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Cambridge IGCSE® & O Level Essential Chemistry

Third Edition

Sample student material

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Oxford excellence for Cambridge IGCSE® & O Level

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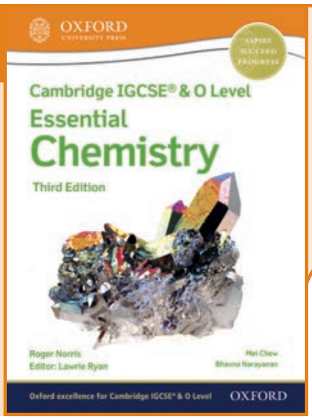

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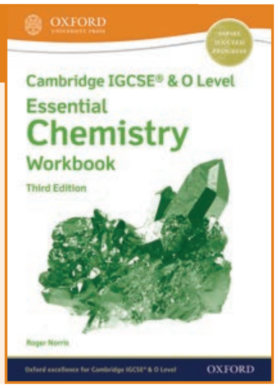

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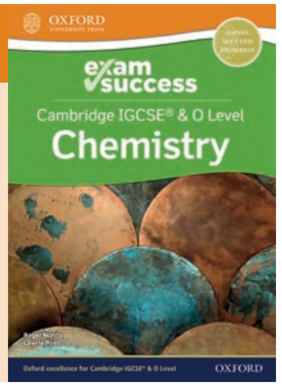

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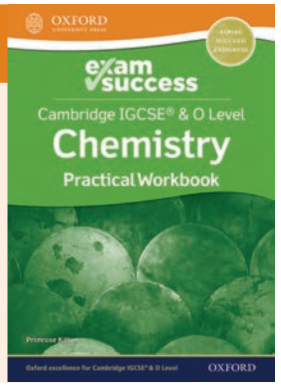


1.1 Solids, liquids and gases

LEARNING OUTCOMES

- Describe the general properties of solids, liquids and gases
- Describe the structures of solids, liquids and gases in terms of particle separation, arrangement and motion
- State the effect of temperature and pressure on the volume of gases using the kinetic particle theory

The three states of matter

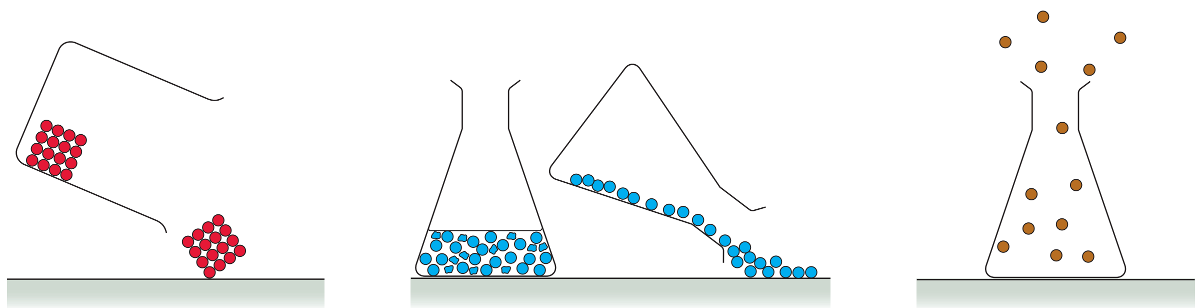
Substances can be solids, liquids or gases. These are the three **states of matter**. Most substances can exist in all three states. For example, water can exist as ice, liquid water or steam.

All matter is made up of particles. Three types of particles make up most matter – atoms, molecules and ions.

An **atom** is the smallest particle that cannot be broken down by chemical means.

A **molecule** is an uncharged particle made of two or more atoms joined together.

An **ion** is an atom or group of atoms that carries a positive or negative electrical charge.



A solid has a definite shape and volume, but cannot flow.

A liquid has a definite volume but takes the shape of its container. It can flow.

A gas has no definite volume. It can spread everywhere throughout its container.

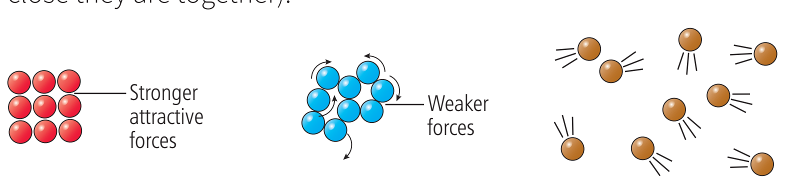
Figure 1.1.1 There are three states of matter: solid, liquid and gas.

Figure 1.1.2 When solid iodine is heated it forms a liquid at 114°C, then soon turns to gas at 184°C

EXAM TIP

Remember that in liquids the particles slip and slide over each other. They are not completely free to move anywhere.

We can explain the properties of solids, liquids and gases by looking at their particle arrangement, motion and separation (how close they are together).



SOLID: arrangement: fixed pattern; motion: only vibrate; separation: close together

LIQUID: arrangement: random – no fixed pattern; motion: slide past each other; separation: close together

GAS: arrangement: random; motion: move every where rapidly; separation: far apart

Figure 1.1.3 The general properties of solids, liquids and gases.

The kinetic particle theory

In liquids and gases, the particles are constantly moving and changing directions as they hit other particles. The idea that particles are constantly in motion is called the **kinetic particle theory**.

The kinetic particle theory states that:

- particles in gases, liquids and solid behave as hard spheres
- particles in gases and liquids move randomly (in any direction)
- particles in gases do not attract each other

Compressing gases

We can picture a gas as a collection of randomly moving particles which collide with each other and with the walls of their container. When we increase the pressure, the particles get closer to each other. So the volume of the gas decreases.

Heating gases

When the volume of gas is not fixed, for example in a gas syringe, the volume of gas increases as the temperature increases. At higher temperatures, the particles have more **kinetic energy**. So they move faster and hit the walls of the syringe with greater force. So the plunger in the syringe is pushed outwards, and the volume of the gas increases.

SUMMARY QUESTIONS

1 Which of these phrases refers to
  a gases **b** liquids **c** solids?
  - The particles are close together
  - The particles are randomly arranged
  - The particles only vibrate.

2 Describe how a solid differs from a gas in its general properties.

3 State how the motion and average distance between the gas particles changes in **a** closed container when a the temperature increases and **b** the pressure increases.

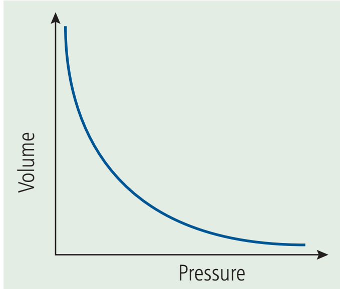


Fig.1.1.4 As the pressure of a gas increases, its volume decreases (at constant temperature).

EXAM TIP

Note that increasing the temperature increases the average speed of the gas particles, but increasing the pressure at constant temperature has no effect on the speed of the gas particles.

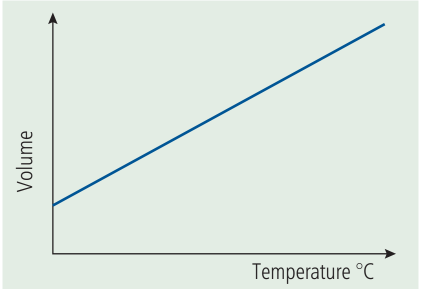


Figure 1.1.5 As the temperature of a gas increases, its volume increases (at constant pressure).

KEY POINTS

- Solids, liquids and gases can be distinguished by their shapes and how easily they flow or spread out.
- The properties of solids, liquids and gases can be explained in terms of the closeness, arrangement and motion of their particles.
- The closer the particles in a gas, the higher the pressure and the lower the volume.
- Increasing the temperature of a gas increases the speed at which its particles move.

1.2 Using the kinetic particle theory

LEARNING OUTCOMES

- Describe the changes of state in terms of melting, boiling, evaporation, freezing and condensation.
- S Explain the effects of pressure and temperature on the volume of a gas using the kinetic particle theory.

LINK

Energy changes are looked at in more detail in Topic 8.1

EXAM TIP

Remember that most of the particles in liquids are touching one another. It is a common error to think that all the particles are separated.

Figure 1.2.1 Water changes to steam at its boiling point, 100°C

EXAM TIP

Remember the difference between boiling and evaporation. Boiling takes place at the boiling point of the liquid. Evaporation takes place at temperatures below its boiling point.

Changes of state

Melting

When we heat a solid, energy is transferred to the solid. Its particles gain energy and their vibrations are stronger. The **forces of attraction** between the particles are weakened and the solid **melts**. The solid turns to a liquid. The **melting point** is the temperature at which a solid turns to a liquid.

Boiling and evaporation

Heating a liquid to a higher temperature weakens the forces of attraction between particles further. When a high enough temperature is reached, the attractive forces keeping the liquid's particles grouped together are broken. The particles can form bubbles of gas that escape from the surface of the liquid. So as the bubbling liquid turns into a gas, we say that the liquid **boils**. The **boiling point** is the temperature at which a liquid turns to a gas.

At temperatures below the boiling point of a liquid, some of its particles have enough energy to escape from the surface. They form a vapour. This process is called **evaporation**. Energy needs to be taken in to melt, boil or evaporate a substance.

Condensing and freezing

Cooling a gas makes it **condense** into a liquid. Further cooling results in the liquid **freezing (solidifying)**. Energy is released (given out or transferred) to the surroundings when a substance condenses or freezes. The surroundings include the air as well as the container in which the solid, liquid or gas is placed.

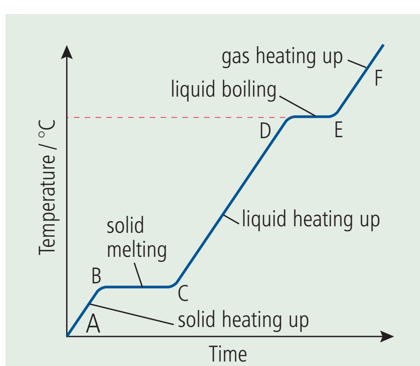


Figure 1.2.2 The changes of state. Energy must be absorbed to melt and boil a substance. Energy is released on condensing and freezing.

Supplement

Gases and the kinetic particle theory

Pressure and volume

The gas particles exert a force on the walls of their container, causing pressure. When we decrease the volume of a fixed mass of gas, the molecules get closer together and hit the walls of the container more frequently. This causes an increase in gas pressure (see Figure 1.2.3). The higher the pressure, the closer the particles are to each other.

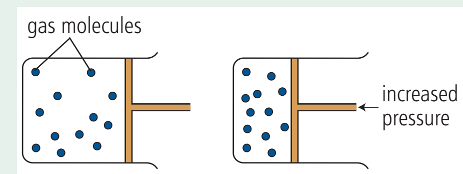


Figure 1.2.3 When the volume of the container is decreased, the gas molecules are squashed closer together and hit the walls of the container more frequently.

Pressure and temperature

A closed container has a fixed volume. If we heat a gas in a closed container, as the temperature increases, the gas particles move faster and hit the walls of the container with increased force. We say that the molecules have greater kinetic energy (energy associated with movement) at a higher temperature. Since the volume of a closed container does not change, the pressure increases when the temperature increases.

Temperature and volume

If the volume of the gas is not fixed, as for example in a gas syringe, the volume of gas increases when the temperature increases. This is because at higher temperatures, gas molecules have more kinetic energy and move faster. The higher the temperature, the greater is the force of the gas molecules on the syringe plunger. The plunger is pushed out until the pressure is balanced by the pressure of the atmosphere.

SUMMARY QUESTIONS

1 Give the names of these changes of state:
   a liquid to gas   b solid to liquid
   c gas to liquid

2 Describe what happens to the energy and motion of the particles when ice changes to water.

S 3 Explain, using the kinetic particle theory, how the volume of a gas in a gas syringe changes when the temperature decreases. The pressure is constant.

4 Explain, using the kinetic particle theory, how the volume of a gas in a gas syringe changes when the pressure decreases.

EXAM TIP

When writing about the energy in moving particles, make sure that you state kinetic energy and not just energy.

KEY POINTS

- The terms melting, boiling, condensing and freezing are used for specific changes of state.
- In melting, boiling and evaporation energy is absorbed (put in).
- In condensing and freezing, energy is released.
- The volume of a gas decreases when pressure increases because the particles are pushed closer together.
- S The volume of a gas in a syringe increases when temperature increases. This is because the particles hit the walls of the syringe with more force at higher temperatures. The volume increases as the plunger moves outwards until the gas pressure in the syringe equals the atmospheric pressure.

1.3 Heating and cooling curves

LEARNING OUTCOMES

- Explain differences in physical state in terms of melting points and boiling points
- S Explain changes of state using the kinetic particle theory
- Interpret cooling curves and heating curves

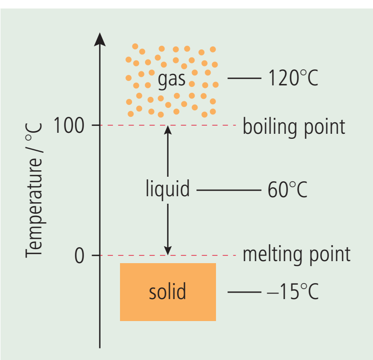


Figure 1.3.1 Water is a gas above 100°C and a solid below 0°C.

EXAM TIP

When using melting and boiling point data remember, for example, that –200°C is a lower temperature than –100°C.

Using melting and boiling point data

We can determine the physical state of a substance at any given temperature by comparing the temperature with its melting point and boiling point. Figure 1.3.1 shows the melting point and boiling point of water.

- At 120°C water is a gas because 120°C is above its boiling point (100°C)
- At 60°C water is a liquid because 60°C is above its melting point (0°C) but below its boiling point (100°C)
- At –15°C water is a solid because –15°C is below its melting point (0°C)

Supplement

Explaining changes of state

Energy is absorbed or released when the particles in solids, liquids or gases rearrange themselves during a change of state. We can explain the shape of a heating or cooling curve of temperature against time using ideas about the motion of the particles and energy changes.

Heating curves

PRACTICAL

A heating curve for stearic acid

A sample of solid stearic acid is heated at a constant rate using the apparatus shown. The temperature of the stearic acid is recorded every 30 seconds.

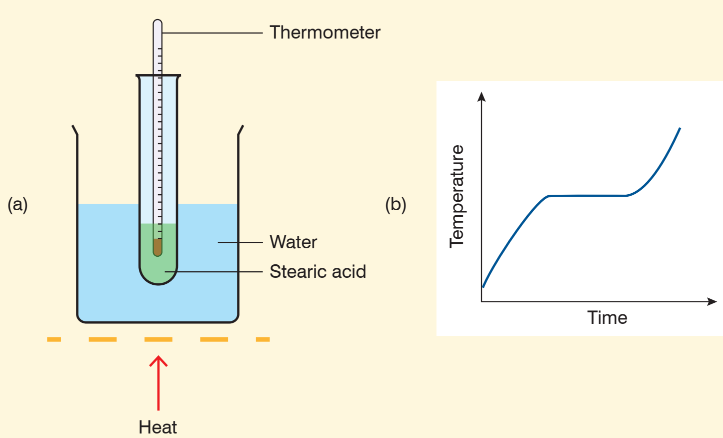


Figure 1.3.2 a apparatus and **b** graph of results.

The flat part of the graph in Figure 1.3.2 shows where the solid is changing to liquid. This is the melting point of stearic acid. There is no temperature rise here. So the energy supplied is not raising the temperature. The energy is being absorbed to overcome the attractive forces holding the particles of solid in position.

Cooling curves

A **cooling curve** is a graph which shows temperature against time when a substance is cooled at a constant rate. Figure 1.3.3 shows a cooling curve obtained when a gas at a temperature above its boiling point is cooled to form a solid below its melting point.

We can explain the cooling curve using ideas about the energy and motion of the particles.

- A–B: Decreasing the kinetic energy decreases the speed of the gas particles. So the temperature of the gas falls.
- B–C: The forces of attraction between the particles are strengthened. The temperature is constant here because heat energy is released when intermolecular attractive forces are formed. The heat given out during condensation stops the temperature from falling.
- C–D: Decreasing the kinetic energy decreases the speed of the particles in the liquid. So the temperature of the liquid falls.
- D–E: The temperature is constant because heat energy is released when a liquid changes to a solid. The heat given out during freezing stops the temperature from falling.
- E–F: Decreasing kinetic energy decreases the vibration of the particles in the solid. So the temperature decreases.

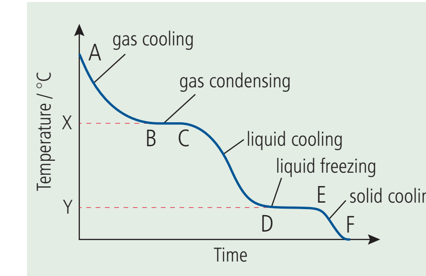


Figure 1.3.3 A cooling curve for the change of state from gas to solid showing the boiling point, X, and the melting point, Y.

KEY POINTS

- The physical state of a substance at a particular temperature can be deduced from its melting point and boiling point.
- In melting, boiling and evaporation energy is absorbed.
- In condensing and freezing, energy is released.
- S The horizontal (flat) parts of cooling and heating curves show the melting point and boiling point.

SUMMARY QUESTIONS

1 Sodium chloride melts at 801°C and boils at 1413°C. Describe the physical state of sodium chloride at **a** 970°C **b** 1500°C. Explain your answers.

2 Methane condenses at –164°C and freezes at –182°C. Describe the physical state of methane at **a** –190°C **b** –150°C. Explain your answers.

3 S Copy and complete using the words below:

absorbed **flat** **forces** **energy** **melting**

When we heat a solid, _____ is absorbed and raises the temperature of the solid. At the _____ point, the energy is _____ to overcome the attractive _____ between the particles rather than raising the temperature. That is why there is a _____ part to the heating curve.

4 Sketch a graph to show how temperature changes when a solid is heated at a constant rate to form a liquid and then a gas. Label the melting point of the liquid.

5 Explain why there is no change in temperature when a solid melts.

1.4 Solvents, solutes and solutions

LEARNING OUTCOMES

- Define the terms solvent, solute, solution and saturated solution
- State that concentration can be measured in g/dm^3 or mol/dm^3
- Describe the chemical tests for water
- Explain why distilled water is used in practical chemistry

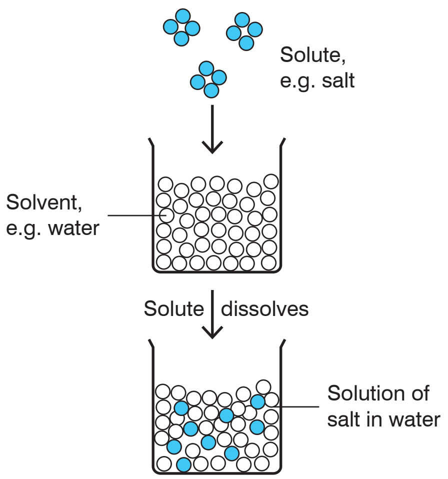


Figure 1.4.1 In a solution, the solute and solvent particles are completely mixed up.

EXAM TIP

When calculating the concentration of a solution, remember to convert cm^3 to dm^3. You can do this by dividing the number of cm^3 by 1000.

Solutes, solvents and solutions

- A **solvent** is a substance which dissolves another substance. Water, ethanol and hexane are examples of solvents which are often used in chemistry.
- A **solute** is a substance which dissolves in a solvent. Salt dissolves in water. So salt is a solute. Solutes can be solids, liquids or gases.
- A **solution** is a mixture in which a solute is spread evenly throughout a solvent.
- An **aqueous solution** is formed when a solute dissolves in water.
- A **saturated solution** contains the maximum concentration of a solute dissolved in a solvent at a specified temperature.

When a solution is made, the solute particles are completely mixed up with the solvent particles (Figure 1.4.1). Every part of the solution has the same concentration of particles. We know that the substance has dissolved completely when we cannot see the solute any more.

Solution concentration.

If we dissolve a lot of salt in 100 cm^3 of water, we say that the solution is concentrated. If we dissolve only a little salt in the same amount of water, we say that the solution is dilute. We measure concentration in grams per decimetre cubed (written as g/dm^3).

$$1 \text{ decimetre cubed (dm}^3\text{)} = 1000 \text{ cm}^3$$

We can also measure concentration in moles per decimetre cubed (written as mol/dm^3). Moles are the unit used by scientists to measure 'amount of substance'.

We can use this equation to calculate **concentration** in g/dm^3:

$$\text{concentration (in g/dm}^3\text{)} = \frac{\text{mass of substance (in g)}}{\text{volume of solution (in dm}^3\text{)}}$$

Example:

Calculate the concentration of a solution of magnesium chloride containing 5 g of magnesium chloride in 200 cm^3 of water.

Step 1: change cm^3 into dm^3. 200 cm^3 = $\frac{200}{1000}$ = 0.2 dm^3

Step 2: use the equation for concentration: concentration = $\frac{5}{0.2}$ = 25 g /dm^3

Solubility

You can only dissolve a certain amount of substance in a solvent. When we can dissolve no more substance, we say that the solution is saturated. A **saturated solution** contains the maximum concentration of a solute dissolved in a solvent at a particular temperature. Different substances have different solubilities in a solvent. The **solubility** in g/dm^3 is the maximum number of grams of solute that can be dissolved to make 1 dm^3 of solution. For example, you can dissolve up to 340 g of potassium chloride in water to make 1 dm^3 of potassium chloride solution. We say that potassium chloride is soluble in water.

You can only dissolve about 0.3 g of iodine in water to make 1 dm^3 of iodine solution. We say that iodine is very slightly soluble in water. Its solubility is so low that we can think of iodine as being **insoluble**. Sand is a substance that does not dissolve in water at all. Sand is insoluble in water.

Figure 1.4.2 Blue cobalt chloride paper turns pink if water is present

Water

Testing for water

There are two common chemical tests for water:

1. When we add water to white **anhydrous** copper(II) sulfate it turns blue.
2. When we add water to anhydrous cobalt(II) chloride the cobalt chloride changes from blue to pink.

Anhydrous means 'without water'. When water is added to anhydrous copper(II) sulfate or anhydrous cobalt(II) chloride, these compounds become **hydrated**. Hydrated means that the crystals have water chemically combined in their structure. This water is called **water of crystallisation**.

Water as a solvent

Water from the tap or from the ground contains soluble impurities. We use pure water in chemistry rather than tap water because these impurities can interfere with chemical experiments. For example, magnesium compounds in tap water can react with chemicals added during an experiment, such as sodium hydroxide. This can cause the solution to go cloudy. For most work in the chemical laboratory, distilled water is used because this contains very few chemical impurities.

KEY POINTS

- A solvent is a substance which dissolves another substance.
- A solute is a substance which dissolves in a solvent.
- A solution is a mixture in which a solute is spread evenly throughout a solvent.
- Concentration in g/dm^3 = mass in g / volume in dm^3
- Anhydrous copper(II) sulfate and anhydrous cobalt(II) chloride are used to test for water.

SUMMARY QUESTIONS

1. Give the meaning of these terms: **a** solution **b** anhydrous **c** insoluble **d** aqueous solution
2. Explain why tap water is not used for making solutions for chemical experiments.
3. Calculate the concentration in g/dm^3 of a solution which contains 4 g of sodium hydroxide in 125 cm^3 of water.
4. Describe the colour change of anhydrous cobalt(II) chloride when an aqueous solution of sodium chloride is added.

1.5 Diffusion

LEARNING OUTCOMES

- Describe and explain diffusion using the kinetic particle theory
- S Describe and explain the effect of molecular mass on the rate of diffusion in gases

EXAM TIP

You may be asked to explain using the kinetic particle theory why the colour of a crystal spreads through the water in which it is placed. Don't forget to write about the particles going into solution as well as writing about diffusion.

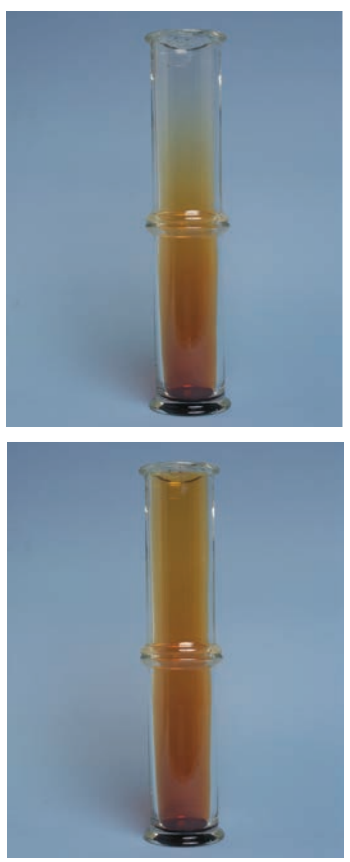


Figure 1.5.2 Bromine gradually diffuses throughout the space available

If we put a drop of ink into some water and leave it, the colour of the ink will spread throughout the water. Why is this?

The gradual spreading out and mixing up of different particles by random movement is called **diffusion**.

Diffusion results in the particles spreading throughout the space available. The overall direction of the movement is from where the particles are more concentrated to where the particles are less concentrated.

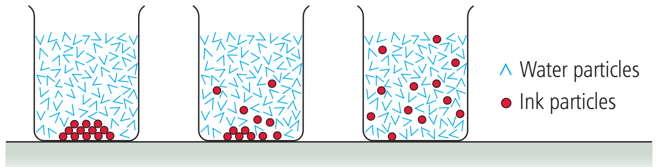


Figure 1.5.1 The colour of the ink spreads because the moving particles of ink mix with the moving water particles.

Diffusion occurs only in liquids and gases because the particles are able to move. Diffusion in gases is faster than in liquids. This is because in gases the particles move rapidly but in liquids they move less rapidly. Diffusion does not occur readily in solids because the particles are packed tightly together and, although they vibrate, they cannot move around.

Diffusion in gases

Diffusion provides evidence for the kinetic particle theory. Diffusion occurs in gases because the molecules in gases are constantly moving, colliding with each other and changing directions. This results in the gases spreading out and mixing. If we put a gas jar containing (colourless) oxygen above a gas jar of bromine vapour (brown), the molecules of the bromine vapour and oxygen gradually mix because all the particles are moving and colliding randomly.

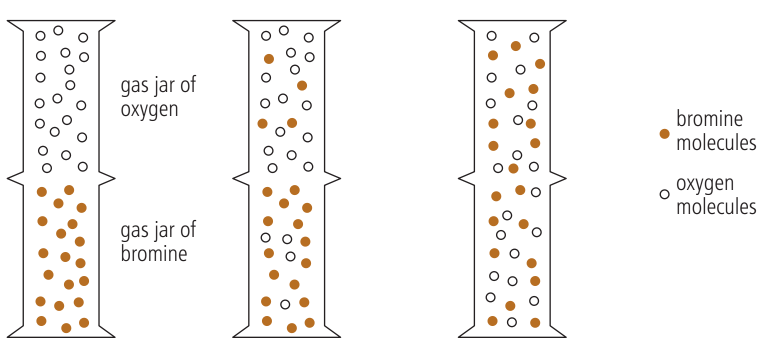


Figure 1.5.3 The molecules in the gas jars collide and move randomly. This leads to the gases mixing by diffusion.

PRACTICAL

Diffusion along a glass tube

A long glass tube is set up as shown.

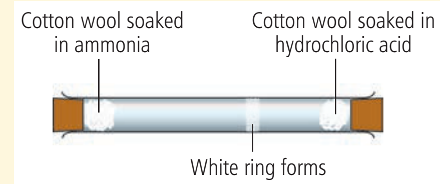


Figure 1.5.4 Apparatus to show the diffusion of gases.

Concentrated hydrochloric acid gives off fumes of a colourless gas called hydrogen chloride. Concentrated ammonia solution gives off colourless ammonia gas. These gases diffuse along the tube. After a few minutes a white ring is seen nearer one end of the tube. When the molecules of ammonia and hydrogen chloride collide with each other they react and form a white solid, ammonium chloride.

Supplement

Speed of diffusion and molecular mass

The speed at which a gas diffuses depends on the mass of its molecules. We compare the mass of molecules with each other by using their relative molecular masses, M_r. The greater the relative molecular mass, the heavier the molecule.

At the same temperature, molecules with a lower M_r move faster than molecules with a higher M_r. The white ring is nearer the hydrogen chloride end of the tube. This shows that hydrogen chloride has heavier molecules than ammonia. So hydrogen chloride diffuses more slowly than ammonia.

KEY POINTS

- Diffusion is the gradual spreading out and mixing up of different particles by random movement.
- Diffusion in liquids is slower than diffusion in gases.
- S A gas with a higher molecular mass diffuses more slowly than a gas with a lower molecular mass.

SUMMARY QUESTIONS

1 Copy and complete using the words below:

different diffusion gases mixed particles random

The kinetic particle theory states that the _____ in liquids and _____ are in constant _____ motion. When freely moving particles collide, they bounce off each other in _____ directions. If the particles are different, they get _____ up together. This process is called _____.

2 Explain the following using the kinetic particle theory:

a A red-coloured crystal is placed at the bottom of a beaker of water. At the start of the experiment no colour is seen in the water. After two days, the red colour has spread throughout the water.

b A bottle of perfume is opened at the front of the classroom. After a little while, you can smell the perfume at the back of the classroom.

S 3 The relative molecular masses of four gases are: carbon dioxide 44; methane 16; nitrogen 28; oxygen 32. Put these gases in order of their rate of diffusion, with the fastest first.

SUMMARY QUESTIONS

1 Give definitions of:

(a) diffusion

(b) evaporation

(c) condensation.

2 Match each of the words on the left with two of the statements on the right.

solid	particles close together particles move everywhere
liquid	particles far apart can flow but has a definite surface
gas	has a definite shape particles only vibrate

3 State whether energy is absorbed or released in these changes of state.

(a) A solid changes to a liquid.

(b) A gas changes to a liquid.

4 Match the words A to D with the definitions 1 to 4.

A anhydrous:	1 a substance which dissolves in a solvent
B hydrated:	2 a substance which does not contain water of crystallisation
C solute:	3 a substance which dissolves a solid, liquid or gas
D solvent:	4 a substance which contains water of crystallisation

5 Describe and explain using the kinetic particle theory how the volume of a gas changes when the temperature is gradually increased. Pressure is constant.

6 Use ideas about particles to explain why:

(a) a balloon gets bigger when you blow into it

(b) solids have a fixed shape

(c) you can't squash a sealed syringe full of water.

Practice questions

1 Sodium chloride is a solid which dissolves in water but not in hexane. Iodine is a solid which dissolves in hexane but not in water. Choose the mixture of substances which forms a solution.

A a mixture of iodine and sodium chloride
B a mixture of sodium chloride and hexane
C a mixture of iodine and hexane
D a mixture of sodium chloride and hexane [1]

(Paper 1)

2 A solution contains 2.0 g of copper(II) sulfate dissolved in 50 cm^3 of water. Choose the correct concentration of copper(II) sulfate solution.

A 0.4 g/cm^3 **C** 40 mol/dm^3
B 25 g/cm^3 **D** 40 g/dm^3 [1]

(Paper 2)

3 A crystal of a water-soluble red dye was placed in a beaker of water.

(a) Describe what you would see:
(i) after 10 minutes
(ii) after several days. [2]

(b) Describe the arrangement and motion of the particles in:
(i) the crystal [2] **(ii)** the water. [2]

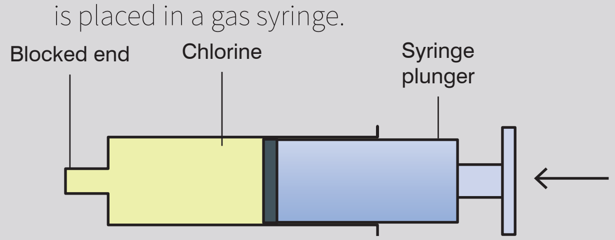
4 (a) Name the change of state from:
(i) solid to liquid **(ii)** liquid to gas
(iii) gas to liquid. [3]

(b) Which two of these changes of state occur when energy is absorbed? Explain your answer using ideas about forces between particles. [2]

(c) Describe the arrangement and motion of the particles in a gas. [2]

(Paper 3)

5 Chlorine is a green gas. A sample of chlorine is placed in a gas syringe.



(a) Describe and explain what happens when pressure is applied to the syringe plunger. The temperature was kept at 20 °C. [2]

(b) The experiment is repeated at 40 °C. The pressure is constant. Describe and explain the difference in the volume of gas in the syringe. [2]

(c) Chlorine dissolves in hexane to form a solution.

(i) Choose from the list, the word that best describes the chlorine in this solution.

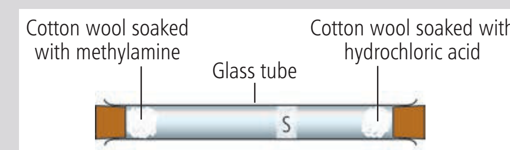
gas saturated solute solvent [1]

(ii) State the units of concentration in a solution. [1]

(d) Chlorine is a liquid at −120 °C. Describe the arrangement and motion of the particles in liquid chlorine. [2]

(Paper 3)

6 A student set up the apparatus shown.



Methylamine and hydrochloric acid give off vapours which react with each other to form a white ring at point S in the tube.

(a) Use ideas about moving particles and energy to explain:

(i) the process of evaporation from the cotton wool [2]

(ii) how the particles of methylamine and hydrogen chloride move along the tube. [2]

(b) Describe and explain the position of the white ring, S, in the tube. [2]

(c) An ammonia molecule has about half the mass of a methylamine molecule. If ammonia is used in this experiment in place of methylamine:

(i) predict the position of the white ring [1]

(ii) suggest why the white ring would be in this position by referring to molecular mass. [2]

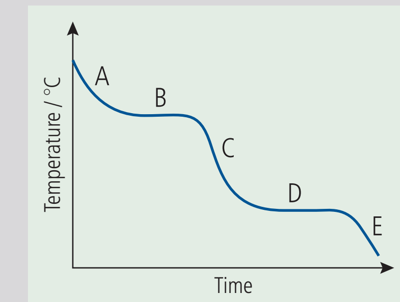
(Paper 4)

7 Sodium reacts with water to produce hydrogen gas.

(a) Describe and explain using the kinetic particle theory, the effect of decreasing the volume on the pressure of hydrogen gas in a gas syringe. The temperature stays the same. [3]

(b) Describe and explain the change in state when water changes into steam. Use the kinetic particle theory and ideas about energy changes. [3]

(c) The diagram shows the cooling curve when sodium gas is cooled to form solid sodium.



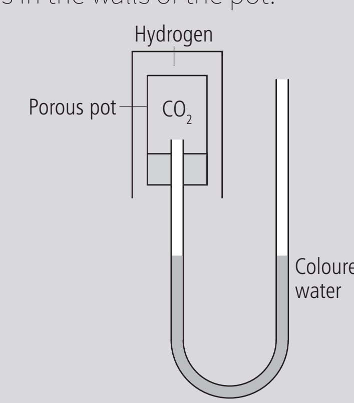
(i) State which letter on the curve shows:
- a liquid cooling
- a gas changing to liquid at the boiling point. [2]

(ii) Explain what happens to the motion and separation of the particles when a gas changes to a liquid. [2]

(iii) Explain, in terms of energy changes, the shape of the curve between C, D and E. [3]

(Paper 4)

8 The diagram shows a porous pot, which allows the passage of gases through tiny holes in the walls of the pot.



(a) Describe how this apparatus can be used to show that hydrogen has a lower molecular mass than carbon dioxide. [3]

(b) Explain your answer to part (a) using the kinetic particle theory. [5]

(Paper 4)

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