1 States of matter

1.1 The three states of matter

LEARNING OUTCOMES

At the end of this topic you should be able to:

- describe the three states of matter in terms of arrangement, motion and proximity of particles
- explain the nature of solids, liquids and gases in terms of the particulate theory of matter.

DID YOU KNOW?

Atoms are so small that there are millions and millions of them in a pinhead. To line up hydrogen atoms the width of a large pinhead, you would need 10 000 000 000 000 000 atoms.

EXAM TIP

Many of the particles in a liquid are touching one another. Make sure that you don't draw them well separated from each other.

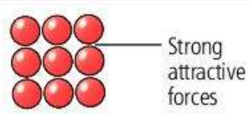

Figure 1.1.1 Particles in a solid

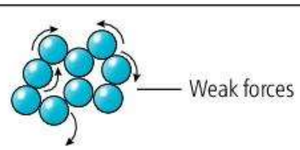

Figure 1.1.2 Particles in a liquid

Solids, liquids and gases

The three states of matter are solids, liquids and gases. Most substances can exist in all three states depending on the temperature. For example, water is

- solid (ice) below 0 °C
- liquid (water) between 0 °C and 100 °C
- gas (steam) above 100 °C.

The particulate theory of matter

- All matter is made up of particles.
- The particles either vibrate (as in solids) or move from place to place (as in liquids and gases).
- There are forces of attraction and repulsion between the particles.

The particles that make up matter can be atoms, molecules or ions.

- An **atom** is the smallest particle that cannot be broken down by chemical means.
- A **molecule** is a particle containing two or more atoms. The atoms can be the same or different.
- An **ion** is an atom or group of atoms with either a positive or negative charge.

We can explain the nature of solids, liquids and gases by looking at:

- how the particles are arranged
- how close the particles are to each other
- the motion of the particles
- the strength of the attractive forces between the particles.

(See Figures 1.1.1–3.)

Solids

Arrangement of particles: regular pattern

Closeness of particles: very close or touching each other

Motion of particles: vibrate around a fixed point but do not move from place to place

Attractive forces between the particles are strong.

Liquids

Arrangement of particles: irregular – no particular pattern

Closeness of particles: very close or touching each other

Motion of particles: move (slide) over each other slowly

Attractive forces between the particles are weaker than in solids but stronger than in gases.

Gases

Arrangement of particles: irregular pattern

Closeness of particles: far apart

Motion of particles: move everywhere rapidly

There are almost no attractive forces between the particles.

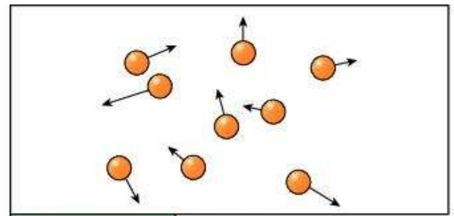

Figure 1.1.3 Particles in a gas

Explaining the nature of solids, liquids and gases

Solids

Solids have a definite shape and volume and cannot be compressed (squashed together). They do not flow like liquids (see Figure 1.1.4). This is because the strong attractive forces between the particles keep the particles close or touching each other.

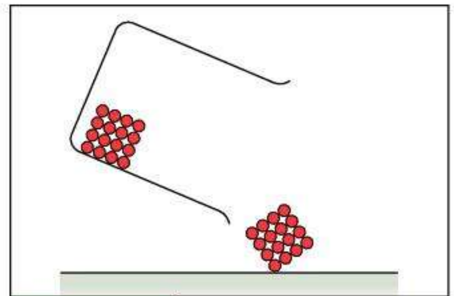

Figure 1.1.4 Solid

Liquids

Liquids have a definite volume but they do not have a definite shape and they can flow (see Figure 1.1.5). For this reason, they can take the shape of the container in which they are placed. The forces of attraction between the particles are not very strong, so the particles have enough energy to slide over each other. Liquids cannot be compressed (squashed) very easily. This is because the particles are close together.

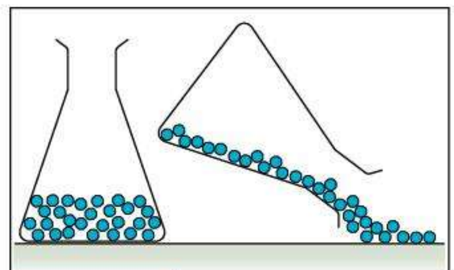

Figure 1.1.5 Liquid

Gases

Gases do not have a definite shape or volume. They can spread everywhere (Figure 1.1.6). This is because there are hardly any forces of attraction between the particles. Their density is very low compared with that of solids or liquids. They can be compressed because the particles are far apart.

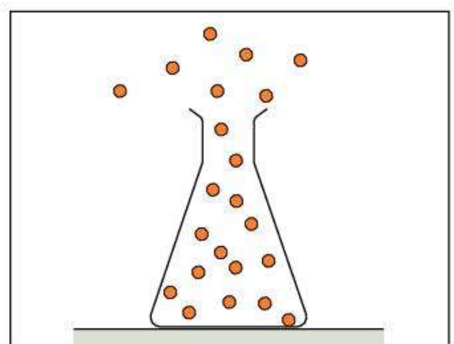

Figure 1.1.6 Gas

KEY POINTS

1. The three states of matter are solids, liquids and gases.
2. In solids the particles are regularly arranged and close together, and only vibrate on the spot.
3. In liquids the particles are irregularly arranged and close together, and slide over each other.
4. In gases the particles are irregularly arranged and far apart, and move rapidly everywhere.
5. Solids have a definite shape, liquids take the shape of their container and gases spread everywhere.
6. Solids and liquids cannot be compressed easily, but gases can be.

Diffusion

LEARNING OUTCOMES

At the end of this topic you should be able to:

- explain the terms diffusion and osmosis
- explain how evidence from experiments on diffusion and osmosis supports the particulate theory
- describe why salt or sugar are used as preservatives and to control garden pests.

Diffusion

In liquids and gases, the particles are in constant random movement. Random movement means that the particles go in any direction. The particles in liquids and gases are constantly changing direction and colliding with others. The idea that particles are in constant motion is called the **kinetic particle theory**.

Diffusion is the spreading movement of one substance through another due to the random movement of the particles.

- In diffusion the overall direction of movement is from where the particles are more concentrated to where they are less concentrated.
- Diffusion in gases is faster than in liquids. This is because the particles in gases move faster than those in liquids.

Examples of diffusion

Diffusion of potassium manganate(VII) in water

A crystal of potassium manganate(VII) (also called potassium permanganate) is placed in water. The colour of the manganate(VII) gradually spreads out through the water until there is the same depth of colour throughout (Figure 1.2.1). This is because both the manganate(VII) particles and the water particles in solution are in constant motion, bumping into and bouncing off each other.

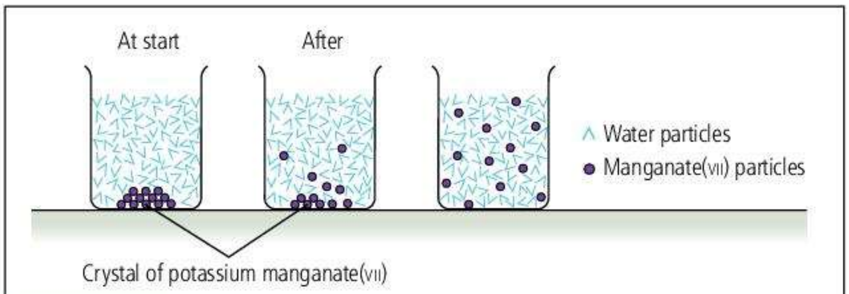

Figure 1.2.1 After the crystal of potassium manganate(VII) has dissolved, the colour of the manganate(VII) gradually spreads throughout the water.

Diffusion of gases

Hydrogen chloride and ammonia are gases. A long glass tube is set up as shown in Figure 1.2.2.

- The hydrochloric acid gives off hydrogen chloride gas and the aqueous ammonia gives off ammonia gas.
- After a few minutes a white ring is seen nearer one end of the tube.
- The ring is nearer the hydrochloric acid end.

EXAM TIP

If you are asked to define diffusion, it is better to give an answer about the spreading or random movement of particles rather than the movement of particles from high to low concentration. Although the overall direction of movement of particles is from where their concentration is high to where it is low, some particles are moving in the opposite direction because the movement is random.

We can explain this using the particle model.

- The hydrogen chloride and ammonia particles (molecules) are in constant motion.
- They bump into and bounce off air molecules and so move along the tube.
- The white ring is formed where the hydrogen chloride and ammonia have met and reacted to form a white solid.
- The white ring is nearer the hydrochloric acid end because hydrogen chloride is a heavier molecule than an ammonia molecule. Heavier molecules move more slowly than lighter ones.

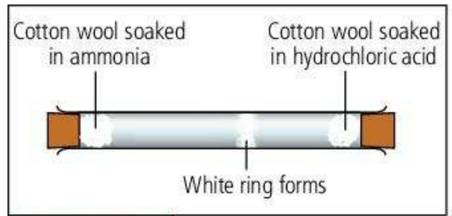

Figure 1.2.2 Reaction of hydrogen chloride and ammonia

Osmosis

Osmosis is a special case of diffusion. **Osmosis** is the overall movement of water molecules through a selectively permeable membrane from where the water is at a higher concentration to where it is at a lower concentration.

Osmosis can be demonstrated using thin strips of pawpaw fruit placed in distilled water or sugar solution (Figure 1.2.3). The contents of the cells of the fruit can be thought of as being a solution of different substances in water. The cell membrane is selectively permeable.

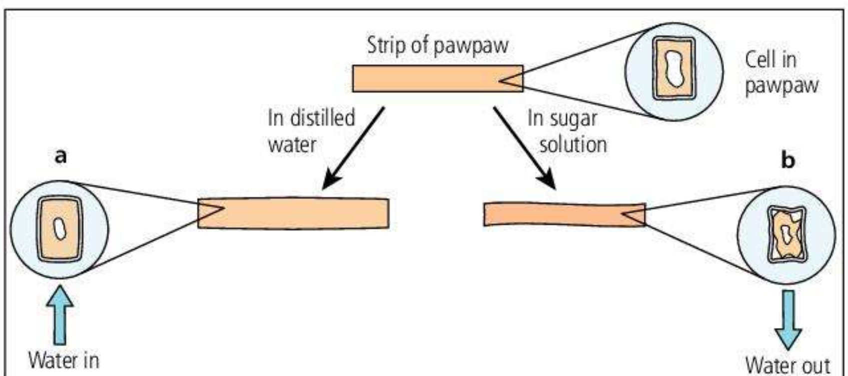

Figure 1.2.3 Strips of pawpaw fruit are placed in **a** distilled water, **b** sugar solution.

In distilled water the strips become longer and more rigid. This is because:

- the water outside the cells is more concentrated than inside the cells
- water passes into the cells by osmosis.

In sugar solution the strips become shorter and softer (flaccid).

- The water outside the cells is less concentrated than the water inside the cells. This is because there is sugar as well as water in the solution.
- Water passes out of the cells by osmosis.

Some uses of sugar and salt

Sugar or salt are used to preserve food. They stop bacteria and fungi from growing. The cells of all organisms depend on water for survival. Foods with a high concentration of sugar or salt remove water from bacteria or fungi by osmosis, so they die.

DID YOU KNOW?

Salts such as Epsom salts (magnesium sulfate) can be used to control garden pests such as slugs and beetles. The salt is sprayed on the earth around the plants or on the leaves. Slugs avoid the plants because of the water-withdrawing properties of the salt. Some gardeners use sodium chloride for this purpose but this may cause 'leaf burn'.

KEY POINTS

1. Diffusion is the spreading movement of one substance through another due to the random movement of the particles.
2. Osmosis is the movement of water molecules through a selectively permeable membrane from where the water is at a higher concentration to where it is at a lower concentration.
3. Results from experiments on diffusion and osmosis provide evidence for the particle theory.

1.3 Changing states

LEARNING OUTCOMES

At the end of this topic you should be able to:

- explain the terms freezing, melting, boiling, evaporation, condensing and sublimation
- interpret heating and cooling curves in terms of forces between the particles.

EXAM TIPS

- The terms 'evaporation' and 'boiling' have slightly different meanings. Evaporation of a liquid can happen below its boiling point. Boiling occurs when the whole liquid bubbles and both gas and liquid are present in balance with one another.
- We usually use the term 'vapour' for the gaseous form of a substance that is normally liquid or solid at room temperature.
- We sometimes use the term 'vaporisation' for the change liquid ⟶ gas.

Changes of state

When we heat a solid it turns into a liquid. Further heating turns the liquid into a gas. On cooling, the gas turns into a liquid. Further cooling turns the liquid into a solid. These changes of state are given special names.

- **Melting**: solid ⟶ liquid
- **Boiling/evaporation**: liquid ⟶ gas
- **Condensing**: gas ⟶ liquid
- **Freezing**: liquid ⟶ solid

Energy and changes of state

- In melting and boiling/evaporation, energy is absorbed (taken in).
- In condensing and freezing, energy is released (given out).

(See Figure 1.3.1.)

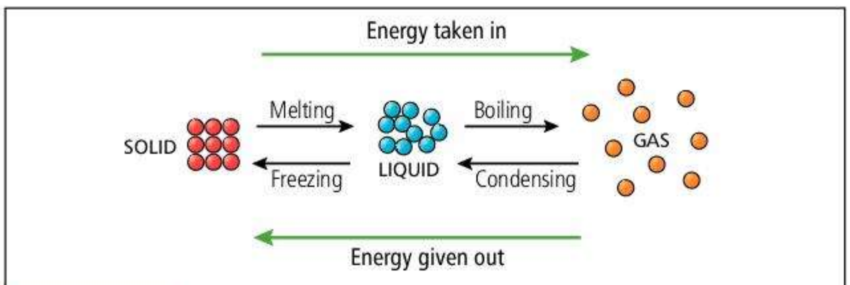

Figure 1.3.1 Energy is required to melt and boil a substance. Energy is released when a substance condenses or freezes.

Heating and cooling curves

Figure 1.3.2 shows how the temperature of a solid changes when it is heated slowly to form a liquid and then a gas.

We can explain the shape of the curve using ideas of energy (heat) transfer to the particles.

1 AB: Increasing heat energy increases the vibrations of the particles in the solid. So the temperature of the solid increases.

2 BC: The forces of attraction between the particles are weakened enough so that the particles slide over each other. The temperature is constant because the energy is going in to overcome the forces between the particles instead of raising the temperature. The substance melts.

3 CD: Increasing the energy increases the movement of the particles in the liquid. So the temperature of the liquid increases.

4 DE: The forces of attraction between the particles are weakened enough so that the particles move well away from each other. The temperature is constant because the energy is going in to overcome the forces between the particles instead of raising the temperature. The substance boils.

5 EF: Increasing the energy increases the speed of the gas particles. So, the temperature increases.

DID YOU KNOW?

The metal gallium has such a low melting point that it will change from a solid to a liquid if you hold it in your hand.

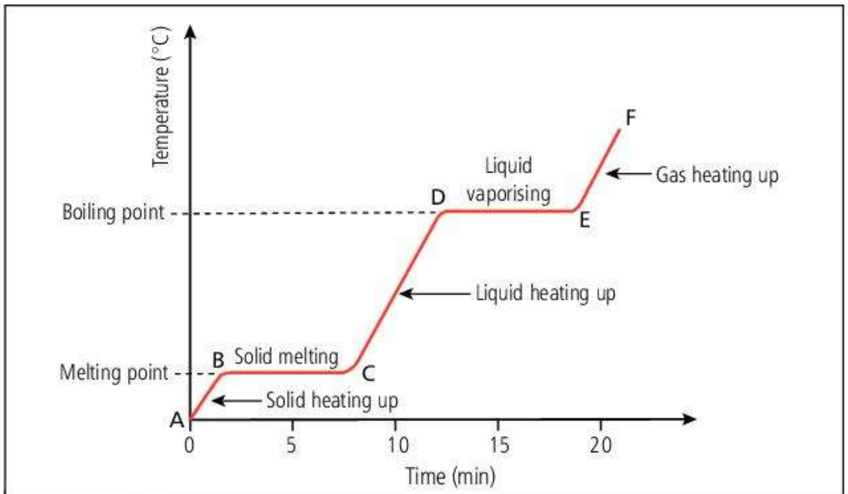

Figure 1.3.2 A substance is heated at a constant rate. The flat parts of the curve show where the substance is melting (B to C) and boiling (D to E).

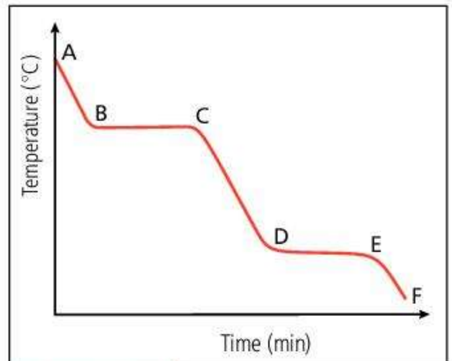

Figure 1.3.3 A substance is cooled at a constant rate. The flat parts of the curve show where the substance is condensing (B to C) and freezing (D to E).

Figure 1.3.3 shows how the temperature of a gas changes when it is cooled to form a liquid and then a solid.

1 When the gas is cooled, the particles lose kinetic energy (movement energy). The temperature falls (AB).

2 The particles become attracted to each other.

3 Energy is released and the gas turns to a liquid (BC).

4 When the liquid is cooled, the particles lose more energy. The temperature falls (CD).

5 Energy is released and the liquid turns to a solid (DE).

Sublimation

Sublimation is the direct change of a solid to a gas on heating without any liquid state being formed. It also refers to the direct change of a gas to a solid on cooling without the liquid state being formed.

$$\text{Solid} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \text{Gas}$$

For example, solid carbon dioxide changes directly to carbon dioxide gas when heated.

KEY POINTS

1 Melting is the change solid $\longrightarrow$ liquid.

2 Boiling is the change liquid $\longrightarrow$ gas.

3 Condensing is the change gas $\longrightarrow$ liquid.

4 Freezing is the change liquid $\longrightarrow$ solid.

5 Sublimation is the change solid $\longrightarrow$ gas or gas $\longrightarrow$ solid.

6 Energy is absorbed when a solid melts and a liquid changes to a gas/vapour.

7 Energy is released when a gas condenses and when a liquid freezes.