Cambridge

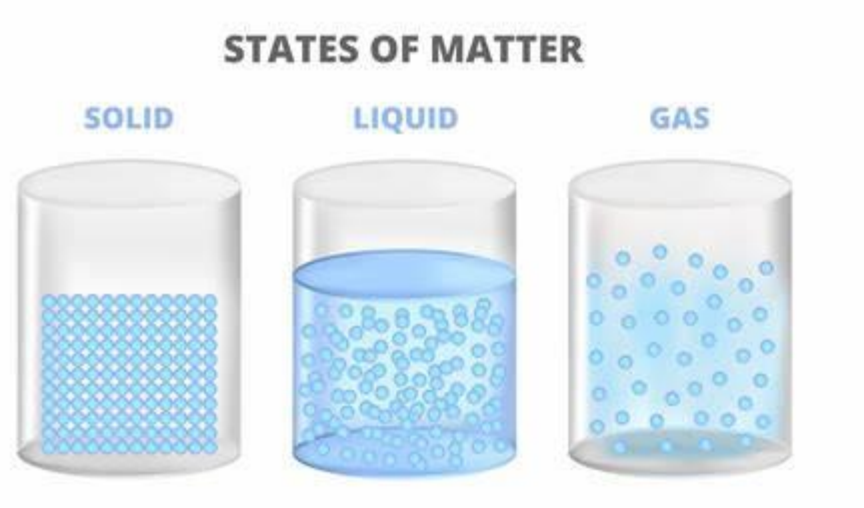
OL

Chemistry

CODE: (5070)

Chapter 01

States of matter

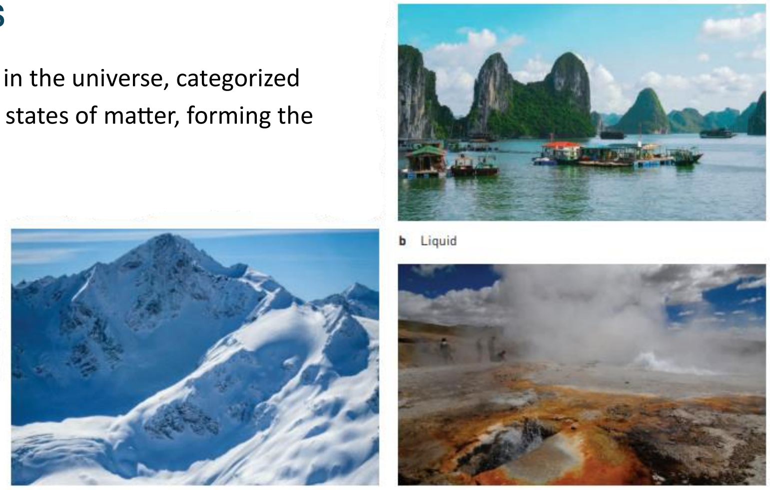


Chapter 01

1.1 Solids, liquids and gases

Matter encompasses all substances and materials in the universe, categorized into solids, liquids, and gases, which are the three states of matter, forming the physical universe.

Solids have a definite volume and shape at a given temperature, which can be affected by temperature changes. They increase slightly when heated and decrease when cooled. Liquids have a fixed volume and shape, while gases have neither. Gases are compressible, meaning their volume can be reduced by pressure, making them more compressible than liquids.



b Liquid

a Solid

c Gas

▲ **Figure 1.1** Water in three different states

1.2 The kinetic particle theory of matter

The kinetic particle theory, based on the idea that matter is composed of tiny particles, provides a comprehensive explanation for its physical properties.

The main points of the theory are:

» All matter is composed of tiny, moving particles, invisible to your eye. Different substances have different types of particles (atoms, molecules or ions) of varying sizes.

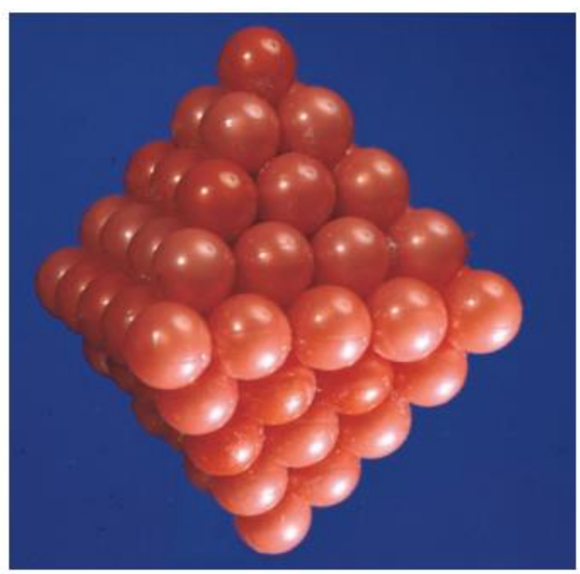
» The particles move all the time. The higher the temperature, the faster they move on average.

» Heavier particles move more slowly than lighter ones at a given temperature.

Explaining the states of matter

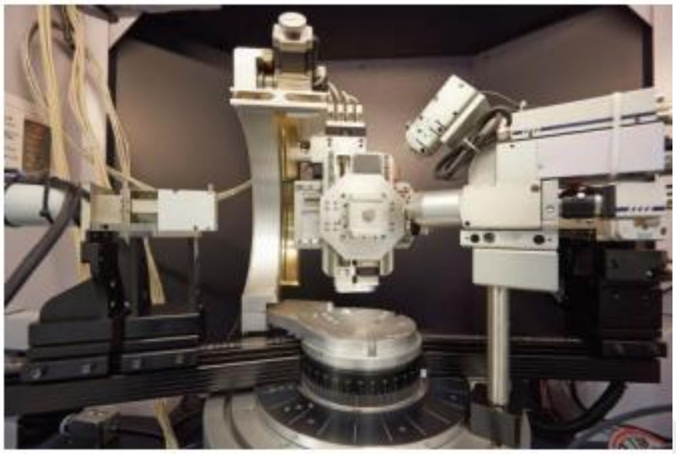
Crystals are formed in solids due to attractive forces between particles, resulting in a regular arrangement. Modeling such crystals using spheres, such as those in chrome alum **crystals**, allows for a similar shape to the actual crystal structure.

X-ray crystallography confirms particle arrangement in crystal structures, with pure substance crystals always packed in the same way. However, particles may be packed differently in different substances, like sodium chloride.



a A model of a chrome alum crystal

In a liquid, particles move randomly and often collide, with weaker forces of attraction than in a solid. They have more energy on average. In a gas, particles are far apart, moving at high velocities, colliding less often, and colliding with the container walls. They exert minimal attraction forces, but these forces are crucial for solids and liquids.



▲ **Figure 1.4** A modern X-ray crystallography instrument used for studying crystal structure

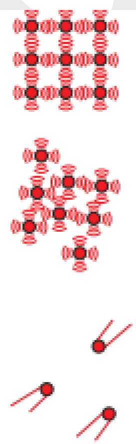
▲ **Figure 1.5** Sodium chloride crystals

1.3 Changes of state

The kinetic particle theory model explains how a substance changes from one state to another. When heated, particles vibrate faster, pushing each other away, causing the solid to expand. This expansion weakens attraction forces, causing the solid to melt. The melting point is the temperature at which this happens. High melting points have stronger forces of attraction between particles, making the substance a liquid.

b An actual chrome alum crystal

▲ **Figure 1.3**



▲ **Figure 1.6** The arrangement of particles in solids, liquids and gases

▼ **Table 1.1** Melting points and boiling points of substances

Substance	Melting point/°C	Boiling point/°C
Aluminium	661	2467
Ethanol	−117	79
Magnesium oxide	827	3627
Mercury	−30	357
Methane	−182	−164
Oxygen	−218	−183
Sodium chloride	801	1413
Sulfur	113	445
Water	0	100

Evaporation occurs when a liquid's energy overcomes attraction between particles, causing them to escape and form a gas.

The boiling point of a substance is the temperature at which gas bubbles form inside the liquid, where the pressure of the gas created above the liquid equals atmospheric pressure. High boiling points have stronger forces between particles.

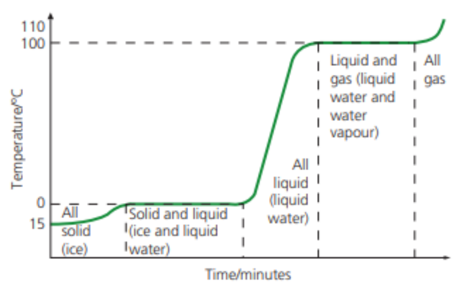
Physical changes involve the **condensing** of gas into a liquid, which then freezes to form a solid. These changes release energy, and no new substance is formed during these changes, ensuring constant temperature.

Heating and cooling curves

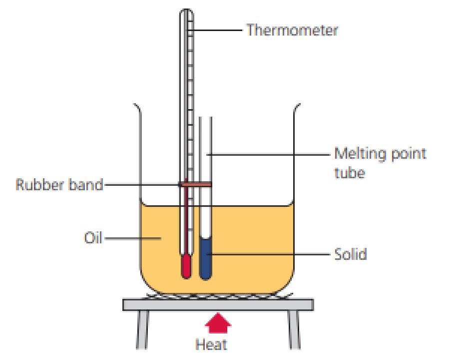
Figure 1.7 shows a graph of water temperature as heated from -15°C to 110°C, showing changes in state, initially ice, but flattening after heat energy is added.

Ice melts due to the attraction between water particles, requiring heat energy to overcome these forces. A sharp melting point indicates pure samples, while impurities lower it. The melting point of a substance can be found using an apparatus, and a mixture of substances has a lower melting point than a pure substance, with a range of temperatures.

Boiling a liquid requires extra energy, as shown in Figure 1.7, where the boiling point of water is 100°C. Solids and liquids are identified by their melting and boiling points. Condensing and freezing occur when a substance is cooled, giving energy when gas condenses to the liquid and freezing to form the solid.



▲ **Figure 1.7** Graph of temperature against time for the change from ice at −15°C to water to steam

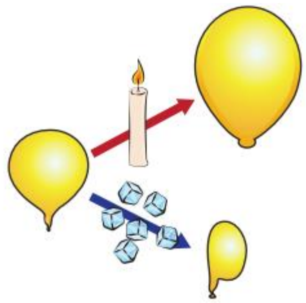


▲ **Figure 1.8** If a substance, such as the solid in the melting point tube, is heated slowly, this apparatus can be used to find the melting point of the substance

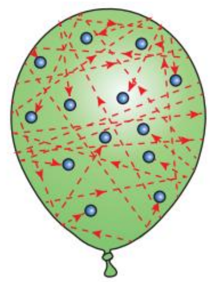
1.4 The effects of temperature and pressure on the volume of a gas

The difference between balloons in Figure 1.9 is due to the pressure inside the balloon caused by gas particles striking the inside surface. At higher temperatures, the particles move faster, resulting in more frequent hits, increasing pressure inside the balloon.

The balloon's elastic nature causes increased pressure to stretch, resulting in a higher volume. This phenomenon is a property of all gases, as observed by French scientist J.A.C. Charles in 1781. Similarly, changing the pressure of a fixed volume of a gas affects its temperature. For example, when a bicycle pump is used to blow up a tire, the increased pressure causes gas molecules to move closer together, leading to more frequent collisions. This frictional force increases the temperature, and as molecules move closer, intermolecular bonds form, increasing the gas's temperature. This process leads to faster molecules moving and more collisions.



▲ **Figure 1.9** Temperature changes the volume of the air in a balloon. Higher temperatures increase the volume of the balloon and cold temperatures reduce its volume.



▲ **Figure 1.10** The gas particles striking the surface create the pressure

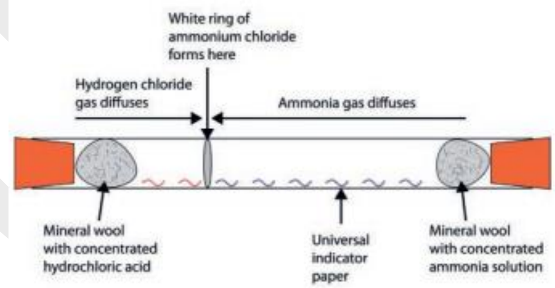
1.5 Diffusion

In a restaurant, the smell of food is a result of diffusion, where gas particles leave the pans and spread through the air. All gases diffuse to fill available space. In a diagram, liquid bromine is placed in a gas jar, causing brown-red fumes.

Kinetic particle theory explains diffusion as matter consists of small, constantly moving particles that vibrate around a fixed point, unlike in a gas where particles randomly collide.

Gases diffuse at different rates, with lighter ammonia particles moving faster than hydrogen chloride particles, resulting in a white cloud of ammonium chloride. This experiment is a teacher demonstration and should be carried out in a fume cupboard. Liquid diffusion is slower due to slower particle movement. For full guidance and safety notes, teachers should refer to the Practical Skills Workbook.

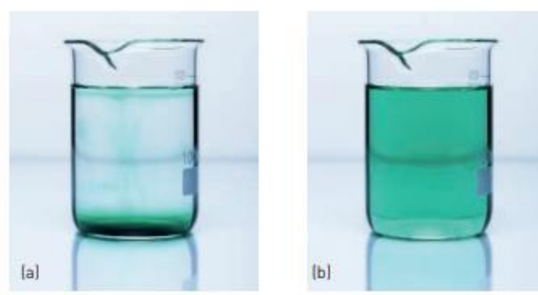
Diffusion can also take place between a liquid and a gas. Kinetic particle theory can be used to explain this process. It states that collisions are taking place randomly between particles in a liquid or a gas and that there is sufficient space between the particles of one substance for the particles of the other substance to move into



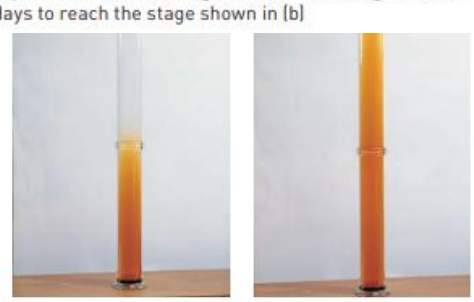
Where the white ring forms:

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$$

▲ **Figure 1.12** Hydrochloric acid (left) and ammonia (right) diffuse at different rates



▲ **Figure 1.13** Diffusion of green food colouring can take days to reach the stage shown in (b)



▲ **Figure 1.11** After 24 hours the bromine fumes have diffused throughout both gas jars

Revision questions

(1) Kinetic theory explains the properties of matter in terms of the arrangement and movement of particles.

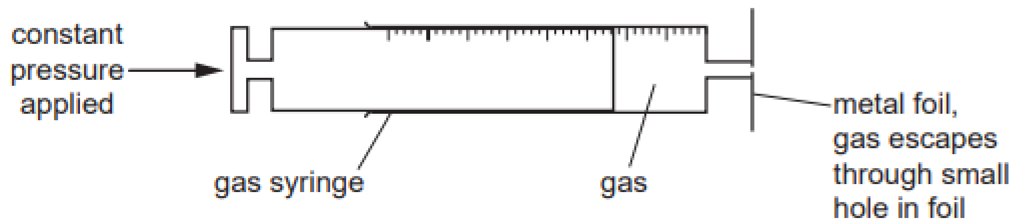
(a) Nitrogen is a gas at room temperature. Nitrogen molecules, N2, are spread far apart and move in a random manner at high speed.

(i) Draw the electronic structure of a nitrogen molecule. Show only the outer electron shells

(ii) Compare the movement and arrangement of the molecules in solid nitrogen to those in nitrogen gas

(b) A sealed container contains nitrogen gas. The pressure of the gas is due to the molecules of the gas hitting the walls of the container. Use the kinetic theory to explain why the pressure inside the container increases when the temperature is increased

The following apparatus can be used to measure the rate of diffusion of a gas.



The following results were obtained.

gas	temperature / °C	rate of diffusion in cm^3/min
nitrogen		1.00
chlorine		0.63
nitrogen		1.05

(c) Explain why nitrogen gas diffuses faster than chlorine gas.
(ii) Explain why the nitrogen gas diffuses faster at the higher temperature.

(2)(a) Different gases diffuse at different speeds.
(i) What is meant by the term diffusion?
(ii) What property of a gas molecule affects the speed at which it diffuses?

(b) Helium is a gas used to fill balloons. It is present in the air in very small quantities. Diffusion can be used to separate it from the air.

Air at 1000°C is on one side of a porous barrier. The air which passes through the barrier has a larger amount of helium in it.
(i) Why does the air on the other side of the barrier contain more helium?
(ii) Why is it an advantage to have the air at a high temperature?

(c) Most helium is obtained from natural gas found in the USA. Natural gas contains methane and 7% helium. One possible way to obtain the helium would be to burn the methane.

(i) Write an equation for the complete combustion of methane
(ii) Suggest why this would not be a suitable method to obtain the helium.
(iii) Suggest another method, other than diffusion, by which helium could be separated from the mixture of gases in natural gas

3) Explain each of the following in terms of the kinetic particle theory.

(a) The rate of most reactions increases at higher temperatures.
(b) A liquid has a fixed volume but takes up the shape of the container. A gas takes up the shape of the container but it does not have a fixed volume

4)The Kinetic Theory explains the properties of matter in terms of the arrangement and movement of particles.

(a) Nitrogen is a gas at room temperature. Nitrogen molecules, N2 , which are spread far apart move in a random manner at high speed.

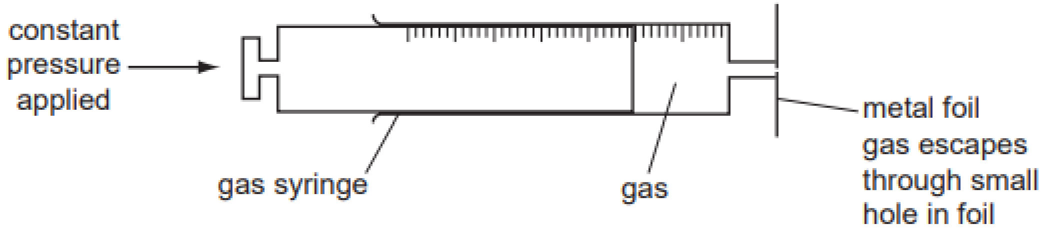
(i) Draw a diagram showing the arrangement of the valency electrons in a nitrogen molecule. Use × to represent an electron from a nitrogen atom.

(ii) How does the movement and arrangement of the molecules in a crystal of nitrogen differ from those in gaseous nitrogen?

(b) Use the ideas of the Kinetic Theory to explain the following.

(i) A sealed container contains nitrogen gas. The pressure of a gas is due to the molecules of the gas hitting the walls of the container. Explain why the pressure inside the container increases when the temperature is increased

5) The following apparatus can be used to measure the rate of diffusion of a gas



The following results were obtained.

gas	temperature / °C	rate of diffusion in cm^3 / min
nitrogen	25	1.00
chlorine	25	0.63
nitrogen	50	1.05

Explain why nitrogen diffuses faster than chlorine.

Explain why the nitrogen diffuses faster at the higher temperature

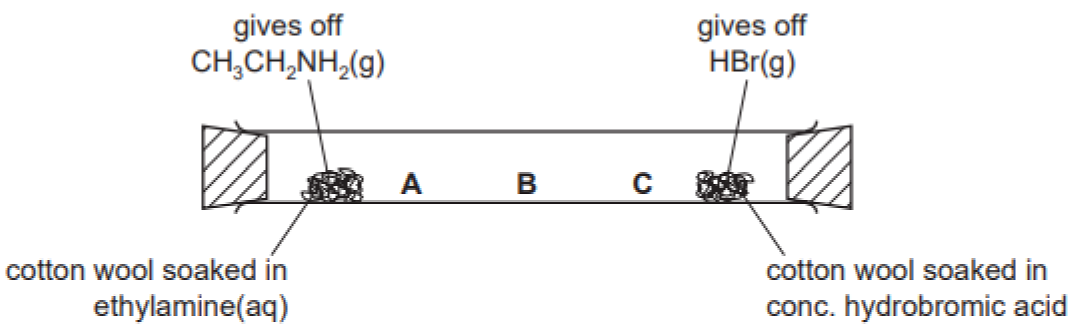
6) Gases diffuse, which means that they move to occupy the total available volume.

(i) Explain, using kinetic particle theory, why gases diffuse.

(ii) When the colourless gases hydrogen bromide and ethylamine come into contact, a white solid is formed.

$$CH_3CH_2NH_2(g) + HBr(g) \rightarrow \underset{\text{white solid}}{CH_3CH_2NH_3Br(s)}$$

The following apparatus can be used to compare the rates of diffusion of the two gases ethylamine and hydrogen bromide.



Predict at which position, A, B or C, the white solid will form. Explain your choice