When we walk past a fast food restaurant, we are often drawn in by the smell of fried chicken or fries. In contrast, when we walk past a rubbish dump, we find the stench unpleasant. These are both examples of diffusion of particles, which enables us to detect the pleasant or unpleasant smell!

$E_k = \frac{3}{2} k \cdot \Delta T$ (change in temperature)

Conditions That Affect the Rate of Diffusion

Effect of Temperature

Particles have more kinetic energy at higher temperatures. This means that particles in liquids and gases move more quickly, as compared to particles in solids. This is also why hot liquids and gases diffuse faster than cold ones. The smell from a pot of hot stew can be detected from a further distance than when it has cooled (Figure 2.22).

We can observe the effect of temperature on the random motion of particles in Let's Investigate 2B.

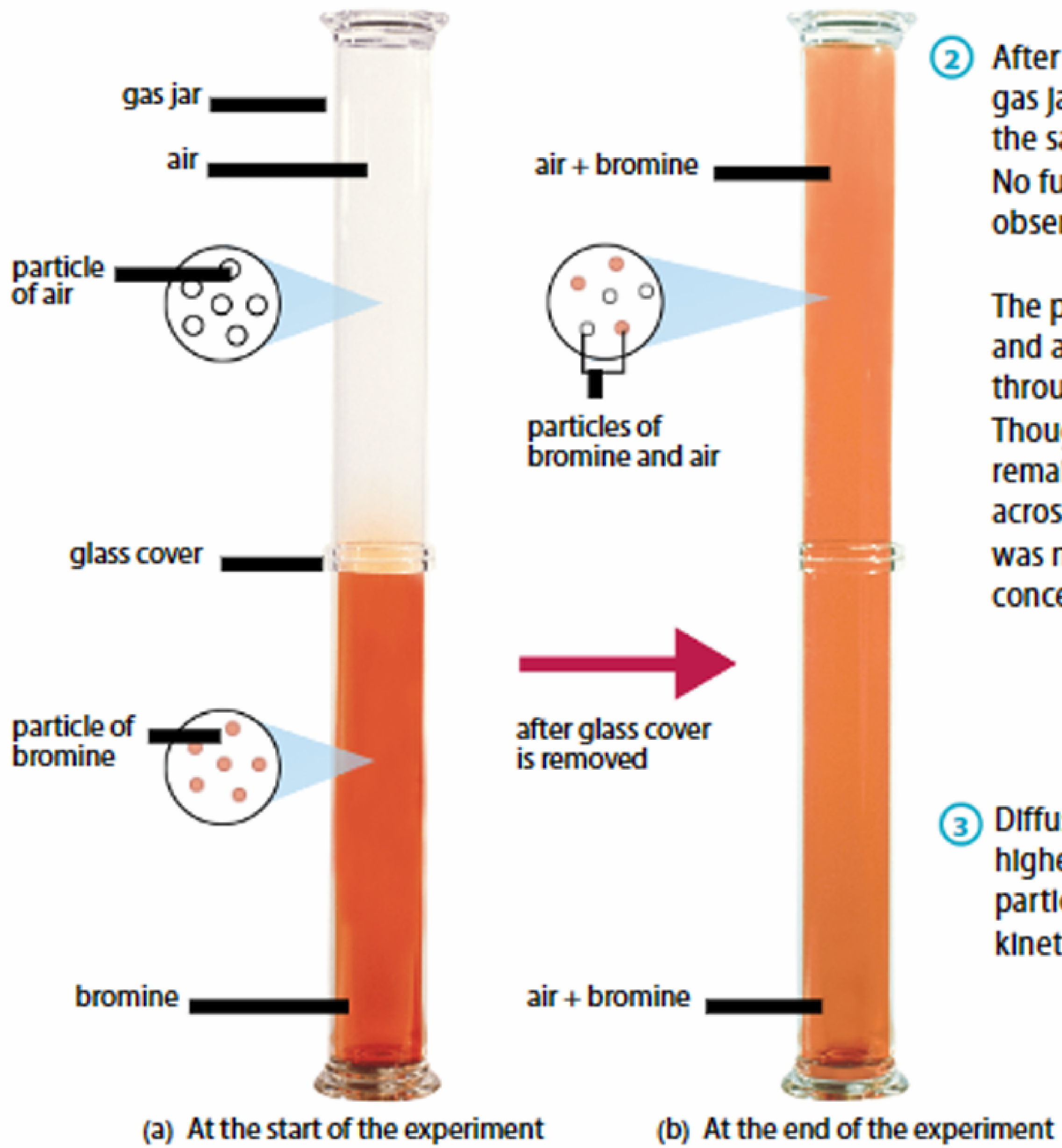
Figure 2.22 The smell from a pot of stew diffuses faster when it is hot than when it has cooled.

Disciplinary Idea

As the temperature of a substance increases, the rate of diffusion also increases due to the greater average kinetic energy possessed by the particles.

① Particles of bromine are heavier than air. In the absence of random motion, the brown bromine vapour should remain at the bottom when the glass cover is removed.

However, because of random motion, some of the particles of bromine started to move upwards into the gas jar on top. Similarly, the particles of air moved in the opposite direction.



② After a few minutes, both gas jars appeared to be of the same shade of brown. No further change was observed.

The particles of bromine and air had spread evenly throughout the gas jars. Though the particles remained constantly moving across the gas jars, there was no overall change in concentration.

③ Diffusion occurred faster at higher temperatures as the particles possessed greater kinetic energy.

Figure 2.23 Diffusion of bromine gas

Effect of Particle Mass

Since particles with greater mass will require more kinetic energy to move at a given speed, heavier particles will diffuse more slowly than lighter particles at any given temperature. This is true for both liquids and gases where the particles are free to diffuse, but not for solids where the particles vibrate or rotate only about fixed positions.

Particles of chlorine have a greater mass than particles of nitrogen dioxide. Hence, chlorine diffuses more slowly than nitrogen dioxide when introduced into a container of air.

There's a difference at the rate of diffusion when we are dealing with particles of heavier mass.

Let's Investigate 2C

Helpful Note

The mass of particles can be quantified using the relative molecular mass (M_r), which you will learn about in Chapter 7. The M_r of hydrochloric acid is 36.5 while that of ammonia is 17.

① Hydrogen chloride gas vaporised from the concentrated hydrochloric acid and ammonia gas vaporised from the concentrated ammonia solution. The gases diffused from the ends of the glass tube towards each other.

② When the two gases met, they reacted to form white ammonium chloride. The white ring formed was nearer to the end with hydrogen chloride. This is because the lighter particles of ammonia move faster than the heavier particles of hydrogen chloride.

particles of ammonia are lighter.

Figure 2.24 Diffusion of hydrogen chloride and ammonia

Table 2.2 Conditions that affect the rate of diffusion in liquids and gases

Conditions	Rate of Diffusion	Reason
Increase in Temperature	increase	More thermal energy is converted to kinetic energy of the particles.
Increase in Particle Mass	decrease	Particles with higher mass require more kinetic energy to move at the same speed.

Chemistry Connect

Launch this resource to observe how particles behave under different conditions.

Practical Examples of Particle Movement

We can alter conditions like temperature and particle mass to change diffusion rates and their effects on the change in state of substances in our everyday life.

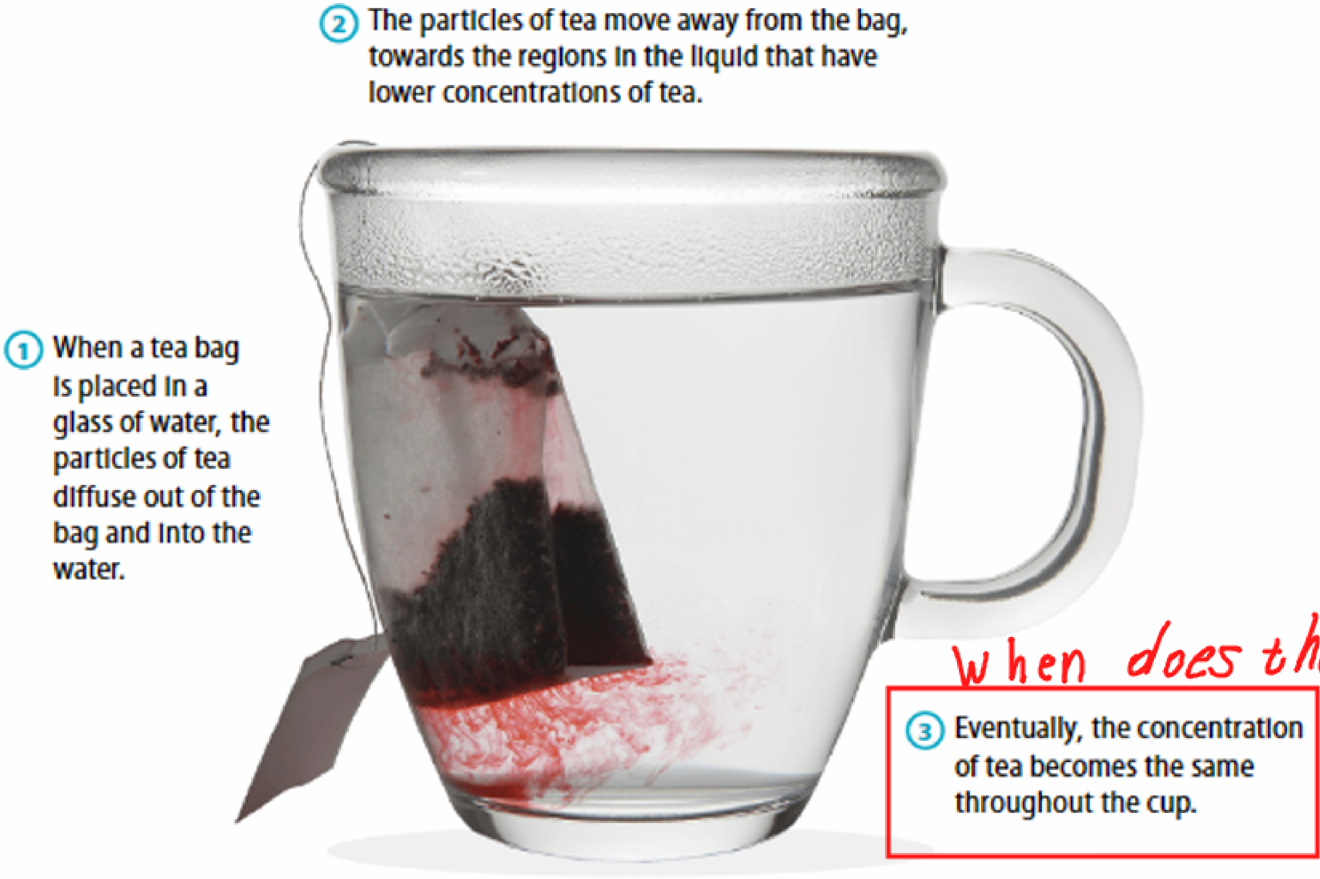
Tea

When we add a tea bag into a glass of water, we observe the movement of coloured particles of tea spread through the liquid. The colour of the liquid slowly becomes darker, but stops after some time when all the liquid have become the same colour. Figure 2.25 shows how particles of tea diffuse through a glass of water.

Figure 2.25 How particles of tea diffuse through a glass of water

Tea

When we add a tea bag into a glass of water, we observe the movement of coloured particles of tea spread through the liquid. The colour of the liquid slowly becomes darker, but stops after some time when all the liquid have become the same colour. Figure 2.25 shows how particles of tea diffuse through a glass of water.



when does the process stop?

Figure 2.25 How particles of tea diffuse through a glass of water

Cool Career

Perfumer

Just as artists might choose various colours for their paintings to evoke a range of senses, skilled perfumers blend chemicals with different volatilities to create layered effects of fragrances. Initial smells of perfumes are made from substances which evaporate faster and whose particles travel more quickly. Chemicals which have particles of greater mass travel more slowly, and leave a longer lasting impression.

Perfumes

A perfume is a fragrant liquid comprising a blend of substances. As seen in Figures 2.26 and 2.27, some of the substances are extracted from natural sources, while others are made in laboratories.

Figure 2.26 Extraction of natural fragrances

Figure 2.27 A perfumer creating a blend of fragrances

Figure 2.28 shows how the particles of perfume diffuse through the air.

Figure 2.28 How particles of perfume diffuse through the air

Word Alert

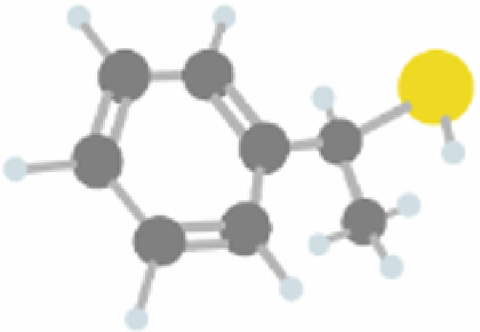
volatile: turns into a gas easily

Let's Practise 2.2

✓ 1 When an apple is removed from a refrigerator and is left on a table for a few minutes, fine droplets of water appear on the apple. Describe how the water droplets are formed. (We have condensation)

✓ 2 Air fresheners are commonly used when odours are detected in a room. Would you expect the fragrance to be stronger on a warmer or cooler day? Explain your answer. (Higher temperature leads to higher rate of diffussion because the particles have more Kinetic Energy.

✓ 3 The smell of curry lingers in the kitchen long after it is cooked. However, the smell of a gas leak from the kitchen stove clears very quickly. The particles responsible for the smell of curry and cooking gas are shown in Figure 2.31. Using the kinetic particle theory, suggest why the smell of curry lingers far longer than the odour of a gas leak.



$C_8H_{10}S$

Particle responsible for the smell of curry ($M_r = 138$)

it is easier for CH_4S to be diffused because it is lighter

CH_4S

Particle responsible for the smell of cooking gas ($M_r = 48$)

Figure 2.31

Link

Theory Workbook

Worksheet 2B

Let's Assess

Let's Reflect

Let's Map It

Kinetic Particle Theory

describes

States of Matter

which are

Solid
- Definite shape and volume
- Cannot be compressed as particles are very closely packed in an orderly manner
- Particles vibrate and rotate about fixed positions
- Particles possess very low kinetic energy
- Very strong forces of attraction between particles

Liquid
- Indefinite shape but definite volume
- Cannot be compressed though particles are less closely packed than in a solid, and are in a disorderly manner
- Particles slide past each other throughout liquid
- Particles possess low kinetic energy
- Strong forces of attraction between particles

Gas
- Indefinite shape and volume
- Can be compressed as particles are far apart in a disorderly manner
- Particles move rapidly and randomly
- Particles possess high kinetic energy
- Very weak forces of attraction between particles

melting

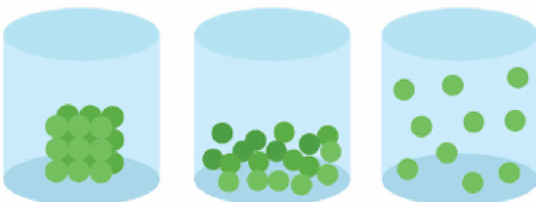
freezing

evaporation/ boiling

condensation

sublimation

vapour deposition



explains

Diffusion

examples

- Spreading of ink in water
- Spreading of perfume across a room

rate increases with

Lower particle mass

Higher temperature

Section A: Multiple-choice Questions

In Figure 2.32, **P**, **Q** and **R** show the particle arrangements for a substance at different temperatures. Use the figure to answer **Questions 1** and **2**.

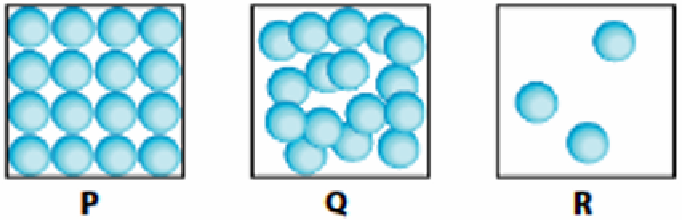


Figure 2.32

✓1 Which of the following shows the state change during melting?

- A P ➡ Q
- B Q ➡ P
- C Q ➡ R
- D R ➡ Q

✓2 Which of the following shows the state change during sublimation?

- A P ➡ R
- B Q ➡ P
- C R ➡ P
- D R ➡ Q

✓3 A solid is heated until it melts into a liquid, and then boils into a gas. Which of the following lists the three states of matter in order of decreasing volume?

- A gas, liquid, solid
- B gas, solid, liquid
- C liquid, solid, gas
- D solid, liquid, gas

Section B: Structured Questions

1 Figure 2.33 shows the temperature of gaseous substance **Z** as it is cooled over time.

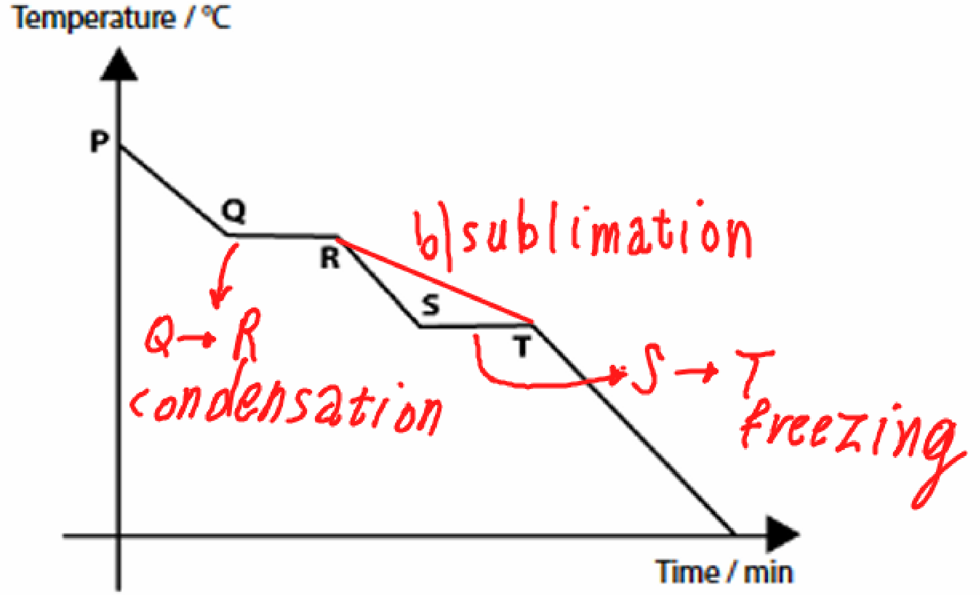


Figure 2.33

(a) Name the **two** processes occurring between points **Q** to **R** and **S** to **T**.

(b) Explain, in terms of the kinetic particle theory, what happened to the particles in substance **Z** from **R** to **T**. Gas particles become solid at a very quick rate

2 Explain the following observations in terms of particle arrangement and/or their movement, including any energy

matter in order of decreasing volume?

A gas, liquid, solid B gas, solid, liquid

C liquid, solid, gas D solid, liquid, gas

4 Based on the kinetic particle theory, which of the following processes does **not** absorb energy from its surroundings?

A boiling B condensation

C melting D sublimation

5 Two gases, **X** and **Y**, with distinct smells were released from their closed containers at the front of a room. The time taken before it was detected at the far end of the room was recorded. The same experiment was repeated on a warmer day. The mass of a particle of gas **X** is about half that of gas **Y**. In which of the following will the gas reach the far end of the room in the shortest time?

	Gas	Temperature
A	X	cooler
B	X	warmer
C	Y	cooler
D	Y	warmer

half mass warmer day.

2 Explain the following observations in terms of particle arrangement and/or their movement, including any energy changes, where relevant.

(a) ice cream softening when removed from the freezer

(a) Energy is absorbed. movement of particles increases. the arrangement becomes less organised.

(b) smell emerging from eggs frying in a pan

particles move faster due to frying, increased rate of diffusion due to increase in temperature.

(c) wet clothes drying faster when hung outside on a sunny day compared to a cloudy day

energy absorption particles move faster.

3 Figure 2.34 shows the set-up of an experiment involving colourless hydrogen gas and brown nitrogen dioxide gas. A particle of nitrogen dioxide is 23 times the mass of a particle of hydrogen.

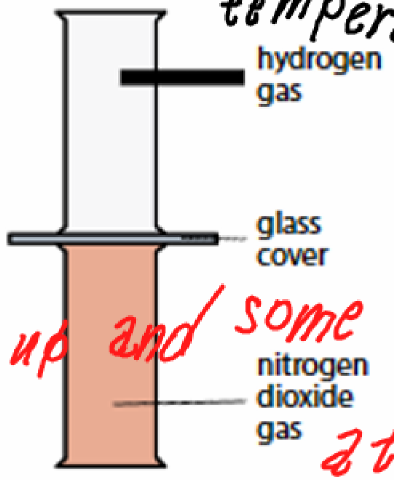


Figure 2.34

(a) Describe what happens when the glass cover is removed.

(a) Some particles will move up NO_2 and some particles of H_2 will move down at a slow pace (diffusion will take place) until we have equal concentration to all parts of the tube

(b) The experiment is repeated but with the positions of the two gases switched. How would your answer in (a) change? Explain.

the end the result will be the same (diffusion until equal concentration everywhere), but at a much faster rate because NO2 is 23 times heavier than H2

4 25 cm^3 of distilled water and 25 cm^3 of ethanol were transferred into a measuring cylinder. Figure 2.35 shows the structure of a particle of water and ethanol.

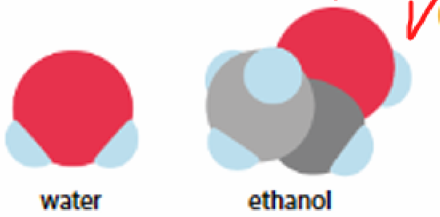


Figure 2.35

(a) Some particles of water vaporised

The motion of water particles will make them vaporize

(b) The whole process will take place at a much higher pace, since a raise in temperature increases the rate of diffusion.

Also at the same time, particles of water and ethanol will vaporise as well.

(a) The volume reading shown on the measuring cylinder was less than 50 cm^3. Suggest why this is so, based on your knowledge of the kinetic particle theory.

Hint *Study the arrangement of the particles in pure water, pure ethanol and in the mixture.* because they move.

(b) The measuring cylinder was then left to stand on a laboratory bench near the window on a hot day. After two hours, the volume reduced further. Explain what happened.

5 District cooling systems (DCS) will be increasingly used in Singapore as it is more energy-efficient than traditional air conditioners.

(a) DCS uses chilled water to cool buildings. Explain, in terms of the kinetic particle theory, what happens to the particles in chilled water when they encounter heat in the warm rooms.

(b) Traditional air conditioners use refrigerant gases which are constantly condensed and evaporated in the air conditioning unit. Explain what happens to the particles of the liquid refrigerant (within the unit), when they

(a) Tom thinks that the particles in the ice are the heaviest particles and the steam at the mouth of the boiling tube are the lightest. Is Tom correct? Explain your answer.

(b) Jill thinks that because steam is hot, energy is released when water boils. Is Jill correct? Explain your answer.

(c) It was observed that when the boiling tube was heated at the position shown, steam was formed quickly. However, the ice wrapped in wire gauze remained at the bottom, melting only some time later. Using the kinetic particle theory, explain what happened to the particles of water within the boiling tube.

2 Figure 2.37 shows the set-up of an experiment at the start and at the end. (Assume that the particles of the pumped gas have a greater mass than the particles of air.)