which of these four substances are the particles arranged in a **lattice** (a regular structure) at room temperature?

Substance	Melting point / °C	Boiling point / °C
A	−115	79
B	80	218
C	−91	−88
D	−23	77

Table 1.4: Melting and boiling points of four unknown substances.

4 Iodine is often seen as an example of sublimation. However, data books that give the standard physical measurements for substances show values for the melting point (114 °C) and boiling point (184 °C) of iodine at atmospheric pressure.

a Explain why iodine seems to sublime if crystals are heated strongly in a boiling tube.

b Suggest how you could demonstrate that iodine can melt to form a liquid at atmospheric pressure.

KEY WORD

lattice: a regular three-dimensional arrangement of atoms, molecules or ions in a crystalline solid

Heating and cooling curves

The melting point of a solid can also be measured using the apparatus shown in Figure 1.9. A powdered solid is put in a narrow melting-point tube so that it can be heated easily. An oil bath can be used so that melting points above 100 °C can be measured. We can follow the temperature of the sample before and after melting.

On heating, the temperature rises until the solid starts to melt. However, close observation shows that the temperature stays constant until all the solid has melted. The temperature then rises as the liquid warms further.

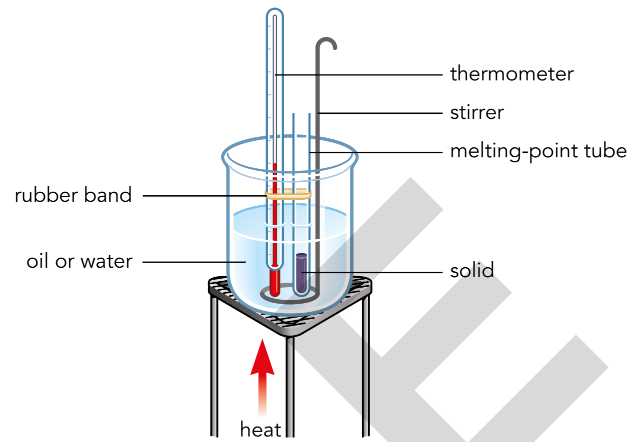


Figure 1.9: Apparatus for measuring the melting point of a solid. A water-bath can be used for melting points below 100 °C and an oil bath for melting points above 100 °C.

It is possible to continue to heat the liquid in the same apparatus until its boiling point is reached. Again, the temperature stays the same until all the liquid has completely evaporated.

We can perform this experiment in reverse. Similar apparatus can be used to produce a cooling curve, but the thermometer must be placed in a test-tube containing the solid being studied. The solid is then melted completely and the liquid heated. Heating is then stopped. The temperature is noted every minute as the substance cools. This produces a cooling curve (Figure 1.10). The level (horizontal) part of the curve occurs where the liquid freezes, forming the solid.

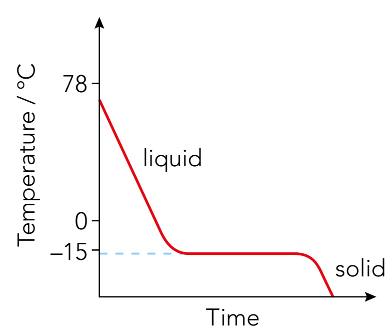


Figure 1.10: A cooling curve. The temperature stays constant while the liquid solidifies. A cooling mixture of ice and salt could be used to lower the temperature below 0 °C.

These experiments show that heat energy is needed to change a solid into a liquid, or a liquid into a gas. During the reverse processes, heat energy is given out.

EXPERIMENTAL SKILLS 1.1

Plotting a cooling curve

In this experiment, you are going to plot cooling curves for two substances, A and B. This experiment investigates the energy changes taking place as a liquid cools down below its freezing point.

You will need:

- two beakers (250 cm³)
- Bunsen burner
- tripod
- gauze
- heat-resistant mat
- stopwatch, stopclock or other timer
- two boiling tubes labelled A and B
- two stirring thermometers (−10 to 110 °C).

Substance A is paraffin wax (choose a low m.p. type, m.p. around 55 °C). Substance B is either octadecanoic acid (stearic acid) m.p. 70 °C or phenyl salicylate (salol) m.p. 43 °C.

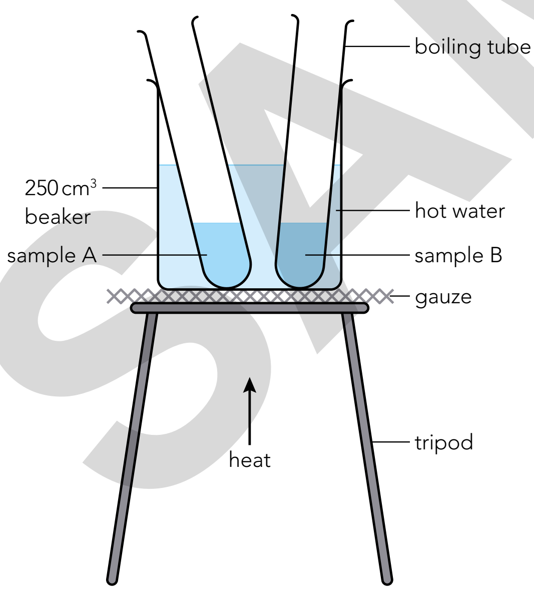


Figure 1.11: Samples A and B are melted in a water-bath.

Safety

It is important that you follow the safety rules set out by your teacher for all practicals. In particular, pay attention to the type of Bunsen burner flame needed as well as the concentrations and volumes of chemicals used. Wear eye protection throughout.

Getting started

Before starting the experiment, make sure you are familiar with the scale on the thermometer you are using. You will need to be able to read it confidently. You can check on your reading of the thermometer as you are heating up the water-bath.

Make sure you and your partner are clear as to the tasks you each have.

Method

1. Fill a 250 cm³ beaker three-quarters full of water and heat using a Bunsen burner to make a water-bath. Place a thermometer in the water. Heat the water until it is at 90 °C.
2. Put boiling tubes containing a sample of each solid A and B into the water-bath (Figure 1.11).
3. When the solid has melted, place a thermometer in each tube. There should be enough liquid to cover the bulb at the base of the thermometer.
4. Remove the tubes from the water-bath and stand them in an empty beaker for support.
5. Look at the thermometer and record the temperature in each tube. Then start the timer.
6. Look at the thermometer and record the temperature in each tube every minute until the temperature reaches 40 °C.
7. Plot a graph for each set of readings with time on the x-axis and temperature on the y-axis.

Questions

1. Which of the two substances is a pure substance? Explain your answer.
2. Explain any ways in which your method could be improved to give more reliable results.

CONTINUED

Self-assessment

Complete the self-assessment checklist below to assess your graph drawing skills.

For each point, award yourself:

2 marks if you did it really well

1 mark if you made a good attempt at it and partly succeeded

0 marks if you did not try to do it, or did not succeed

Checkpoint	Marks awarded
Have you drawn the axes with a ruler, using most of the width and height of the grid?	
Have you used a good scale for the *x*-axis and the *y*-axis, going up in 0.25 s, 0.5 s, 1 s or 2 s? (Note that the axes do not necessarily need to start at the origin (0,0).)	
Have you labelled the axes correctly, giving the correct units for the scales on both axes?	
Have you plotted each point precisely and correctly?	
Have you used a small, neat cross or encircled dot for each point?	
Have you drawn a single, clear best-fit line through each set of points?	
Have you ignored any anomalous results when drawing the line through each set of points?	
Total (out of 14):	

Your total score will reflect how clear and well-presented your graph is. Drawing graphs is an important skill in chemistry as you need be able to deduce reliable information from your graph.

Take a look at where you gave yourself 2 marks and where you gave yourself less than 2 marks. What did you do well, and what aspects will you focus on next time? Having thought about your assessment, talk it through with your teacher to gain further advice on areas that would help you improve your presentation of graphical data.

Questions

5 Sketch a cooling curve for water from 80 °C to −20 °C, noting what is taking place in the different regions of the graph.

6 Energy is needed to overcome the forces of attraction holding the particles in position in a solid. Energy is absorbed during melting. Figure 1.12 shows how energy is involved in the different changes of state. Complete Figure 1.12 by providing labels for the positions A, B and C.

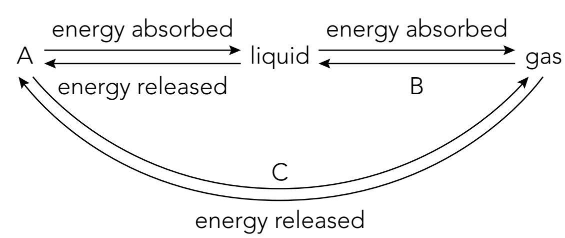


Figure 1.12: Energy changes involved in different changes of state.

7 As an alternative to following the cooling of a substance, it is possible to draw a heating curve. Figure 1.13 shows the heating curve for substance X.

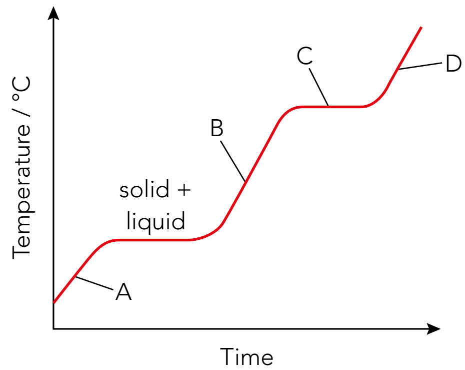


Figure 1.13: Heating curve for substance X.

What physical state, or states, will X be in at points A, B, C and D on the curve?

1.2 Kinetic particle theory of matter

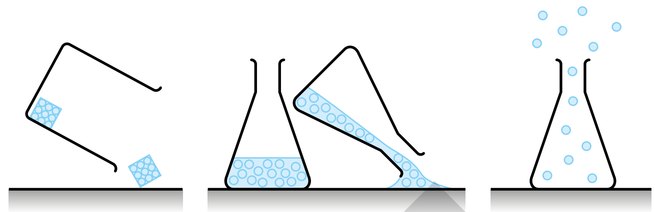
Existence of atoms and molecules

Elements and compounds mix and react to produce the world around us. They produce massive objects such as the 'gas giants' (the planets Jupiter and Saturn) that we met at the start of this chapter. They also give rise to the tiny highly structured crystals of solid sugar or salt. How do the elements organise themselves to give this variety? How can an element exist in the three different states of matter simply through a change in temperature?

Our modern understanding is based on the idea that all matter is divided into very small particles known as **atoms**. The key ideas in our understanding are that:

- each element is composed of its own type of atom
- atoms of different elements can combine to make the molecules of a compound.

This idea that all substances consist of very small particles begins to explain the structure of the three different states of matter. The different levels of freedom of movement of the particles explains some of the different features of the three states. Figure 1.14 illustrates the basic features of the three states we discussed earlier (see Table 1.1).



A solid cannot flow. It has a definite shape and volume. | A liquid can flow; it is a fluid. It has a definite volume but takes the shape of its container. | A gas is a fluid and spreads throughout its container. It has no definite volume.

Figure 1.14: The basic differences between the physical properties of the three states of matter.

Main points of the kinetic particle theory

The **kinetic particle theory** of matter describes the three different states, and the changes between them, in terms of the movement of particles. The major points of the theory are:

- All matter is made up of very small particles (different substances contain different types of particles, such as atoms, **molecules** or ions).
- Particles are moving all the time (the higher the temperature, the higher the average energy of the particles).
- The freedom of movement and the arrangement of the particles is different for the three states of matter.
- The pressure of a gas is produced by the atoms or molecules of the gas hitting the walls of the container. The more often the particles collide with the walls, the greater the pressure.

KEY WORDS

atom: the smallest particle of an element that can take part in a chemical reaction

kinetic particle theory: a theory which accounts for the bulk properties of the different states of matter in terms of the movement of particles (atoms or molecules) – the theory explains what happens during changes in physical state

molecule: a group of atoms held together by covalent bonds

Figure 1.15 is a more detailed summary of the organisation of the particles in the three states of matter and explains the changes involved in the different changes in state.

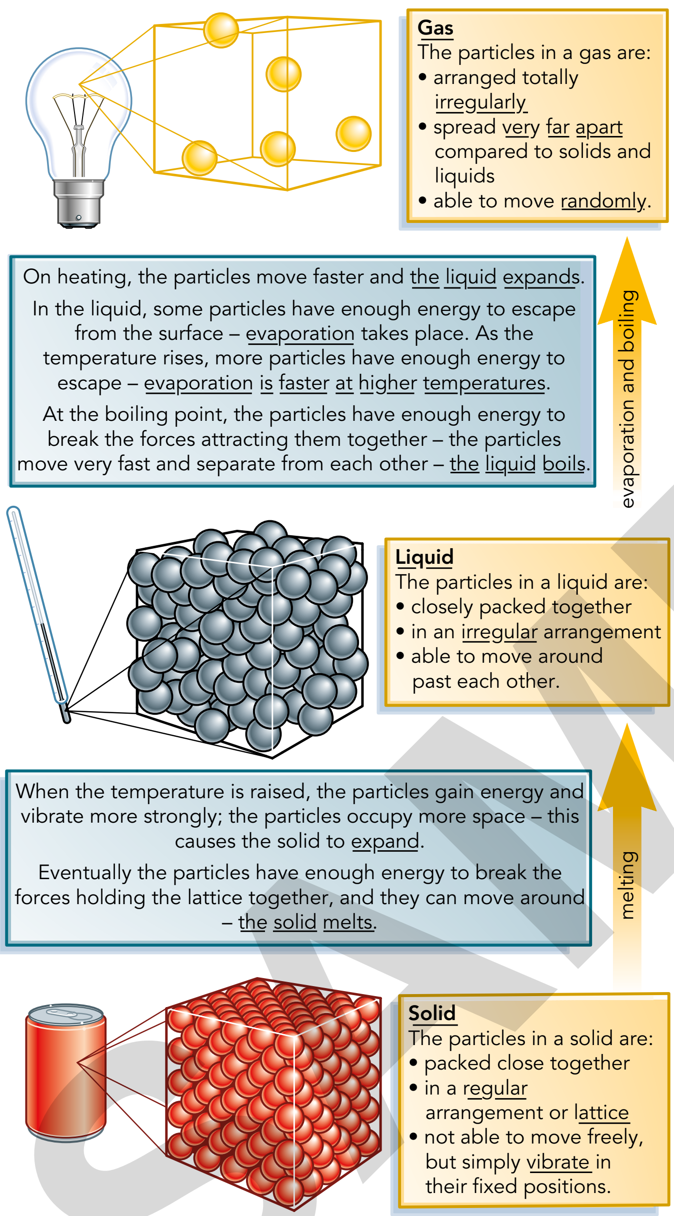


Figure 1.15: Applying the kinetic particle theory to changes in physical state.

The highly structured, ordered microscopic arrangements in solids can produce the regular crystal structures seen in this state. In a solid, the particles are packed close together. The particles cannot move freely. They simply vibrate about fixed positions in their regular arrangement (lattice).

In a liquid, the particles are still close together. However, they can now move about past each other. The separation between particles is much greater in a gas. In a gas, the particles are very far apart and move randomly.

The ability of the particles to move in the liquid and gas phases produces their fluid properties. The particles are very widely separated in a gas, but close together in a liquid or solid. The space between the particles is called the **intermolecular space**. In a gas, the intermolecular space is large and can be reduced by increasing the external pressure. Therefore, gases are easily compressible. In liquids, this space is very much smaller. As a result, liquids are not very compressible.

Changing the external pressure on a sample of a gas produces a change in volume that can easily be seen.

- An increase in external pressure produces a contraction in volume. The gas is compressed.
- A decrease in external pressure produces an increase in volume. The gas expands.

The volume of a gas is also altered by changes in temperature.

- An increase in the temperature of a gas produces an increase in volume. The gas expands.
- A decrease in temperature produces a contraction of the volume of a gas.

KEY WORDS

intermolecular space: the space between atoms or molecules in a liquid or gas. The intermolecular space is small in a liquid, but relatively very large in a gas.

The movement of particles in a liquid also helps to explain evaporation from the surface of a liquid. Some of the particles are moving faster than other particles. At the surface, these faster moving particles may have enough energy to escape into the gaseous state (Figure 1.16).

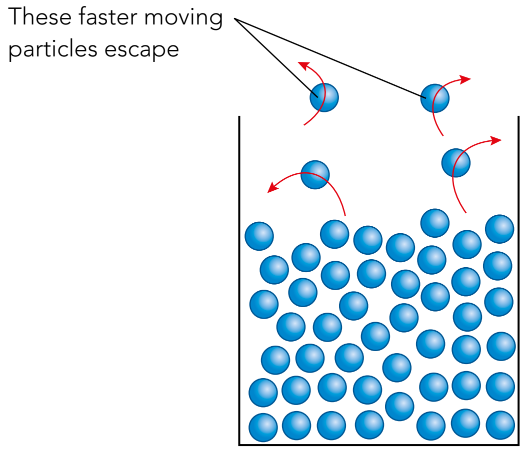


Figure 1.16: Faster moving particles leaving the surface of a liquid, causing evaporation.

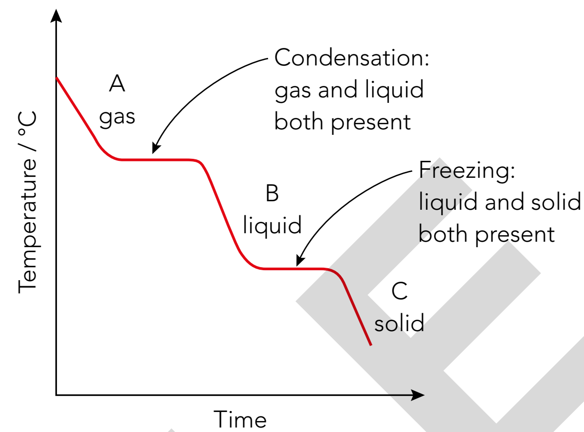


Figure 1.17: The energy changes taking place during the cooling of a gas to a solid.

The fact that the space between the rapidly moving particles in a gas is much greater than in the other two states of matter explains why the volume of a gas is much more easily changed by conditions of temperature and pressure. If the temperature is raised then the gas particles move faster and there is less chance of interaction between them. The gas particles move faster and more freely and occupy a greater volume. The opposite is true if the temperature is lowered. The particles are moving more slowly. They are more likely to interact with each other and move together to occupy a smaller volume.

Changes in pressure also affect the volume of a gas sample. An increase in pressure pushes the particles closer together meaning that the moving particles are more likely to interact with each other and move closer together. The opposite is true when the external pressure is lowered. The particles occupy a greater space and interactions between the particles are less likely.

The interpretation of a cooling curve

The way the particles in the three states are arranged and interact with each other also helps to explain the energy changes involved when a substance is heated or cooled. Figure 1.17 summarises the energy changes that take place at the different stages of a cooling-curve experiment.

The cooling of the gas gives rise to a sequence of changes during which the particles move less rapidly and interact more strongly with each other. The substance passes through the liquid state, eventually becoming a solid. Over the course of the experiment the temperature falls. However, the graph shows two periods during which the temperature remains constant. These regions are the time when first condensation, and then freezing takes place.

In region A (Figure 1.17), the temperature is falling. The energy of the particles decreases. The particles move more slowly and interact with each other more strongly. The particles begin to come together to form the liquid. As the **intermolecular forces** increase between the particles, energy is given out. This results in the temperature staying constant until the gas is completely condensed to liquid.

Once the liquid is formed the temperature starts to fall again (region B). The liquid cools. The particles in the liquid slow down and eventually the solid begins to form. The forces holding the solid together form and energy is given out. While the solid is forming this release of energy keeps the temperature constant. The temperature stays the same until freezing is complete.

After the solid has formed the temperature falls again (region C). The particles in the solid vibrate less strongly as the temperature falls.

KEY WORDS

intermolecular forces: the weak attractive forces that act between molecules

The key points about the processes taking place during condensation and freezing are:

- as the particles come closer together, new forces of interaction take place
- this means that energy is given out during these changes
- therefore, the temperature remains unchanged until the liquid or solid is totally formed.

As energy is given out during these changes, condensation and freezing are **exothermic changes** (Chapter 7).

Carrying out the experiment in the opposite direction, starting from the solid, would give a heating curve. In this case, the temperature stays constant during melting and boiling. At these stages, energy has to be put in to overcome the forces between the particles. The energy put in breaks these interactions and the particles are able to move more freely and faster. As energy has to be put during these changes, melting, evaporation and boiling are **endothermic changes** (Chapter 7).

What are the forces that hold a solid or liquid together? They must be attractive forces between the particles. They are the forces that act when a substance condenses or freezes. Their formation releases energy. However, their nature depends on the substance involved. For substances such as water or ethanol they act between the molecules present, and so are intermolecular forces.

KEY WORDS

exothermic changes: a process or chemical reaction in which heat energy is produced and released to the surroundings. ΔH for an exothermic change has a negative value.

endothermic changes: a process or chemical reaction that takes in heat from the surroundings. ΔH for an endothermic change has a positive value.

1.3 Mixtures of substances and diffusion

The chemical world is very complex, owing to the vast range of pure substances available and to the variety of ways in which these pure substances can mix with each other. Each **mixture** must be made from at least two parts, which may be either solid, liquid or gas. There are a number of different ways in which the three states can be combined. In some, the states are completely mixed to become one single state or phase. Technically, the term **solution** is used for this type of mixture composed of two or more substances.

Solid salt dissolves in liquid water to produce a liquid mixture. This is called a salt solution (Figure 1.18). The solid has completely disappeared into the liquid. In general terms, the solid that dissolves in the liquid is called the **solute**. The liquid in which the solid dissolves is called the **solvent**. In other types of mixture, the states remain separate. One phase is broken up into small particles, droplets or bubbles, within the main phase. The most obvious example of this type of mixture is a **suspension** of fine particles of a solid in a liquid, such as we often get after a precipitation reaction (Chapters 12 and 22).

KEY WORDS

mixture: two or more substances mixed together but not chemically combined - the substances can be separated by physical means

solution: is formed when a substance (solute) dissolves into another substance (solvent)

solute: the solid substance that has dissolved in a liquid (the solvent) to form a solution

solvent: the liquid that dissolves the solid solute to form a solution; water is the most common solvent but liquids in organic chemistry that can act as solvents are called *organic solvents*

suspension: a mixture containing small particles of an insoluble solid, or droplets of an insoluble liquid, spread (suspended) throughout a liquid

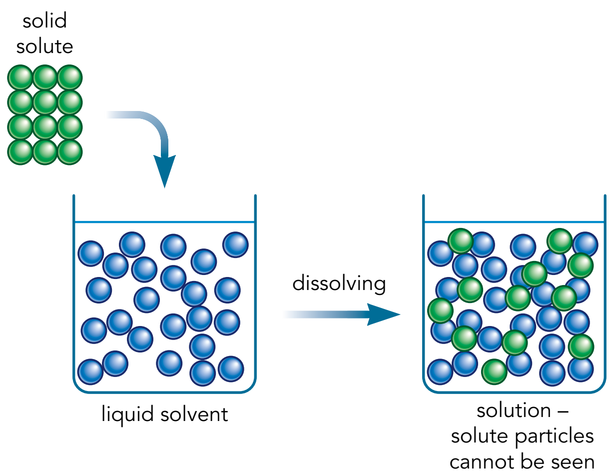


Figure 1.18: When solute dissolves in a solvent, the solute particles are completely dispersed in the liquid.

Solutions

We most often think of a solution as being made of a solid dissolved in a liquid. Two-thirds of the Earth's surface is covered by a solution of various salts in water. The salts are totally dispersed in the water and cannot be seen. However, other substances that are not normally solid are dissolved in seawater. For example, the dissolved gases, oxygen and carbon dioxide, are important for life to exist in the oceans.

A closer look at solutions

Water is the commonest solvent in use, but other liquids are also important. Most of these other solvents are organic liquids, such as ethanol, propanone and trichloroethane. These organic solvents are important because they will often dissolve substances that do not dissolve in water. If a substance dissolves in a solvent, it is said to be **soluble**; if it does not dissolve, it is **insoluble**.

Less obvious, but quite common, are solutions of one liquid in another. Alcohol mixes (dissolves) completely with water. Alcohol and water are completely **miscible**: this means that they make a solution.

Alloys are similar mixtures of metals, though we do not usually call them solutions. They are made by mixing the liquid metals together (dissolving one metal in the other) before solidifying the alloy.

Solubility of solids in liquids

If we try to dissolve a substance such as copper(II) sulfate in a fixed volume of water, the solution becomes more concentrated as we add more solid. A *concentrated* solution contains a high proportion of solute. A *dilute* solution contains a small proportion of solute. If we keep adding more solid, a point is reached when no more will dissolve at that temperature. This is a **saturated solution**. To get more solid to dissolve, the temperature must be increased. The concentration of solute in a saturated solution is the **solubility** of the solute at that temperature.

The solubility of most solids increases with temperature. The process of crystallisation depends on these observations. When a saturated solution is cooled, the solution can hold less solute at the lower temperature and some solute crystallises out. The solubility of most solids increases with temperature. The process of crystallisation depends on these observations. When a saturated solution is cooled, it can hold less solute at the lower temperature and some solute crystallises out.

KEY WORDS

soluble: a solute that dissolves in a particular solvent

insoluble: a substance that does not dissolve in a particular solvent

miscible: if two liquids form a completely uniform mixture when added together, they are said to be miscible

alloys: mixtures of elements (usually metals) designed to have the properties useful for a particular purpose, e.g. solder (an alloy of tin and lead) has a low melting point

saturated solution: a solution that contains as much dissolved solute as possible at a particular temperature

solubility: a measure of how much of solute dissolves in a solvent at a particular temperature

Solubility of gases in liquids

Unlike most solids, gases become less soluble in water as the temperature rises. The solubility of gases from the air in water is quite small, but the amount of dissolved oxygen is enough to support fish and other aquatic life.

The solubility of gases increases with pressure. Sparkling drinks contain carbon dioxide dissolved under pressure. They 'fizz' when the pressure is released by opening the container. They go 'flat' if the container is left to stand open, and more quickly if left to stand in a warm place.

Diffusion in fluids

Some of the earliest evidence for the kinetic model of the states of matter came from observations on **diffusion**, where particles spread to fill the space available to them.

The main ideas involved in diffusion are:

- particles move from a region of higher concentration towards a region of lower concentration; eventually, the particles are evenly spread. Their concentration is the same throughout.
- the rate of diffusion in liquids is much slower than in gases.
- diffusion does not take place in solids as the particles cannot move from place to place.

KEY WORD

diffusion: the process by which different fluids mix as a result of the random motions of their particles

Dissolving

A potassium manganate(VII) crystal is placed at the bottom of a dish of water. The dish is then left to stand. At first the water around the crystal becomes purple as the solid dissolves (Figure 1.19). Particles move off from the surface of the crystal into the water. Eventually, the crystal dissolves completely and the purple colour spreads through the liquid. The whole solution becomes purple. The particles from the solid become evenly spread through the water.

Figure 1.19: The diffusion of potassium manganate(VII) in water.

Whether a solid begins to break up like this in a liquid depends on the particular solid and liquid involved. But the spreading of the solute particles throughout the liquid is an example of diffusion. Diffusion in solution is also important when the solute is a gas. This is especially important in breathing. Diffusion contributes to the movement of oxygen from the lungs to the blood, and of carbon dioxide from the blood to the lungs.

Diffusion of gases

A few drops of liquid bromine are put into a gas jar and the lid is replaced. The liquid bromine evaporates easily. Liquid bromine is highly volatile. After a short time, the brown gas begins to spread throughout the jar. The jar becomes full of brown gas. Bromine vaporises easily and its gas will completely fill the container (Figure 1.20). Gases diffuse to fill all the space available to them. Diffusion is important for our 'sensing' of the world around us. It is the way that smells reach us.

The atoms or molecules in gases move at high speeds. We are being bombarded constantly by nitrogen and oxygen molecules in the air, which are travelling at about 1800 km/h. However, these particles collide very frequently with other particles in the air (many millions of collisions per second), so their path is not direct. These frequent collisions slow down the overall rate of diffusion from one place to another. The pressure of a gas is the result of collisions of the fast-moving particles with the walls of the container.

Figure 1.20: Bromine vapour diffuses throughout the container to fill the space available.

Not all gases diffuse at the same rate. The speed at which a gas diffuses depends on the mass of the particles involved. At the same temperature, molecules that have a lower mass move, on average, faster than those with a higher mass. This is shown by the experiment in Figure 1.21. The ammonia and hydrochloric acid fumes react when they meet, producing a white smoke ring of ammonium chloride. This smoke ring is made of fine particles of solid ammonium chloride. The fact that the ring is not formed halfway along the tube shows that ammonia, the lighter molecule of the two, diffuses faster.

The important points derived from the kinetic particle theory relevant here are:

- heavier gas particles move more slowly than lighter particles at the same temperature
- larger molecules diffuse more slowly than smaller ones
- the rate of diffusion is inversely related to the mass of the particles
- the average speed of the particles increases with an increase in temperature.

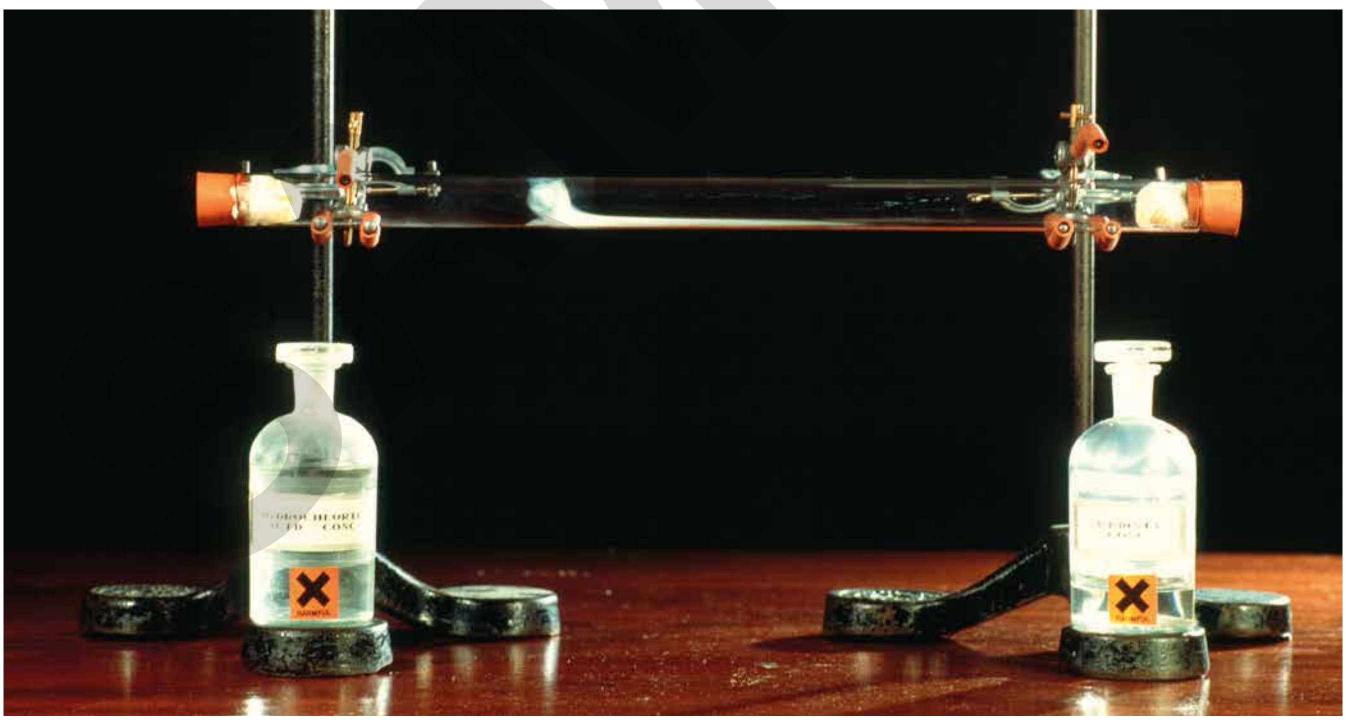


Figure 1.21: Ammonia and hydrochloric acid fumes diffuse at different rates.

EXPERIMENTAL SKILLS 1.2

Investigating diffusion in liquids

This experiment helps to demonstrate the process of diffusion in a liquid. Diffusion is shown by the formation of an insoluble precipitate where the ions meet in a solution.

You will need:

- Petri dish
- tweezers
- white tile
- silver nitrate, one crystal
- potassium iodide, one crystal
- distilled or deionised water
- test-tubes
- silver nitrate solution
- potassium iodide solution
- dropping pipettes.

Safety

Wear eye protection throughout. Use tweezers to handle the crystals. Be careful with chemicals. Never ingest them and always wash your hands after handling them. Note that silver nitrate is corrosive (C), oxidising (O) and can stain the skin. Silver nitrate is also hazardous to the aquatic environment (N).

Getting started

Before starting, try the reaction between potassium iodide and silver nitrate solutions in a test-tube. Add 1 cm^3 of aqueous silver nitrate to a similar volume of potassium iodide solution. Note the formation of the precipitate, particularly its colour.

Method

1 Put a Petri dish on a white tile or piece of white paper. Fill the Petri dish nearly to the top with deionised water.

2 Using tweezers, put a crystal of silver nitrate at one side of the dish and a crystal of potassium iodide at the other side (Figure 1.22).

3 Look at the crystals. Notice that as crystals begin to dissolve in the water, a new compound is formed within the solution.

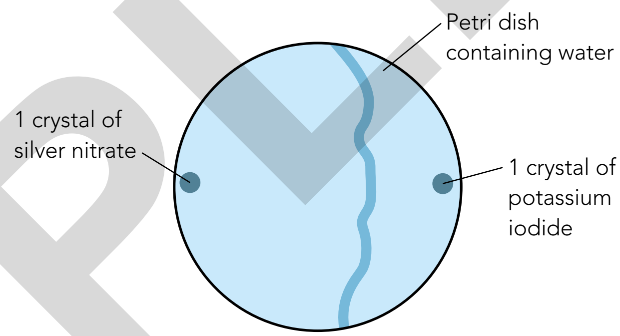


Figure 1.22: Experiment to investigate diffusion through water.

Questions

1 What is the precipitate formed in this reaction?

2 Write a word equation to show the reaction taking place.

3 What factors control where the solid is formed in the Petri dish?

4 Why does the solid not form exactly in the middle of the dish?

Questions

8 A small amount of liquid bromine is placed in a gas jar, which is then sealed with a lid. Evaporation of the liquid bromine takes place.

$Br_2(l) \rightarrow Br_2(g)$

Use the ideas of the kinetic theory to explain why, after about an hour, the gaseous bromine molecules have spread to evenly occupy the whole container.

9 A teacher carried out a class demonstration on diffusion similar to that using ammonia (M_r = 17) and hydrochloric acid (M_r = 36.5) (Figure 1.21). However, they replaced the ammonia with methylamine (M_r = 31), which reacts in a similar way to ammonia (note that M_r is the relative molecular mass of the substance).

- **a** Where would you predict the position of the smoke ring to be in this experiment? Explain your answer.
- **b** Suggest other gases similar to hydrochloric acid that could replace it in this demonstration (use textbooks or the internet to find a possible acid).

10 Experiments comparing the rate of diffusion of different gases can be done using the apparatus shown in Figure 1.23.

A cylinder of **porous pot** is used through which gas molecules are able to pass. Any change in pressure in the cylinder pot shows itself in a change of liquid levels in the side tube. When there is air both inside and outside the pot, the liquid levels are the same.

Explain why the levels of liquid change when hydrogen is placed *outside* the porous pot cylinder (Figure 1.23 b).

KEY WORDS

porous pot: an unglazed pot that has channels (pores) through which gases can pass

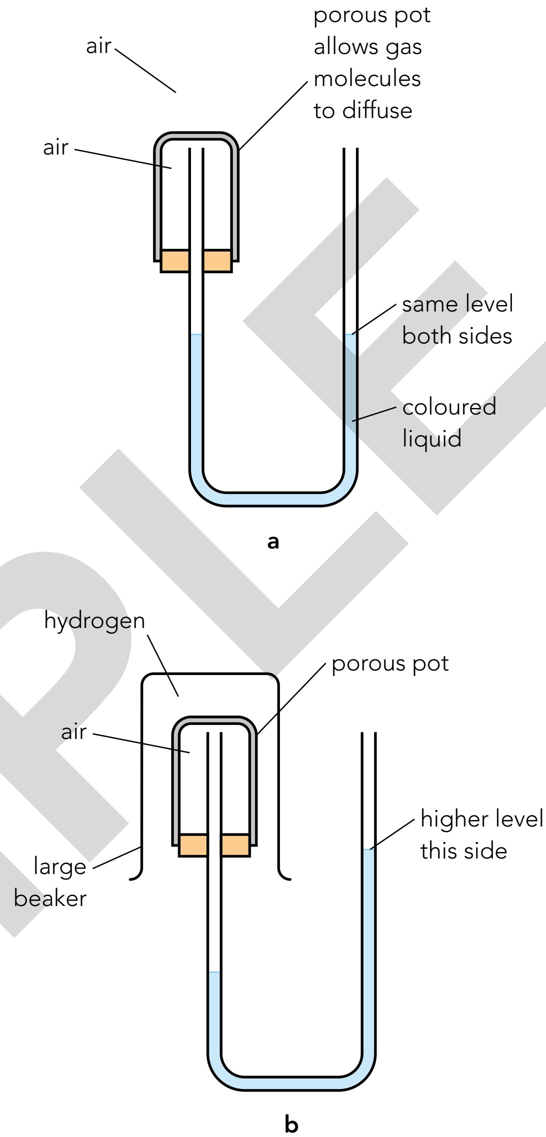


Figure 1.23: Gas diffusion through a porous pot (**a**) with air inside and outside the pot, (**b**) with hydrogen outside, air inside, the pot.

ACTIVITY 1.1

The kinetic model of matter

Modelling the arrangement of the particles in a solid, liquid or gas is one way to help understand the properties of the different states of matter.

Working in a small group, create a model or visual representation that explains the movement of the particles in the different states. Think about:

- What could you use to represent the particles? (Balls or marbles in a tray or dish, circular pieces of card on a plate, groups of people, symbols perhaps?)
- How will you arrange the particles to demonstrate solids, liquids and gases?
- How could you represent the movement of the particles?

Your model, diagram or display should answer three of the following questions:

- Why can three states of matter exist?
- Why is it that it takes time for a solid to melt?
- Why do solids not diffuse over a normal time period?
- What is different about substances that means that they each have different melting points?
- Different substances also have different boiling points. Is the reason for this similar to why they have different melting points?
- Why is it that you can feel a liquid cool when it evaporates in your hand?

After you have taken time to answer the questions, each group should choose one of the questions to demonstrate how your model works to the rest of the class.

REFLECTION

To understand some the ideas introduced in this chapter, you need to be able to think about the behaviour of particles smaller than you can see.

- What strategies could you use to help you to visualise particles such as atoms and molecules?
- Are there any experiments which give you clues to the existence of sub-microscopic particles?
- How useful do you find the different approaches?

SUMMARY

There are three different physical states in which a substance can exist: solid, liquid or gas.
The structures of solids, liquids and gases can be described in terms of particle separation, arrangement and motion.
Different changes in state can take place, including melting and freezing, evaporation and condensation, and boiling.
Changes of state can be produced by changing conditions of temperature and/or pressure.
Pure substances have precise melting and boiling points.
The kinetic particle model describes the idea that the particles of a substance are in constant motion and that the nature and amount of motion of these particles differs in a solid, liquid or gas.

CONTINUED

Changing physical state involves energy being absorbed or given out, the temperature of the substance staying constant while the change takes place (as illustrated by the experimental construction of cooling curves).
Changes in temperature or the external pressure produce changes in the volumes of gases which can be explained in terms of the kinetic particle theory.
Diffusion in liquids and gases is the spreading of particles to fill all of the space available.
The rate of diffusion of a gas is dependent on molecular size, with molecules of lower mass diffusing more quickly than those of higher mass.

PROJECT

The 'Goldilocks principle'

How we experience the world around us depends upon the physical conditions and states in which substances exist. This is particularly true in the case of water. The Earth is the only body in our solar system where water exists in all three states of matter.

Work in a group of three or four. Use the internet to search for some information on the topics listed here. Then select one to research in detail.

The presence of water: What is distinctive about the physical conditions on Earth that mean that life could begin, and continue to exist, here? Why is water so important when thinking about how life began? Is Earth the only planet to have water and therefore life? Have other planets had water in their past? Recent space probes have been sent to try to find water on Mars and the moons of Jupiter and Saturn (Figure 1.24). Research the various missions to find out whether there are other planets in our solar system where life may have existed.

Figure 1.24: Saturn's moon Enceladus has a global ocean of liquid salty water beneath its crust.

The 'Goldilocks Zone': Earth orbits the Sun at just the right distance for liquid water to exist on its surface. It is neither too hot nor too cold for this. Research this situation, which is known as the 'Goldilocks Zone', and its meaning. Then think how it applies to the orbits of Venus, Earth and Mars.

Exo-planets and life beyond our solar system: The *Kepler* and *CHEOPS* probes have searched for planets outside our solar system (exo-planets) where life may have evolved. Research these missions and find out the characteristics of the other solar systems and planets they were hoping to find.

Decide how you will share out the tasks between the members of your group. Then bring your research together as an illustrated talk delivered to the whole class. A good illustrated talk should include the following:

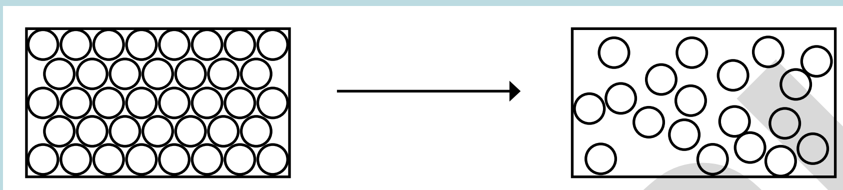
- a clear structure
- a strong introduction that includes details of the question(s) you have investigated
- a short summary of the different areas you researched: make sure your points are in a sensible order
- a list of the key conclusions at the end
- the key information presented in a graphic format (e.g. as a table, chart, pie chart) instead of just text: illustrations will make your presentation much easier for your audience to understand and help them to remember your key points.

EXAM-STYLE QUESTIONS

1 A group of friends sit sharing a special meal together. When the food was put on the table, they could all smell the appetising food. How did the smell reach them when the dishes were placed on the table?

A decomposition
B diffusion
C distillation
D decolourisation **[1]**

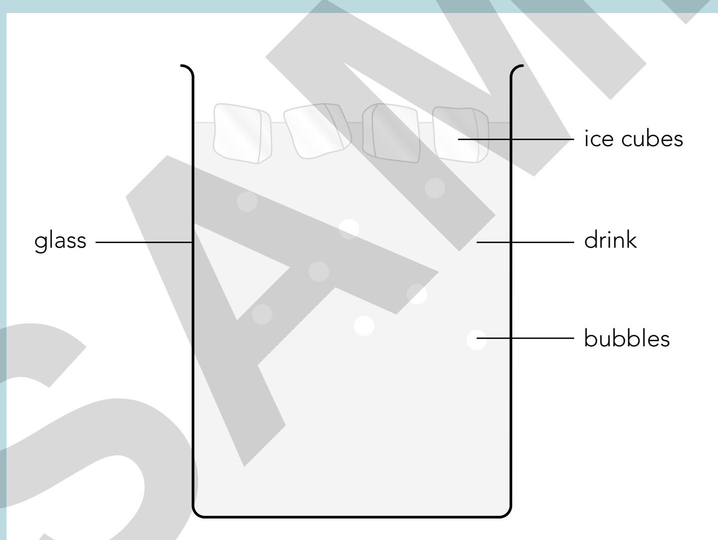
2 The figure shows one of the changes of physical state.



Which change of state is shown?

A boiling
B condensation
C melting **[1]**

3 The figure shows ice cubes floating on the surface in a glass of fizzy drink.

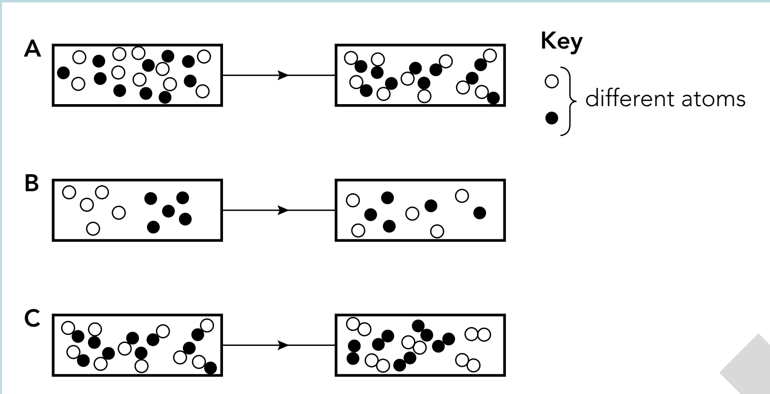


In which of **A–D** are the particles close together but free to move past each other?

A bubbles **B** glass **C** drink **D** ice cubes **[1]**

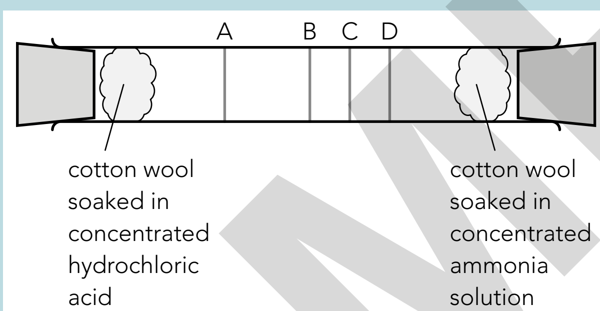
CONTINUED

4 Which of A–C in the figure shows the process of diffusion?



[1]

5 An experiment on the diffusion of ammonia and hydrogen chloride gases is carried out in a glass tube. The gases are given off by solutions held at each end of the tube.

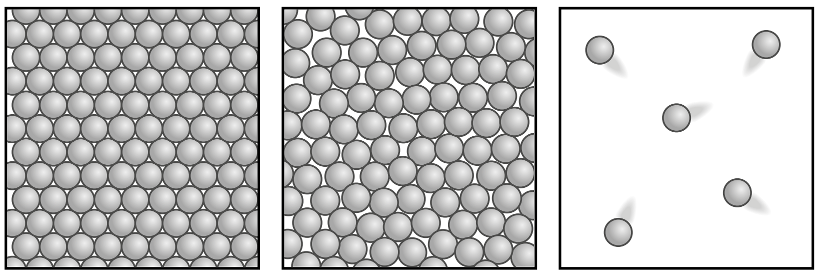


When the two gases meet, they react to produce a white solid, ammonium chloride.

Which line (A–D) shows where the white solid is formed? **[1]**

CONTINUED

6 The figure shows the arrangement of particles in each state of matter.



a In a gas, the particles are moving rapidly and randomly. **Describe** the movement of the particles in a liquid. [2]

b How does the movement of the particles in a solid change when it is heated? [1]

c What name is given to the process which happens when liquid water changes to water vapour at room temperature? [1]

d Which change of state is described by the term *sublimation*? [1]

e What is meant by the term *freezing*? [1]

[Total: 6]

7 A teacher opens a bottle of perfume at the front of her laboratory. She notices a smell of flowers. A few minutes later, students at the front of the lab notice the smell too. Those students at the back do not notice it until later.

a What two processes must take place for the smell from the perfume to reach the back of the lab? [2]

Later in the day, when the room had cooled, the teacher tries the same experiment with a different class. The smell is the same but it takes longer to reach the back of the lab.

b **Explain** this observation by reference to the particles of perfume. [2]

[Total: 4]

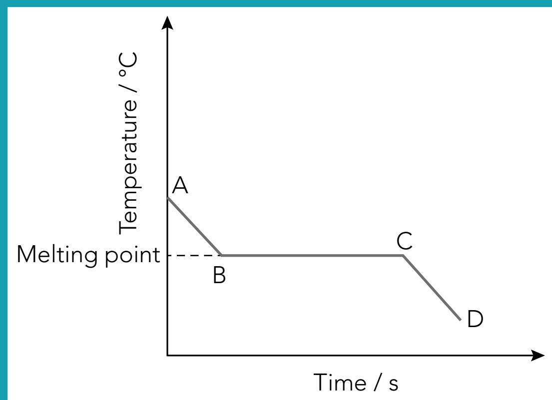
COMMAND WORDS

describe: state the points of a topic / give characteristics and main features

explain: set out purposes or reasons/make the relationships between things evident/provide why and/or how and support with relevant evidence

CONTINUED

8 The figure shows the change in temperature as a substance cools down.



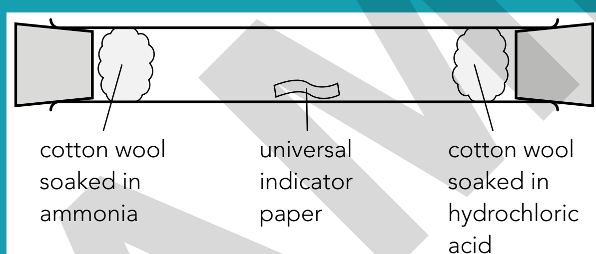
a What is happening to the substance between **C** and **D**? **[2]**

b What is happening to the particles of the substance between A and **B**? **[2]**

c Why does the temperature not change between **B** and **C**? **[1]**

[Total: 5]

9 Ammonia gas (M_r = 17) is a base that changes universal indicator to purple. Hydrogen chloride gas (M_r = 36.5) is an acid that changes universal indicator to red.

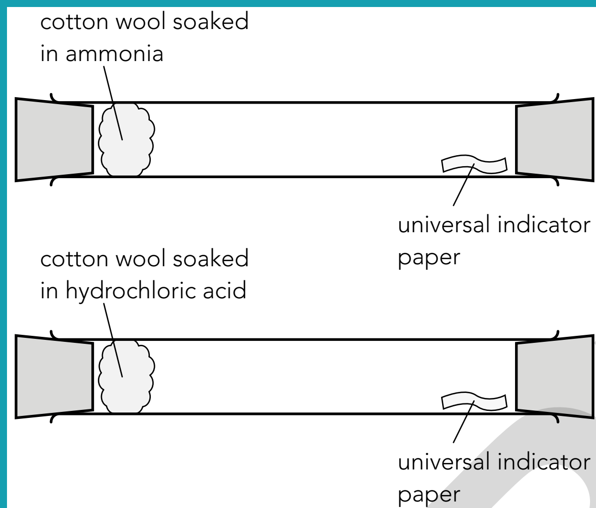


The figure shows an experiment done with these two gases. After two minutes, the universal indicator paper changed to purple.

a Why did the universal indicator change to purple and not red? **[3]**

CONTINUED

b A further experiment is shown in the figure, measuring the rates of diffusion of ammonia and hydrogen chloride.



In the ammonia tube, the colour changed in 34 s. Estimate approximately how long it took for the indicator paper in the HCl tube to change colour? Choose your answer (A–D) and give a reason.

A 34 s

B 100 s

C 50 s

D 25 s **[2]**

[Total: 5]

SELF-EVALUATION CHECKLIST

After studying this chapter, think about how confident you are with the different topics. This will help you to see any gaps in your knowledge and help you to learn more effectively.

I can	See Topic…	Needs more work	Almost there	Confident to move on
state the major differences between the three states of matter	1.1			
describe the changes of state observed with increasing or decreasing temperature	1.1			
describe the effect of changes in temperature on the motion of particles in the different states of matter	1.2			
interpret the shape of a cooling curve for a substance in terms of the kinetic particle theory	1.2			
state the effects of changing temperature and pressure on the volume of a gas	1.2			
explain, in terms of the kinetic particle theory, the effects of changing temperature and pressure on the volumes of gases	1.2			
understand how solids and gases can dissolve in liquids and the terms used to describe this	1.3			
describe diffusion in gases and liquids	1.3			
describe the effect of relative molecular mass on the rate of diffusion of a gas	1.3			

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Chemistry

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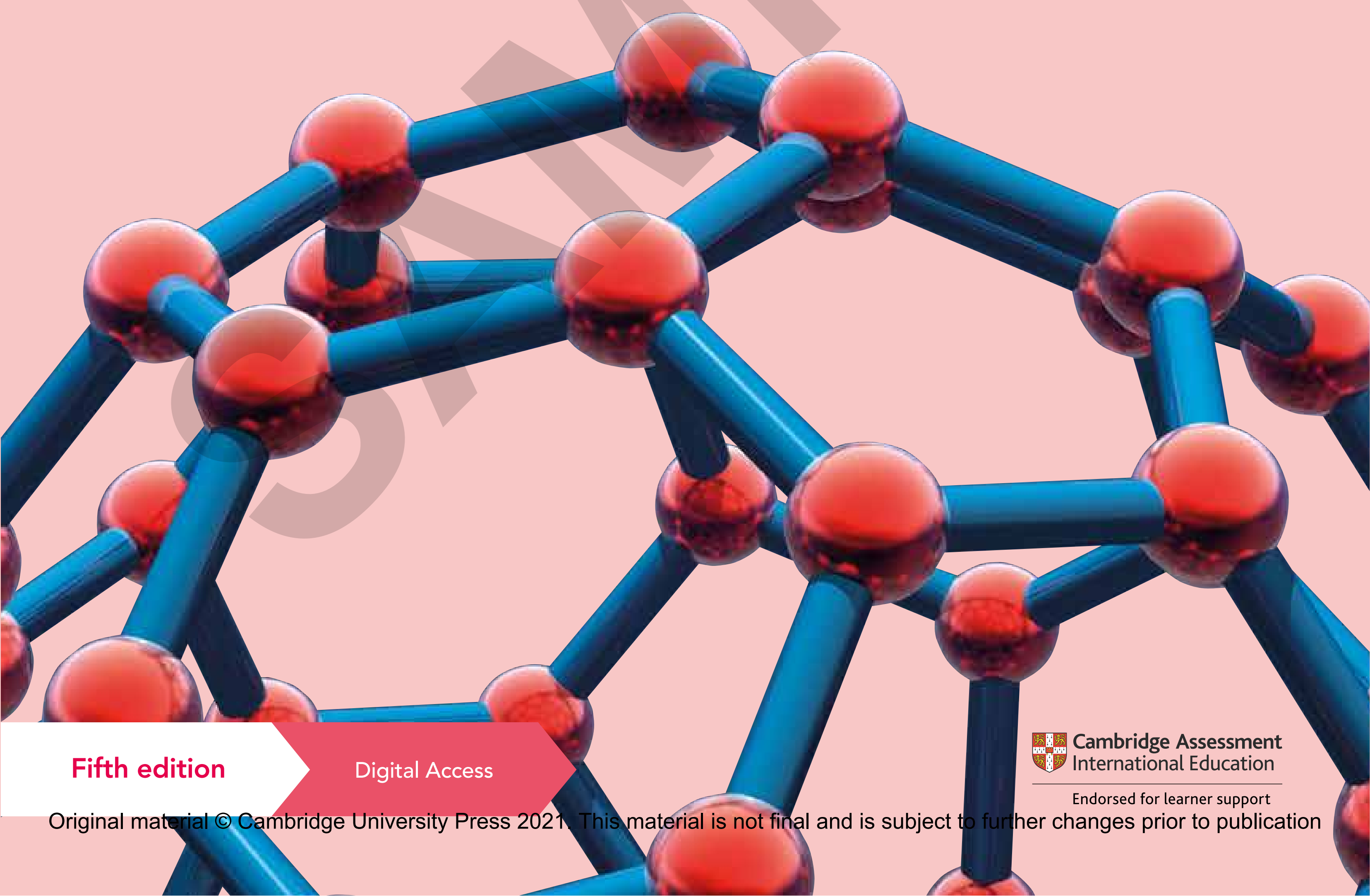
WORKBOOK

Richard Harwood, Ian Lodge & Mike Wooster



Fifth edition

Digital Access

Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below. Answers are accessible to teachers for free on the 'supporting resources' area of the Cambridge GO website.

KEY WORDS

Definitions for useful vocabulary are given at the start of each section. You will also find definitions for these words in the Glossary at the back of this book.

Supplement content: In the key word boxes, Supplement content is indicated with a large arrow, as in this example.

LEARNING INTENTIONS

These set the scene for each exercise, beginning with 'In this exercise you will:', and indicate the important concepts.

In the learning intentions box, Supplement content is indicated with a large arrow and a darker background, as in this example.

TIPS

The information in these boxes will help you complete the exercises, and give you support in areas that you might find difficult.

Exercises

These help you to practise skills that are important for studying Cambridge IGCSE Chemistry.

Questions within exercises fall into one of three types:

- Focus questions will help build your basic skills.
- Practice questions provide more opportunities for practice, pushing your skills further.
- Challenge questions will stretch and challenge you even further.

SELF/PEER ASSESSMENT

At the end of some exercises, you will find opportunities to help you assess your own work, or that of your classmates, and consider how you can improve the way you learn.

Supplement content

Where content is intended for students who are studying the Supplement content of the syllabus as well as the Core, this is indicated with the chevron, as you can see on the left here.

Chapter 1

States of matter

Changing physical state

KEY WORDS

boiling: a condition under which gas bubbles are able to form within a liquid – gas molecules escape from the body of the liquid, not just from its surface

freezing: the change of state from liquid to solid at the melting point

melting: the change of state from solid to liquid

physical state: a substance can exist in one of three states of matter (solid, liquid or gas) depending on the conditions of temperature and pressure

Exercise 1.1

IN THIS EXERCISE YOU WILL:

- develop your understanding of the distinguishing properties of solids, liquids and gases
- show how the properties of each state of matter are linked to the organisation of the particles present
- use data on melting and boiling points to determine the physical state of a substance at a given temperature.

Focus

1 There are three states of matter, which have different basic physical properties. For all physical states, complete the sentences by adding two properties they show.

A solid has a fixed .... and ....

A liquid has a fixed .... but its .... changes to that of the container in which it is placed.

A gas has no fixed .... or .... A gas completely fills the container that it is in.

2 Complete Figure 1.1 to show how the particles of a substance are arranged in the three states of matter.

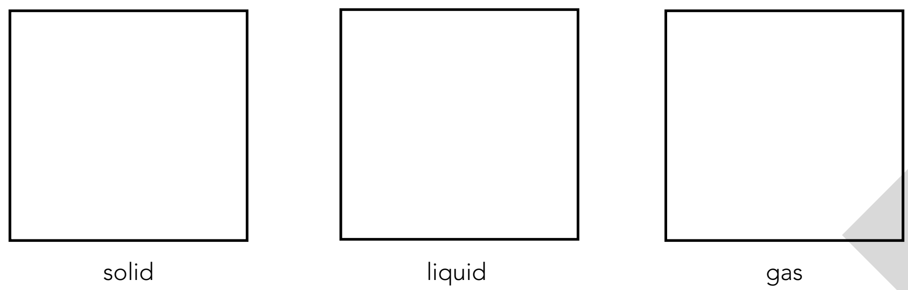


Figure 1.1: The three states of matter.

Practice

Question 2 illustrates the differences in structure and organisation of the particles in the three states. The differences can also be expressed in words. Table 1.1 describes the arrangement of the particles in four different substances, A, B, C and D.

Substance	Distance between particles	Arrangement of particles	Movement of particles
A	Very far apart	Randomly arranged	Moving about with high speed
B	Very close together	Regularly ordered	Vibrating about fixed positions
C	Very far apart	Regularly ordered	Vibrating about fixed positions
D	Close together	Irregularly arranged	Moving about

Table 1.1: The arrangement and movement of particles in substances A, B, C and D.

3 Which of substances A, B, C and D is:

a a solid ……….

b unlikely to be a real substance ……….

c a gas ……….

d a liquid ……….

> **TIP**
>
> In a liquid, the particles are still close together. However, the particles are not regularly arranged and can move around and move past each other.

4 Changing the temperature can result in a substance changing its physical state. What are the changes of state A, B, C and D in Figure 1.2?

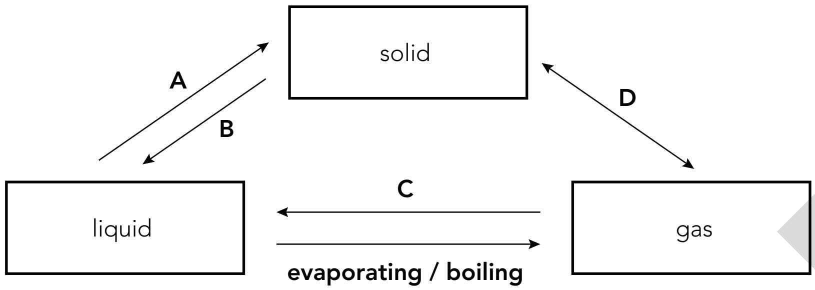


Figure 1.2: Changes of physical state.

A ....

B ....

C ....

D ....

Challenge

5 Use the data provided in Table 1.2 to answer the questions about the physical state of the substances listed when at a room temperature of 25 °C and at atmospheric pressure.

Substance	Melting point / °C	Boiling point / °C
Sodium	98	883
Radon	−71	−62
Ethanol	−117	78
Cobalt	1492	2900
Nitrogen	−210	−196
Propane	−188	−42
Ethanoic acid	16	118

Table 1.2: Melting points and boiling points of various substances.

a Which substance is a liquid over the smallest range of temperatures?

....

b Which two substances are gaseous at −50 °C?

.... and ....

c Which substance has the lowest freezing point?

....

d Which substance is liquid at 2 500 °C?

....

e A sample of ethanoic acid was found to boil at 121 °C at atmospheric pressure. Use the information provided in Table 1.2 to comment on this result.

....

....

TIP

Be careful when dealing with temperatures below 0 °C, and remember that −100 °C is a higher temperature than −150 °C.

Plotting a cooling curve

KEY WORDS

evaporation: a process occurring at the surface of a liquid, involving the change of state from a liquid into a vapour at a temperature below the boiling point

kinetic (particle) theory: a theory which accounts for the bulk properties of the different states of matter in terms of the movement of particles (atoms or molecules) – the theory explains what happens during changes in physical state

sublimation: the direct change of state from solid to gas or gas to solid: the liquid state is bypassed

Exercise 1.2

IN THIS EXERCISE YOU WILL:

- use data from an experiment to plot a cooling curve for a substance
- develop your understanding of the changes in organisation and movement of particles that take place as a substance changes state
- look at examples of substances that sublime
- link the different changes of state to the kinetic (particle) theory of matter and explain the changes taking place.

Focus

A student carried out the following data-logging experiment as part of a project on changes of state. An organic crystalline solid was melted by placing it in a tube in a boiling water-bath. A temperature sensor was placed in the liquid.

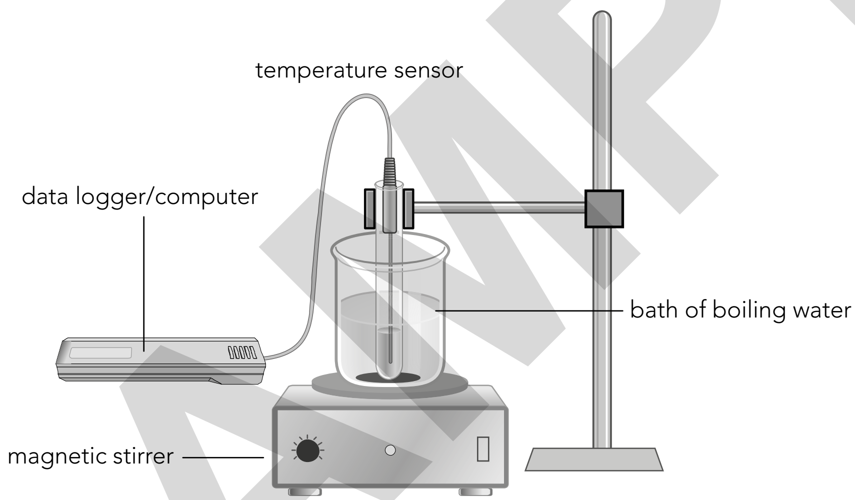


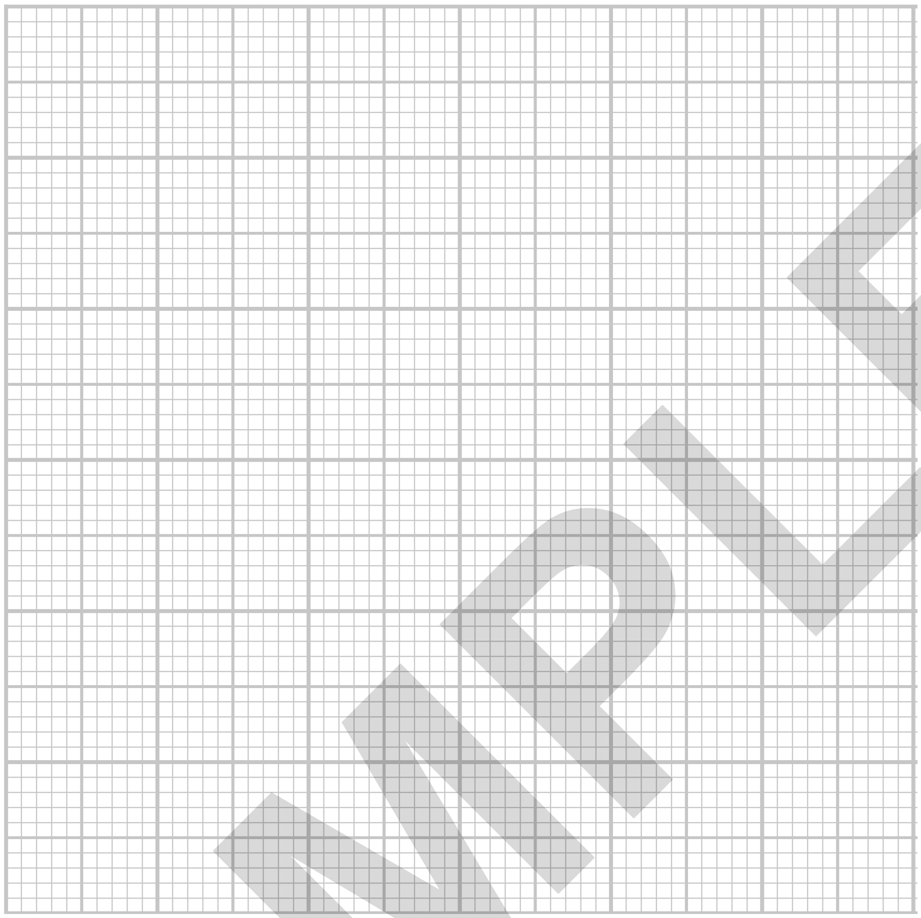
Figure 1.3: Using a temperature sensor to plot a cooling curve.

The student followed the temperature change as the liquid was allowed to cool. The data shown in Table 1.3 are taken from the computer record of the temperature change as the liquid cooled to room temperature.

Time / min	0	0.5	1.0	1.5	2.0	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0
Temperature / °C	96.1	89.2	85.2	82.0	80.9	80.7	80.6	80.6	80.5	80.3	78.4	74.2	64.6	47.0

Table 1.3: Results for cooling curve experiment.

6 On the grid provided, plot a graph of the temperature change that took place in this experiment.



7 The student decided to carry out the experiment using a compound that has a melting point greater than 100 °C. What change would she need to make to carry out the experiment?

....

8 What change is taking place over the second minute of the experiment?

....

Practice

9 Why does the temperature remain almost constant over this period of time? When giving your answer, think about how the organisation of the molecules of the substance is changing.

....

....

....

....

....

10 Another student carried out a similar experiment to demonstrate the cooling curve for paraffin wax.

a In the space below, sketch the shape of the graph you would expect the student to produce.

b Explain why you have chosen the shape for the curve you drew in **a**.

....

....

> **TIP**
>
> Pure substances have definite, precise melting points and boiling points. When a substance contains impurities, changes in melting points and boiling points will be spread over a range of temperatures.

Challenge

11 Sublimation occurs when a substance passes between the solid and gaseous states without going through the liquid phase. Both carbon dioxide and water can sublime under certain conditions of temperature and pressure.

Dry ice is the name given to the solid form of carbon dioxide. Dry ice is used in commercial refrigeration. At atmospheric pressure, it has a sublimation point of −78.5 °C.

a What difference can you see between solid carbon dioxide and water ice at atmospheric pressure?

....

....

b If you gently shake a fire extinguisher filled with carbon dioxide (Figure 1.4), you will feel the presence of liquid within the extinguisher. What conditions within the extinguisher mean that the carbon dioxide is liquid?

....

....

Figure 1.4: A carbon dioxide fire extinguisher.

c Frost is ice crystals that form on surfaces when conditions are very cold. Using the words provided, complete the following paragraph about a particular type of frost known as hoar frost.

colder crystals humid ice liquid surrounding white

Hoar frost is a powdery .... frost caused when solid ....

forms from .... air. The solid surface on which it is formed must be

.... than the .... air. Water vapour is deposited on a surface

as fine ice .... without going through the .... phase.

d For most substances, the change from a solid to a gas involves a liquid phase. The final stage of this, from liquid to gas, takes place by evaporation and/or boiling. Use the ideas of kinetic (particle) theory to explain the difference between these two processes.

Evaporation:

....

....

....

....

Boiling:

....

....

....

....

12 Experiments that allow a student to plot a cooling curve can be reversed, and a heating curve can be plotted instead. Figure 1.5 shows the heating curve for a pure substance. The temperature rises with time as the substance is heated.

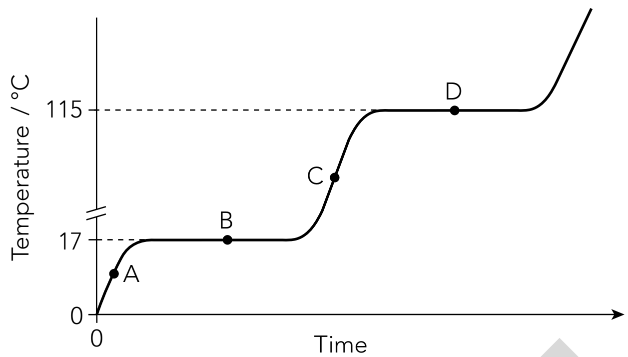


Figure 1.5: A heating curve for a pure substance.

a What physical state(s) is the substance in at points A, B, C and D?

A ....

B ....

C ....

D ....

b What is the melting point of the substance?

....

c What is the boiling point of the substance?

....

d How does the temperature change while the substance is changing state?

....

e The substance is not water. How do you know this from the graph?

....

SELF-ASSESSMENT

Use the checklist below to give yourself a mark for the graph you drew in question **6**.

For each point, award yourself:

2 marks if you did it really well

1 mark if you made a good attempt at it and partly succeeded

0 marks if you did not try to do it, or did not succeed

Then ask your teacher to mark you on the skills as well.

Checklist	Marks awarded	
	You	Your teacher
Have you drawn the axes with a ruler, using most of the width and height of the grid?		
Have you used a good scale for the x-axis and the y-axis, which goes up in 0.25 s, 0.5 s, 1 s or 2 s? [Note that the axes do not necessarily need to start at the origin (0,0).]		
Have you labelled the axes correctly? Have you given the correct units for the scales on both axes?		
Have you plotted each point precisely and correctly?		
Have you used a small neat cross or dot for each point?		
Have you drawn a single, clear best-fit line through each set of points?		
Have you ignored any anomalous (unexpected) results when drawing the line through each set of points?		
Total (out of 14):		

Your total score will reflect how clear and well-presented your graph is. You should be able to deduce reliable information from your graph.

Look at where you scored yourself two marks and where you gave yourself less than that. What did you do well, and what aspects will you focus on next time? Having thought about your assessment, talk it through with your teacher to gain further advice on areas that would help you improve your presentation of graphical data.

Dissolving and diffusion

KEY WORD

diffusion: the process by which different fluids mix as a result of the random motions of their particles

Exercise 1.3

IN THIS EXERCISE YOU WILL:

- consider how the process of diffusion explains how a solid can dissolve in a liquid
- examine how diffusion in a liquid or gas results from the spreading of particles to fill the space available to them
- consider the relationship between the rate of diffusion in gases and their molecular mass.

Focus

13 A student placed some crystals of potassium manganate(VII) at the bottom of a beaker of distilled water. She then left the contents of the beaker to stand for one hour.

Figure 1.6 shows what she saw during the experiment. After one hour, the student observed that all the solid crystals had disappeared and the solution was purple throughout.

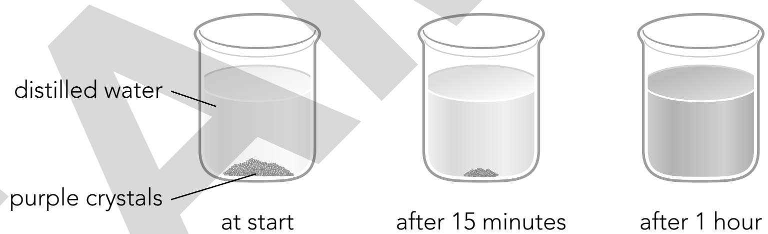


Figure 1.6: A crystal of potassium manganate(VII) placed in water.

a Use the ideas of the kinetic (particle) theory to explain the student's observations.

You may wish to use some or all of the following phrases in constructing your answer.

crystal surface **evenly spread** **particles move**

solid dissolves completely **spread out** **the crystals are soluble**

....

....

....

....

....

b If the student had used warm water at 50 °C, would the observations have taken place in a longer or shorter time? Explain your answer.

....

....

....

Practice

14 Ammonium chloride is often given as an example of a compound that sublimes when heated (Figure 1.7). The white solid enters directly into the vapour state when heated, but the solid then reforms on the cooler upper part of the tube.

Figure 1.7: Sublimation of ammonium chloride.

This sublimation is thought to involve two chemical reactions. The first reaction is the thermal decomposition of the solid ammonium chloride. The products are two gases: ammonia and hydrogen chloride.

a Write a word equation for the decomposition of ammonium chloride.

....

b In the cooler part of the tube the two gases react to form ammonium chloride.

Complete the following chemical equation for this reaction (include the state symbol for the missing reactant).

$NH_3(g)$ + ... → $NH_4Cl(s)$

Challenge

15 Figure 1.8 shows a laboratory demonstration of this reaction. The apparatus is arranged so that the two gases, ammonia and hydrogen chloride, diffuse towards each other in a sealed tube.

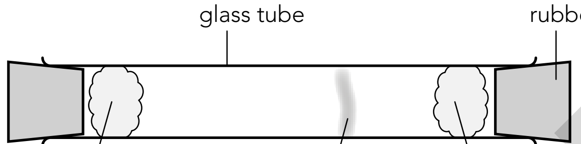


Figure 1.8: Demonstration of the different rates of diffusion for gases.

Where the gases meet within the sealed tube, they react to form a white smoke ring of ammonium chloride.

a The white solid forms nearer the end of the tube containing the concentrated hydrochloric acid. Explain why.

....

....

....

b If the distance between the cotton wool balls is 45 cm, approximately how far along from the end of the tube containing the ammonia will the white ring form?

....

....

Table 1.4 shows the formulae and relative molecular masses of four different gases.

Gas	Formula	Relative molecular mass (*Mr*)
Oxygen	O_2	32
Hydrogen	H_2	2
Chlorine	Cl_2	71
Methane	CH_4	16

Table 1.4: Formulae and relative molecular masses of several gases.

c List the four gases in order of their rate of diffusion (with the quickest first).

....

TIP

When asked to list things in increasing or decreasing, order, make sure you understand which order to put the items. Make sure you use the 'greater than' (>) and 'less than' (<) symbols correctly.

d A gas, G, diffuses slower than methane, but faster than oxygen. What can you say about the relative molecular mass of G?

....

....

16 Complete the paragraphs using the words provided.

different diffuse diffusion gas inversely lattice

molecular particles random spread temperature vibrate

The kinetic model states that the .... in a liquid and in a .... are constantly moving. In a gas, the particles are far apart from each other and their movement is said to be .... The particles in a solid are held in fixed positions in a regular .... In a solid, the particles can only .... about their fixed positions.

Liquids and gases are fluids. When particles move in a fluid, they can collide with each other. When they collide, they bounce off each other in .... directions. If two gases or liquids are mixed, the different types of particle .... out and get mixed up. This process is called ....

In gases at the same ...., particles that have a lower mass move faster than particles with higher mass. This means that the lighter particles will spread and mix more quickly. The lighter particles are said to .... faster than the heavier particles. When gaseous molecules diffuse, the rate at which they do so is .... related to the relative .... mass (M_r) of the gas.

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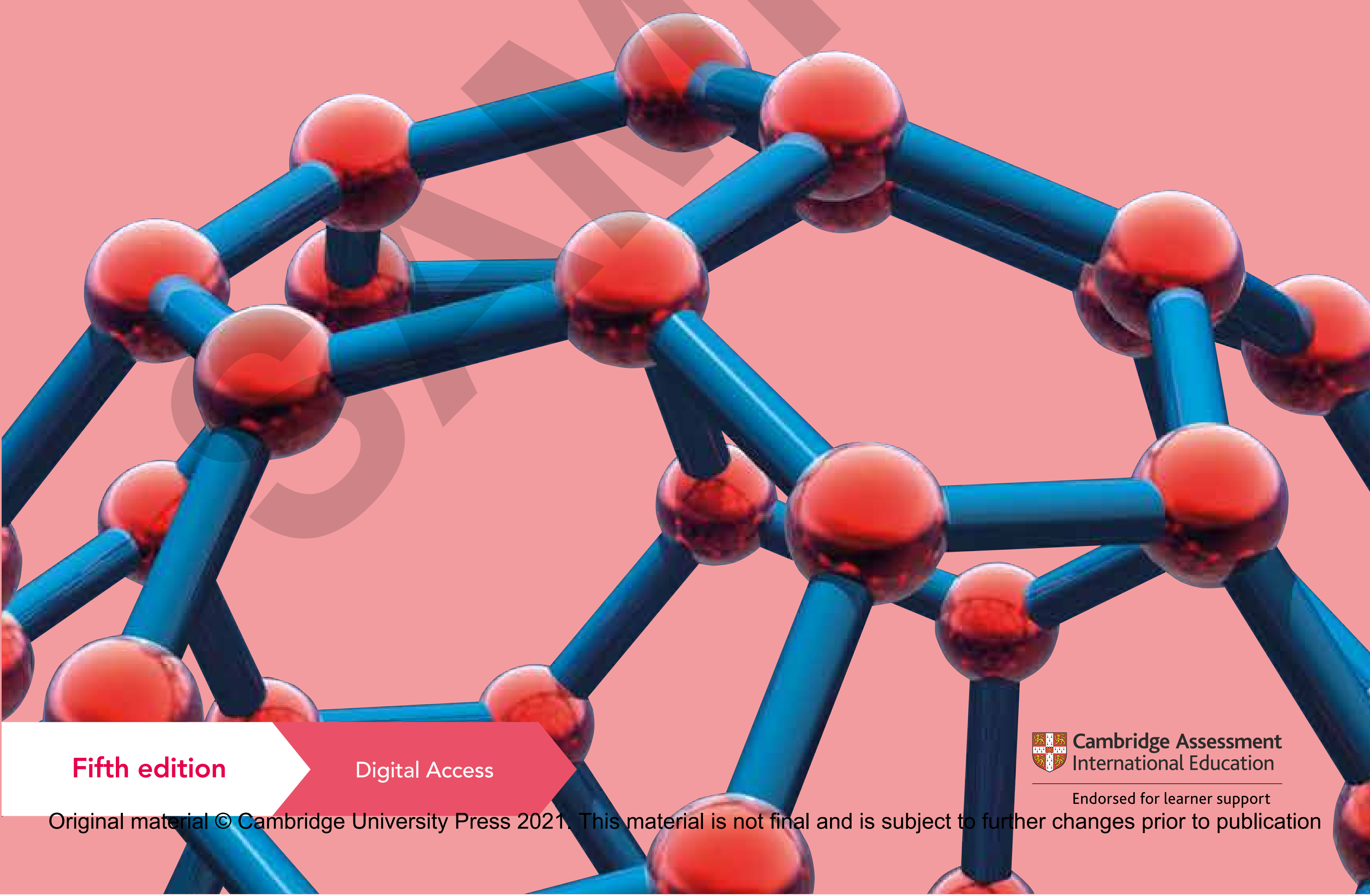
PRACTICAL WORKBOOK

Michael Strachan & Mike Wooster



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Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

INTRODUCTION

These set the scene for each chapter and indicate the important concepts. These start with the sentence 'The investigations in this chapter will:'.

KEY WORDS

Key vocabulary and definitions are given at the start of each investigation. You will also find definitions of these words in the Glossary at the back of this book.

COMMAND WORDS

Command words that appear in the syllabus and might be used in exams are highlighted in the exam-style questions. In the margin, you will find the Cambridge International definition. You will also find these definitions in the Glossary at the back of the book.

LEARNING INTENTIONS

These set out the learning intentions for each investigation.

The investigations include information on **equipment**, **safety considerations** and **method**. They also include **questions** to test your understanding on recording data, handling data, analysis and evaluation.

Remember that there is a **safety section** at the start of this book – you should refer to this often, as it contains general advice that is applicable to many of the investigations.

REFLECTION

These encourage you to reflect on your learning approaches.

TIPS

The information in these boxes will help you complete the questions, and give you support in areas that you might find difficult.

Supplement content

Where content is intended for students who are studying the Supplement content of the syllabus as well as the Core, this is indicated using the chevron, as on the left here. Some practical investigations that include both core and supplement content use this chevron where the main focus of the investigation is on supplement content.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions, some of which may require use of knowledge from previous chapters. The answers to these questions are accessible to teachers for free on the Cambridge GO site.

Note for teachers:

The teacher's resource in this series includes sample data and support notes for each of the practical investigations in this practical workbook. You can find information about planning and setting up each investigation, further safety guidance, common errors to be aware of, differentiation ideas and additional areas for discussion.

Answers to all questions in this practical workbook are also accessible to teachers at www.cambridge.org/go

Chapter 1

States of matter

THE INVESTIGATIONS IN THIS CHAPTER WILL:

- develop your knowledge of three states of matter: solid, liquid and gas
- focus on the changes between each state
- show you that by changing the temperature of a substance, you can change the state that it exists in
- enable you to explain that when changing states, energy is needed to break the intermolecular forces between molecules.

Practical investigation 1.1: Changing the physical state of water

KEY WORDS

boiling point: the temperature at which a liquid boils, when the pressure of the gas created above the liquid equals atmospheric pressure

freezing point: the temperature at which a liquid turns into a solid – it has the same value as the melting point; a pure substance has a sharp freezing point

intermolecular force: the weak attractive force that acts between molecules

matter: anything that occupies space and has mass

melting point: the temperature at which a solid turns into a liquid – it has the same value as the freezing point; a pure substance has a sharp melting point

IN THIS INVESTIGATION YOU WILL:

- examine changes of state in terms of melting, boiling and freezing
- learn how to use a Bunsen burner safely
- draw a graph to show trends in the data.

YOU WILL NEED:

- clamp stand with clamp and boss • heat-resistant mat • ice • timer
- Bunsen burner or heating element • thermometer • beaker (250 cm^3) • pestle
- mortar • tripod • gauze • stirring rod • safety glasses • lab coat • gloves.

Safety

- Wear eye protection throughout.
- As you will be using hot liquids, you will need to stand for the practical.
- Remember to take care when handling hot glassware and be careful when the water is boiling as the steam will be very hot.

Getting started

Think about how ice keeps a drink cold even on a very hot day. Why does the drink not get warm until all the ice has melted?

....

You will be using a Bunsen burner in this experiment. To be successful you will need to be able to change the type of flame produced by the burner. This is done by adjusting the small collar at the base of the burner to make the vent hole larger or smaller. When the collar is adjusted so that the vent is closed, a yellow flame is produced. This is the lowest temperature flame. If the vent is halfway open, a gentle blue flame is produced. When the vent is fully open, a roaring blue flame is produced. This is the hottest temperature flame. It is important to use the correct flame to get the appropriate temperature.

Method

1 Add seven ice cubes to the mortar and crush them with the pestle until you are left with only small pieces. Do this carefully so that the ice cubes do not escape from the mortar.

> **TIP**
>
> If you have large ice cubes, it might be best to crush the cubes one at a time.

2 Place the crushed ice in the beaker until the beaker is half full.

3 Set up the Bunsen burner on the heat-resistant mat.

4 Place the beaker on the tripod and gauze. Use the clamp and clamp stand to hold the thermometer in the beaker. You can use the diagram in Figure 1.1 to help you.

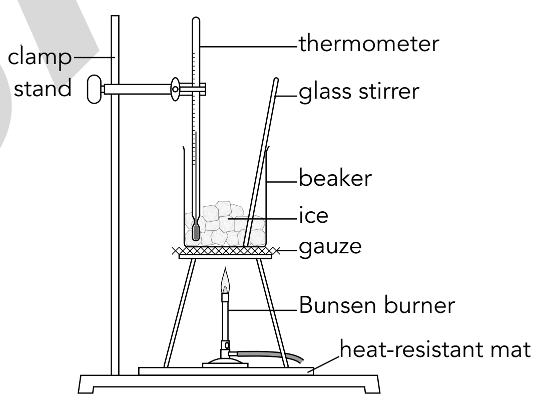


Figure 1.1: Setup for measuring the changing state of ice.

5 Measure the temperature of the ice in the beaker. Record the result in the results table in the Recording data section.

6 Start the timer. Begin to heat the beaker of water with the Bunsen burner on a gentle blue flame.

7 Record the temperature every minute. Use the stirring rod to make sure the ice melts evenly. Once the water is boiling (you can see bubbles forming within the liquid), only take one more reading.

Recording data

1 Record your results in the table provided. The units are missing and need to be added.

Time /	0	1	2	3	4	5	6	7	8
Temperature /									

Handling data

2 Construct a graph to show the results of your experiment. Think about whether you will need to plot a line graph or a bar graph.

TIP

Use a sharp pencil and a ruler to draw your graph.

Points on the graph should be clearly marked as crosses (×) or encircled dots (⊙).

Analysis

3 Use the words below to complete the conclusions.

boiling **gas** **heating** **intermolecular**

liquid **melting** **molecules** **temperature**

At first the ……………………… inside the beaker did not change. This is because the energy being added by ……………………… was being used to break the ……………………… forces between the water ……………………… in the solid state. This is called ……………………….

Once all the solid water had turned into ……………………… water, the temperature began to increase. The temperature stopped increasing once the water reached its ……………………… point. The energy being added was now used to break the intermolecular forces between the water molecules in the liquid state. This meant that the water could turn into a ……………………….

4 Look at the graph in Figure 1.2.

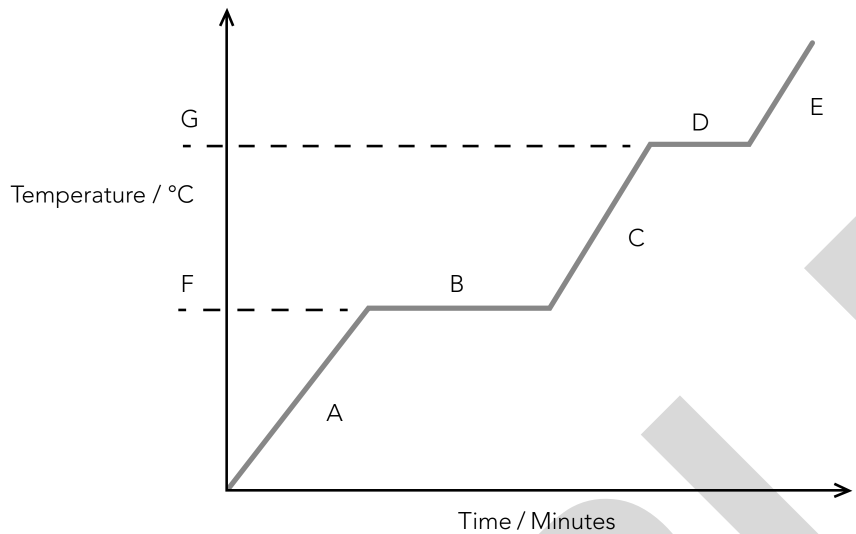


Figure 1.2: A graph to show the heating of a substance.

Match the correct letter to each of the following words or terms:

a Melting point: ……….

b Boiling point: ……….

c Solid: ……….

d Liquid: ……….

e Gas: ……….

Evaluation

5 Think about your experiment. How could you have made the results more accurate?

……….

……….

……….

……….

6 You could add an impurity, such as salt, to the ice in this experiment.
Suggest how this impurity would affect the results. Sketch a graph to support your ideas.

……….

……….

……….

……….

REFLECTION

Practical experiments are an important part of chemistry. Think about how you performed this practical.

Were you confident handling the apparatus?

Were you able to use your background knowledge of the subject to help you in the analysis and evaluation?

Practical investigation 1.2: Cooling curves

IN THIS INVESTIGATION YOU WILL:

- examine the effect of temperature on the movement of particles in liquids and solids
- construct a cooling curve from the data you obtain

› interpret a cooling curve.

YOU WILL NEED:

- clamp stand with two clamps and bosses • heat-resistant mat
- Bunsen burner or heating element • thermometer • beaker (250 cm^3)
- timer • tripod • gauze • boiling tube containing stearic acid
- safety glasses • lab coat • gloves.

Safety

- Wear eye protection throughout.
- As you will be using hot liquids, you will need to stand for the practical.
- Remember to take care when handling hot glassware and also to be careful when the water is boiling as the steam will be very hot.

Getting started

As substances cool, they can change from one state into another state. What do you think will happen to the temperature recorded during these changes of state?

....

You will be using a thermometer in this investigation. Make sure you know how to use the thermometer to accurately measure temperature.

See the Practical skills and support section at the start of this workbook for more information about how to take reliable readings with a thermometer.

Method

1. Set up the Bunsen burner on the heat-resistant mat. Place the tripod over the Bunsen burner and add the gauze to the tripod.
2. Measure 150 cm^3 of water and add the water to the beaker. Place the beaker onto the gauze.
3. Fix the clamps and bosses to your clamp stand and place the apparatus next to your tripod.
4. Clamp the boiling tube with the stearic acid so that the boiling tube is held in the beaker of water. See Figure 1.3 for guidance.

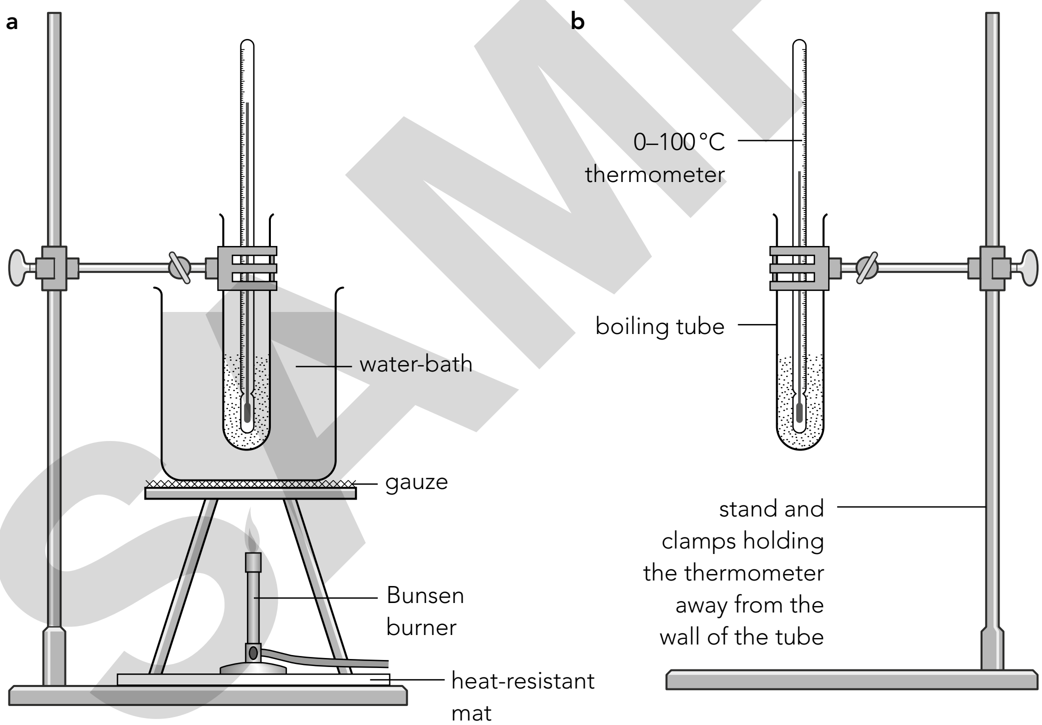


Figure 1.3 a: Heating the stearic acid in a water-bath. **b:** Cooling the stearic acid.

5. Light the Bunsen burner and heat the beaker of water on a gentle blue flame. Heat the water so that it is just boiling gently. You will need to move the Bunsen burner from under the tripod to achieve a gentle boil.

6 As the stearic acid melts, add the thermometer to the boiling tube. Use a clamp to hold the thermometer away from the wall of the boiling tube (Figure 1.3a). Once the thermometer reads 75 °C turn off the Bunsen burner and lift the clamp so that the boiling tube is out of the water (Figure 1.3b).

7 You will need to design your data collection table in the Recording data section. Then record the temperature and start the timer. Record the temperature every 30 seconds until the temperature reaches 45 °C. Do not remove the thermometer from the boiling tube or attempt to stir the stearic acid, as the thermometer might break.

Recording data

1 Design a results table for your investigation in the space provided. You do not yet know how many readings you will need to take. Think about this when you are drawing your table.

Handling data

2 Construct a graph to show the results of your experiment. Think about whether you will need to plot a line graph or a bar graph.

3 Add a curve of best fit to the graph to show the temperature change. You will need to draw the curve freehand without using a ruler.

Analysis

4 The graph you have drawn is known as a cooling curve. Look at your graph to help you complete the following sentences.

The substance cooled from a temperature of ....°C to a temperature of

.................°C in .... minutes.

The freezing point was ....°C.

5 How long did it take for your sample to freeze?

....

Evaluation

6 Describe how you could improve the method to get more accurate readings for the temperature.

....

....

....

7 Why was the stearic acid heated in a water-bath and not heated directly with a Bunsen flame?

....

....

8 Stearic acid is a waxy solid found in various animal and plant fats. Suggest why stearic acid was used instead of water for this investigation.

....

....

9 How could you make the experiment safer? Suggest one improvement.

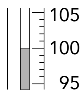
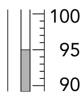
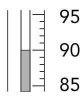
....

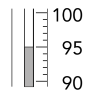
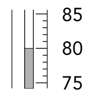
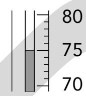
....

EXAM-STYLE QUESTIONS

1 Two students were investigating how a new type of antifreeze affects the boiling point of water.

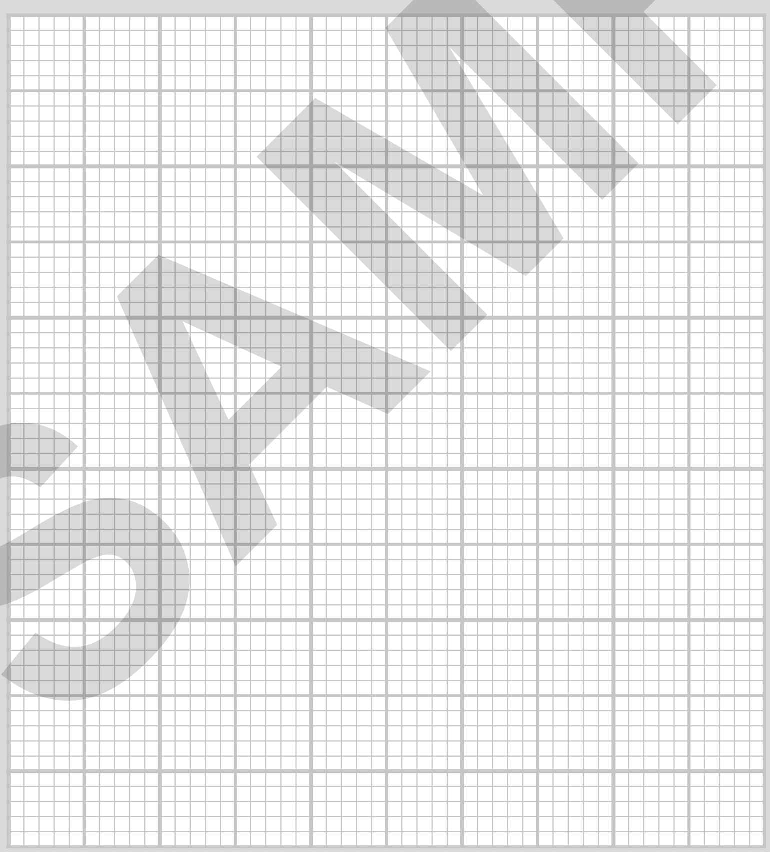
a Use the thermometer diagrams in each table to complete the results column for the boiling point temperature.

Mass of antifreeze added / g	Thermometer diagram	Boiling point / °C
0		
20		
40		

Mass of antifreeze added / g	Thermometer diagram	Boiling point / °C
60		
80		
100		

[6]

b Plot the points on the grid and draw a smooth line graph.



[6]

CONTINUED

c **Consider** which of your results is an anomaly.

....

.... [1]

d Use your graph to find the boiling point of water with 90 g of antifreeze dissolved in it.

.... [1]

e **Suggest** one control variable for this experiment.

....

.... [1]

[Total: 15]

2 Two students are investigating changes of state by heating ice cubes in a beaker using a Bunsen burner. They are recording the temperature of the contents of the beaker every minute. The students suggest four improvements to the method that they think will make their experiment more reliable.

a Read the student's four suggestions.

Tick the box if you think the suggestion will make the experiment more reliable.

- Use a silver tripod instead of a black tripod. ☐
- Repeat the experiment and calculate a mean temperature for melting and boiling point. ☐
- Weigh the mass of ice used. ☐
- Use a machine to stir the water, instead of stirring the water by hand. ☐

[2]

b Find an example of where adding an impurity to water to change its melting or boiling point is used in everyday life. **Explain** why the melting point or boiling point is changed, with reference to the intermolecular forces between water molecules.

....

....

....

.... [2]

[Total: 4]

COMMAND WORDS

consider: review and respond to given information

suggest: apply knowledge and understanding to situations where there are a range of valid responses in order to make proposals / put forward considerations

COMMAND WORD

explain: set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence

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Chemistry

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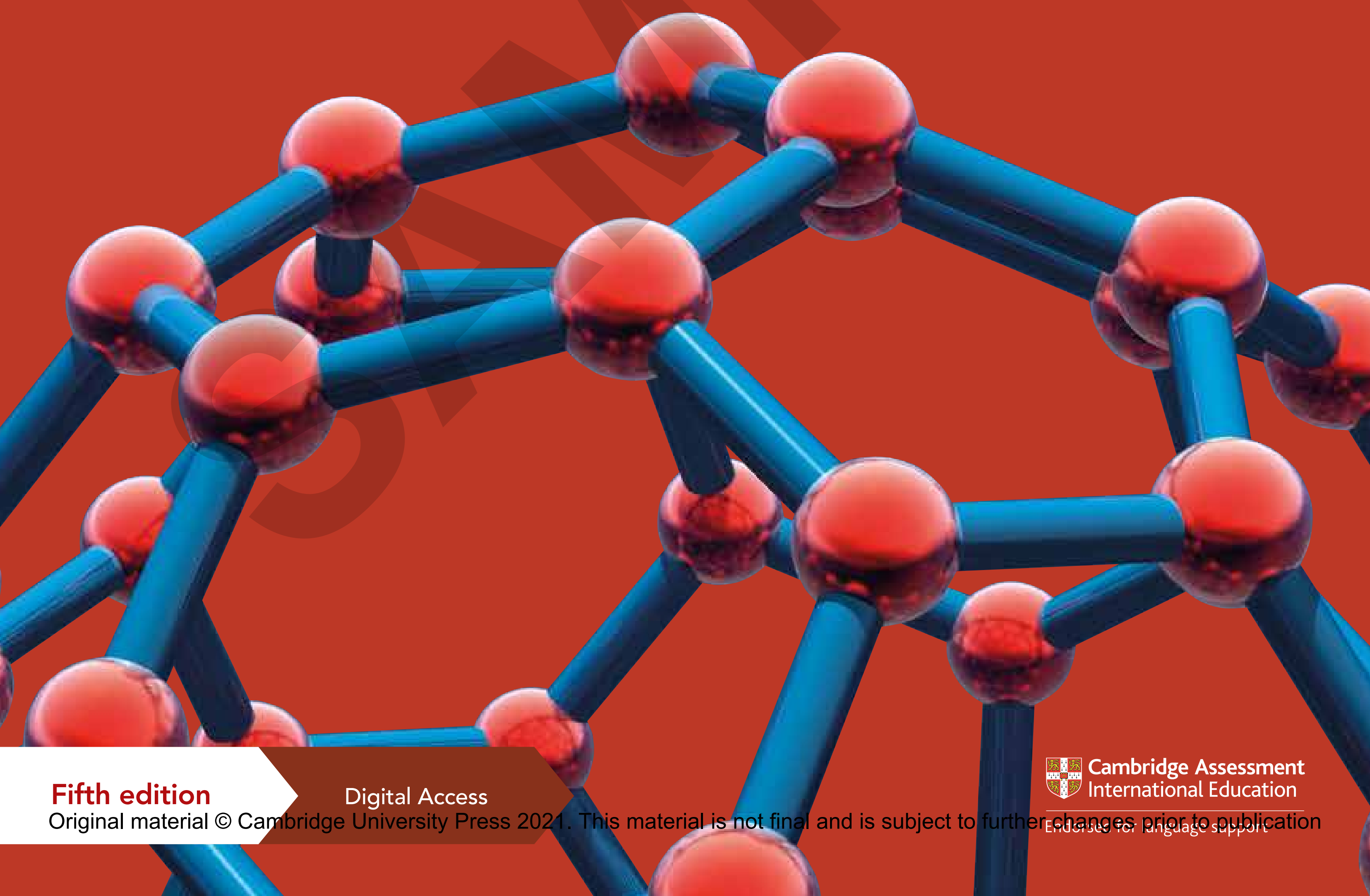
ENGLISH LANGUAGE SKILLS WORKBOOK

Richard Harwood & Tim Chadwick



Fifth edition

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Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

INTRODUCTION

This sets the scene for each chapter.

LEARNING INTENTIONS

These set out the learning intentions for each exercise. Each exercise will help you to develop both your English skills and your chemistry skills.

KEY WORDS

Key vocabulary and definitions are given in boxes at the start of exercises. You will also find definitions of these words in the Glossary at the back of this book.

Exercises

These help you to develop and practise your English skills alongside your Chemistry skills.

LANGUAGE FOCUS

These give you more information about parts of the English language that you may find challenging, to help you use English more fluently.

LANGUAGE TIPS

The information in these boxes will help you complete the questions using correct English, and give you support in areas that you might find difficult.

Chapter 1

States of matter

IN THIS CHAPTER YOU WILL:

Science skills:

- describe the key properties of the physical states of matter and the changes that take place between them
- understand the kinetic particle theory of matter and the nature of diffusion and dissolving

English skills:

- understand the verbs involved in describing changes of physical state and the nouns resulting from them
- develop the ability to construct sentences linking facts and their consequences.

Exercise 1.1 The three states of matter

IN THIS EXERCISE YOU WILL:

Science skills:

- look at the basic properties of the different physical states of matter and the changes of state brought about by changing temperature

English skills:

- develop your confidence in using the words involved with changes of state and help you discuss comparisons between the states.

KEY WORDS

boil: a process under which gas bubbles can form within a liquid. When a liquid boils, gas molecules escape from the body of the liquid, not just from its surface.

evaporate: when a liquid changes to vapour, at a temperature below the boiling point

fluidity: the ability to flow; a property of fluids (gases or liquids)

matter: anything that has mass and occupies space

physical states (of matter): there are three: solid, liquid and gas

1 Look at the diagrams in Figure 1.1, which show how the particles are arranged in a solid, a liquid and a gas. Use the diagrams, and what you know about substances you have used, to help you fill in the gaps in Table 1.1.

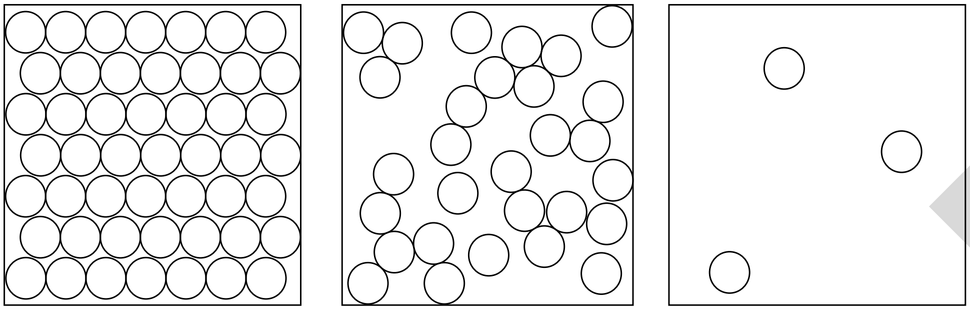

Figure 1.1: The arrangement of particles in a solid, a liquid and a gas.

Physical state	Volume	Density	Shape	Fluidity
solid	has a fixed volume	....	has a definite shape	does not flow
liquid	has a fixed volume	moderate to high	does not have a .... – takes the shape of the container	generally ....
Gas	does not have a .... – expands to fill the container and can be compressed	....	does not have a definite shape – takes the shape of the container	flows easily

Table 1.1: Physical properties of the different states of matter.

2 Complete the comparisons below using words given in the list. Each word should be used only once.

fixed lower expands higher fluid
more compressed pressure

a Most solid substances have a .... density than the liquid or gas.

b The density of a gas is .... than that of the liquid state.

c The volumes of a solid and a liquid are .... while a gas .... to fill the container it is in.

d Both gases and liquids are .... states. A gas is .... fluid than a liquid.

e Solids and liquids have a fixed volume which is not changed by increasing the pressure. However, gases can be .... by increased ....

LANGUAGE TIP

Liquids and gases can both *flow* and adjust to the shape of their container. This means they are *fluid*. They can be poured into and out of a container. Liquids and gases are called *fluids*.

flow = verb *fluid* = adjective *fluid(s)* = noun

3 **a** Read the following description and use the information from the passage to complete the labels in Figure 1.2.

All chemical substances can exist in three different forms (or **physical states**) depending on the conditions. These different states of **matter** are known as solid, liquid and gas. Changing the temperature can change the state in which the substance exists. Increasing the temperature will eventually cause most solids to melt. The temperature at which a solid melts is the melting point of that substance. The substance then becomes liquid.

If a liquid is left alone, it will slowly **evaporate**. It becomes a vapour or gas. This evaporation can happen at any temperature, but if the temperature is increased enough, it will reach a point where the liquid **boils**. Bubbles of gas form in the liquid and this temperature is the boiling point. Some substances evaporate and boil very easily. They are *volatile*. At normal pressures, a very few substances can pass from the solid state directly to a gas: this process of missing out the liquid stage is known as sublimation.

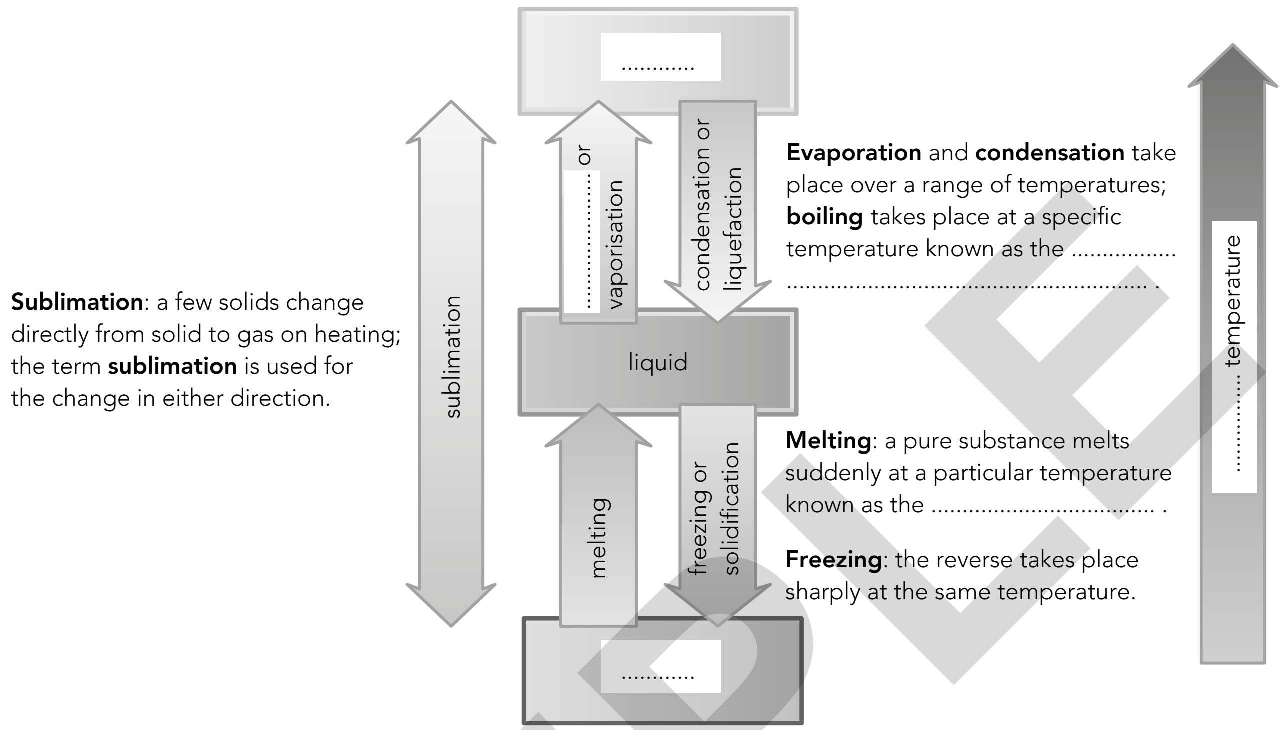

Figure 1.2: Diagram for completion with missing words.

b Write a suitable title for Figure 1.2 to describe what it shows.

....

c What do you think will happen if we increase the temperature of a liquid?

I think that if we increase the temperature of a liquid

....

....

....

d Table 1.2 contains words that describe changes in states of matter, or of a solid suddenly appearing as the result of a chemical reaction, which is known as *precipitation*.

LANGUAGE FOCUS

When you describe the *action* of a substance changing state, or of an agent (e.g. a person) carrying out an *action*, you use a verb. For example, the verb to *sublime*:

When heated strongly, the iodine *sublimed* to give a purple vapour.

The *names* of the processes taking place are nouns. For example:

Maya carried out the sublimation of iodine by heating the solid strongly.

Note! Most nouns describing processes end in *-ation*. If the verb ends in *-e*, change the *-e* for *-ation*. However, with some verbs, particularly verbs ending in *-fy* (e.g. solidify) you need to change *-y* for *-ication*.

The product of the change is also a noun. For example:

Maya collected the *sublimate* on a cold glass surface.

4 Complete the left-hand column of the table with the verb forms of the missing words. Then add the missing nouns that describe the processes, in the second column. Finally, in the third column, add the missing nouns that are the general name for the product of the process.

Verb	Noun: name of process	Noun: product of process
to condense		
	evaporation	vapour
	sublimation	
to precipitate		precipitate
	solidification	solid

Table 1.2: Nouns and verbs about changes of state.

Exercise 1.2 Explaining physical processes

IN THIS EXERCISE YOU WILL:

Science skills:

- develop your familiarity with the key ideas of scientific observation, explanation and definition

English skills:

- further increase your confidence in talking about changes of state.

LANGUAGE FOCUS

Compare these sentences:

1 *The melting point of ice is 0 °C,* ***so*** *it becomes liquid at higher temperatures.*

2 *Ice becomes liquid at temperatures higher than 0 °C* ***because*** *it is above its melting point.*

The melting point of ice is 0 °C = a **fact**.

It becomes liquid at higher temperatures = a **consequence**, **result** or **logical conclusion**.

fact > consequence = fact *so* consequence

However,

consequence > fact = consequence *because* fact

Sometimes a fact can give us an idea for a new theoretical explanation, or hypothesis. If so, we can link the fact and the hypothesis using 'which suggests that':

Fact / Hypothesis

Liquids are fluid, *which suggests that* the particles in liquids can move around.

1 The following sentences are made up of two parts. Some contain a fact and a consequence. Others contain a fact and a hypothesis. Complete each sentence using *because*, *so* or *which suggests*. Here is an example to help you:

Puddles of water disappear after the rain has stopped ..because.. water evaporates into the air.

a Iron is denser than water .... a block of solid iron sinks when placed on the surface of water.

b Ice floats on water .... , unusually, solid water (ice) is less dense than the liquid.

c Ethanol is more volatile than water .... it evaporates more quickly than water.

d A gas spreads out to fill its container .... that the particles of a gas can move around freely.

e Water evaporates more quickly the higher the temperature .... puddles disappear quickly on a warm day.

f A liquid can be poured from one beaker to another .... a liquid is fluid and can flow from one place to another.

g A gas can be compressed when pressure is applied .... that there is space between the particles in a gas.

Some of these facts are the basis of the kinetic particle theory of matter. We will consider that theory further in the next exercise.

2 The following statements *define* terms used to talk about changes of state. You have already met the terms in this chapter.

LANGUAGE FOCUS

The word *define* is often used at the start of instructions, in science. It means you must give a short, but complete, meaning of the term.

Definitions often use *which* or *that* to link parts of the definition together, for example:

Melting is the process *that* takes place when a solid turns into a liquid.

Match the sentence halves. The first one has been done for you.

i Freezing is the process … D ....

ii Fluids are substances … ....

iii The melting point is the temperature at … ....

iv Boiling is a process … ....

A … *that* can flow from one place to another.
B … *which* a solid turns into a liquid.
C … *that* turns a liquid into a gas.
D … *that* turns a liquid into a solid.

LANGUAGE TIP

Sentences like the complete sentences in **2** are useful for you to learn; make a note of this kind of sentence and look at them from time to time.

Cover the second half with your hand and try to test yourself!

3 Put the words in the correct order, then write the definitions of the words. The first one has been done for you.

a **boiling point**

which temperature the gas bubbles of at formed are a liquid throughout boils and liquid the.

The temperature at which bubbles of gas are formed throughout a liquid and the liquid boils.

b volatile

a word describe to used liquid boiling point that a has and easily low a evaporates.

....

....

c freezing

reverse which the is process the melting of can solidification called also be and.

....

....

d evaporation

turns into liquid the a which gas below a point boiling its process.

....

....

e sublimation

solids process which by the certain directly into turn gases. example this carbon is an of solid dioxide.

....

....

4 Table 1.3 summarises the trends in the properties of the different states of matter. Complete the table by circling the correct word in each case.

Property	Solid	Liquid	Gas
density	increases / decreases		
compressibility (the ability to change its volume at constant temperature)	increases / decreases		
fluidity (the ability to flow)	increases / decreases		

Table 1.3: Trends in the properties of the different states of matter.

Exercise 1.3 The kinetic particle theory

IN THIS EXERCISE YOU WILL:

Science skills:

- describe the nature of the different states and the changes between them in terms of how the particles present are organised

English skills:

- learn how to describe the different states and the movement of the particles in them.

KEY WORDS

kinetic particle theory: a theory which accounts for the bulk properties of the different states of matter in terms the arrangement and movement of particles

The **kinetic particle theory** helps us understand the different states of matter. All substances are made up of *particles*, which can be atoms or molecules (see Chapter 2). The theory describes the organisation and movement of these particles in the three states of matter.

1 The diagrams in Figure 1.3 show the organisation of the particles in the three physical states of matter. Below the diagrams, there are descriptions of how the particles are organised and move. Follow the instructions to complete each description.

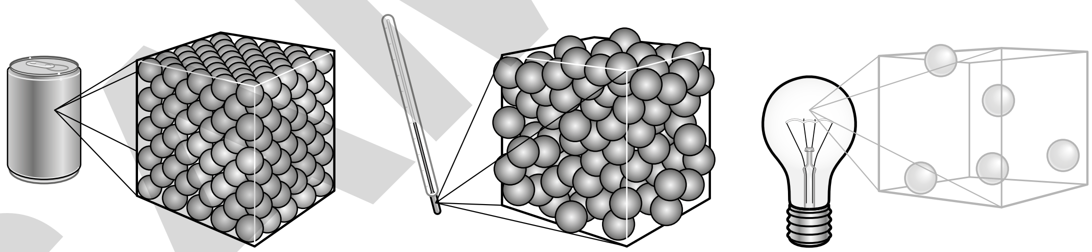

Figure 1.3: The three states of matter.

a Delete the incorrect options to complete this description of a gas.

The particles in a gas are far apart in *fixed/random* positions. Their arrangement is totally *regular/irregular*. The particles are *able/unable* to move around freely; they *can/can't* collide, or bounce off each other.

LANGUAGE FOCUS

In sentence **1 a** there are two prefixes. A prefix is a group of letters added to the front of a word to change its meaning. Here, the 'root' words are able and regular. The prefixes are *ir-* and *un-*. Both prefixes mean **not**.

Ir- is used with adjectives beginning with *r-*; e.g. *responsible* > *irresponsible*.

Un- is used with adjectives and adverbs; e.g. *untested*, *uninteresting*, *unexpectedly*.

b Write the correct words to complete this description of a liquid. Use the description of a gas in **1 a** as a model.

The particles in a liquid are packed closely together. Their arrangement is .... The particles are .... to move around freely, though they .... stay in contact with each other.

c Add sentences to complete this description of a solid. Use the descriptions of a gas and a liquid as models.

The particles are

....

....

Their arrangement is

....

....

The particles are ....

....;

they can only vibrate in their fixed positions.

2 **a** The kinetic particle theory also explains the changes taking place when a substance is heated and changes state. In Figure 1.4, circle the correct words in the descriptions of what is happening to the movement of the particles as a solid substance is heated.

As the ***volume/temperature*** rises the particles in a liquid ***lose/gain*** more energy and move around ***faster/slower***. Some particles can escape from the surface; this is ***evaporation/condensation***. The temperature increases until the ***boiling point/evaporation point*** is reached. At this point the particles have enough energy to break the forces holding the liquid together. Gas ***bubbles/drops*** form in the liquid and the liquid ***steams/boils***.

As a solid is heated the particles ***rotate/vibrate*** more ***strongly/weakly***. At the ***condensation point/melting point*** the particles have enough ***energy/power*** to break the forces holding them in one place. Now they can ***move/step*** past each other. And so we see that the solid **freezes/melts** and turns to ***liquid/vapour***.

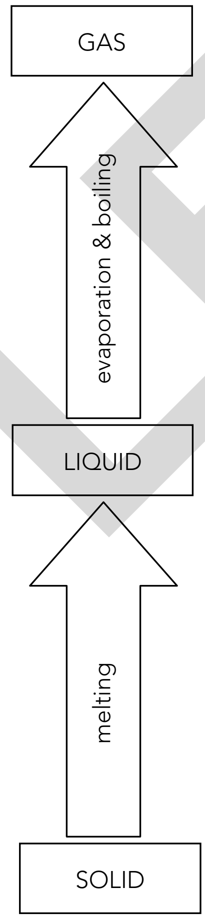

Figure 1.4: How changes of state take place on heating.

b Write a short paragraph describing how the particles change their movement and organisation when a liquid freezes. You can use the following phrases in your paragraph.

forces between particles **lose energy** **move more slowly**
become stronger **at freezing point** **become held**
fixed positions **liquid freezes** **becomes solid**

As the liquid cools, the particles

....

....

....

....

....

Exercise 1.4 Diffusion and dissolving

IN THIS EXERCISE YOU WILL:

Science skills:

- describe how the movement of particles in a liquid or gas results in the processes of diffusion and dissolving

English skills:

- become more familiar with the specific words used to describe diffusion and dissolving.

KEY WORDS

diffusion: in this process, different fluids (gases or liquids) mix as a result of the random movement of their particles

dissolving: a process that produces a solution of a solid or gas in a liquid e.g. when sugar dissolves in water

1 **Diffusion** allows substances to spread and mix; the particles move to fill all the available volume. It is a key part of the process of **dissolving**. Figure 1.5 shows the diffusion of a gas and in a liquid.

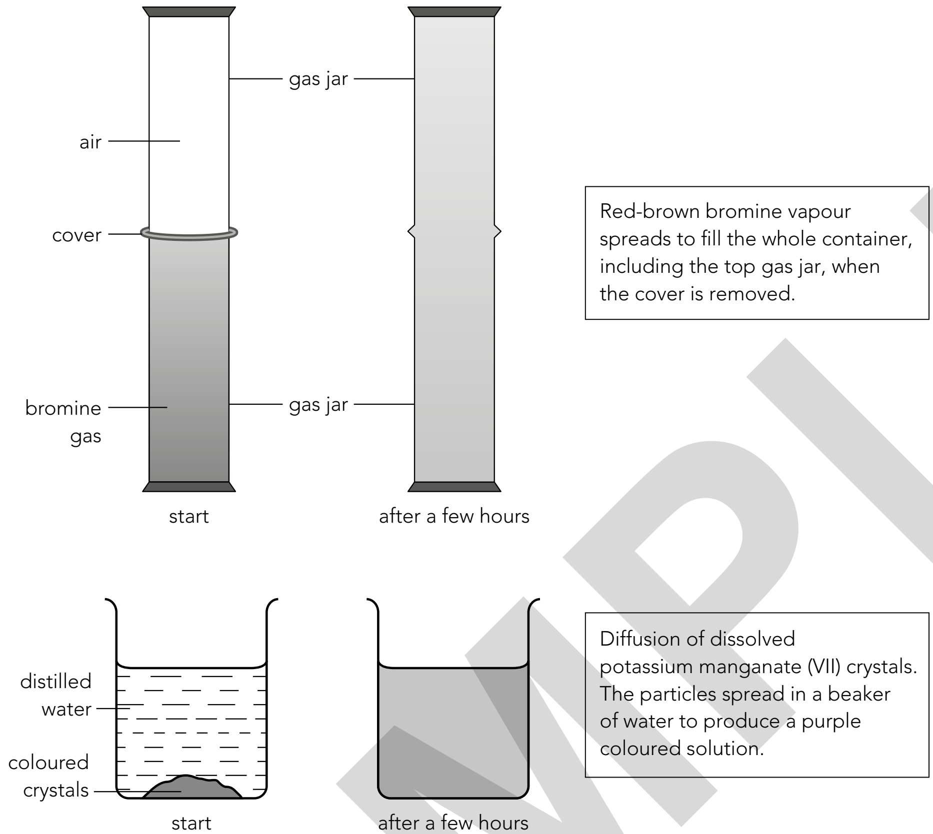

Figure 1.5: Diffusion of a gas and in a liquid.

Circle the best option to complete the following statements.

a Diffusion is the process by which *objects/particles* mix and spread through movement and *collision/interference* with other particles.

b Over a period of a few hours, bromine vapour spreads by diffusion. At the end, the concentration of bromine in the gas jars is *half/double* what it was at the start.

This effect shows because the colour of the vapour is *darker/paler*.

c Diffusion is a random process and can only take place in *solid/fluid* states such as a liquid or a gas.

d Diffusion is much faster in *gases/solids* than liquids as the particles are moving *slower/faster* in this state.

e At higher temperatures diffusion is *faster/slower* because the particles have more *mass/energy* and are moving faster.

f When the crystal is placed in the water the colour slowly spreads throughout the liquid as *particles/bits* from the crystal mix with the water *atoms/molecules*. Eventually the colour is spread evenly throughout the liquid and the solid has *dissolved/gone completely*.

2 a This type of puzzle is known as a wordsearch. In the wordsearch, there are TEN words that are important in describing how substances dissolve in solvents to form solutions. The words can be horizontal (–), vertical (|) or diagonal (/) . The word *solvent* has been circled for you. List the other words in the space below.

S	B	X	S	T	M	D	I	L	U	T	E
I	A	I	O	L	F	Q	N	Y	N	R	D
N	S	T	L	V	G	D	B	J	D	H	S
S	O	L	U	T	E	I	Y	W	I	Z	O
O	F	C	T	R	P	L	U	F	S	L	L
L	E	O	I	P	A	U	V	W	S	R	U
U	A	K	O	W	D	T	E	D	O	B	B
B	L	Z	N	C	M	E	E	F	L	P	L
L	D	Y	P	V	W	Y	G	D	V	L	E
E	A	Q	U	H	S	O	L	V	E	N	T
L	D	I	S	S	O	L	V	E	D	J	N
C	O	N	C	E	N	T	R	A	T	E	D

....

....

....

....

....

....

b Look at the words that you found in the wordsearch and make **three** pairs of words with opposite meanings. One pair has been made for you.

dilute .... concentrated ....

....

....

....

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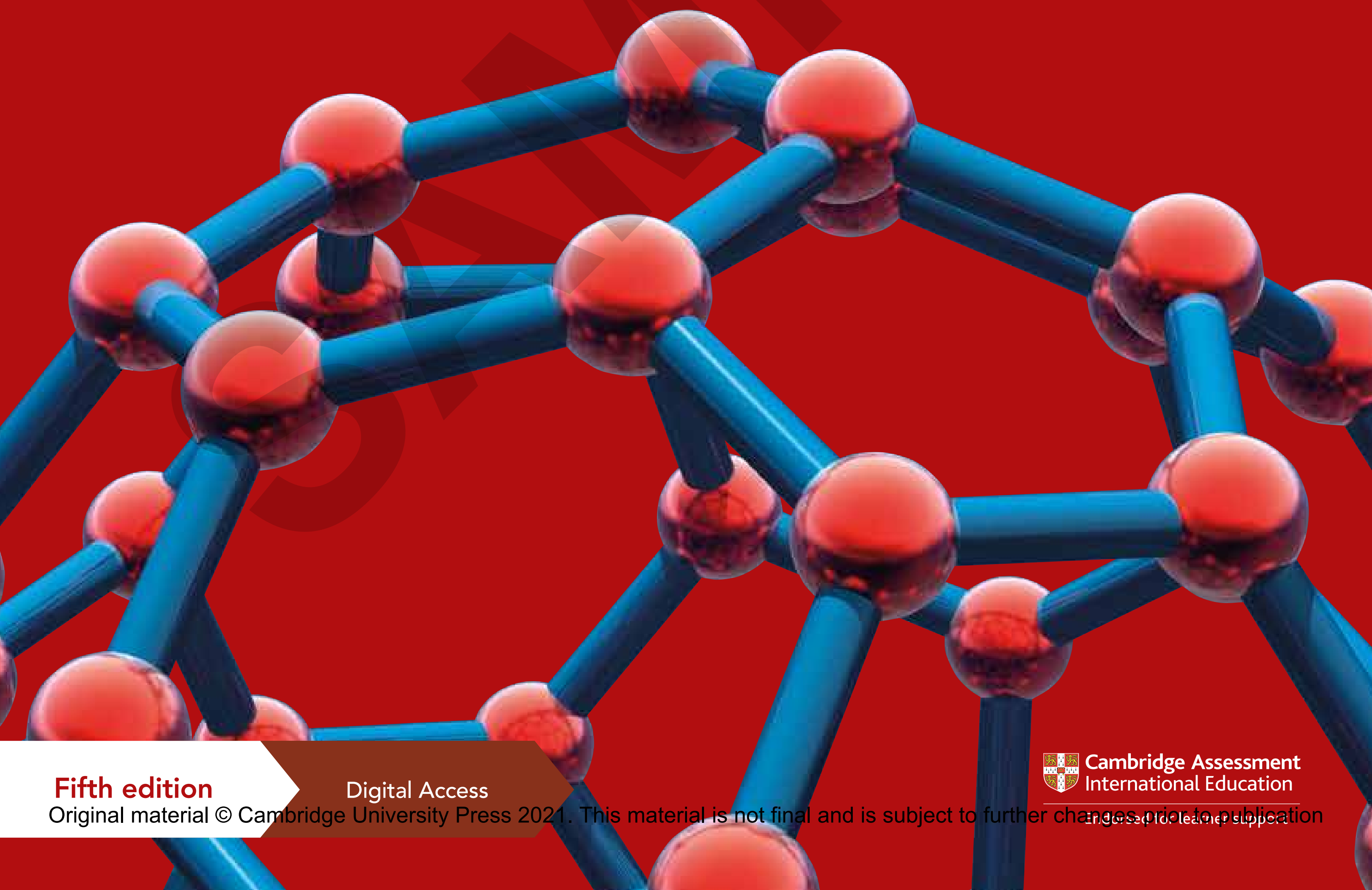
Chemistry

for Cambridge IGCSE™

MATHS SKILLS WORKBOOK

Helen Harden



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Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

OVERVIEW

This sets the scene for each chapter, and explains why the maths skills in that chapter are important for you to understand.

WORKED EXAMPLE 1.5

These show a maths concept in action, giving you a step-by-step guide to answering a question related to that concept.

LOOK OUT

The information in these boxes will help you complete the questions, and give you support in areas that you might find difficult.

Practice questions

Questions give you a chance to practise the skills in each Maths focus. You can find the answers to these questions in the Teacher's Resource.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions. Answers to these questions can be found in the Teacher's Resource.

APPLYING MORE THAN ONE SKILL

At the end of this Workbook you will find a section of exam-style questions covering any of the topics covered in the chapters. This will give you a chance to think about how to apply your maths skills to different contexts.

Throughout the book, you will see important words in **bold** font. You can find definitions for these words in the Glossary at the back of the book.

Chapter 1

Representing values

WHY DO YOU NEED TO REPRESENT VALUES IN CHEMISTRY?

- You need to be able communicate any measurements that you make.
- You must make sure that another person is able to understand your measurements, so how you represent (write down) the measurements is important. As well as the numerical value, you must also include the correct **unit**.
- You need to be able understand numbers that are much larger or much smaller than numbers you usually work with.
- Writing these numbers in different ways will make measurements easier to understand and compare.

Maths focus 1: Using units

Units of measurements used in chemistry are based upon Standard International (SI) units.

Table 1.1 shows some SI base units that are commonly used in chemistry.

Quantity	Unit	SI abbreviation
length	metre	m
mass	kilogram	kg
time	second	s
amount of substance	mole	mol

Table 1.1: SI base units for common quantities.

The SI base unit for temperature is the kelvin (K), but the Celsius **scale** (°C) is more useful for many laboratory measurements in chemistry. Most thermometers use the Celsius scale. On the Celsius scale, the freezing point of water is 0 °C and the boiling point of water (at 1 atmosphere pressure) is 100 °C.

LOOK OUT

Remember that a temperature can have a negative value on the Celsius scale, such as –4 °C.

What maths skills do you need to be able to use units?

1	Choosing the correct unit	• Identify the type of quantity that the apparatus measures. • Select an appropriate unit for the quantity being measured.
2	Writing the unit symbol	• Recall or look up the unit symbol. • Check if the unit requires **index** notation, for example cm^2 or cm^3.
3	Writing symbols for derived units	• Work out how the quantity is calculated. • Write the derived units, which are based on the units in the calculation.

Maths skill practice

How can units help you to communicate values that you measure during chemical reactions?

When you do experimental (practical) work in chemistry, always use the appropriate units when you record any measurements.

It is meaningless to give the volume of gas produced during a chemical reaction simply as '16'. Using units clearly specifies (describes) the volume measured. A volume of 16 cm^3 is completely different from a volume of 16 litres.

A mass of 3 g is a thousand times smaller than 3 kg, so it is essential to use the correct **unit prefix** as well as the correct unit. The unit prefix tells you the **power of 10** by which to multiply the measurement.

See Maths skills 2 and 3 in Maths focus 2 for more information about powers of 10 and unit prefixes.

Most values used in chemistry require units as they are measures of particular quantities, such as:

- length
- mass
- temperature
- time
- volume
- amount of a substance.

LOOK OUT

The kilogram (kg) is the only base SI unit whose name and symbol, for historical reasons, use a prefix.

LOOK OUT

Not all values require units. For example, relative atomic mass is a simple **ratio** (a comparison of two numbers) and therefore does not need units.

Maths skill 1: Choosing the correct unit

It is important that you know the names of the units that are often used for measurements in chemistry.

WORKED EXAMPLE 1.1

Choose the correct unit of measurement associated with the small beaker shown in Figure 1.1.

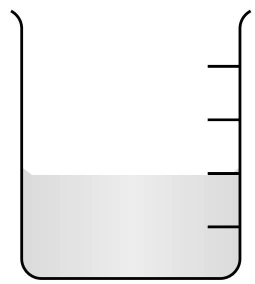


Figure 1.1: A beaker.

A centimetres **B** litres

C square centimetres **D** cubic centimetres

Step 1: Identify the type of quantity that the apparatus measures.

A beaker measures volume.

Step 2: Select an appropriate unit for the quantity being measured.

Key questions to consider:

- What units are used to measure this type of quantity?

  Volume may be measured in a variety of units, including litres (l) or cubic centimetres (cm^3).

- Which units are appropriate for the scale on the measuring apparatus?

  A small beaker will not measure litres (l). The scale is likely to be in cubic centimetres (cm^3).

So, the correct answer is **D** (cubic centimetres).

LOOK OUT

Always stop and think 'are the units appropriate for the measuring apparatus that is being used?' You will not be able to measure litres in a test-tube!

Questions

1 Draw lines to connect each item of measuring apparatus with the appropriate unit of measurement in Table 1.2.

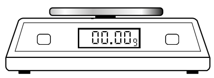
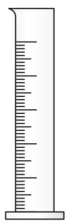
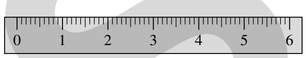
balance 	cubic centimetres (cm^3)
measuring cylinder 	grams (g)
thermometer 	cubic centimetres (cm^3)
ruler 	degrees Celsius (°C)
gas syringe 	centimetres (cm)

Table 1.2: Measuring apparatus with the appropriate unit of measurement.

2 Work in pairs.

Choose a unit of measurement. Ask your partner to name a piece of chemistry apparatus that can be used to measure the unit you have chosen.

Check your partner's answer. Has your partner chosen apparatus that is the correct size for measuring the unit?

Now swap roles and start again, so that your partner names a unit and you name the piece of apparatus.

LOOK OUT

A small measuring cylinder does measure volume, but it is unlikely to measure in litres.

Maths skill 2: Writing the unit symbol

When you write down measurements from an experiment you do not need to write the name of the units in full. Each unit has a symbol. This is an abbreviation (short version) that uses one, two or three letters (Table 1.3).

Quantity	Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
temperature	degrees Celsius	°C
amount of substance	mole	mol

Table 1.3: Symbols for some commonly used base units.

Most base unit symbols start with a lower-case letter and not a capital letter (e.g. metres are abbreviated as 'm' not 'M'). Some other unit symbols start with a capital letter. A unit symbol starts with a capital letter if it is named after a person. For example, the Celsius temperature scale is named after the Swedish astronomer, Anders Celsius.

Other units are created by placing a prefix in front of the SI unit. For example, centimetres (cm) are used for measuring shorter distances than metres (m).

1 cm is $\frac{1}{100}$ m or 0.01 m.

See Maths skills 3 in Maths focus 2 for more information about unit prefixes.

Always remember to include the correct index or **power** when necessary. The index is the small number to the right and above the base number that tells you the power (how many times you need to multiply the base number by itself). Three **squared** is written as 3^2. The index '2' shows you that the power is 2, so $3 \times 3 = 9$.

It is incorrect to write a volume of liquid as 10 cm because centimetres are a unit of length.

- **Area** is always measured in square units (such as m^2 or cm^2). You calculate the area of a rectangle by multiplying length × width, for example m × m or cm × cm (think about counting squares on a grid to find areas).
- **Volume** is always measured in cubic units (such as m^3 or cm^3). You calculate the volume of a cuboid by multiplying length × width × height, for example m × m × m or cm × cm × cm (think about counting cubes in a cuboid made from unit cubes, as shown in Figure 1.2).

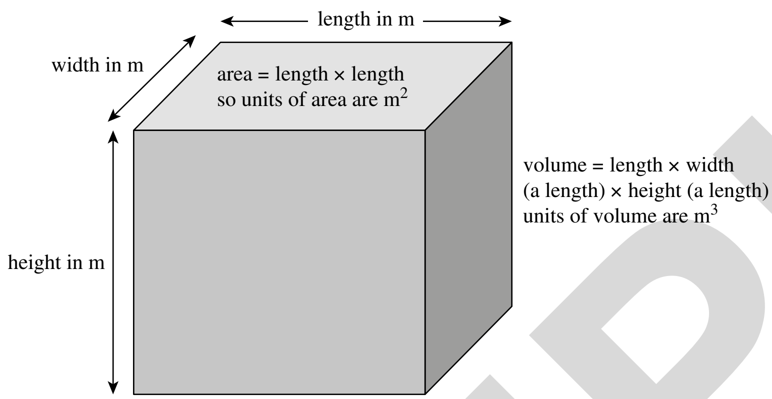


Figure 1.2: Comparing the area of a face and the volume of a cuboid.

WORKED EXAMPLE 1.2

The length and the width of a piece of paper have been measured in centimetres. Write down the correct unit for the area of the paper.

Step 1: Recall or look up the unit symbol.

In this case the unit symbol for the measurements is cm (centimetres).

Step 2: Check if the unit requires index notation.

Area is found by multiplying length by width (cm × cm), so area must be measured in square units. This is shown by using an index of '2'.

The unit is square centimetres (cm^2).

Questions

3 **a** Write down the correct unit symbol for each measurement.

i Mass of copper sulfate, measured on a digital balance that measures in grams. ……….

ii Temperature of water, measured using a thermometer marked in degrees Celsius. ……….

iii Time taken for a reaction to occur, measured using a stopwatch that displays seconds. ……….

iv Length of magnesium ribbon, measured using a ruler marked in centimetres. ……….

v Area of the floor in a laboratory, where the length and the width are measured in metres. ……….

vi Volume of liquid in a measuring cylinder that is marked in cubic centimetres. ……….

b Check your partner's answers from part **a**. Complete the checklist in your partner's workbook.

	Was index notation required?	Was index notation used?
i	☐	☐
ii	☐	☐
iii	☐	☐
iv	☐	☐
v	☐	☐
vi	☐	☐

4 Work in pairs.

Discuss with your partner why index notation is important for writing units. You should include the following words in your explanation.

area **index** **length** **units** **volume**

Write your explanation below.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Maths skill 3: Writing symbols for derived units

The units for some quantities are based on a calculation using other units. The units obtained are called derived units.

For example, when a chemical reaction produces a gas, you can calculate the **rate** of reaction (how fast the reaction takes place) by dividing the volume of gas produced by the time taken to collect this volume of gas. If the volume of gas is measured in cubic centimetres (cm^3) and the time is measured in seconds (s), the derived units of rate of reaction are cubic centimetres per seconds (cm^3/s).

See Chapter 8 of the Chemistry Coursebook for more information about rates of reaction.

LOOK OUT

The symbol '/' (called a solidus) is also used as a separator between a variable name and its unit, in tables and on graphs. Here, you read the '/' sign as 'in', so 'Temperature / °C' means 'temperature in degrees Celsius'.

WORKED EXAMPLE 1.3

The density of a substance is the mass of the substance that occupies a particular volume. You can calculate the density of an aluminium cube by dividing the mass of the cube (in grams) by the volume of the cube (in cubic centimetres).

Write down the correct derived unit for density.

Step 1: Work out how the quantity is calculated.

The calculation for density is:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Step 2: Write the derived units, which are based on the units in the calculation.

The derived units are grams per cubic centimetre (g/cm^3).

Questions

5 Write down the correct derived unit for each calculated quantity:

a The rate of a chemical reaction, calculated by dividing the mass of product made (in grams) by the time taken for the reaction (in seconds).

....

b The density of a large metal statue, calculated by dividing the mass of the statue (in kilograms) by its volume (in cubic metres).

....

6 Work in pairs.

The units of a rate of reaction are cm^3/s. Discuss with your partner what this tells you about the product of a chemical reaction. Write your answer below.

....

Maths focus 2: Understanding very large and very small numbers

In chemistry you need to understand very large numbers.

- 12 g of carbon contains about 602 000 000 000 000 000 000 000 atoms.

You also need to understand very small numbers.

- A single carbon atom has a **diameter** of about 0.000 000 000 17 m.

It is very important to use the correct number of zeros. The value of the number depends upon the **place value** of the **digits**. If you use the wrong number of zeros, the value of the number will change.

However, writing out this many zeros takes a lot of time, so very large and very small numbers are often written using powers of 10 instead of many zeros.

- The number of atoms in 12 g of carbon can also be written as 6.02×10^{23}.
- The diameter of a carbon atom can also be written as 1.7×10^{-10} m.

6.02×10^{23} is an important number in chemistry and is also known as the Avogadro constant.

See Chapter 5 of the Chemistry Coursebook for more information on the Avogadro constant.

Sometimes in chemistry, units are changed for very large and very small numbers by adding a prefix to the unit such as kilo- (k) or nano- (n). These prefixes replace the power of 10.

So, 3 kg = 3×10^3 g or 3000 g.

What maths skills do you need to be able to understand very large and very small numbers?

1 Understanding place value	• Compare the digits with the highest place value. • Compare the digits with the next highest place values.
2 Understanding powers of 10	• Write out the multiplication. • Calculate the number as it would be written in full.
3 Understanding unit prefixes	• Write the measurement using a power of 10. • Calculate the number as it would be written in full.

Maths skill practice

How does understanding very large and very small numbers help to improve your understanding of the size and number of different particles?

Some numbers used in chemistry are so large, or so small, that they are difficult to imagine. Writing these numbers in a clearer way, such as using powers of 10 or prefixes, helps to understand how the size of different particles compare.

Particulate air pollution is made of very small particles of pollutants (substances present in the atmosphere, such as dust and carbon produced by industry, vehicles and burning fossil fuels). These particles have different sizes and are given a PM (particulate matter) number based on their diameter.

A particle of $PM_{2.5}$ air pollution has a diameter of about 2.5×10^{-6} m or 2.5 μm, whereas a particle of PM_{10} air pollution is about 10×10^{-6} m or 10 μm in diameter. If you understand powers of 10 and unit prefixes, you can instantly see that these particles are much larger than a typical atom, which is about 1×10^{-10} m in diameter.

Before you can compare sizes like this, it is important that you have a good understanding of place value in numbers that are written out in full.

Maths skill 1: Understanding place value

The place value of a digit is based on the digit's position in a number. The left-most digit in a number has the highest place value.

For example, the number in Table 1.4 (reading from left to right) is:

three hundred and twenty-three billion, four hundred and fifty-six million, three hundred and forty-five thousand, six hundred and forty-seven

Hundreds of billions 10^{11}	Tens of billions 10^{10}	Billions 10^{9}	Hundreds of millions 10^{8}	Tens of millions 10^{7}	Millions 10^{6}	Hundreds of thousands 10^{5}	Tens of thousands 10^{4}	Thousands 10^{3}	Hundreds 10^{2}	Tens 10^{1}	Units 10^{0}
3	2	3	4	5	6	3	4	5	6	4	7

Table 1.4: Place values for large numbers.

The **decimal** fraction in Table 1.5 is one billionth.

		Tenths	Hundredths	Thousandths	Ten-thousandths	Hundred-thousandths	Millionths	Ten-millionths	Hundred-millionths	Billionths
0	.	0	0	0	0	0	0	0	0	1

Table 1.5: Place values for small numbers.

WORKED EXAMPLE 1.4

Find the largest number in the following list:

A	7 242 519	**B**	8 143 921
C	8 349 321	**D**	924 107

Step 1: Compare the digits with the highest place value.

A, **B** and **C** all have millions as the highest place value. **B** and **C** both have digits showing 8 million, so are larger than **A**, which has 7 million.

Step 2: Compare the digits with the next highest place values.

The next highest place value is hundreds of thousands. **B** has 1 hundred thousand, but **C** has 3 hundred thousand.

So, the largest number is **C**.

LOOK OUT

Read the number from left to right. The place value of the first non-zero number helps you decide how big the number is.

Questions

7 Draw a circle around the **largest** number in each list.

a	674 591	92 342	141 294	692 381
b	1 943 986	1 949 789	1 942 987	1 944 098
c	0.09	0.12	0.17	0.06
d	0.09	0.015	0.026	0.07
e	0.000 007 2	0.000 008 5	0.000 000 1	0.000 000 165

8 Draw a circle around the **smallest** number in each list.

a	1 232 452	123 532	723 453	115 362
b	0.123 451	0.345 984	0.135 034	0.124 093
c	0.000 002 234	0.000 002	0.000 002 4	0.000 002 34
d	234.56	234.25	232.12	232.013 4
e	104 985.99	110 374.12	104 895.99	104 895.82

9 Table 1.6 shows the size of different molecules in metres. Each of the molecules is made of two or three atoms that are joined together.

Molecule	Size / m
carbon dioxide (CO_2)	0.000 000 000 24
water (H_2O)	0.000 000 000 27
oxygen (O_2)	0.000 000 000 12

Table 1.6: Sizes of different molecules.

a List the molecules in order of size from the smallest to the largest.

Smallest: ……………………….

……………………….

Largest: ……………………….

b Explain to your partner how you worked out the order of size.

Maths skill 2: Understanding powers of 10

Powers of 10 are the result of multiplying 10 by itself (see Table 1.7).

A negative power of any number is the **reciprocal** of the corresponding positive power. This means, for example, that $10^{-1} = \frac{1}{10}$ or $1 \div 10$ (the reciprocal of 10).

$10^1 = 10$	$10^{-1} = \frac{1}{10}$ or 0.1
$10^2 = 10 \times 10 = 100$	$10^{-2} = \frac{1}{10 \times 10} = \frac{1}{100}$
$10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100\,000$	$10^{-5} = \frac{1}{10 \times 10 \times 10 \times 10 \times 10} = \frac{1}{100\,000}$ $= 1 \div 10 \div 10 \div 10 \div 10 \div 10$ or 0.000 01

Table 1.7: Powers of 10.

Very large and very small numbers are often recorded as multiples of powers of 10. This makes it easier to write these numbers because you do not have to write lots of zeros.

For example: $4\ 10^3 = 4 \times 10 \times 10 \times 10 = 4000$

So, multiplying by 10^3 means that you need to multiply by 10 three times (see Table 1.8).

4×10^1	4×10	40
4×10^2	$4 \times 10 \times 10$	400
4×10^3	$4 \times 10 \times 10 \times 10$	4000
4×10^4	$4 \times 10 \times 10 \times 10 \times 10$	40 000
4×10^5	$4 \times 10 \times 10 \times 10 \times 10 \times 10$	400 000
4×10^6	$4 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$	4 000 000

Table 1.8: Multiplying by powers of 10.

Multiplying a number by a negative power of 10 tells you how many times to divide the number by 10.

For example: $4 \times 10^{-3} = 4 \times \frac{1}{10 \times 10 \times 10} = 4 \div 10 \div 10 \div 10$

WORKED EXAMPLE 1.5

Positive powers of 10

Write 5×10^5 in full.

Step 1: Write out the multiplication.

$5 \times 10^5 = 5 \times 10 \times 10 \times 10 \times 10 \times 10$

Step 2: Calculate the number as it would be written in full.

$= 5 \times 100\,000$

$= 500\,000$

WORKED EXAMPLE 1.6

Negative powers of 10

Write 3×10^{-4} as a decimal.

Step 1: Write out the multiplication.

$3 \times 10^{-4} = 3 \times \frac{1}{10 \times 10 \times 10 \times 10} = 3 \div 10 \div 10 \div 10 \div 10$

Step 2: Calculate the number as it would be written in full.

$= 3 \times 0.0001 = 0.0003$

Questions

10 These numbers are expressed as multiples of powers of 10. Write the numbers in full.

a 3×10^3 ....

b 45×10^6 ....

c 4×10^1 ....

d 123×10^{10} ....

11 Write each of these negative powers of 10 as a decimal.

a 2×10^{-2} ....

b 34×10^{-6} ....

c 9×10^{-9} ....

d 43×10^{-5} ....

12 Table 1.9 shows the size of different objects in metres. The sizes are written using powers of 10. Complete Table 1.9 by writing the sizes in full.

Object	Size / m	Size / m (in full)
particle of smoke	2×10^{-6}	
molecule of water	2.7×10^{-10}	0.000 000 000 27
crystal of table salt	100×10^{-6}	

Table 1.9: Sizes of different objects.

Maths skill 3: Understanding unit prefixes

Rather than writing a number either in full or using powers of 10, you can often just change the unit by using a prefix.

The unit prefix tells you the power of 10 by which to multiply the measurement to find the full number.

Table 1.10 shows some unit prefixes used in chemistry.

Unit prefix	Unit prefix symbol	Multiplying factor	Example unit names	Example unit symbols
kilo-	k	10^3	kilogram	kg
deci-	d	10^{-1}	cubic decimetre	dm^3
centi-	c	10^{-2}	cubic centimetre	cm^3
milli-	m	10^{-3}	milligram millimetre	mg mm
micro-	µ	10^{-6}	microgram micrometre	µg µm
nano-	n	10^{-9}	nanometre	nm

Table 1.10: Unit prefixes used in chemistry.

LOOK OUT

In chemistry, dm^3 are used instead of litres. Think about why 1 litre = 1 dm^3.

For example:
7 kg means
$7 \times 10^3 = 7000$ g

WORKED EXAMPLE 1.7

Write 8 mg without using the unit prefix.

Step 1: Write the measurement using a power of 10.

$8\,mg = 8 \times 10^{-3}\,g$

Step 2: Calculate the number as it would be written in full.

$$8 \times 10^{-3} = 8 \times \frac{1}{10 \times 10 \times 10} = 8 \div 10 \div 10 \div 10 = 0.008$$

So, $8\,mg = 8 \times 10^{-3}\,g = 0.008\,g$

Questions

13 Write each measurement without the unit prefix.

a **i** 3 mg ....

ii 4 μg ....

iii 3 kg ....

b **i** 4 mm ....

ii 2 cm ....

iii 7 nm ....

c **i** 4 cm ....

ii 2 dm ....

14 Write each measurement without the unit prefix.

a **i** 42 mg ....

ii 402 μg ....

iii 345 kg ....

b **i** 74 nm ....

ii 7.4 nm ....

iii 704 nm ....

15 Work in groups of three or four.

In your group, discuss which unit prefix (k (kilo-), m (milli-), μ (micro-), c (centi-)) should be used for each measurement. Write down your answers individually. Only use each unit prefix once.

a The diameter of a gold coin is 3 ....m.

b The thickness of a gold ring is 3 ....m.

c The mass of a gold bar is 12.4 ....g.

d The thickness of gold leaf (sheet) is 0.1 ....m.

e Try to explain how you worked out the appropriate unit prefix for each measurement. How did you compare the sizes of the different objects? Did you picture each object in your mind or use another method? How successful was your way of thinking?

Maths focus 3: Writing numbers in a required form

Sometimes in chemistry you need to write a number in a particular form.

When very large or very small numbers are written using a power of 10, the standard way of doing this is to use a system called **standard form or standard index form**. A standard system is a system that can be understood by scientists in different laboratories and even in different countries.

A number in standard form is expressed as a number greater than or equal to 1, but less than 10, multiplied by a power of 10. For example, 54 000 can be written as 5.4×10^4. However, 54×10^3 is **not** in standard form because 54 is not between 1 and 10.

The results of calculations should be rounded up or down to an appropriate number of **significant figures**.

If something is significant, it is important. A number written to two significant figures shows the first two, and therefore the most important, digits. The results of calculations should be written to the same number of significant figures as the lowest number of significant figures of the numbers used in the calculation.

A rounded number is an approximation that uses fewer significant figures than the original number. **Rounding** makes numbers easier to work with.

What maths skills do you need to be able to understand very large and very small numbers?

1 Writing numbers in standard form	• Write the digits as a number that is greater than or equal to 1 and less than 10. • Work out how many times you need to multiply or divide the number by 10 to get to your original number. • Write the number, using the correct power of 10.
2 Writing numbers to the required number of significant figures	• Identify the correct number of significant figures. • Decide whether to round up or down.

Maths skill practice

How does writing numbers in a required form help you to communicate numbers in chemistry?

Standard form helps to compare very small and large numbers. The power of 10 gives a useful **estimate** of the size of the number.

It is important that all values in chemistry are recorded to an appropriate number of significant figures. For example, a student does a calculation that contains measurements, to three significant figures. The student writes the result of the calculation as $34.938\,475\,cm^3$. The student's answer suggests a much greater degree of **accuracy** than was achieved in the experiment.

Maths skill 1: Writing numbers in standard form

A number in standard form always includes a number that is greater than or equal to 1, but less than 10, multiplied by a power of 10. Another way of thinking about this is that in standard form the **decimal point** always comes after the most significant figure.

So, for the number 4 060 000:

- 4.06×10^6 is in correct standard form because 4.06 is between 1 and 10.
- 406×10^4 is in index form, but it is **not** in standard form because 406 is greater than 10.

Standard form on your calculator

Calculators do not all work in the same way, so you must make sure you know how to use your calculator. This is especially important when you need to enter or read numbers in standard form. This may involve using the E key (or the [EE] key). E is short for the mathematical term 'exponent' (another name for the index).

For example, to enter 1.67×10^{11}, a typical key sequence (the order in which the keys are pressed) would be:

1.67 E11

The screen would show the number as in Figure 1.3.

Figure 1.3: The number 1.67×10^{11} shown on a calculator.

WORKED EXAMPLE 1.8

12 g of carbon contains 6.02×10^{23} carbon atoms.

Use your calculator to work out how many carbon atoms there are in 24 g of carbon.

$2 \times 6.02 \times 10^{23} = 1.20 \times 10^{24}$ carbon atoms

WORKED EXAMPLE 1.9

Large numbers

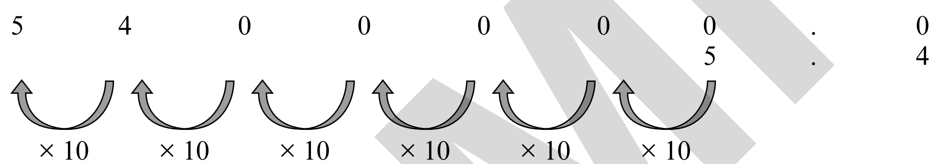
Write 5 400 000 in standard form.

Step 1: Rewrite the non-zero digits as a number that is greater than or equal to 1 and less than 10.

5.4

Step 2: Work out how many times you need to multiply this number by 10 to get your original number.

5.4 must be multiplied by 10 six times ($5.4 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$) to reach 5 400 000.



Step 3: Write the number, using the correct power of 10.

$5.4 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 5.4 \times 10^6$

LOOK OUT

If there are significant zeros between the digits in a number, these must appear in the number written in standard form, for example $3\,050\,000 = 3.05 \times 10^6$.

You can also use standard form to write very small numbers. For this you use negative powers of 10. The method for converting very small numbers into standard form is slightly different.

19 Write these measurements in standard form.

a 0.000 000 000 15 m ....

b 0.003 g ....

c 0.000 000 023 g ....

d 0.0009 m^3 ....

20 Convert these measurements into metres. Write the measurements in standard form.

a 9 nm ....

b 92 nm ....

c 6 µm ....

d 73 µm ....

e Explain to your partner why some measurements were easy to convert to standard form and why other measurements were more difficult to convert to standard form.

Maths skill 2: Writing numbers to the required number of significant figures

The rules for rounding to a given number of significant figures are similar to the rules for rounding to the nearest 10 or 100 or to a given number of decimal places. The significant figures in a number are counted from the first non-zero digit.

WORKED EXAMPLE 1.11

Write 124 321 correct to two significant figures.

Step 1: Identify the correct number of significant figures.

The first two significant figures (sf) are the first and second digits in the number, which have the two highest place values. These are the two digits on the left of the digit to be rounded.

1st sf	2nd sf				
↓	↓				
1	2	4	3	2	1

Step 2: Decide whether to round up or down.

Look at the digit in the third significant place.

If the third digit is 0, 1, 2, 3 or 4, leave the first two digits as they are and replace all the other digits in the number with 0.

If the third digit is 5, 6, 7, 8 or 9, increase the digit in the second place by 1 and replace all the other digits in the number with 0.

The next digit is 4 so round down, giving 120 000.

LOOK OUT

If there is a zero between non-zero digits, e.g. 207 224, this counts as a significant figure.

WORKED EXAMPLE 1.12

Write 0.267 93 correct to two significant figures.

Step 1: Identify the correct number of significant figures.

Identify the first two significant figures (sf). The third figure is the one to be rounded.

	1st sf ↓	2nd sf ↓			
0.	2	6	7	9	3

Step 2: Decide whether to round up or down.

Look at the digit in the next place.

The next digit is 7, so round up the second significant figure.

This gives 0.27.

Questions

21 a Round 423 912 atoms to:

i 1 sf ……………………

ii 3 sf ……………………

b Round 1 064 126 atoms to:

i 2 sf ……………………

ii 3 sf ……………………

22 a Round a mass of 0.324 g to:

i 1 sf ……………………

ii 2 sf ……………………

b Round a mass of 0.417 312 g to:

i 1 sf ……………………

ii 2 sf ……………………

EXAM-STYLE QUESTIONS

1 The atomic radius of an atom is the distance from the central nucleus to the outermost electrons. Atomic radius is measured in picometres (a picometre is 10^{-12} m). The table shows the atomic radius of atoms for elements in Group I (alkali metals) of the Periodic Table.

Element (symbol)	Atomic radius / pm
lithium (Li)	134
sodium (Na)	154
potassium (K)	196
rubidium (Rb)	211

a Write the atomic radius of lithium in metres.

.... **[1]**

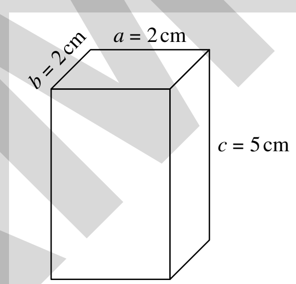
b Describe the trend in atomic radius going down Group I.

....

.... **[2]**

[Total: 3]

2 A student measures the dimensions of a cuboid block of aluminium, as shown.



a Write each length in metres.

....

....

.... **[3]**

b **i** Use the lengths in metres to calculate the volume of the cuboid ($a \times b \times c$).

.... **[2]**

ii Write the volume in standard form.

.... **[1]**

CONTINUED

The mass of the cuboid was measured as 0.054 kg.

c **i** Calculate the density of the cuboid $\left(\frac{\text{mass}}{\text{volume}}\right)$.

....

.... **[2]**

ii Write the density rounded to one significant figure.

.... **[1]**

[Total: 9]

3 Beaker **A** contains 12 g of carbon. Beaker **B** contains 1.2 g of magnesium.

a Beaker **A** contains 602 000 000 000 000 000 000 000 atoms of carbon.

Write this number in standard form.

.... **[1]**

b A magnesium atom is two times heavier than a carbon atom.

i Calculate how many grams of magnesium contain the same number of atoms as 12 g of carbon.

.... **[1]**

ii Calculate the number of atoms in 12 g of magnesium. Write your answer in standard form.

.... **[2]**

iii Calculate the number of atoms of magnesium in beaker **B**. Write your answer in standard form.

.... **[2]**

[Total: 6]