8 The particle theory

- The particle theory of matter
- The properties of matter and the particle theory
- When states of matter change
- Pressure
- Diffusion

The particle theory of matter

The particle theory states that matter is made from **particles**. The particles are so tiny that they cannot be seen with the naked eye. Different substances are made from different particles and the particles have different sizes. The particles are made from **atoms** and **molecules**.

The properties of matter and the particle theory

There are three states of matter: solids, liquids and gases. Each of the three states has its own special properties. The particle theory can be used to explain these properties.

Solids

The properties of solids

A **solid** has a definite **mass**, a definite shape and its **volume** does not change. It does not flow and it is hard to compress (squash) it.

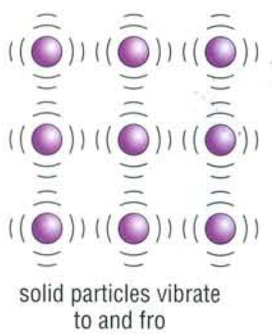


Figure 8.1 The arrangement of particles in a solid

The particles in a solid

In solids, strong forces of attraction hold the particles together in a three-dimensional structure. In many solids the particles form an orderly arrangement called a lattice. The particles in solids can move a little. They do not change position but vibrate to and fro about one position.

Figure 8.2 These crystals found in Shark's Mouth Cave, Mexico demonstrate the properties of a solid. They have a definite shape and volume and cannot be squashed.

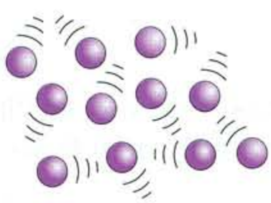
The particles and properties

The strong forces of attraction between the particles stop the particles from moving around each other and making the solid flow. As the particles cannot move in this way the shape of the solid cannot change. The particles are close together so they need to be compressed hard to get them any closer.

Liquids

The properties of liquids

A **liquid** has a definite mass and its volume does not change. It is hard to compress but it flows easily. The shape of the liquid varies and depends on the shape of the container holding it.



liquid particles have some freedom and can move around each other

Figure 8.3 The arrangement of particles in a liquid

The particles in a liquid

In liquids, the forces that hold the particles together are weaker than in solids. The particles in a liquid can change position by moving around each other.

Figure 8.4 The water in this waterfall in Croatia demonstrates the properties of a liquid. It has definite volume and flows easily but is contained in pools by the rock around it.

1 You have a rock, a jug of water and a bucket. You place the rock in the bucket and then pour the water over it. What change of shape would you expect to find and why?

The particles and properties

The weaker forces of attraction between the particles allows them to move more and this explains why the liquid can flow. As the forces are not strong enough for the liquid to keep a definite shape, it gains support from the walls of its container and takes up the shape of any container into which it is poured. The particles are close together so they need to be compressed hard to get them any closer.

Gases

The properties of gases

A **gas** has a definite mass but its volume can vary and it takes up the shape of the container holding it. It flows easily and it is easy to compress.

The particles in a gas

In gases, the forces of attraction between the particles are very small and the particles can move away from each other and travel in all directions. When they hit each other or the surface of their container they bounce and change direction.

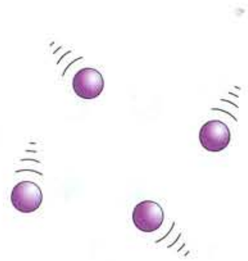


Figure 8.6 The arrangement of particles in a gas

Figure 8.5 When gas, such as nitrogen oxide shown here, escapes it spreads out in air.

The particles and properties

The weakness of the forces between the particles in a gas lets them move freely so that they can move far apart or come closer together. This variation in the distance between the particles explains why the volume of a gas can change. The larger distances between the gas particles also means that when they are compressed there is plenty of space into which they can move and this makes compression easy. The weak forces also allow the gas to flow easily. When it is placed in a container the particles can spread out in all directions as they hit each other and the container walls so the whole of the space inside the container is occupied by moving gas particles.

2 You have 500 cm^3 of a liquid and 500 cm^3 of a gas. You place the liquid and the gas into separate litre bottles. Do the liquid and the gas occupy the same volume in the two bottles? Explain your answer.

When states of matter change

The state of matter of a substance can be changed. This type of change is called a physical change and is a reversible reaction. Melting, freezing, evaporating, boiling, condensing, sublimation and dissolving are all examples of physical change.

3 Some of the physical changes of matter can be arranged in pairs to show that they are reversible reactions.

a) Identify a pair of physical changes between a solid and liquid.

b) Identify two pairs of physical changes between a liquid and a gas.

Melting

When a solid is heated to its **melting point** it loses shape and starts to flow. This is due to the energy supplied by the heat, making the particles vibrate more strongly so they push each other further away. This weakens the forces of attraction between the particles and allows them to move around each other.

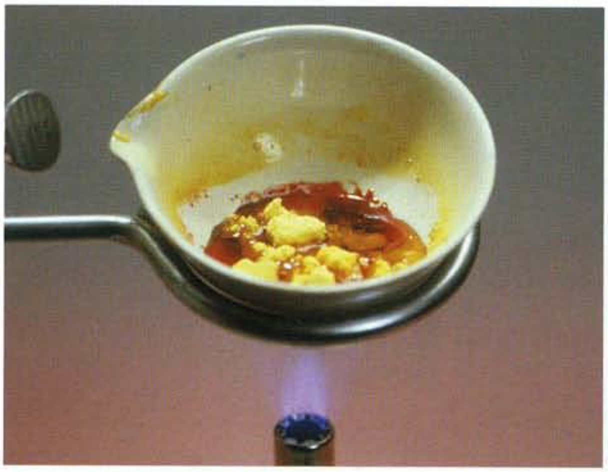


Figure 8.7 When sulfur reaches a temperature of 115 °C it melts.

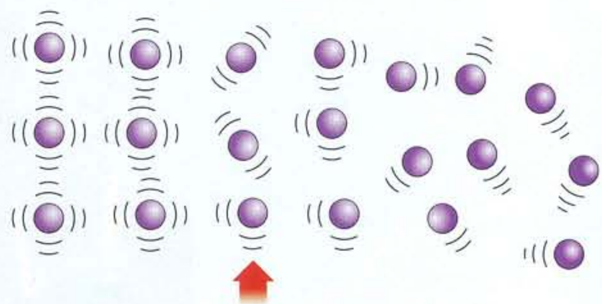


Figure 8.8 The particle arrangement in a solid (on the left) changes as the heat turns it into a liquid (on the right).

Freezing

4 a) Draw a diagram to show how the arrangement of the particles in a liquid changes when it freezes into a solid.
b) What causes the change in the arrangement of the particles?

When a liquid is cooled to its **freezing point** the particles lose so much energy that they can no longer move around each other. The only movement possible is the vibration to and fro about one position in a lattice and the liquid becomes a solid.

Figure 8.9 As the temperature fell below 0 °C water dripping off these twigs froze and formed icicles.

Evaporating

A liquid can turn into a gas over a range of temperatures without boiling by a process called **evaporation**. In this process some of the liquid at the surface changes into a gas and mixes with the air. It happens because the particles in a liquid have different amounts of energy and those with the most energy move the fastest. At the surface these fast-moving particles break away from the others, escape into the air and form a gas.

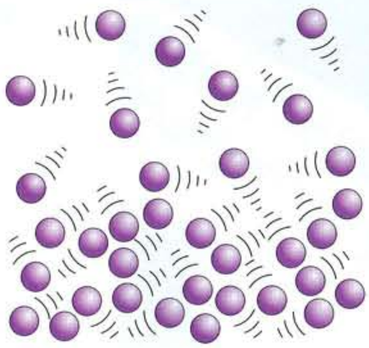


Figure 8.10 Particles evaporating from the surface of a liquid

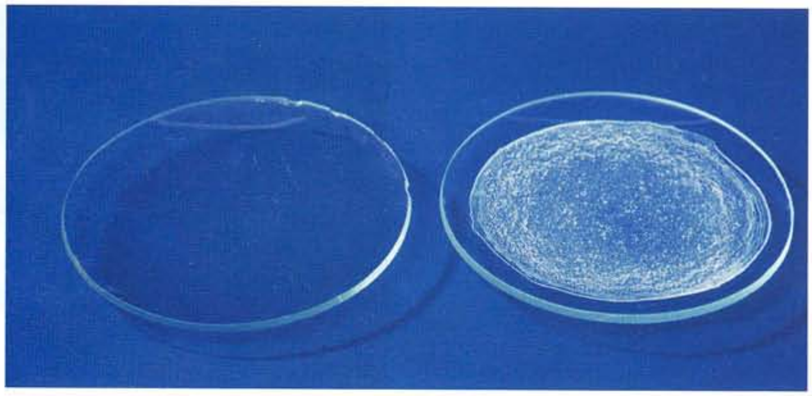


Figure 8.11 When evaporation occurs in a solution (see page 127) the solvent escapes into the air and the solute remains behind.

Boiling

When a liquid reaches its **boiling point** bubbles of gas form in it which rise to the surface and burst into the air. This process is called **boiling**. If the boiling liquid is heated more strongly, its temperature does not rise but it boils more quickly. The heat makes all the particles in the liquid move more quickly and the fastest-moving particles escape from the surface of the liquid or collect in the liquid to form bubbles which then rise to the surface and burst into the air. These fast-moving particles released from the liquid form a gas.

5 In what ways are evaporation and boiling:
a) similar
b) different?

6 Draw a diagram to show how you think a bubble in a liquid would look according to particle theory.

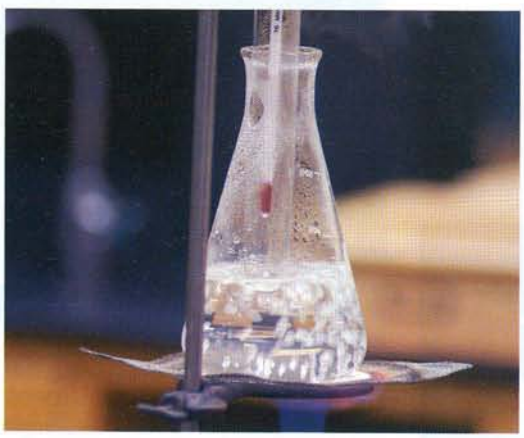


Figure 8.12 The rising bubbles in the liquid in this flask show the liquid has reached its boiling point.

Condensing

If a gas cools down far enough it **condenses** and forms a liquid. The particles in a gas lose some of the energy which allows them to move so quickly and they slow down so much that they can no longer bounce off each other when they meet. They stay close to each other and form a liquid.

7 Draw a diagram to show how the arrangement of the particles in a gas changes when the gas condenses and forms a liquid.

Figure 8.13 Steam passing through this condenser has cooled and condensed to form water.

Sublimation

8 a) In sublimation which state of matter is absent?

b) Draw a diagram to show how the arrangement of the particles in a substance changes when sublimation takes place.

A few substances can change from a solid to a gas or a gas to a solid without forming a liquid. This process is called **sublimation**. When the solid changes into a gas the forces which bind the particles together are quickly lost and they move away from each other completely. When a gas forms directly into a solid the particles lose their energy so quickly that they come together and are held by the forces between them.

Figure 8.14 When solid iodine is heated it sublimes to form a gas. This is always done in a fume cupboard.

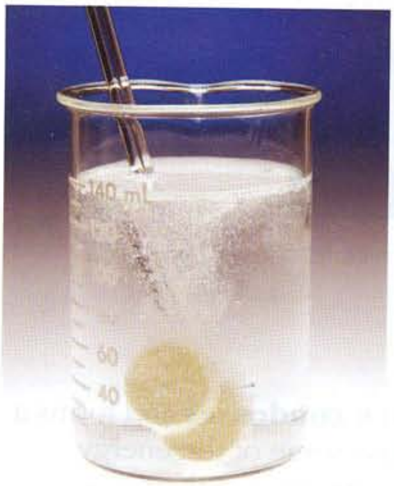


Figure 8.15 These tablets, placed in water, are starting to dissolve.

Dissolving

When a solid dissolves in a liquid it seems to disappear into it (see Figure 8.16). If it is a coloured substance it may colour the liquid. However it does not disappear, its particles simply separate and spread out through the liquid. This is possible because the liquid has gaps between its particles and it is into them that the particles of the dissolving substance pass.

9 Draw a series of diagrams to show how the arrangement of the particles in a solution changes as the solvent evaporates and the solute remains behind.

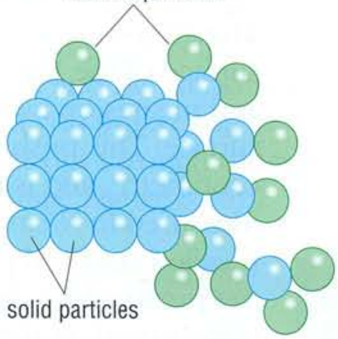


Figure 8.16 Dissolving

Gas pressure

Solids can generate **pressure** – think of a brick pressing down on your toes. Liquids can generate pressure too. A dam has to be built with thick walls to withstand the pressure of the water that collects in the reservoir behind it. Gases also generate pressure due to the action of their particles.

A gas contains millions of quickly moving particles. Every second, large numbers are bouncing off the walls of the gas container. The force of these particles as they push against the surface generates the gas pressure.

If the gas is heated the particles move faster and bounce off the container surface more frequently and with more force, so the gas pressure rises. When the gas is cooled the particles move more slowly. They bounce off the container's surface less frequently and with less force and the gas pressure falls.

When a gas is squashed into a smaller volume but its temperature is kept the same, as shown in Figure 8.17, the particles have less space in which to move. They bounce off the container walls more frequently and the gas pressure rises.

10 What two things can make the pressure of a gas rise?

11 a) What happens to the gas pressure if the gas is released from a small container into a large container?

b) Why does the gas pressure in part **a)** change?

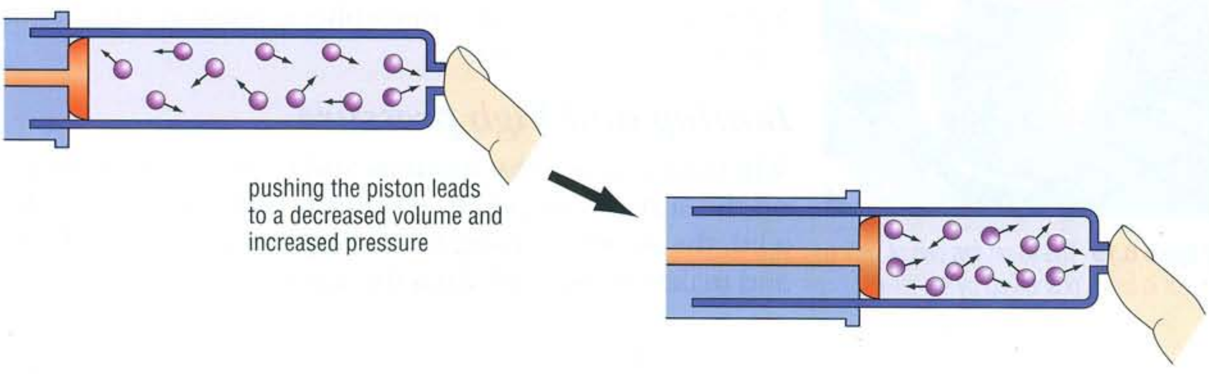


Figure 8.17 Gas pressure can be explained using the particle theory.

Atmospheric pressure

The atmosphere is a mixture of gases that covers the surface of the Earth. The atmosphere is 1000 km thick and pushes on every square centimetre of the Earth's surface. This push is a force on a specific area, the square centimetre, and is known as atmospheric pressure. It is measured in N/cm^2. The atmospheric pressure at sea level is called standard pressure and is about $10\,N/cm^2$. It is the pressure at which the boiling point of any substance is measured. At the top of very high mountains the atmospheric pressure is less than at sea level.

Boiling and low pressure

12 If you boiled water at the top of a mountain, would you expect it to boil at 100 °C? Explain your answer.

If a flask containing a liquid is connected to a vacuum pump and some of the air above the liquid is sucked out, there is less air inside the flask to push on the surfaces and the air pressure is smaller.

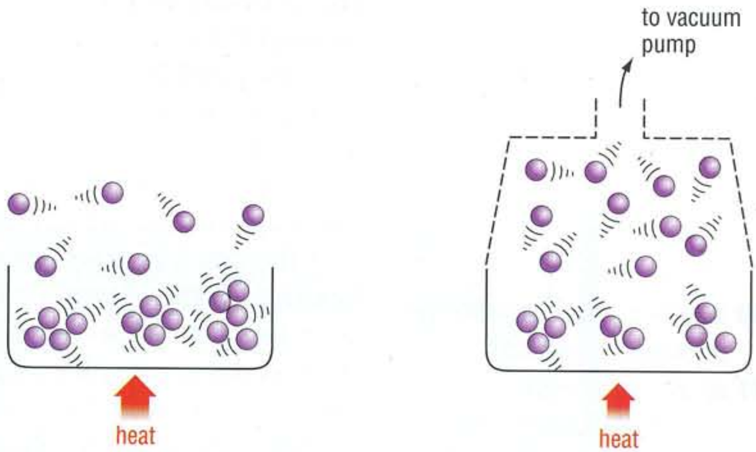


Figure 8.18 Lowering the pressure lowers the boiling point of a liquid.

The reduced air pressure allows evaporation to take place more quickly and less heat is needed to make the liquid boil. Lowering the atmospheric pressure on a liquid lowers its boiling point.

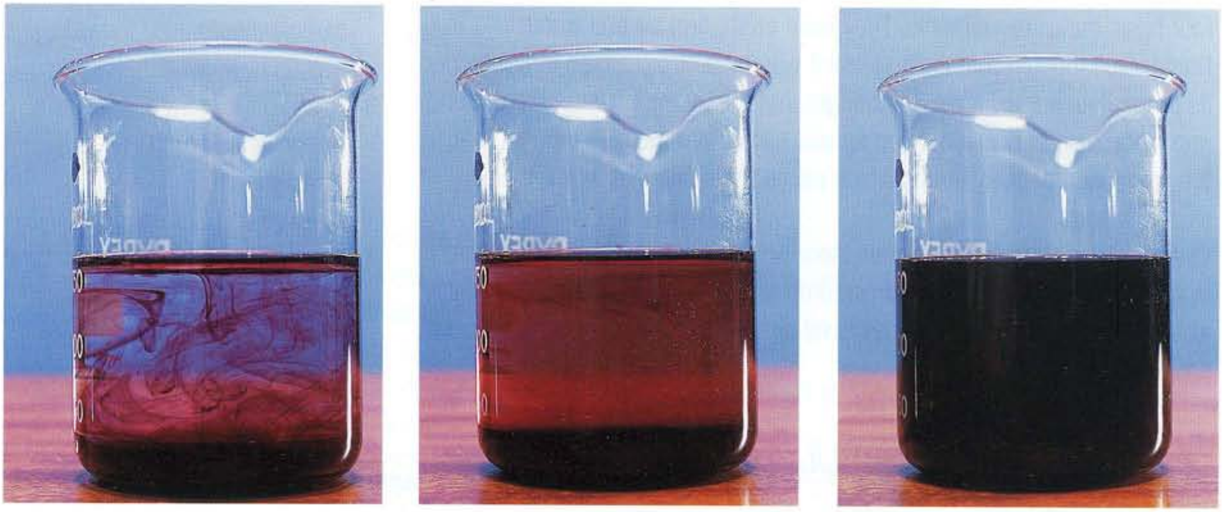
Figure 8.19 The lid on this pan of boiling water is being pushed up by the steam.

Boiling and high pressure

When a gas gets hot it expands and increases its pressure on the surfaces around it. If water is boiled in a pan with a lid, the steam escaping from the water pushes on the lid and makes it rise – allowing the gas to escape.

Diffusion

Diffusion is a process in which one substance spreads out through another. It occurs in liquids and gases. For example, if you put a drop of ink in a beaker of water the ink spreads out through the water by diffusion and colours it (see Figure 8.20).



At the start — After an hour — After a day

Figure 8.20 Black ink diffusing through a beaker of water

> **13** Draw a diagram to show how the particles of one substance diffuse through the particles of another.

The gases escaping from food cooking in the kitchen can move by diffusion to other rooms in the home. The moving particles in the different liquids move around each other and the particles in the different gases bounce off each other. These movements eventually spread all the particles of one substance evenly through the other. Liquids are denser than gases and this makes diffusion in liquids much slower than diffusion in gases.

Steps on the way to the particle theory

Democritus (about 470–380 BCE) was a Greek philosopher who thought about the structure of matter. He wondered what would happen if you took a substance and divided it into two and then carried on dividing. He believed that a tiny piece would be produced that could not be divided. He called this tiny piece of matter an atom. The word 'atom' means indivisible.

In Ancient Greece it was believed that everything was made up from four basic things or elements. They were earth, fire, air and water. Democritus thought that each element was made from atoms that matched its properties. For example, he thought that the atoms of water were round and smooth so they could move around each other. He also thought that fire was made of spiky atoms which caused the pain that was felt when skin was burnt.

About four hundred years later there was a Greek inventor called Hero. In one of his inventions, a wind-powered organ, he had an air pump which was driven by a windmill and delivered air to a row of pipes so that sounds could be made.

1 How might Democritus have described the shape of the atoms of the Greek 'element' earth?

2 How does Hero's idea about the air compare with the particle theory used today to explain how gases behave?

3 How did the work of scientists like Boyle add to the Greek ideas of atoms and help Maxwell and Boltzmann?

4 Why was it logical to develop the ideas that solids and liquids were made of particles too?

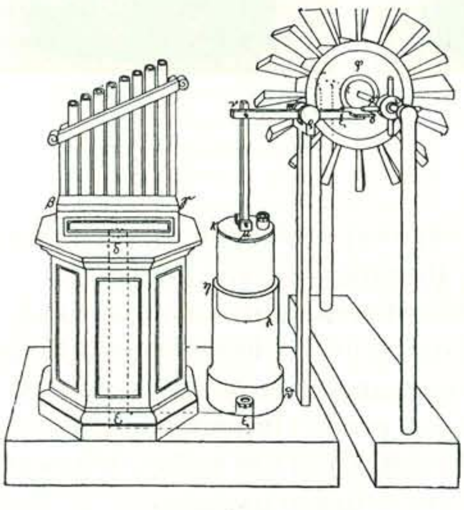


Figure A Hero's wind organ

Table A

Pressure/atmospheres	Volume/litres
1.0	12
1.5	8
2.0	6
2.5	5
3.0	4

Hero used the idea about atoms to explain his observations about air. He thought that the air was made of tiny particles with space between them. He believed that this idea explained how air could be squashed. When air was squashed the particles moved closer together and there was less space between them. He was unable to test his ideas because the Greeks at that time did not think that experiments had any importance.

Robert Boyle (1627–1691) was both a chemist and a physicist. In one of his experiments he investigated how the volume of a gas changed when he changed the pressure acting on it. He knew that a change in temperature could make a gas expand or contract so he kept the gas he was working on at the same temperature during the experiment. Table A shows some results which have been produced by repeating Boyle's experiment. The units in the table are the units Boyle would have used, which are called atmospheres, so that the data looks as it might have done in Boyle's time.

Boyle also believed that his observations could be explained by gases being made of atoms.

James Clerk Maxwell (1831–1879), a Scottish physicist, and Ludwig Boltzmann (1844–1906), an Austrian physicist, studied the results of experiments on gases and the idea of gases being made of atoms. They took the idea that gases were made of particles and performed calculations on the speed of particles. Their calculations matched the way gases behaved and from them the particle theory of matter was developed.

5 What example of creative thinking did Hero use in his explanation of what happened when air is squashed?

6 The pressure, temperature and volume of a gas are all variables.

a) Which variable did Boyle:

i) control

ii) change

iii) measure?

b) What trend or pattern can you see in Boyle's results?

7 a) How does the volume of the gas change when the pressure is increased:

i) from 1 atmosphere to 2 atmospheres

ii) from 1.5 atmospheres to 3 atmospheres?

b) What relationship do the two changes in pressure and volume in part **a)** show?

8 a) Draw a line graph of the information in Table A.

b) Use your line graph to predict the volume of the gas when the pressure is 4 atmospheres.

◆ SUMMARY ◆

- The particle theory states that matter is made from particles (*see page 96*).
- The properties of solids, liquids and gases can be explained by the particle theory (*see pages 96–99*).
- The physical changes of state can be explained by the particle theory (*see page 99*).
- The pressure of a gas can be explained by the particle theory (*see page 103*).
- Diffusion can be explained by the particle theory (*see page 105*).

End of chapter questions

1 a) Will evaporation be quicker from a large surface area of liquid or a small surface area?

b) Use the particle theory to explain the reason for your answer in part **a)**.

c) Devise an investigation to test your answer.

2 Why does a bicycle tyre get harder when you pump it up?