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Unit 1

The nature of matter

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Chapter 1

The particulate nature of matter

CHAPTER OUTLINE

In this chapter you will:

- understand the terms *element*, *compound* and *mixture*
- understand the differences between heterogeneous and homogeneous mixtures
- understand how to separate the components of a mixture
- use kinetic molecular theory to understand the properties of solids, liquids and gases
- understand that temperature in K is proportional to the average kinetic energy of particles
- understand how to convert temperatures between K and °C
- use state symbols in chemical equations
- use kinetic molecular theory to explain changes of state.

KEY TERMS

Make sure you understand the following key terms before you do the exercises.

atom: the smallest part of an element that can still be recognised as that element; in the simplest picture of the atom, the electrons orbit around the central nucleus; the nucleus is made up of protons and neutrons (except for a hydrogen atom, which has no neutrons)

element: a chemical substance that cannot be broken down into a simpler substance by chemical means. Each atom has the same number of protons in the nucleus

compound: a pure substance formed when two or more elements combine chemically in a fixed ratio

mixture: two or more substances mixed together. The components of a mixture can be mixed together in any proportion (although there are limits for solutions). The components of a mixture are not chemically bonded together, and so, retain their individual properties. The components of a mixture can be separated from each other by physical processes

CONTINUED

molecule: an electrically neutral particle consisting of two or more atoms chemically bonded together

heterogeneous mixture: a mixture of two or more substances, that does not have uniform composition and consists of separate phases. A heterogeneous mixture can be separated by mechanical means. An example is a mixture of two solids

chemical properties: how a substance behaves in chemical reactions

chromatography: a technique used to separate the components of a mixture due to their different affinities for another substance and/or solubility in a solvent

deposition: the change of state from a gas to a solid

filtration: a separation technique used to separate insoluble solids from a liquid or solution

physical properties: properties such as melting point, solubility and electrical conductivity, relating to the physical state of a substance and the physical changes it can undergo

solvation: a process used to separate a mixture of two or more substances, due to differences in solubility

states of matter: solid, liquid and gas

state symbols: used to indicate the physical state of an element or compound; these may be either written as subscripts after the chemical formula or in normal type: (aq) = aqueous (dissolved in water); (g) = gas; (l) = liquid; (s) = solid

boiling: change of state from a liquid to a gas at the boiling point of the substance

boiling point: the temperature at which a liquid boils under a specific set of conditions - usually we will be considering the boiling point at atmospheric pressure

distillation: a separation technique used to separate the solvent from a solution or separate liquid components of a mixture that have different boiling points

sublimation: the change of state from a solid to a gas

melting: the change of state from a solid to a liquid

freezing: the change of state from a liquid to a solid

melting point: the temperature at which melting occurs

homogeneous mixture: a mixture of two or more substances with the same (uniform) composition throughout the mixture – it consists of only one phase. Examples are solutions or a mixture of gases

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solution: that which is formed when a solute dissolves in a solvent

evaporation: the change of state from a liquid to a gas that can occur at any temperature above the melting point

solute: a substance that is dissolved in another substance (the solvent) to form a solution

solvent: a substance that dissolves another substance (the solute); the solvent should be present in excess of the solute

temperature: a measure of the average kinetic energy of particles

Exercise 1.1 Elements, compounds and mixtures

This exercise will check you understand the key terms **element**, **compound**, **mixture**, **atom** and **molecule**, which are important fundamental ideas in chemistry.

1 Approximately how many different elements are there?

2 Some elements exist as individual atoms, some as a small group of atoms bonded together into a molecule and others are bonded together into a giant structure.

- **a** Name two elements that exist as giant structures at 25 °C.
- **b** Name an element that exists as a single atom.
- **c** Name an element that exists as a molecule made of two atoms joined together (a diatomic molecule).

3 Identify which of the following formulas represent atoms and which represent molecules:

- **a** He
- **b** O_2
- **c** H_2O
- **d** C

4 Identify which of the following formulas represent elements and which represent compounds:

- **a** He
- **b** O_2
- **c** H_2O
- **d** C

TIP

An atom is a single particle.

A molecule is made up of more than one atom.

The atoms in a molecule can be of the same element.

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5 This statement is incorrect, explain why:

Elements are made of atoms and compounds are made of molecules.

6 An alloy is a mixture of a metal and other elements. Give one way in which the composition of an alloy differs from that of a compound.

7 Compounds have both different **chemical properties** and **physical properties** from the elements from which they are formed.

a What is meant by the term *physical properties*?

b What is meant by the term *chemical properties*?

8 Most everyday substances are mixtures although they are often labelled as pure. Pure orange juice is a common example. The manufacturers simply mean that nothing has been added to the orange juice. In chemistry, the term *pure* is not used in the same way.

In chemistry, what is meant by the term *pure*?

9 Why do the components of a mixture retain their individual properties?

10 Group the following substances into elements, mixtures and compounds:

air, water, sodium chloride solution, sodium chloride crystals, iron, chlorine gas, carbon dioxide gas.

11 What name is given to a mixture that has a uniform composition and only consists of one phase?

12 What name is given to a mixture that does not have a uniform composition and consists of separate phases?

13 Why is a mixture of the solids sodium chloride and sand not a **homogeneous mixture**?

14 When a small amount of salt and water is mixed together, it forms a homogeneous mixture, but this is not true when flour is mixed with water, why?

15 Are chemical or physical processes typically used to separate the components of a mixture?

TIP

Question 5 is linked to ideas in Chapter 6.

TIP

Solid, liquid, gas and solution are all examples of phases.

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16 Match the name of the separation technique with the type of mixture it can be used to separate.

Technique	Types of mixture
A **filtration**	**1** substances with very different solubilities in a **solvent**
B **distillation**	**2** an insoluble solid from a liquid
C **evaporation**	**3** a **solute** with very different solubilities in two different solvents
D **solvation**	**4** the solute from a **solution**
E solvent extraction	**5** a mixture of substances with small differences in their solubilities in a solvent
F paper **chromatography**	**6** liquids with a large difference in their boiling points
G recrystallisation	**7** a mixture containing a solute with different solubilities in a solvent at different temperatures

Exercise 1.2 Kinetic molecular theory

Kinetic molecular theory is used to explain the observed properties of solids, liquids and gases.

1 Complete Table **1.1**, which describes the arrangement and movement of particles in solids, liquids and gases.

Description	Solids	Liquids	Gases
diagram showing the arrangement of the particles			
relative distance of the particles from one another			
relative energy of the particles			
movement of particles			
relative force of attraction between the particles			

Table 1.1: Arrangement and movement of particles.

2 Which of the descriptions of particles in Table **1.1** can explain the fixed shape of solids and the lack of a fixed shape in liquids and gases?

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3 Which of the descriptions in Table **1.1** explain why, at a given **temperature**, the volume of a gas is not fixed but the volume of solids and liquids are?

4 Younger students are often confused by the observed properties of a powder. A powder can flow like a liquid and take up the shape of its container but does not completely spread out into a puddle like a liquid.

  a How would you explain that a powder is a solid?

  b How would you explain the ability of a powder to flow like a liquid?

5 Which scale is the SI scale for temperature?

6 On the kelvin scale, what does zero K (or absolute zero) represent?

7 Complete Table **1.2** to show equivalent temperatures on the kelvin and Celsius scales.

Celsius scale	Kelvin scale
0	
	373
40	
	74
946	
	3
	500

Table 1.2: Equivalent temperatures on the kelvin and Celsius scales.

> **TIP**
> Absolute zero equals –273.15 °C, but you can use –273 °C for your chemical calculations.

8 Temperature is used in some chemical calculations. When it is, the kelvin scale is always used, unless the calculation involves a temperature change.

Explain why either Celsius or kelvin can be used to measure temperature change.

Exercise 1.3 Temperature and kinetic energy

Not all of the particles in a sample have the same amount of energy, and so, they do not all move with the same speed. In this exercise, you will explore the distribution of kinetic energies at different temperatures.

1 Consider a sample of oxygen at a constant temperature.

  a Do all the oxygen particles have the same kinetic energy? Explain your answer.

  b Do all the particles of the gas move at the same speed? Explain your answer.

2 Consider a mixture of the gases nitrogen and helium at a constant temperature.

a The average kinetic energy of the particles will be higher for which gas?

b The average speed of the particles will be higher for which gas?

3 Describe how the following change when the temperature of a gas is increased:

a the average kinetic energy of the particles

b the average speed of the particles

c the most probable kinetic energy of the particles

d the fraction of particles with the most probable kinetic energy.

TIP

The most probable kinetic energy is the energy at the peak of a Maxwell–Boltzmann distribution curve.

Exercise 1.4 Changes of state

Heating or cooling a substance can cause it to change state, as these processes involve the breaking or formation of forces of attraction between the particles. In this exercise, you will check that you understand these processes and can work out the state of a substance at a given temperature from its **melting point** and **boiling point**.

Figure **1.1** summarises the changes of state.

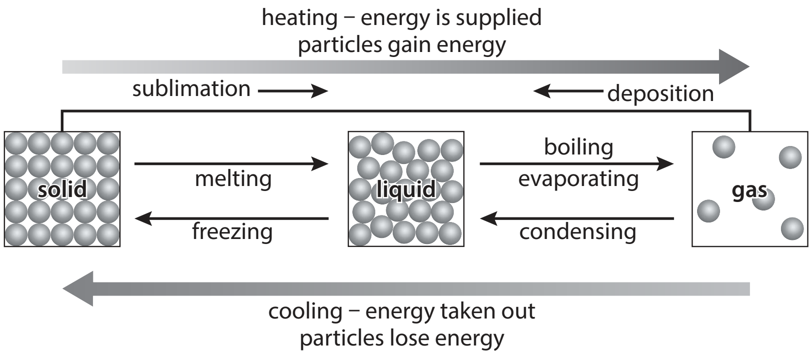

Figure 1.1: The changes of state.

1 Which change of state does not take place only at a fixed temperature for a given pressure?

2 Identify which changes of state are exothermic and which are endothermic.

3 What name is given to the temperature at which a substance changes from a liquid to a solid?

4 What name is given to the temperature at which a substance changes between gas and liquid?

5 Carbon dioxide and iodine are two examples of substances that undergo **sublimation**.

a What is meant by the term *sublimation*?

b What term is used to describe the reverse of sublimation?

TIP

The same name for the temperature at which the change in question 3 happens is used, no matter in which direction the change happens.

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6 Complete the table to show whether a substance is a solid, liquid or gas at the temperature stated in the column header.

Substance	Melting point / °C	Boiling point / °C	State at –50 °C	State at 115 °C	State at 245 K
A	15	125			
B	253	578			
C	–83	78			
D	–169	–87			

7 Figure **1.2** shows the cooling curve for a substance.

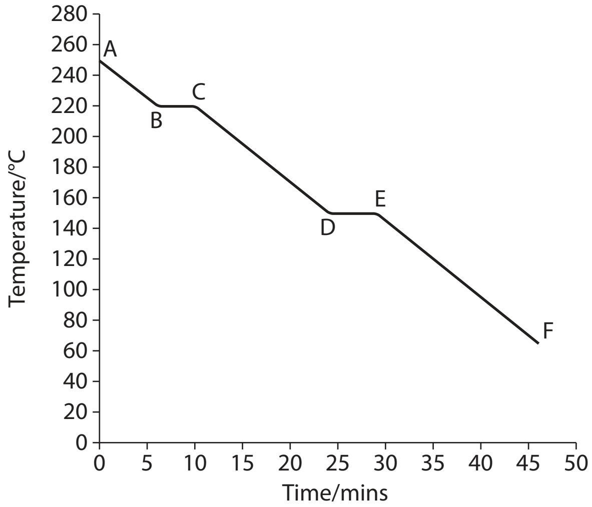

Figure 1.2: The cooling curve for a substance.

a Label the diagram to show the following:

i the region where the substance is a solid

ii the region where the substance is a liquid

iii the region where the substance is a gas

iv the region where the substance is freezing

v the region where the substance is condensing

vi the melting point of the substance

vii the boiling point of the substance.

b Explain, in terms of the movement and arrangement of the particles, why the temperature of the substance remains the same during a change of state.

EXAM-STYLE QUESTIONS

1 Which of the following lists substances that are all made up of molecules?

A C, O_2, CO_2

B Na, Cl_2, NaCl

C H_2, He, Li

D P_4, S_8, O_3

2 Which of the following statements is **true** of heterogeneous mixtures?

A Their components cannot be separated by physical means.

B They have the same composition throughout the mixture.

C The components are in a fixed ratio.

D The components are in separate phases.

3 Which of the following is **not** a heterogeneous mixture?

A cola

B tea with milk

C tea with sugar

D milk

4 Which of the following shows the correct sequence of the changes of state involved in distillation?

A boiling, condensing

B condensing, boiling

C evaporation, cooling

D boiling, cooling

5 What is the name given to the separation technique that is used to separate the components of a mixture that have different solubilities in a solvent at different temperatures?

A distillation

B recrystallisation

C evaporation

D paper chromatography

6 Mercury is a liquid at 25 °C, which of the following could be its melting and boiling points?

	Melting point	Boiling point
A	–38.9 °C	83.7 K
B	–38.9 K	629.7 °C
C	–38.9 K	356.7 K
D	–38.9 °C	356.7 °C