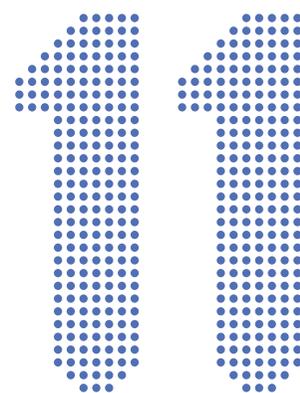


PEARSON
CHEMISTRY
QUEENSLAND
STUDENT BOOK



UNITS 1 & 2

Sample pages

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ONLINE CHAPTER

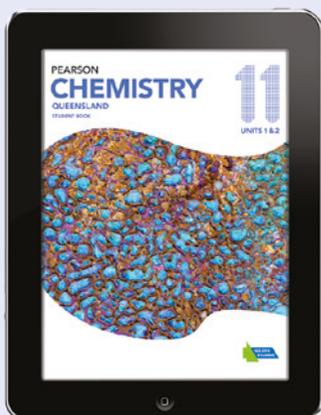
Chapter 1 Chemistry Skills and Assessment toolkit

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How to use this book

PEARSON CHEMISTRY 11 UNITS 1 & 2 QUEENSLAND

Pearson Chemistry 11 Queensland has been written to the new QCE Chemistry Syllabus. The book is an easy-to-use resource that covers Units 1 & 2 as well as comprehensively addresses the Skills and Assessment. Explore how to use this book below.

Design

Featuring best-practice literacy and instructional design, this series supports all learners with careful scaffolding of concepts and defined learning objectives.

A simple to navigate, predictable design enables ease of use. The high-quality, relevant photos and illustrations assist student understanding of concepts.



9.1 The mass of particles

BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- describe the concepts of atomic mass and relative atomic mass
- explain how 1 atomic mass unit is equal to $\frac{1}{12}$ the mass of a carbon-12 atom
- calculate relative atomic mass
- describe the concepts of relative molecular mass and relative formula mass
- calculate relative molecular mass and relative formula mass.

Chapter opener

The Syllabus subject matter addressed in each chapter is clearly listed, along with any Science as a Human Endeavour features and Mandatory Practicals.

Module opener

Module openers outline the key concepts and skills developed and link to syllabus subject matter listed in the Chapter opener.



CHAPTER 07 Ionic compounds

Rocks, plates, molten lava and electrical insulators belong to a group of substances called ionic compounds. They form the majority of the Earth's crust and, when dissolved, are key components of biological systems. At the end of this chapter you will be able to explain the structure and properties of these compounds. Ionic compounds are made by the chemical combination of metallic and non-metallic elements. You will see that properties are a direct result of the bonding between particles in the compound. The writing of chemical formulas and the naming of ionic compounds are other skills that you will learn in this chapter.

Syllabus subject matter

Topic 1 • Properties and structure of atoms

- recognise that the properties of atoms, including their ability to form chemical bonds, are explained by the arrangement of electrons in the atom and by the stability of the valence electron shell
- understand that the number of electrons lost, gained or shared is determined by the electron configuration of the atom and recall that transitional elements can form more than one ion
- recognise that ions are atoms or groups of atoms that are electrically charged due to an imbalance in the number of electrons and protons and recognise that ions are represented by formulas which include the number of constituent atoms and the charge of the ion
- understand that chemical bonds are caused by electrostatic attractions that arise because of the sharing or transfer of electrons between participating atoms and the valency is a measure of the number of bonds that an atom can form
- determine the formula of an ionic compound from the charges on the relative ions and name the compound

Topic 2 • Properties and structure of materials

- BONDING AND PROPERTIES**
- recognise that the properties of ionic compounds, including high melting point, brittleness, and ability to conduct electricity when liquid or in an aqueous solution, can be explained by modelling ionic bonding as ions arranged in a crystalline lattice structure with strong electrostatic forces of attraction between oppositely charged ions (metallic cations, giant covalent molecules, atomisation — carbon)
- understand that the type of bonding within ionic, metallic and covalent substances explains their physical properties, including melting and boiling points, thermal and electrical conductivity, strength and hardness
- analyse and interpret given data to identify the properties, structure and bonding of ionic, covalent and metallic compounds
- SCIENCE AS A HUMAN ENDEAVOUR**
- Nanomaterials:** Development of organic and inorganic nanomaterials is important to meet a range of contemporary needs, including consumer products, health care, transportation, energy and agriculture.

The ground-out section of this dot point is addressed explicitly in another chapter.
Chemistry 2019 v1.3 General Senior Syllabus © Queensland Curriculum & Assessment Authority

Science as a Human Endeavour

The SHE features provides an opportunity to appreciate the development of science and its use and influence on society. The SHE features provide a segue into the development of claims and research questions for the Research Investigation. Questions are included to help students formulate ideas and delve more deeply into the concepts.



SCIENCE AS A HUMAN ENDEAVOUR

Nanomaterials

Nanomaterials have unique physical, chemical, magnetic, mechanical, thermal and imaging characteristics. This makes them attractive for use in medical, pharmaceutical, electronic and engineering sectors.

Gold nanoparticles in cancer treatment

Gold nanoparticles are the subject of substantial research with a wide range of applications (Figure 6.5.6). One area of development is in using gold nanoparticles as a targeted chemotherapy treatment method.

Figure 6.5.7 A sound dressing with silver nanoparticles to kill bacteria

In similar antibacterial applications, Samsung has created and marketed a material called Silver Nano, which adds silver nanoparticles to the surface of household appliances. Silver nanoparticles have been embedded in the surfaces of plastic storage bins, as well as in balines used by astronauts, babies and outdoor enthusiasts.

Copper nanoparticles go into space

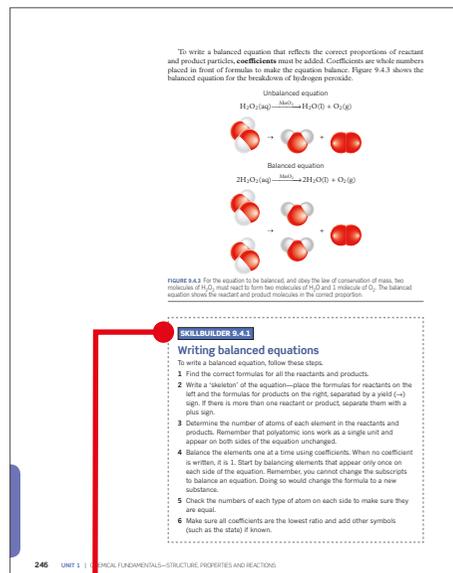
Solder is a filler metal used to join two or more metals. Solders are essential to plumbing and metal construction, including in satellites and spacecraft. For most of history, solders have contained a high amount of lead. Concerns about the toxicity of lead have driven the development of lead-free solder.

The complex electronics in satellites, such as the solar-powered satellites in Figure 6.5.8 on page 162, must be reliable and efficient over a very long time. Space scientists have developed a nanotechnology copper-based solder that offers far superior performance over the materials currently in use. It is expected that the new solder material will produce up to 10 times the electrical and thermal conductivity of current solders, with a wide range of space and defence applications.

Silver nanoparticles kill bacteria

Silver ions have long been known to kill bacteria. The ions can rapidly penetrate bacterial membranes and interact with proteins in the bacteria, disrupting the cell structure of the bacteria and preventing them from reproducing. Technology has enabled silver nanoparticles to be included in many different types of wound dressings.

CHAPTER 6 | METALS 161



To write a balanced equation that reflects the correct proportions of reactant and product particles, coefficients must be added. Coefficients are whole numbers placed in front of formulae to make the equation balance. Figure 9.4.3 shows the balanced equation for the breakdown of hydrogen peroxide.

Unbalanced equation

$$2\text{H}_2\text{O}_2(\text{aq}) \xrightarrow{\text{Mn}^{2+}} 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$$

Balanced equation

$$2\text{H}_2\text{O}_2(\text{aq}) \xrightarrow{\text{Mn}^{2+}} 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$$

FIGURE 9.4.3 For the equation to be balanced, and obey the law of conservation of mass, two molecules of H_2O_2 must react to form two molecules of H_2O and 1 molecule of O_2 . The balanced equation shows the reactant and product molecules in the correct proportions.

SKILLBUILDER 9.4.1

Writing balanced equations

To write a balanced equation, follow these steps.

- 1 Find the correct formulas for all the reactants and products.
- 2 Write a 'skeleton' of the equation—place the formulas for reactants on the left and the formulas for products on the right, separated by a plus (+) sign. If there is more than one reactant or product, separate them with a plus sign.
- 3 Determine the number of atoms of each element in the reactants and products. Remember that polyatomic ions work as a single unit and appear on both sides of the equation unchanged.
- 4 Balance the elements one at a time using coefficients. When no coefficient is written, it is 1. Start by balancing elements that appear only once on each side of the equation. Remember you cannot change the subscripts to balance an equation. Doing so would change the formula to a new substance.
- 5 Check the numbers of each type of atom on each side to make sure they are equal.
- 6 Make sure all coefficients are the lowest ratio and add other symbols (such as the state) if known.

246 UNIT 1 | CHEMICAL FUNDAMENTALS—STRUCTURE, PROPERTIES AND REACTIONS

Heat (Q) is the energy that flows from one object to another because of a difference in temperature.

Highlight box

Highlight features focus students' attention on important information such as key definitions, formulas and salient points.

Skillbuilder

A Skillbuilder outlines a method or technique. Each is instructive and self-contained. Skillbuilders step students through the skills to support science application required when analysing or utilising knowledge.

Worked Examples

Worked Examples use sequential steps of thinking and working. This research-based approach greatly enhances student understanding and application of formulas to subject matter. Each Worked Example is followed by a Try Yourself task where students apply their learning to a mirrored problem to practise the skill. Fully worked solutions to all Try Yourself problems are available on *Pearson Chemistry 11 Queensland Teacher Support*.

Worked example 9.4.1

WRITING A BALANCED EQUATION

Hydrogen and oxygen gas react to form water vapour. The reaction releases energy and is used to fuel rockets. Write a balanced equation for this reaction.

Thinking	Working								
Write the correct formulae to give a skeleton.	$H_2 + O_2 \rightarrow H_2O$								
Tally the number of each type of atom.	<table border="1"> <tr> <td>Reactants:</td> <td>Products:</td> </tr> <tr> <td>2 hydrogen</td> <td>2 hydrogen</td> </tr> <tr> <td>2 oxygen</td> <td>1 oxygen</td> </tr> </table>	Reactants:	Products:	2 hydrogen	2 hydrogen	2 oxygen	1 oxygen		
Reactants:	Products:								
2 hydrogen	2 hydrogen								
2 oxygen	1 oxygen								
Use coefficients to balance the number of atoms. You may need to use trial and error. If the H_2O is doubled to 2, then the O_2 will balance. This unbalances the hydrogen, but that can be corrected by putting a 2 in front of the H_2 .	<table border="1"> <tr> <td>Reactants:</td> <td>Products:</td> </tr> <tr> <td>$2H_2 + O_2 \rightarrow 2H_2O$</td> <td>4 hydrogen</td> </tr> <tr> <td>4 hydrogen</td> <td>2 oxygen</td> </tr> <tr> <td>2 oxygen</td> <td></td> </tr> </table>	Reactants:	Products:	$2H_2 + O_2 \rightarrow 2H_2O$	4 hydrogen	4 hydrogen	2 oxygen	2 oxygen	
Reactants:	Products:								
$2H_2 + O_2 \rightarrow 2H_2O$	4 hydrogen								
4 hydrogen	2 oxygen								
2 oxygen									
Check to make sure both sides balance and write the balanced equation with any known symbols.	$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$								

► Try yourself 9.4.1

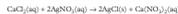
WRITING A BALANCED EQUATION

Iron metal and chlorine gas react to form solid iron(II) chloride. Write a balanced equation for this reaction.

STOICHIOMETRY AND THE MOLE RATIO

The coefficients used to balance the equations also show the ratio between the reactants and products involved in the reaction. The study of ratios of moles of substances is called **stoichiometry**. Stoichiometric calculations are based on the law of conservation of mass.

Consider the equation for the precipitation reaction that occurs when a solution of calcium chloride reacts with a solution of silver nitrate:



The equation indicates that 1 mole of $CaCl_2$ reacts with 2 moles of $AgNO_3$ to form 2 moles of solid $AgCl$ and 1 mole of $Ca(NO_3)_2$.

In more general terms, the number of moles of $AgNO_3$ that reacts will always be double the number of moles of $CaCl_2$ that reacts. The number of moles of $AgCl$ produced will be equal to the number of moles of $AgNO_3$ used and double the number of moles of $CaCl_2$ produced.

You can use the coefficients of this reaction to write relationships that show the **mole ratios** of any two chemicals involved in the reaction:



Stoichiometric calculations allow you to use the mole ratio established in a chemical equation to predict the amount of a product that will be formed or how much reactant will be used.

Module review

Each module finishes with key questions to test students' understanding and ability to recall the key concepts of the module. Questions are carefully categorised under the relevant cognitive level—Retrieval, Comprehension or Analysis—and are developed to assess the syllabus requirements.

4.2 Review

SUMMARY

- The effective nuclear charge of an atom is a measure of the attractive force felt by the valence electrons towards the nucleus.
- The effective nuclear charge is calculated by subtracting the total number of inner-shell electrons from the number of protons in the nucleus.
- Electronegativity is the ability of an element to attract electrons towards itself.
- Atomic radius is a measurement used for the size of atoms. It can be regarded as the distance from the nucleus to the outermost electrons.
- The first ionisation energy is the energy required to remove one electron from an atom of an element in the gas phase and is represented by the equation $M(g) + \text{energy} \rightarrow M^+(g) + e^-$.
- Table 4.2.14 summarises how properties of elements have specific trends within the groups and periods of the periodic table.

TABLE 4.2.14 Summary of changes in properties of elements in the periodic table

Property	Group	Period
Effective nuclear charge	increases	decreases
Atomic radius	decreases	increases
Electronegativity	increases	decreases
First ionisation energy	increases	decreases

KEY QUESTIONS

Retrieval

- Define the term **effective nuclear charge** of an atom and determine the effective nuclear charge of an atom of calcium.
- Define the first ionisation energy of an atom.

Comprehension

- Determine the electron configurations in the following atoms or ions.
 - Ca
 - N
 - P
- Explain the relationship between electronegativity and effective nuclear charge.
- Figure 4.2.13 on page 76 shows electronegativity values for the elements in groups 1 and 17 of the periodic table.
 - Determine the name and symbol of the element that has the highest electronegativity.
 - Identify the group which has the following changes:
 - greatest change in electronegativity as you go down the group
 - smallest change in electronegativity as you go down the group

- Explain why the elements of group 18 are usually omitted from tables that give electronegativity values.
- Explain why ionisation energy increases from left to right across a period.
- Explain why the size of the Al^{3+} cation is different from the size of the atom from which it was formed.

Analysis

- Compare and contrast the trends in atomic and ionic radii in the periodic table using specific examples to illustrate your explanation.
- Sort the following in order of increasing atomic radius based on your understanding of the trends in the periodic table: Na, B, Ca, Al, Cl.
- Organise the following elements in order of increasing first ionisation energy, using the periodic table on page 76 (Figure 4.1.1): Na, He, Al, K, S, Ca and P.
- Predict whether Mg^{2+} is larger than F^- using the periodic table on page 76 (Figure 4.1.1). Explain your choice based on the structure of the two ions.
- Deduce why the number of subatomic particles in an atom increases across a period but the size of the atom decreases.

Module summary

Each module concludes with a summary to help students consolidate the key points and concepts.

Mandatory practicals

All Mandatory practicals are included in the Student Book and have been comprehensively developed to ensure they fully address the syllabus requirements. Each practical has been trialled and tested to ensure it can be safely performed and yields effective results, and includes a depth of questions and applications that enable students to develop and demonstrate required manipulative skills.

MANDATORY PRACTICAL 4

Determining the molar volume of hydrogen

Research and planning

Aim

To determine the molar volume of hydrogen gas at STP (0°C and 100 kPa).

Rationale (scientific background to the experiment)

Gases are produced when fuels burn. An understanding of the behaviour of gases and gas laws allows us to calculate the volume of gaseous products and compare volumes of gaseous gases released by different fuels. In this experiment you will determine the number of moles of hydrogen gas produced in a reaction. From measurements of the gas volume and pressure, the molar volume of hydrogen at standard temperature and pressure (STP) can be calculated.

Timing

40 minutes

Materials

- 20 mL 2 M HCl
- 4.5 to 5 cm length of magnesium ribbon that has a mass of no more than 0.08 g
- 100 mL gas syringe
- set of apparatus to clamp the syringe to a retort stand
- 250 mL conical flask
- one-hole stopper to fit conical flask
- 4 cm length of glass tubing to fit the one-hole stopper
- approx. 50 cm length of rubber tubing to connect the gas syringe to the glass tubing in the one-hole stopper
- 100 mL measuring cylinder
- electronic balance
- emery paper or steel wool for cleaning the magnesium ribbon
- safety glasses

PRE-LAB SAFETY INFORMATION

Hazard level	Risk	Control
2/3 HCl	Irrits by all routes of exposure; lung irritation	Wear eye and skin protection

Please indicate that you have understood the information in the safety table.

Name (print):

I understand the safety information (signature):

Method

Risk assessment

Consideration of risks includes chemical and physical risks. Before you commence this practical activity you must conduct a risk assessment. Complete the template in your Skills and Assessment book or download it from your eBook.

- Clamp the stoppered gas syringe to its retort stand and connect the conical flask and syringe using the rubber tubing as shown in Figure 4.4.1. Check that the equipment is secure.

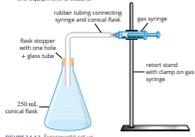


FIGURE 4.4.1 Experimental set-up

- Remove the stopper from the conical flask and carefully pour about 15 mL of 2 M hydrochloric acid into the flask without touching the sides.
- Clean and accurately weigh the magnesium ribbon, making sure that it weighs no more than 0.08 g.
- Tilt the flask and carefully place the magnesium ribbon on a dry side of the flask making sure that the magnesium does not contact the acid. Replace the stopper tightly, still keeping the flask tilted.
- Carefully withdraw the plunger of the syringe and then release it. If the system has no leaks, the plunger will return to its original position. Once any leaks have been fixed record the initial volume shown on the syringe in results Table 4.4.1.
- Straighten the conical flask and shake the piece of magnesium into the acid. As gas fills the syringe, rotate the plunger gently to prevent it from sticking.
- Once the magnesium has been used up, allow the conical flask to cool. In Table 4.4.1, record the final volume of gas in the syringe when the plunger has completely stopped moving. Calculate and record in the table the increase in the volume of gas in the syringe.

How to use this book

Chapter review

Each chapter finishes with a list of key terms covered in the chapter and a set of questions to test students' abilities to apply the knowledge gained from the chapter.

Chapter review

KEY TERMS

acid rain, activation energy, active site, adsorption, average rate of reaction, catalyst, chemical reaction, collision theory, concentration-time curve, endothermic, energy profile diagram, enzyme, exothermic, heterogeneous catalyst, homogeneous catalyst, induced fit model, initial rate of reaction, instantaneous rate of reaction, reaction, reaction pathway, kinetic energy distribution diagram, lock-and-key model, Maxwell-Boltzmann distribution curve, photochemical smog, potential energy, pressure, rate of reaction, reactant, reaction pathway, substrate, surface area, transition state

KEY QUESTIONS

Retrieval

- Identify which one of the following is the correct definition of rate of reaction.
A. the time it takes for all of a reactant to be used up
B. how fast a reaction is going at the end of 1 minute
C. how much a reaction is bubbling
D. the change in concentration of reactants or products over time
- Identify which of the following is the correct unit for measuring the rate of a reaction.
A. mol L⁻¹
B. mol L⁻¹ s⁻¹
C. mol² L⁻¹ s
D. mol s⁻¹
- Identify which of the following changes would decrease the rate of the reaction between zinc metal and dilute hydrochloric acid.
A. increasing the temperature of the hydrochloric acid
B. decreasing the size of the pieces of zinc
C. decreasing the concentration of the hydrochloric acid
D. decreasing the volume of hydrochloric acid used
- According to collision theory, select which one of the following is not essential for a reaction to occur.
A. Molecules must collide to react.
B. The reactant particles should collide with the correct orientation.
C. The reactant particles should collide with enough energy to overcome the activation energy barrier.
D. The reactant particles should collide with double the energy of the activation energy.

Comprehension

- Consider the reaction between solutions Y and W that produce X and Z according to the equation:
 $Y(aq) + W(aq) \rightarrow X(aq) + Z(aq)$
The energy profile diagram for this process is shown below:

Determine which one of the following alternatives describes the change that a catalyst produces to increase the reaction rate.
A. Only A is decreased.
B. Only A is increased.
C. A, B and C are decreased.
D. A and C only are decreased.

7. The following changes are made to a reaction mixture. Determine which one of the following changes will lead to a decrease in reaction rate.
A. Smaller solid particles are used.
B. The temperature is increased.
C. A catalyst is added.
D. The concentration of an aqueous reactant is increased.

Unit review

Each Unit concludes with a comprehensive set of exam-style questions, including multiple choice and short answer, that assist students to draw together their knowledge and understanding of the whole Unit.

UNIT 2 • REVIEW

REVIEW QUESTIONS

Molecular interactions and reactions

Topic 1: Intermolecular forces and gases

Multiple-choice questions

- State which of the following gives the correct shape for each of the molecules listed.

	Linear	Bent	Tetrahedral
A	CO ₂	H ₂ S	CH ₄
B	H ₂	CO ₂	NH ₃
C	HF	H ₂ O	NH ₃
D	H ₂ O	NH ₃	CO ₂

- Identify which of the following groups contains only polar molecules.
A. NH₃, H₂S, HCl
B. CO₂, CH₄, H₂O
C. HF, O₂, H₂
D. H₂O, NH₃, CH₄
- Identify which molecules have dispersion forces as the only intermolecular attraction.
A. HF
B. OF₂
C. NF₃
D. SiF₄
- The HPLC chromatogram of a solution containing 4 ppm wolfgram's pastide, is shown below.

Identify which one of the following graphs correctly represents the chromatogram of an 8 ppm wolfgram solution. Assume that all the chromatograms were obtained under identical conditions.

Glossary

Key terms are shown in **bold** throughout the Student Book and are listed at the end of each chapter. A comprehensive glossary at the end of the book defines all the key terms. The glossary aligns with the syllabus context and includes the QCAA defined terminology.

Answers

The Teacher Reader+ eBook provides comprehensive answers and fully worked solutions for all module reviews, Try yourself, Science as a Human Endeavour, chapter reviews and Unit reviews.

Icons

Go To icons make important links to relevant content within the student books in the course. The Go To icons indicate where to engage with Chapter 1 in your eBook.

Every Mandatory practical is supported by a complementary **SPARKlab** alternative practical.

The **Pearson Chemistry 11 Skills and Assessment Book** icons indicate the best time to engage with an activity for practice, application and revision. The type of activity is indicated as follows:

Worksheet (WS)

Practical Activity (PA)

Mandatory Practical (MP)

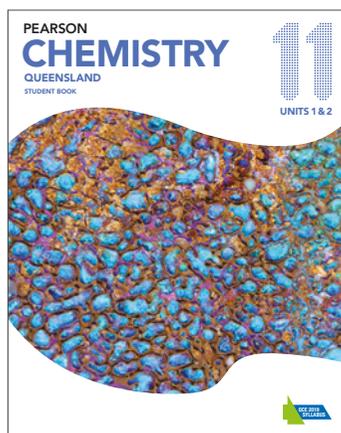
Sample Assessment Task (SAT).

The **Reader+** icon indicates when to engage with an asset via your reader+ eBook. Assets may include videos and interactive activities.

GO TO ➔



Pearson Chemistry 11 Queensland



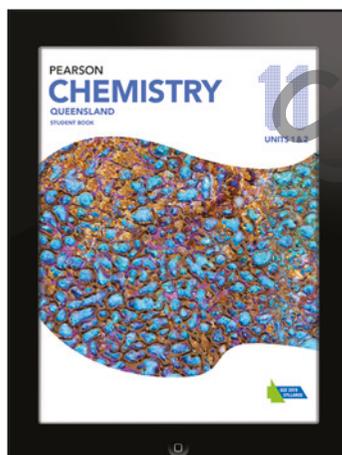
Student Book

Pearson Chemistry 11 Units 1 & 2 Queensland has been developed by experienced Queensland teachers to address all the requirements of the new QCE Chemistry 2019 Syllabus. The series features the very latest developments and applications of chemistry, literacy and instructional design to ensure the content and concepts are fully accessible to all students.



Skills and Assessment Book

The *Pearson Chemistry 11 Skills and Assessment Book* gives students the edge in preparing for all forms of assessment. Specifically prepared to provide opportunities to consolidate, develop and apply subject matter and science inquiry skills, this resource features a toolkit, key knowledge summaries, worksheets, practical activities and guidance, assessment practice and exam-style Topic Review sets.



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Teacher Support

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Chemistry is the study of matter: its properties, composition and transformations; how certain types of matter interact with other types of matter; and how matter interacts with energy such as heat, visible light and ultraviolet radiation. In this chapter, you will learn what matter is, the different types of matter that exist and how matter changes from one type to another. You will also recognise that most matter actually exists in impure forms as mixtures of pure substances (elements and compounds) and that these mixtures can take the form of homogeneous mixtures or heterogeneous mixtures. Finally, you will examine how simple physical processes can be used to separate mixtures into their pure components.

Syllabus subject matter



Topic 2 • Properties and structure of materials

■ COMPOUNDS AND MIXTURES

- recall that pure substances may be elements or compounds
- recognise that materials are either pure substances with distinct measurable properties (e.g. melting and boiling point, reactivity, strength, density) or mixtures with properties dependent on the identity and relative amounts of the substances that make up the mixture
- distinguish between heterogeneous and homogeneous mixtures
- analyse and interpret given data to evaluate the physical properties of pure substances and mixtures.

2.1 Characterising matter



BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- understand that matter can be characterised by its purity
- understand that most matter you encounter in your everyday life is a mixture of pure substances
- recall that mixtures may be homogeneous or heterogeneous
- recognise that mixtures are materials where the properties are dependent on the identity and relative amounts of the substances that make up the mixture
- recall that pure substances are either elements or compounds
- recognise that pure substances have a definite and distinct set of physical and chemical properties.

Chemistry is the study of **matter**, so it is important to understand the different types of matter that exist. You know from everyday experience that a tree, a rock, a glass of water and a piece of gold are examples of matter. You also intuitively know that there are fundamental differences in the observable properties of trees, rocks, water and gold that tell us that they are different types of matter. However, you can identify some properties common to all types of matter. For example, you can see the effect of matter on other matter; think of the book you are reading or the screen you are viewing; think of the wind on your face, the sand between your toes or the water in your bath tub. All are examples of matter.

Another characteristic feature of matter is that you can measure it. Matter has **mass** and you can measure this **physical property**; matter also occupies space and you can measure its **volume**. The following statement is a good working definition of matter that will suit our purposes for studying chemistry.

i Matter can be described as anything that has mass, occupies space and can be perceived by our senses.

PURITY OF MATTER

Matter can be classified, or characterised, in different ways. One way is to look at the purity of matter. It turns out that most of the matter you encounter in your everyday life—including the food you eat, the air you breathe and the water you swim in—is not chemically pure. Most matter actually consists of **mixtures** or **pure substances**. For example, the air you breathe is a mixture of oxygen and nitrogen with trace amounts of other gases, including carbon dioxide, water vapour and argon. Even tap water may appear to be pure but it actually contains trace amounts of dissolved minerals.

The relationship between pure substances and mixtures is shown in Figure 2.1.1. It shows that the matter you observe in your everyday life is ultimately composed of either **elements** or **compounds**. Collectively, elements and compounds are known as pure substances. Pure substances can be physically combined to produce mixtures. Mixtures can either be **homogeneous mixtures** or **heterogeneous mixtures**. The differences between these two types of mixtures will be discussed in detail in Module 2.2 of this chapter.

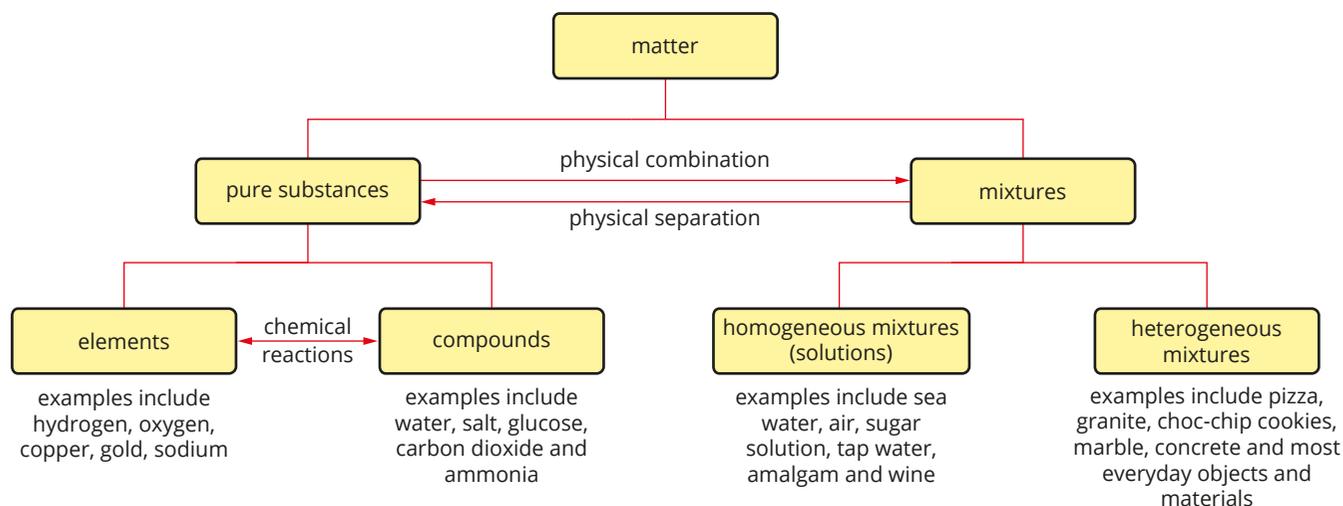


FIGURE 2.1.1 Classification of matter according to purity, showing the relationship between elements, compounds and mixtures

Figure 2.1.2 shows four examples of different types of matter.

- A slice of pizza (Figure 2.1.2a) contains a mixture of carbohydrates, fats and oils, as well as water and dissolved minerals and nutrients. It is a physical mixture of a wide range of pure substances. It also contains visibly distinct ‘chunks’ that are different from other parts, such as the pepperoni slices. This gives us the hint that a slice of pizza is a heterogeneous mixture.
- Food colouring dissolved in water (Figure 2.1.2b) is also a physical combination of two or more pure substances and is, therefore, a mixture. In this case, however, there are no distinct ‘chunks’ of matter that are visibly different from the rest of the coloured solution. The homogeneous nature of a solution of food colouring gives us the hint that it is a homogeneous mixture. Homogeneous mixtures are also known as **solutions**.
- The salt crystal (Figure 2.1.2c) is a pure substance and is not a physical combination of different substances. It is the compound sodium chloride (NaCl) and consists of elements chemically combined in a fixed ratio (i.e. sodium and chlorine in a 1:1 ratio).
- The sample of copper wire (Figure 2.1.2d) is also a pure substance and is an example of an element.

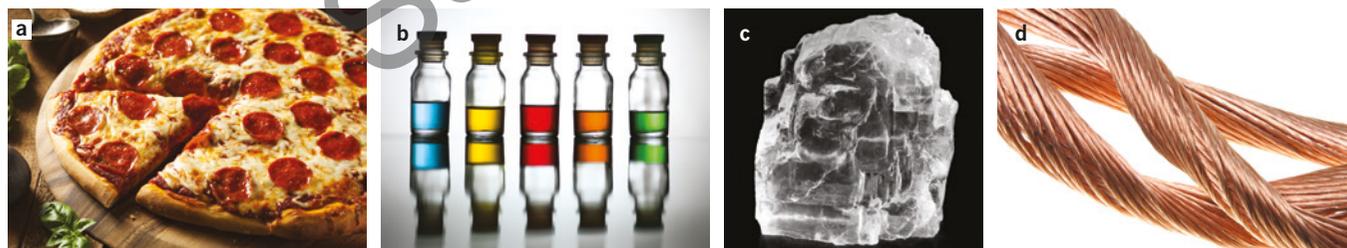


FIGURE 2.1.2 Examples of different types of matter: (a) a slice of pizza (heterogeneous mixture), (b) food colouring dissolved in water (homogeneous mixture and also known as a solution), (c) a salt crystal, which is a pure substance composed of the compound sodium chloride (NaCl) and (d) copper metal, which is an example of an element

PHYSICAL AND CHEMICAL CHANGES IN MATTER

In chemistry, you need to understand how matter can change from one form to another. A change in the form of matter can occur via physical changes and/or chemical changes. Figure 2.1.1 shows that combining pure substances to create mixtures requires a physical change. Separating mixtures into their pure components also requires a physical change. Figure 2.1.1 further shows that to create compounds or to decompose them into their elemental components requires a chemical change or **chemical reaction**.

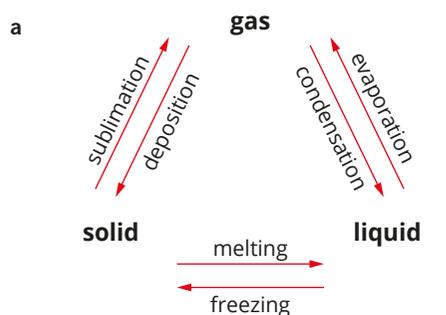


FIGURE 2.1.3 (a) Processes describing the changes of state between solids, liquids and gases. (b) The melting, boiling, condensing and freezing of water can be represented using chemical formulas and chemical equations. The bracketed letters, (s), (l) and (g), represent the solid, liquid and gaseous states of water. The '+ Δ ' and '- Δ ' symbols refer to the need to 'add heat' or 'subtract heat' to induce the changes of state indicated.

Physical changes in matter

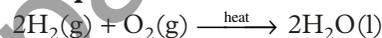
A **physical change** in matter is a process where the form of matter may be changed without changing its chemical identity or its chemical composition. No new substances are formed during physical changes. Cutting a piece of paper, grinding a tablet and bending an iron bar are examples of physical changes.

A change in **physical state** is one of the most important types of physical changes. The melting of ice to produce liquid water or the heating of water to produce gaseous steam are examples of physical changes of state. No new substances are formed in changes of state. The processes involved in changes of state are summarised in Figure 2.1.3a and represented using chemical equations in Figure 2.1.3b.

Chemical changes in matter

Chemical changes of matter (i.e. chemical reactions) involve a change in chemical composition where one or more kinds of matter are transformed into a new kind of matter (or several new kinds of matter). In other words, chemical reactions involve the production of new substances. You can see the results of chemical reactions around you every day. The burning of wood, the spoiling of milk, the digestion of food and the growth of plants via photosynthesis are all examples of chemical reactions.

In simple terms, a chemical reaction can be described as a rearrangement of **atoms**. The combustion of hydrogen (H_2) in the presence of oxygen (O_2) to produce water (H_2O) is one of the simplest chemical reactions. It can be represented using the balanced **chemical equation** below:



Here two elements, hydrogen (H_2) and oxygen (O_2), chemically combine to produce the compound water (H_2O). The equation is balanced so the four hydrogen atoms and two oxygen atoms on the left-hand side of the equation are rearranged and incorporated into the two water molecules on the right-hand side of the equation.

MIXTURES

As Figure 2.1.1 on page 5 suggests, a mixture is a physical combination of two or more pure substances. This means there can be mixtures of:

- two or more elements (such as mercury–gold **amalgam**)
- mixtures of two or more compounds (such as salt water)
- mixtures of elements and compounds (such as oxygen dissolved in water).

Figure 2.1.1 also suggests that mixtures such as these can be physically separated into their pure components by simple physical processes. Processes such as cutting, crushing, sieving, filtration, distillation or centrifugation can produce pure substances from complex mixtures. The ability to separate mixtures into their pure components is crucial in many industrial, environmental and biomedical applications. Different separation methods will be discussed in detail in Module 2.3.

Mixtures can vary in composition from sample to sample with different types and amounts of substances being present. Since the composition of mixtures can vary, it follows that the chemical and physical properties of mixtures can also vary depending on the type and amount of substances present.

Figure 2.1.4 shows how the **boiling point** and **freezing point** of water change with small additions of sodium chloride (NaCl). The boiling point of pure water is 100°C and the freezing point of pure water is 0°C . Both change when other substances are mixed with water. The increase in boiling point is known as **boiling point elevation**. The more salt dissolved, the greater the change in boiling point. Likewise, the decrease in freezing point is known as **freezing point depression** and, again, the more salt dissolved, the greater the change in freezing point.

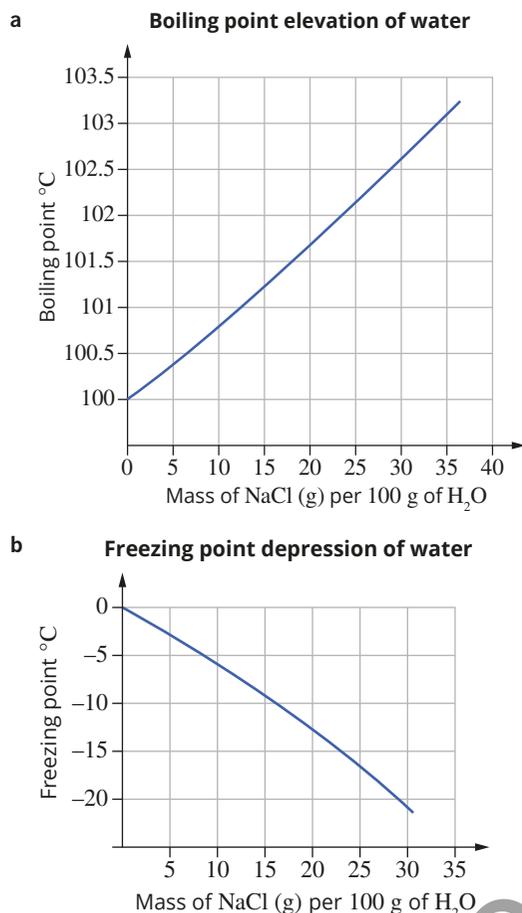


FIGURE 2.1.4 (a) Boiling point elevation—the boiling point of water increases with increasing amounts of NaCl. (b) Freezing point depression—the freezing point of water is lowered with increasing amounts of NaCl.

Changes in physical and chemical properties, like those shown in Figure 2.1.4, are useful for distinguishing between mixtures and pure substances. Mixtures will have different physical and chemical properties depending on the type and amount of substances present. Pure substances, on the other hand, do not vary in composition and therefore do not vary in chemical or physical properties. Some of the chemical and physical properties that can be used when characterising different types of matter are shown in Table 2.1.1.

TABLE 2.1.1 Examples of chemical and physical properties that can be used to characterise different types of matter. These properties can be used to distinguish mixtures from pure substances.

Chemical properties	Physical properties
combustibility/flammability	freezing point
reactivity in water	melting point
reactivity with acids	colour
reactivity with bases	viscosity
oxidisability	density
pH (specifically changes in pH)	solubility
toxicity	electrical conductivity
radioactivity	thermal conductivity
decomposition with heat	malleability/ductility



PURE SUBSTANCES

A pure substance (or simply a substance) is matter that has a definite and distinct set of physical and chemical properties that do not vary in composition from sample to sample. In general, any two samples of matter that have identical chemical and physical properties are said to be the same substance. Therefore, chemical and physical properties (such as those outlined in Table 2.1.1 on page 7) can be used to identify a particular sample of matter. For example, a shiny, silver-coloured metal that has a melting point of 660.3°C , a **density** of 2.70 g cm^{-3} and reacts with acid to produce hydrogen gas (H_2) can only be the element aluminium (Al). This is because only aluminium has this definite and distinct set of chemical and physical properties.

There are two types of substances: elements and compounds. As Figure 2.1.1 on page 5 shows, elements combine by chemical reactions to form compounds, while compounds can be decomposed into elements by chemical reactions. Unlike mixtures, substances cannot be separated into other kinds of matter by simple physical processes such as filtration, distillation and centrifugation.

ELEMENTS

Elements are the simplest form of matter that exists. They cannot be broken down into other substances by simple physical processes, nor can they be broken down into other substances by chemical reactions. Elements are the building blocks of matter since they can combine chemically to form millions of different compounds. The defining feature of elements is that they are substances that contain only one type of atom. The monatomic gases helium (He), neon (Ne) and argon (Ar) are examples of elements; the diatomic **molecules** oxygen (O_2), nitrogen (N_2), hydrogen (H_2) and bromine (Br_2) are also examples of elements; so too are the metals sodium (Na), copper (Cu), aluminium (Al) and iron (Fe).

Most non-metallic elements form molecules with a definite number of atoms. Sulfur, for example, is composed of molecules with eight sulfur atoms (S_8). However, some non-metals form **covalent network lattices** or **giant molecules**. Carbon is an example of such a non-metallic element. Diamond and graphite are both examples of covalent network lattices formed by carbon. Graphene is a giant molecule formed by carbon. (You will learn more about covalent network lattices formed from carbon in Chapter 8.) Representations of the sulfur molecule and a carbon covalent network lattice are shown in Figure 2.1.5. Metallic elements form a different type of network lattice structure, which you will look at in detail in Chapter 6.

i Monatomic elements are those made up of only one atom. Diatomic elements are comprised of two atoms. The prefixes *mon* (or *mono*) and *di* are frequently used in chemistry. They mean 'one' and 'two' respectively.

i A molecule is a definite and discrete group of atoms chemically bonded together. The atoms in molecules are non-metallic atoms bonded to other non-metallic atoms.

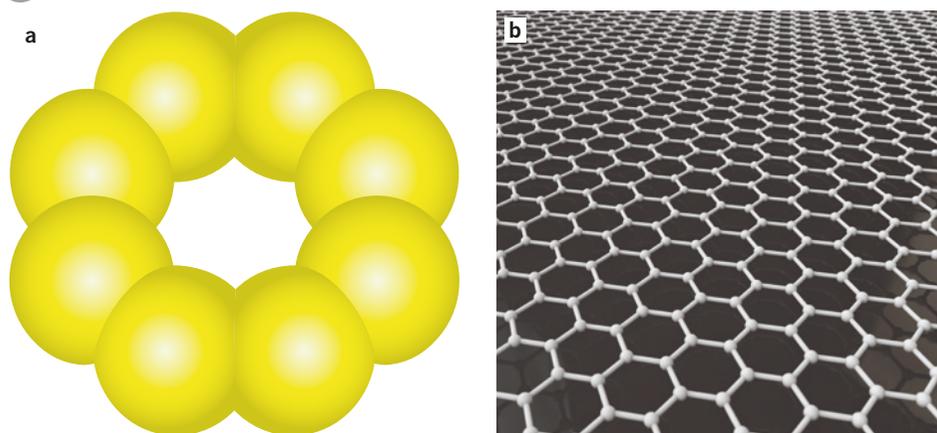


FIGURE 2.1.5 (a) Most non-metal elements, such as sulfur, form molecules. (b) Other elements, such as carbon, form covalent network lattices or giant molecules, given by the example here of graphene.

Element names, symbols and numbers

At present there are 118 known elements, 92 of them naturally occurring, while the other 26 have been synthesised in laboratories and are very unstable. Each element is assigned a unique name and **chemical symbol**. Chemical symbols are typically either a single capital letter (e.g. H for hydrogen) or a single capital letter followed by a lower-case letter (e.g. Ne for neon). Most chemical symbols make sense from their names (e.g. C for carbon or Mg for magnesium). Others symbols make less sense as their symbol may be derived from their Latin name (e.g. Au for gold, from the Latin *aurum*, or K for potassium, from the Latin *kalium*). Table 2.1.2 shows an alphabetical listing of some common elements along with their chemical symbols and some observable physical properties.

TABLE 2.1.2 Alphabetical listing of common elements including names (Latin name in brackets), symbols and physical properties

Element	Chemical symbol	Physical properties
aluminium	Al	silvery metal
barium	Ba	silvery metal
bromine	Br	reddish liquid
calcium	Ca	silvery metal
carbon	C	soft, black solid (graphite)
chlorine	Cl	greenish gas
chromium	Cr	silvery metal
cobalt	Co	silvery metal
copper (cuprum)	Cu	reddish metal
fluorine	F	pale yellow gas
gold (aurum)	Au	soft, yellow metal
helium	He	colourless gas
hydrogen	H	colourless gas
iodine	I	bluish-black solid
iron (ferrum)	Fe	silvery metal
lead (plumbum)	Pb	bluish metal
magnesium	Mg	silvery metal
manganese	Mn	grey metal
mercury (hydrargyrum)	Hg	silvery liquid
neon	Ne	colourless gas
nickel	Ni	silvery metal
nitrogen	N	colourless gas
oxygen	O	colourless gas
phosphorus	P	yellowish solid (white phosphorus)
potassium (kalium)	K	soft, silvery metal
silver (argentum)	Ag	silvery metal
sodium (natrium)	Na	soft, silvery metal
sulfur	S	yellow solid
zinc	Zn	bluish-white metal

Along with a name and chemical symbol, each element is also assigned a number, called the **atomic number**. The atomic number identifies the number of protons in the atom. For our purposes, atomic numbers range from 1 (for hydrogen) up to 92 (for uranium), i.e. the 92 naturally occurring elements. At this stage you should become familiar with the first 20 elements (Table 2.1.3 on page 10).

TABLE 2.1.3 The first 20 elements listed in order of increasing atomic number

Atomic number	Name	Symbol	Atomic number	Name	Symbol
1	hydrogen	H	11	sodium	Na
2	helium	He	12	magnesium	Mg
3	lithium	Li	13	aluminium	Al
4	beryllium	Be	14	silicon	Si
5	boron	B	15	phosphorus	P
6	carbon	C	16	sulfur	S
7	nitrogen	N	17	chlorine	Cl
8	oxygen	O	18	argon	Ar
9	fluorine	F	19	potassium	K
10	neon	Ne	20	calcium	Ca

The periodic table

Figure 2.1.6 shows that elements can be listed in a special way in the **periodic table of elements**. The periodic table groups elements with similar chemical and physical properties into vertical columns called **groups**. Most elements are metals, which appear on the left-hand side of the periodic table, while the non-metals appear towards the upper-right of the periodic table.

You will generally have a copy of the periodic table at hand during your chemistry studies so detailed memorisation is not normally required. However, being able to recall specific information about the first twenty elements or so will be very useful. It is very important to learn how to use the periodic table since it is the most useful tool in chemistry. There are many useful trends in the periodic table that you will learn more about in Chapter 4.

i The periodic table is an arrangement of the elements in order of increasing atomic number in which elements of similar chemical and physical properties are placed in vertical columns known as groups.

1 H hydrogen																	2 He helium						
3 Li lithium	4 Be beryllium																	5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium																	13 Al aluminium	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton						
37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon						
55 Cs caesium	56 Ba barium	57–71 lanthanoids	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon						
87 Fr francium	88 Ra radium	89–103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson						
Lanthanoids		57 La lanthanum	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium							
Actinoids		89 Ac actinium	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium							

FIGURE 2.1.6 The periodic table groups elements according to their chemical and physical properties.

COMPOUNDS

Compounds are substances formed from two or more elements in which the elements are always combined in the same fixed proportion. This means the composition of compounds does not vary, no matter how much of the compound there is. Water is a compound in which hydrogen and oxygen are always combined in the ratio of 2:1 and is represented by the **chemical formula** H_2O .

A chemical formula is a shorthand notation that uses elemental symbols from the periodic table, with numerical subscripts to convey the relative proportions of atoms of the different elements in the compound. You will note that the oxygen atom in the formula H_2O has no subscript. When an element in a chemical formula has no subscript, the subscript is presumed to be the number one.

Compounds are substances that can be broken down by chemical reactions to form other substances. To determine whether a pure substance is an element or a compound, you must determine if the substance can be broken down into elements. For example, when heated, mercury(II) oxide (HgO) decomposes to liquid mercury (Hg) and oxygen gas (O_2) (Figure 2.1.7). If it were not a compound, the mercury(II) oxide would not break down. As oxygen is a colourless gas, you cannot see it.

Types of compounds

There are two major types of compounds: **molecular compounds** and **ionic compounds**. Molecular compounds are composed of molecules all of which are alike and have non-metallic elements chemically bonded to other non-metallic elements in a fixed ratio. They tend to have relatively low boiling points and melting points. Examples of common molecular compounds include water (H_2O), methane (CH_4), ammonia (NH_3), benzene (C_6H_6), ethanol ($\text{C}_2\text{H}_6\text{O}$) and carbon dioxide (CO_2). Note how each example contains only non-metallic elements.

Ionic compounds form when metallic elements bond to non-metallic elements. Ionic compounds are composed of **ions** arranged in a rigid three-dimensional lattice. They contain positively charged ions (called **cations**) and negatively charged ions (called **anions**), which are attracted to each other by the electrostatic attraction of charges of opposite sign. They tend to have relatively high melting points and boiling points compared to molecular compounds. Examples of common ionic compounds include sodium chloride (table salt, NaCl), calcium carbonate (limestone, CaCO_3) and calcium oxide (lime, CaO). Note how each example contains a metallic cation and a non-metallic anion.

You will look at ionic compounds and molecular compounds in more detail in Chapters 7 and 8.



FIGURE 2.1.7 The red powder in this test-tube is mercury(II) oxide (HgO). If you look closely at the test-tube, you will see beads of liquid mercury forming from the decomposition of the compound.

2.1 Review

SUMMARY

- Matter can be characterised and classified according to its purity.
- Pure substances are materials with definite and distinct chemical and physical properties.
- Mixtures are physical combinations of pure substances whose properties are dependent on the identity and relative amounts of the substances that make up the mixture.
- Changes in matter are brought about by physical changes or chemical changes: physical changes do not produce new substances; chemical changes result in the formation of new substances.
- Pure substances may be elements or compounds.
- Every element has a unique name, atomic number and chemical symbol.
- Elements are organised into the periodic table.
- Compounds are formed from two or more elements combined in the same fixed proportion.
- Molecular compounds are composed of non-metals bonded to other non-metals.
- Ionic compounds are composed of metals bonded to non-metals.

KEY QUESTIONS

Retrieval

- 1 Define the term 'matter'.
- 2 Name two types of:
 - a mixtures
 - b pure substances.
- 3 Describe a physical change in matter.
- 4 Define a pure substance.
- 5 Identify the common name of each of the following elements from its Latin name.
 - a ferrum
 - b kalium
 - c argentum
 - d plumbum
 - e hydrargyrum
- 6 Define the term 'compound' and list the two major classes of compounds.
- 7 Select the correct terms to complete the following sentence.

Molecular compounds/ionic compounds are composed of non-metals bonded to non-metals, whereas *molecular compounds/ionic compounds* are composed of metals bonded to non-metals.
- 8 Name two physical properties that could be used to distinguish between these substances.
 - a water and methanol
 - b gold and copper
 - c oxygen gas and chlorine gas

Comprehension

- 9 Describe the change of state associated with each of the following processes.
 - a Water is made into ice cubes.
 - b The inside of your car window fogs up.
 - c Mothballs in the wardrobe disappear with time.
 - d Wet washing dries.
- 10 A certain substance is a silver-grey coloured metal that melts at 420°C . When it is placed in dilute sulfuric acid, hydrogen is given off and the metal dissolves. It has a density of 7.13 g cm^{-3} at 25°C and reacts slowly with oxygen to form a metal oxide. Describe the physical and chemical properties of the substance referred to above.
- 11 Determine if the following is a physical or chemical change.
 - a A sample of mercury(II) oxide was heated in a reaction vessel to produce mercury metal and oxygen gas.
 - b A glowing wood splint was thrust into the reaction vessel and the splint burst into flame.
- 12 Explain the differences between an element, a compound and a mixture.

Analysis

- 13 The following are properties of a certain element. Classify them as physical or chemical.
 - a In powdered form, it burns brilliantly on ignition.
 - b Bulk metal does not react with steam even when red hot.
 - c It has a density of 1.85 g cm^{-3} at 20°C .
 - d It is a relatively soft, silvery-white metal.

- 14** Classify each of the following as a physical change or chemical change.
- a** the evaporation of water
 - b** the rusting of iron
 - c** the grinding of salt crystals into powder
 - d** the burning of wood in a fireplace
- 15** Classify each of the following as an element, a compound or a mixture.
- a** copper
 - b** sand
 - c** water
 - d** carbon dioxide
 - e** muddy water
 - f** sodium chloride
 - g** gold
 - h** lemonade
- 16** About 3.5% (3.5 g per 100 g) of the mass of sea water is the result of dissolved salts, mainly sodium chloride. Determine the freezing point of sea water using the graph in Figure 2.1.4b on page 7.
- 17** Classify each of the following elements on the periodic table on page 10 as a metal, metalloid or non-metal and represent each element using its chemical symbol.
- a** magnesium
 - b** manganese
 - c** silver
 - d** mercury
 - e** neon
 - f** arsenic
 - g** sulfur
 - h** silicon
- 18** Classify the following as ionic compounds or molecular compounds using the periodic table on page 10.
- a** NaCl
 - b** H₂S
 - c** PF₃
 - d** Fe₂O₃
- 19** Identify an element that has similar physical and chemical properties to potassium, K. Explain your reasoning.

2.2 Homogeneous and heterogeneous mixtures



BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- distinguish between homogeneous mixtures and heterogeneous mixtures
- understand that the defining feature of a heterogeneous mixture is the presence of visually distinguishable phases that have different physical and chemical properties
- understand that liquid homogeneous mixtures, also known as solutions, are composed of solutes dissolved in a solvent.

You have already noted that most samples of matter are not chemically pure and consist of a physical combination of two or more pure substances called a mixture. You have also noted that there are two types of mixtures—homogeneous mixtures and heterogeneous mixtures.



i The terms **homogeneous** and **heterogeneous** have Greek origins: *homo*, meaning 'same', *hetero*, meaning 'different', and *genes*, meaning 'of a kind'. Homogeneous therefore translates to 'of the same kind' and heterogeneous translates to 'of a different kind'.

In some instances, mixtures are easily recognised. For example, consider a piece of granite, a choc-chip cookie and salad dressing (Figure 2.2.1). In these examples, you can see that different kinds of substances are present. In other cases, it is not so easy to recognise mixtures. For example, the air you breathe, sea water and sterling silver jewellery (Figure 2.2.2) may all appear to be pure but each consists of different substances. Air is a mixture of elements such as nitrogen (N_2) and oxygen (O_2) combined with compounds such as carbon dioxide (CO_2) and water vapour (H_2O); sea water is mostly a mixture of the compounds water (H_2O) and sodium chloride ($NaCl$); while sterling silver is a mixture of the elements silver (Ag) and copper (Cu). It is the uniformity of these mixtures and the lack of visibly different materials that makes it hard for us to recognise them as mixtures.



FIGURE 2.2.2 Examples of matter not easily recognised as mixtures. (a) Air is a colourless mixture of nitrogen, oxygen and some trace gases. (b) Sea water is a colourless mixture of salt and water. (c) Sterling silver is a mixture of silver and copper but appears to be a single lustrous silver-coloured metal.

FIGURE 2.2.1 Some examples of mixtures: (a) This sample of granite shows at least three visibly distinct regions—white quartz, orange feldspar and black mica minerals. (b) A choc-chip cookie has at least two visibly distinct regions. (c) Some salad dressings are made from oil and water.

HETEROGENEOUS MIXTURES

The piece of granite, the choc-chip cookie and the salad dressing shown in Figure 2.2.1 are examples of heterogeneous mixtures. These samples of matter are not uniform throughout and you can clearly observe the presence of different types of materials. You also know from experience that the different parts of each of these mixtures have different properties, such as colour, taste and hardness.

Heterogeneous mixtures consist of two or more substances that have visibly distinguishable regions, called **phases**, which have different physical and chemical properties. A heterogeneous mixture is not uniform throughout, so two small samples obtained from different parts of the mixture would be different in composition.

Heterogeneous mixtures may have phases in the same physical state or in different physical states. Granite is a heterogeneous mixture of three solid phases—the white quartz mineral (i.e. silica, SiO_2), the orange feldspar mineral and the black mica mineral. The oil and water phases of salad dressing are also both in the same physical state—the liquid state. On the other hand, a sample of muddy water consists of solid dirt particles physically mixed with liquid water.

You will see in Module 2.3 that the different phases in a heterogeneous mixture can be readily separated using simple mechanical separation techniques.

i A phase is a region of matter that is physically and chemically uniform in composition and properties. It is physically distinct from other regions of matter and is mechanically separable from other phases.

HOMOGENEOUS MIXTURES

Homogeneous mixtures consist of a physical combination of two or more substances but have only one visibly distinct phase which has uniform properties. A homogeneous mixture is uniform throughout and samples taken from different parts of the mixture would be identical in composition. The air, sea water and sterling silver shown in Figure 2.2.2 are all examples of homogeneous mixtures where only one visibly distinct phase is observable.

Many homogeneous mixtures are also called solutions and have one substance dissolved in another. The substance present in the greatest amount is called the **solvent** and all other substances present in the mixture are called **solutes**. Solute are said to be dissolved in the solvent.

The most common solutions you will encounter in your chemistry studies will be solid salts dissolved in liquid water (for example, sea water). The salts are the solutes and the water is the solvent. A solution in which water is the solvent is given the special name of an **aqueous solution**—the name being derived from the Latin *aqua*, meaning ‘water’. Examples of some common solutions are shown in Table 2.2.1, which shows that solutions can involve mixtures across all three states of matter.

TABLE 2.2.1 Examples of common solutions

Example	States of matter involved	Solvent	Solute(s)	Physical appearance
air	gas–gas	nitrogen	oxygen, carbon dioxide, argon, water vapour	clear colourless gas
soft drinks	liquid–gas	water	carbon dioxide gas	coloured liquid
vinegar	liquid–liquid	water	ethanoic acid	clear colourless liquid (white vinegar)
sea water	liquid–solid	water	sodium chloride plus other trace salts	clear colourless liquid
sterling silver	solid–solid	silver	copper	lustrous silver-coloured solid metal

Even though any single sample of a homogeneous mixture will be uniform throughout, the composition may vary from sample to sample, depending on the relative ratio of the substances in the solution. For example, two samples of salt water may be prepared by dissolving, firstly, one gram of salt in a litre of water and then, secondly, 10 grams of salt in a litre of water. Both salt water samples will be homogeneous throughout but each sample will have different physical and chemical properties including density, electrical conductivity and boiling point.

You will see in Module 2.3 that the different components of a heterogeneous mixture are often separated using techniques that involve a change of state.

2.3 Separating mixtures

BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- recall separation techniques used to separate both heterogeneous and homogeneous mixtures
- understand that separation techniques use differences in the physical properties of the components to separate them from each other
- understand that separating phases of a heterogeneous mixture involves mechanical separation techniques
- understand that separating components of a homogeneous mixture typically involves a change of state.



Removing impurities from samples of matter or separating mixtures into pure components are crucial processes in many biomedical, environmental and industrial applications. For example, ensuring the purity of pharmaceutical drugs or removing impurities in drinking water supplies have significant health-related consequences.

If you want to separate mixtures, you can generally use the differences in the physical properties of the components of the mixture to separate the components from each other. Since mixtures are physical combinations of substances, relatively simple physical processes can be used to separate them.

SEPARATING HETEROGENEOUS MIXTURES

Heterogeneous mixtures have different phases that are physically distinct and mechanically separable from each other. Depending on the nature of the mixture, mechanical separation can take several forms.

Hand sorting

Hand sorting is perhaps the simplest separation technique and can be used when there are relatively few objects to sort that have differing physical properties such as size, colour and texture. Separating seashells from sand would be a relatively straightforward process that could be done by hand. Similarly, if you needed to isolate the white quartz crystals from a sample of granite, you could use simple physical processes, such as cutting, grinding or crushing, followed by hand sorting—with the aid of a pair of tweezers if required.

Sieving

Sieving can be used as a separation technique if there are many objects to sort and they are of different sizes. Beach-cleaning tractors are used daily on Queensland beaches to sift the sand to remove rocks, shells and rubbish, leaving behind clean sand (Figure 2.3.1). In a similar process, the primary treatment of sewage wastewater uses large rotating mesh screens to screen out (or sieve) large particles or objects, such as food scraps, that are part of the wastewater mixture.

Filtration

Fine grade separation of solids and liquids can be achieved in the laboratory using filter paper and a filter apparatus. In Figure 2.3.2, you can see the result of passing a muddy water sample through a filter apparatus. Muddy water consists of solid particles of dirt and clay suspended in water. During filtration, the solid particles are trapped by the filter paper while the clear liquid water easily passes through, resulting in the separation of the solid and liquid phases. This type of filtration technique is good for separating small samples of undissolved solids from a liquid.



FIGURE 2.3.1 Queensland beaches are cleaned by tractors dragging a rotating mesh drum to sieve large objects such as rocks, shells and other rubbish.



FIGURE 2.3.2 Filtration of muddy water. Solid mud and clay particles suspended in water can be separated from the liquid water by the process of filtration.



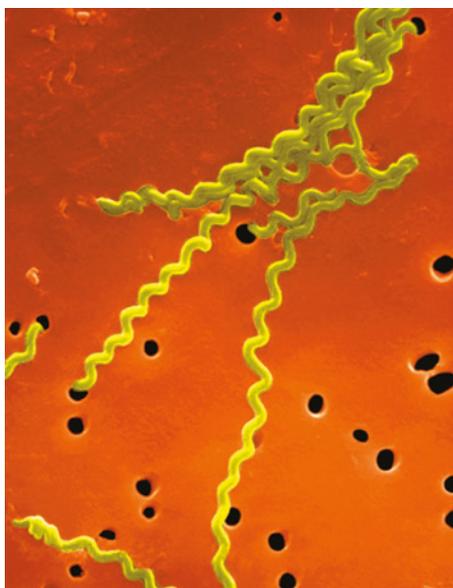


FIGURE 2.3.3 Polycarbonate filter membranes with well-defined pore size allow bacterial cells to be separated from water samples. The bacterial cells shown are the species *Leptospira interrogans*.

Different types of filter paper are used for different types of samples but most are manufactured from ashless paper, nitrocellulose or polycarbonate membranes. They can also be manufactured to separate particles of definite size. Figure 2.3.3 shows a close-up image of a polycarbonate filter membrane with pore sizes of the order of $0.2\mu\text{m}$. This filter membrane will block the passage of particles larger than this size and can effectively sterilise water by filtering bacterial cells from water samples.

Centrifugation

Another way to separate solid particles from liquids is to centrifuge them. **Centrifugation** is a separation technique that uses the centrifugal force of rotational motion to promote rapid settling of solid particles in a heterogeneous solid–liquid mixture. One of the most common uses of centrifugation involves the separation (or fractionation) of blood. Blood samples are placed into centrifuge tubes and rotated at very high speeds (Figure 2.3.4a). The solid components of the blood mixture are forced towards the bottom of the centrifuge tube. The end result is the separation of blood into different fractions with red blood cells settled at the bottom of the tube, white blood cells and platelets forming a layer above the red blood cells, and the liquid blood plasma sitting on top of the other layers (Figure 2.3.4b).



FIGURE 2.3.4 Centrifugation of whole blood is a common technique used in pathology laboratories. (a) Blood samples in centrifuge tubes are placed in a centrifuge and rotated at very high speeds. (b) Blood can be separated into different fractions: red blood cells, white blood cells, platelets and blood plasma.



FIGURE 2.3.5 A separating funnel is used to separate two immiscible liquids.

Flotation

Flotation techniques take advantage of the differences in density of materials to separate heterogeneous mixtures. For example, a mixture of sawdust and sand can be easily separated by placing the mixture in water. The dense sand will sink to the bottom while the less dense sawdust will float on top, allowing it to be skimmed from the surface. This technique is used in the mining industry, in wastewater treatment plants and in paper recycling plants to separate complex mixtures.

Decantation

Decanting is another technique used for separating components of different densities. Decanting involves carefully pouring off the top liquid layer of a heterogeneous mixture. The mixture could be a liquid phase lying over a solid phase or it could be a liquid phase lying over another liquid phase. You can easily separate a mixture of sand and water by decanting the water, leaving behind the sand in the bottom of the container. Similarly, the liquid oil phase of salad dressing is easily decanted from the top of the more dense water layer underneath. Figure 2.3.5 shows that a separating funnel can also be used to separate two immiscible liquids, with the denser bottom layer being drained from the heterogeneous mixture.

Magnetic separation

Magnetic separation can be used to separate heterogeneous mixtures where some components have magnetic properties. Figure 2.3.6 shows that a mixture of fine sand and iron filings can be readily separated using a magnet.

SEPARATING HOMOGENEOUS MIXTURES

Homogeneous mixtures (or solutions) have one or more solutes dissolved in a solvent with only one visibly distinct phase that has uniform properties throughout. Separating solutions, therefore, requires more sophisticated techniques than the mechanical separation methods used for heterogeneous mixtures. One way to separate solutions is to employ changes of state to take advantage of the differences in boiling points or melting points of the components in the mixture.

Evaporation

As mentioned earlier, the most common examples of homogeneous solutions are solids dissolved in a liquid solvent. Evaporation of the solvent is the most convenient way of removing the liquid component and recovering the dissolved solid. Figure 2.3.7 shows that heating a salt solution will evaporate the water, leaving behind the solid salt. This process takes advantage of the differences in boiling points of the two substances involved.



FIGURE 2.3.6 A magnet is used to separate iron filings from the non-magnetic sand particles.

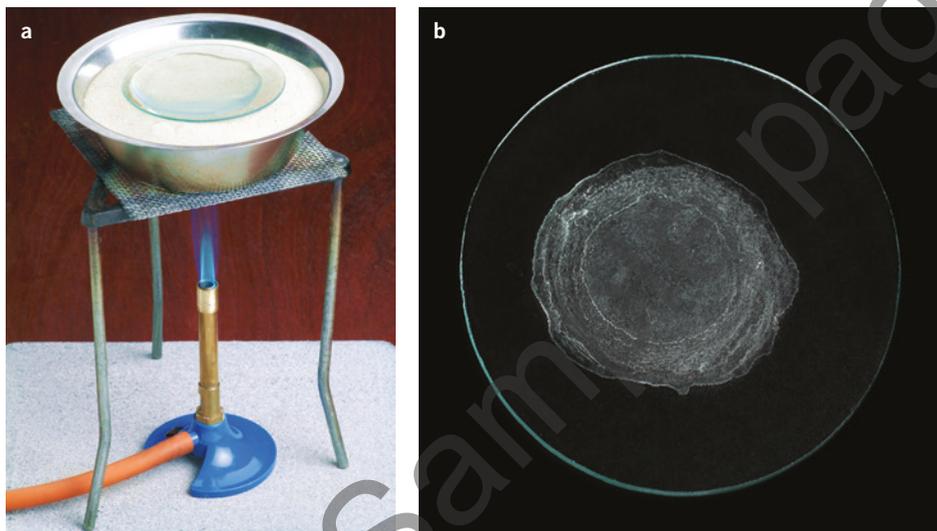


FIGURE 2.3.7 Evaporation of the solvent recovers the solid from a solid–liquid solution. (a) The salt solution is heated to drive off the water. (b) Solid salt residue remains after all of the water has evaporated.

Distillation

If both the solid solute and the liquid solvent need to be recovered then you need to use **distillation**. Distillation is a process of separating mixtures containing a liquid component by first evaporating the liquid to its gaseous state and then condensing it back to its liquid state. Figure 2.3.8 on page 20 shows a diagram of a typical distillation apparatus used in chemistry laboratories. This approach can be used to separate and recover both components of a salt water solution. A flask containing the salt solution is heated so liquid water evaporates. The water vapour is directed through a condensation tube, which is kept cool by a constant supply of cold water. The water vapour condenses to form pure liquid water, which is collected in the receiving flask. When all of the water has evaporated, a layer of pure salt will be retained on the inside surface of the distillation flask. In this way, both the pure salt and pure water are separated and recovered.

i Volatility is a measure of how readily a substance will vaporise by going from its liquid state to its gaseous state. In general, substances with lower boiling points have higher volatility.

You can use the same distillation approach for separating a solution of two liquids by taking advantage of the difference in **volatility** and boiling points of the liquids. For example, a solution of ethanol and water could be separated via distillation by evaporating off the more volatile ethanol, leaving behind the higher boiling point water.

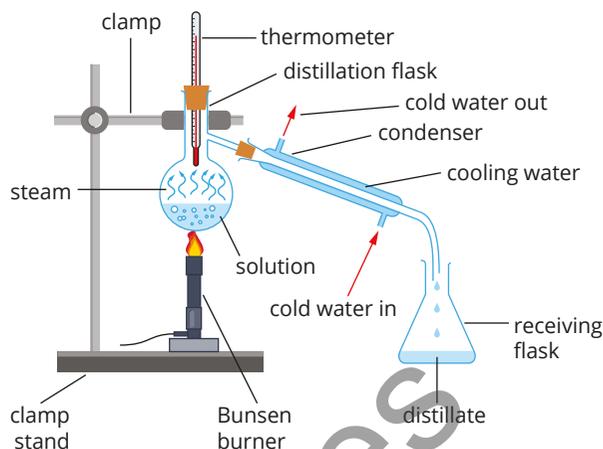


FIGURE 2.3.8 Typical distillation apparatus. A solution is vaporised by heating the distillation flask. Gaseous vapours are condensed in the condenser tube, which is kept cool by a constant supply of water. The pure liquid solvent is collected in the receiving flask and solutes remain in the distillation flask.

Fractional distillation of crude oil

Distillation is also used in one of the most important industrial processes of modern times—the production of petroleum products from crude oil. Crude oil is a complex mixture of different hydrocarbons with different boiling points. The differences in boiling points means that a process of **fractional distillation** can be used to separate and collect the different components (or fractions) of the mixture.

Fractional distillation of crude oil differs from ‘normal’ distillation in that a tall column, or tower, is situated above the liquid mixture with several condensers coming off at different heights. Figure 2.3.9a shows a typical distillation tower used in oil refineries, while Figure 2.3.9b shows a diagrammatic representation of the fractional distillation process used for crude oil. In this process, high temperature oil enters the distillation column at the bottom. As the mixture is vaporised it rises up the column and cools down with increasing height. Different components of the crude oil will condense at different temperatures, and therefore at different heights. Substances with high boiling points will condense at the high temperatures experienced at the bottom of the column; substances with low boiling points will condense at the lower temperatures experienced at the top of the column. Each of the different fractions is captured by condensers located at various heights.

The main fractions of crude oil that are collected include refinery gases (such as propane and butane), gasoline (i.e. petrol), naphtha, kerosene, diesel oil, fuel oil, and a residue containing paraffin wax, various oils and asphalt. Most of these fractions are used as fuels for heating or transport, while others are used as lubricants or in the manufacture of petroleum by-products such as plastics.

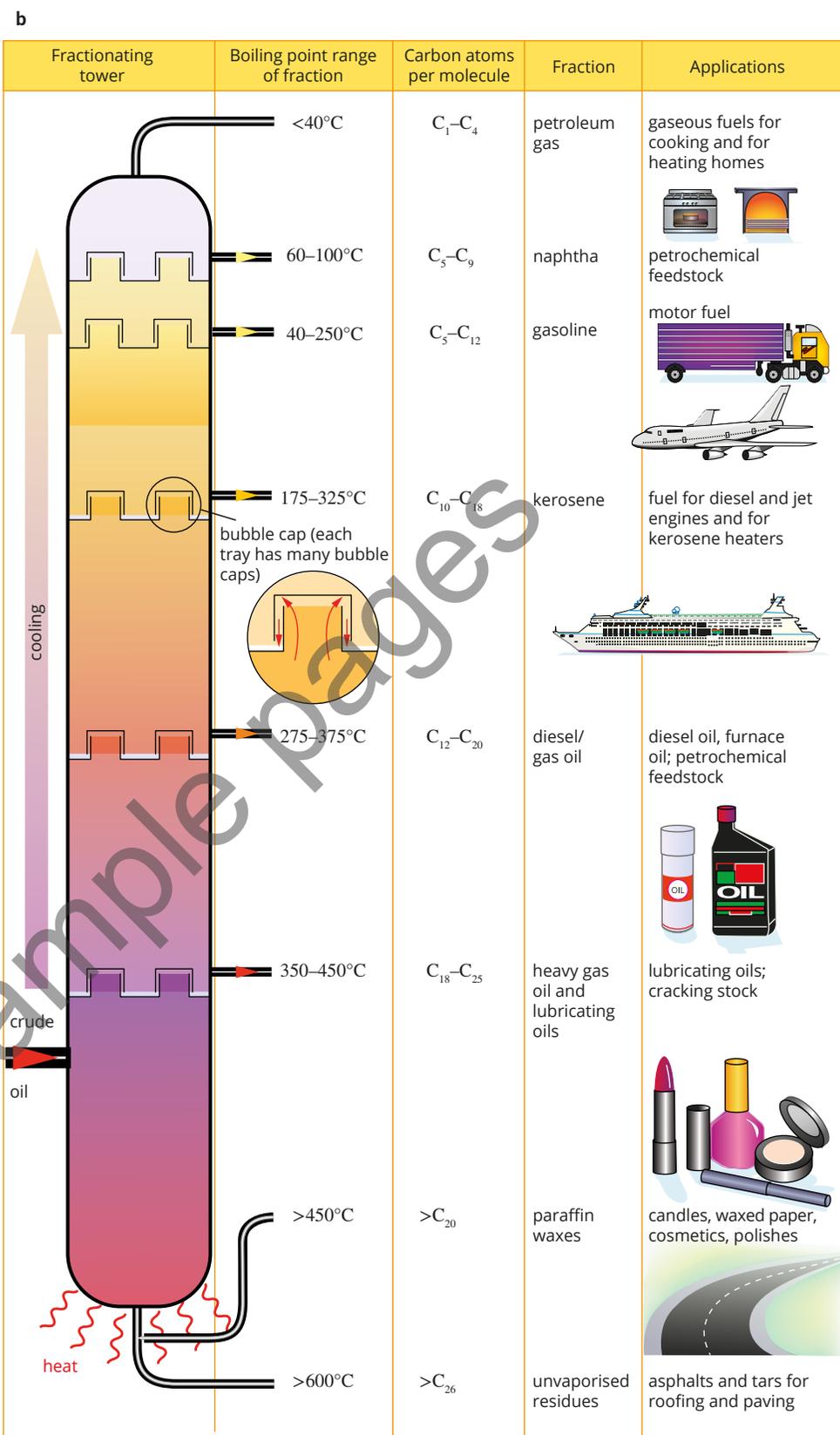


FIGURE 2.3.9 (a) A typical distillation tower used for the fractional distillation of crude oil in oil refineries. (b) A diagrammatic representation of the fractional distillation of crude oil. The crude oil is heated to around 400°C and piped into the bottom of the distillation tower. Different fractions are collected at different levels, depending on their boiling point.

2.3 Review

SUMMARY

- Separating mixtures uses relatively simple physical processes to take advantage of the differences in the physical properties of the components of the mixture.
- Hand sorting is a suitable separation method for mixtures containing a relatively small number of objects with visibly different properties.
- Sieving is a suitable separation method used for large numbers of different-sized particles.
- Filtration, centrifugation and decanting can all be used for separating undissolved solids from a liquid. Decanting can also be used for separating two immiscible liquids.
- Components of mixtures with differing magnetic properties can be separated using magnetic forces.
- Evaporation is a method for separating dissolved solids from the liquid solvent in a solid–liquid solution.
- Distillation is a suitable method for recovering both components of a liquid–solid solution.
- Distillation can also be used for separating two liquids with different boiling points.
- Fractional distillation is a method for separating complex mixtures of components with differing boiling points.

KEY QUESTIONS

Retrieval

- 1 Separating mixtures involves taking advantage of differences in the physical properties of the components that make up the mixture. Name one physical property that could be used to distinguish between the main components of these mixtures.
 - a wine (main components are water and ethanol)
 - b sterling silver (main components are silver and copper)
 - c air (main components are oxygen gas and nitrogen gas)
- 2 Name the type of mixture that is separated into its constituent components by these processes.
 - a sieving
 - b filtration
 - c flotation
 - d distillation
 - e evaporation
- 3 Recall the circumstances under which you would decant a mixture to separate its components.
- 4 Name the separation techniques that take advantage of differences in density.

Comprehension

- 5 Explain the physical properties you would take advantage of to separate the following mixtures. State the separation techniques you would employ.
 - a iron filings and sand
 - b salt and water
 - c water and ethanol
- 6 Explain under what circumstances you would use distillation to separate an aqueous salt solution instead of simply evaporating the solvent.

- 7 Show your understanding of separation techniques by matching each scenario to the most appropriate technique.

Separation technique	Scenario
a sieving	i separation and recovery of each component in a complex aqueous solution of several different alcohols
b filtration	ii production of sea salt from salt water
c evaporation	iii isolation of suspended solid particles from the Brisbane River water for laboratory analysis
d separating funnel	iv separation of the layers in an oil–water based salad dressing
e distillation	v separation of seashell fragments from sand
f fractional distillation	vi separation and recovery of both components of a salt solution
g centrifugation	vii separation of the different fractions of whole blood

- 8 Explain the difference between distillation and fractional distillation when applied to the refining of crude oil.

Analysis

- 9 Identify the separation techniques that would be best used to separate and recover the following components within mixtures.
 - a sand and gravel
 - b boiled potatoes from the water they were cooked in
 - c boiled rice from the water it was cooked in
 - d silt particles from muddy water
 - e hydrocarbon components in crude oil
 - f salt and water from sea water
- 10 Compare and contrast the methods of evaporation and distillation for separating the components of a saltwater solution. Describe the advantages and disadvantages of each separation technique.

Chapter review

KEY TERMS

amalgam
anion
aqueous solution
atom
atomic number
boiling point
boiling point elevation
cation
centrifugation
chemical change
chemical equation
chemical formula
chemical reaction

chemical symbol
compound
covalent network lattice
decanting
density
distillation
element
fractional distillation
freezing point
freezing point depression
giant molecule
group
heterogeneous

heterogeneous mixture
homogeneous
homogeneous mixture
ion
ionic compound
mass
matter
mixture
molecular compound
molecule
periodic table of elements
phase
physical change

02

physical property
physical state
pure substance
sieving
solute
solution
solvent
volatility
volume

KEY QUESTIONS

Retrieval

- Select the response that best describes a sample of matter that has these three characteristics.
 - It is uniform throughout.
 - It cannot be separated into other substances by physical processes.
 - It can be decomposed into other substances by chemical processes.

A a heterogeneous mixture
B a homogeneous mixture
C an element
D a compound
 - Identify the following as either a chemical property or physical property of matter.

a boiling point **b** melting point
c combustibility **d** toxicity
e density
 - Select the correct terms to complete the following sentence.

A physical change/chemical change involves the formation of new substances, whereas a physical change/chemical change does not.
 - Name the vertical columns of the periodic table. State their significance.
- Determine whether each sample of matter listed is a heterogeneous mixture, a homogeneous mixture or a pure substance.

a iron ore
b copper wire
c wet sand
d distilled water
 - Determine which of the following are pure substances and which are mixtures. For each, list all of the different phases present.

a alcohol and its vapour
b paint, containing a liquid solution and a dispersed solid pigment
c partially molten copper
d a sand containing quartz (silicon dioxide) and calcite (calcium carbonate)
 - The water in the Brisbane River is a mixture of water and suspended silt particles. A sample of Brisbane River water shows that the silt particles slowly settle to the bottom of a measuring cylinder under the action of gravity over a period of days. Describe two methods that could be used to rapidly separate the water and silt particles from the river water sample. Discuss the advantages and disadvantages of each method.
 - Describe the circumstances under which you would use distillation to separate an aqueous salt solution instead of simply evaporating the solvent.

Comprehension

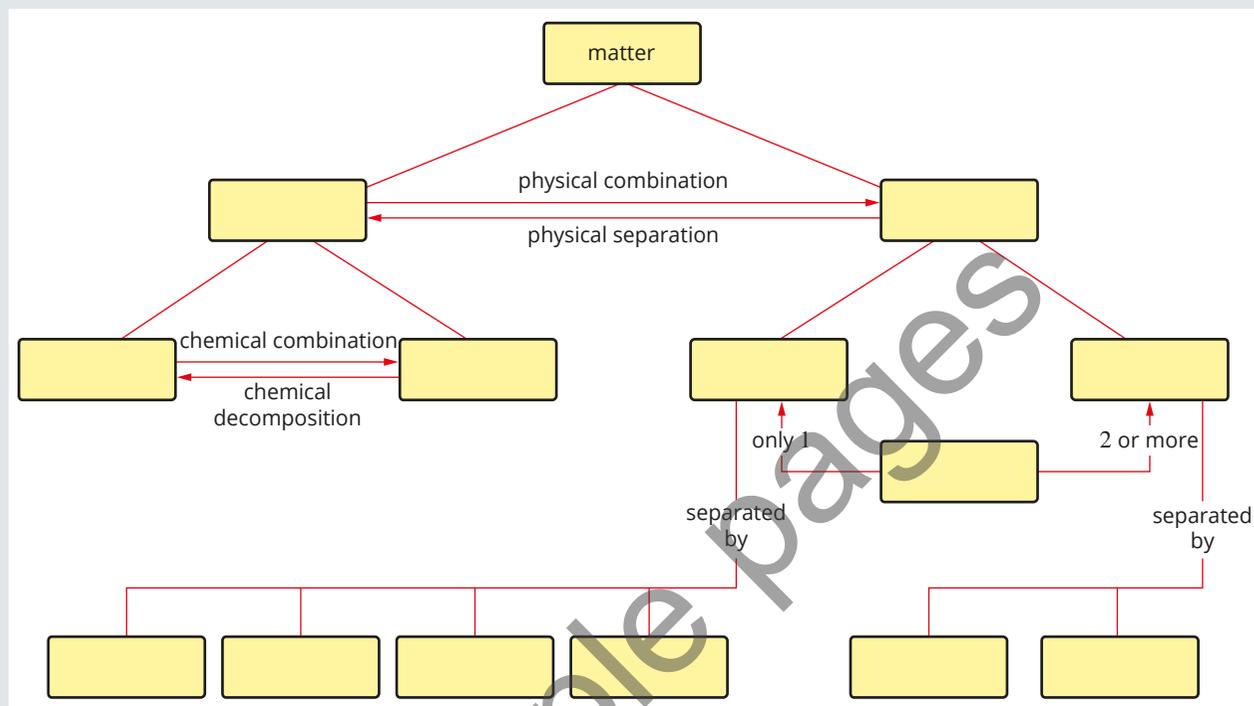
- Explain whether the composition of each of the following can vary. Explain your answer in each case.

a element
b compound
c homogeneous mixture
d heterogeneous mixture

CHAPTER REVIEW CONTINUED

- 10 Use the following list of terms and chart to complete a concept map that summarises the key ideas and their connections for this chapter.

centrifugation	compound	distillation	elements
evaporation	filtration	heterogeneous mixture	homogeneous mixture
mixture	phases	pure substance	sieving
sorting			



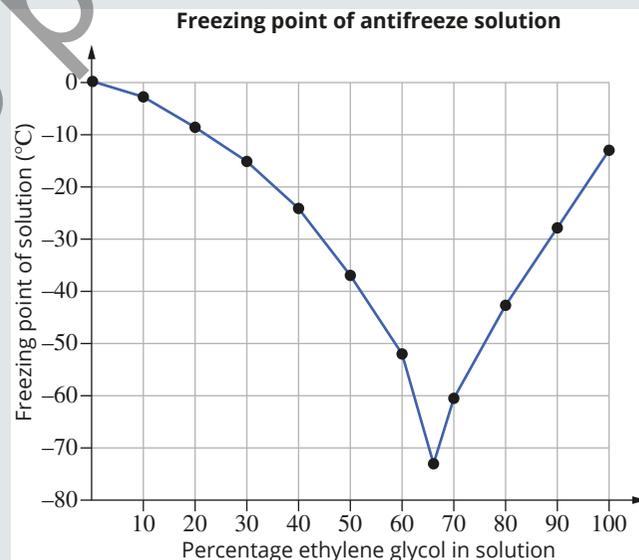
Analysis

- 11 Classify each of the following pure substances as elements or compounds, based on the information given, or indicate that no such classification is possible because of insufficient information.
- Analysis indicates that substance A contains two elements.
 - Substance B decomposes upon heating.
 - Heating substance C to 900°C causes no change.
 - Heating substance D to 400°C causes it to melt.
- 12 The following is a description of the element cadmium (Cd). Classify each descriptor as either a physical property or a chemical property.
- It is a bluish-white coloured lustrous metal.
 - It has a melting point of 321°C .
 - When added to hydrochloric acid the metal dissolves and hydrogen gas is released.
 - It is highly toxic and can adversely affect the kidneys, lungs and bones.
 - It has a density of 8.65 g cm^{-3} .
 - It has a hardness of 2.0 on the Moh hardness scale.
 - If left in air it will form a layer of cadmium oxide (CdO) on its surface.
- 13 Classify each of the following changes as a physical change or chemical change.
- the evaporation of ethanol
 - the rusting of steel
 - the grinding of sugar crystals into powder
 - the burning of coal in a fireplace
- 14 Classify each of the following changes as either a physical change or chemical change.
- corrosion of zinc anodes on boats
 - the melting of iron in a blast furnace
 - the pulverising of a granite sample
 - digesting chocolate
 - the growth of plants via photosynthesis
 - explosion of TNT
- 15 Compare and contrast elements and compounds.
- 16 Identify the elements in the following molecular compounds, writing their name, symbol and atomic number.
- water (H_2O)
 - ammonia (NH_3)
 - benzene (C_6H_6)
 - dinitrogen pentoxide (N_2O_5)
 - sulfur hexafluoride (SF_6)

- 17** Identify what you note about the nature of the elements in the compounds listed in Question 16 and what type of compound they are.
- 18** Identify the elements in the following ionic compounds, writing their name, symbol and atomic number.
- sodium chloride (NaCl)
 - calcium fluoride (CaF_2)
 - aluminium oxide (Al_2O_3)
 - copper(I) sulfate (Cu_2SO_4)
 - iron(III) carbonate ($\text{Fe}_2(\text{CO}_3)_3$)
- 19** Identify what you note about the nature of the elements in the compounds listed in Question 18 and what type of compounds they are.
- 20** If you light a match under a cold metal spoon you may observe one or more of the following. Classify each observation as a physical change or a chemical change.
- The match burns.
 - Carbon soot is produced.
 - The metal spoon gets warmer.
 - Water condenses on the metal spoon.
 - Carbon soot is deposited on the metal spoon.
- 21** Determine all possible answers for each scenario from the list below.
- compound
element
heterogeneous mixture
homogeneous mixture
- matter that cannot be broken down to simpler substances by chemical or physical means
 - matter that can be separated into its constituent components by physical processes
 - matter that can be separated into its constituent components by chemical processes
- 22** Classify each of the following as a mixture or pure substance. If it is a mixture, indicate if it is heterogeneous or homogeneous.
- tomato juice
 - a laptop
 - chocolate-chip ice cream
 - air
 - bromine liquid
 - calcium carbonate
 - vinegar
- 23** Identify the solvent and solute(s) in the following solutions.
- air
 - sea water
 - vinegar
 - white wine
 - fish tank water
- 24** When small amounts of the following solids are mixed with water, determine which mixture is most easily separated into its constituent components. Explain your answer.
- copper(II) sulfate, salt, sand, sugar

Knowledge utilisation

- 25** A glass contains a clear, colourless liquid that looks like water. Develop a test to describe how you can be sure that, if it is water, it is pure and does not contain any dissolved salts.
- 26** Propose how you could differentiate between a piece of pure silver jewellery and a piece of sterling silver jewellery.
- 27** Ethylene glycol is used as an antifreeze additive in vehicle radiators to stop the radiator water from freezing in cold weather. The lowest ever recorded temperature in Australia is -23.4°C recorded at Charlotte's Pass in the NSW Snowy Mountains on 29 June 1994.
- Decide what percentage concentration of ethylene glycol would be required to be confident that a vehicle radiator would not freeze in Australia using the following graph.
 - The lowest recorded temperature in Canberra is -10°C . Determine what percentage concentration of ethylene glycol would be required to be confident that a vehicle radiator would not freeze in Canberra using the following graph.



- 28** Design a test that would enable you to separate:
- oil and water layers in salad dressing
 - rocks from sand.
- 29** Develop a test that would enable you to separate a mixture of sand and sugar crystals, ensuring you recover both the sand and sugar in their solid states.
- 30** A bottle of white wine (a mixture of ethanol and water) has been contaminated by dissolved salt, sand and iron filings. Develop an experiment that would enable you to separate and recover all components of the mixture. Present your answer in a visual way such as a concept map or flow chart.