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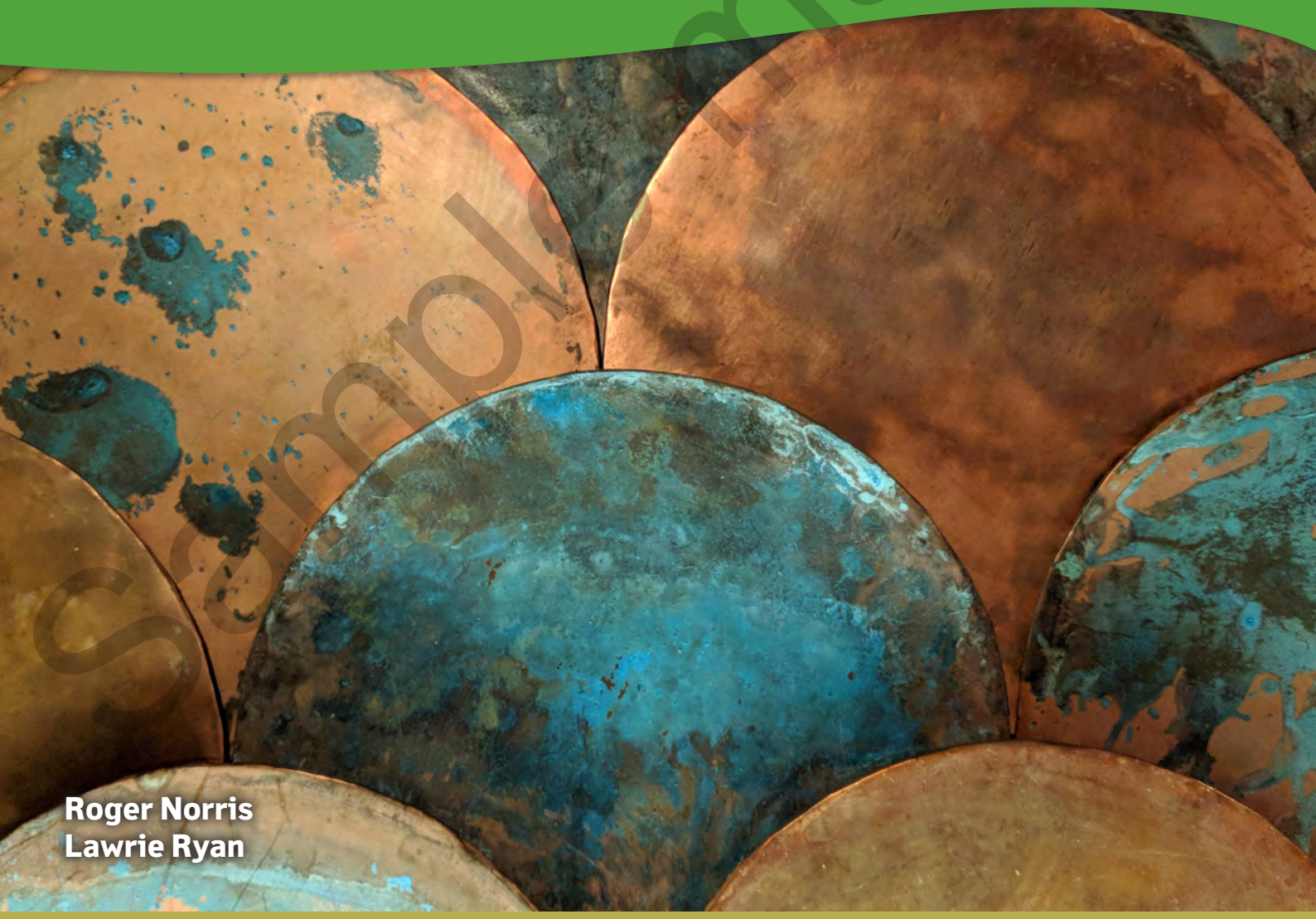
# Cambridge IGCSE® & O Level
# Chemistry



Roger Norris
Lawrie Ryan



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# Particle theory

## Revision checklist

Tick these boxes to build a record of your revision. Columns 2 and 3 can be used if you want to make a record more than once.

| Core/**Supplement** syllabus content | | 1 | 2 | 3 |
|---|---|---|---|---|
| 1.1 | Describe the general properties of solids, liquids and gases. | | | |
| 1.1 | Describe the structures of solids, liquids and gases in terms of particle separation, arrangement and motion. | | | |
| 1.1 | State the effect of temperature and pressure on the volume of gases. | | | |
| 1.2 | Describe the changes of state in terms of melting, boiling, evaporation, freezing and condensation. | | | |
| 1.2 | **Explain, using the kinetic particle theory, the effects of pressure and temperature on the volume of a gas.** | | | |
| 1.3 | Understand differences in physical state in terms of melting points and boiling points. | | | |
| 1.3 | **Explain changes of state using the kinetic particle theory.** | | | |
| 1.3 | **Interpret cooling curves and heating curves.** | | | |
| 1.4 | Define the terms solvent, solute, solution and saturated solution. | | | |
| 1.4 | State that concentration can be measured in $g/dm^3$ or $mol/dm^3$. | | | |
| 1.4 | Describe the chemical tests for water. | | | |
| 1.4 | State the meaning of the terms hydrated, anhydrous and water of crystallisation. | | | |
| 1.4 | Explain why distilled water is used in practical chemistry. | | | |
| 1.5 | Describe and explain diffusion using the kinetic particle theory. | | | |
| 1.5 | **Describe and explain the effect of molecular mass on the rate of diffusion in gases.** | | | |

# 1.1 Solids, liquids and gases

**You need to:**

- Describe the general properties of solids, liquids and gases; understand the term kinetic particle theory.
- 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.

**Recap**

The three physical **states** of matter are solids, liquids and gases.

*Solids* have a definite shape and volume but do not flow.

*Liquids* have a definite volume, take the shape of their container and can flow.

*Gases* have no particular volume and can spread everywhere.

**Exam tip**

**Watch out**

Take care not to muddle the general properties of solids, liquids and gases (flow, definite volume, presence of a surface) with the arrangement, motion and separation of the particles.

**Worked example**

State two differences in the general properties of a solid and a liquid. [2]

A solid has a definite shape. A liquid takes the shape of its container. ✓

A solid cannot flow but a liquid can flow. ✓

**Kinetic particle theory** is the idea that particles behave as hard spheres.

*Separation* of particles refers to how close the particles are.

*Arrangement* is either in fixed positions (in solids) or irregular (in liquids and gases).

*Motion* of particles in solids is only by vibration. In liquids the particles slide over each other. Gas particles bounce off each other.

**Exam tip**

Remember that in liquids the particles are close together. It is a common error to suggest they are some distance apart.

**Worked example**

Use the kinetic particle theory to describe the arrangement and motion of the particles in solid copper and liquid copper. [4]

In solid copper the particles are regularly arranged in fixed positions. ✓

In liquid copper the particles are arranged randomly – there is no particular arrangement. ✓

The particles in solid copper only vibrate. ✓

The particles in liquid copper slide over each other. ✓

**Exam tip**

Make sure that you know the difference between the words arrangement and separation when referring to particles. These are often confused.

## Apply

1. Make a table of the types of motion, separation and arrangement of the particles in solids, liquids and gases.

**Exam tip**

Remember that the motion in solids is vibration only. Movement from place to place only happens in liquids and gases.



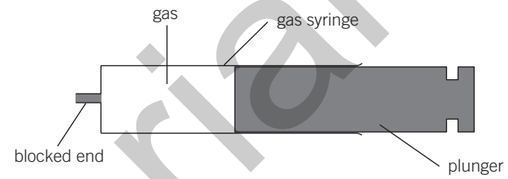


An *increase in pressure* decreases the volume of a gas in a gas syringe.

An *increase in temperature* increases the volume of a gas in a gas syringe.

**Worked example**

A gas syringe has its end blocked.




Describe what happens to the volume and pressure when the plunger of the gas syringe is pushed in. [2]

The volume of gas decreases ✓ and the pressure increases. ✓

**Recap**

- The kinetic particle theory is about the motion of particles under different conditions.
- We imagine the particles as tiny hard spheres to help us.

# 1.2 Using the kinetic particle theory

**You need to:**

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

**Melting** is the change of state from solid to liquid.

**Boiling** is the change of state from liquid to gas at the boiling point.

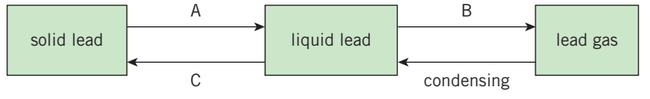
**Evaporation** is the change in state from liquid to vapour below the boiling point.

**Condensation** is the change in state from gas to liquid.

**Freezing** is the change of state from liquid to solid.

**Worked example**

State the changes of state labelled A, B and C. [3]




A is melting ✓ B is boiling or evaporation ✓ C is freezing ✓

**Key skills**

You need to be able to link scientific words such as condensation to the processes that they describe.

Supplement

*Energy is absorbed* during melting and boiling and released in condensing and freezing.

*The effect of pressure and temperature on the volume of a gas* depends on the frequency of particle collisions and the energy of the particles.

**Worked example**

Oxygen is a gas which turns into a liquid at −183 °C.

Describe and explain the change in energy of the oxygen particles which takes place when oxygen turns from a gas to a liquid. [2]

The oxygen particles have lost energy ✓ because energy is given out during condensation. ✓

Use the kinetic particle theory to explain why the pressure of oxygen in a closed container decreases when the temperature decreases from 0 °C to −100 °C. [2]

The particles move more slowly at a lower temperature – they have less **kinetic energy**. ✓

So they hit the walls of the container less frequently. ✓

**Recap**

Energy is absorbed when a substance melts or boils. Energy is released when a substance condenses or freezes.

## Apply

2. State and explain using the kinetic particle theory what happens to the volume of a gas in a gas syringe when the temperature decreases gradually to just below its boiling point. The pressure is constant.

# 1.3 Heating and cooling curves

**You need to:**

- Understand differences in physical state in terms of melting points and boiling points.
- **Explain changes of state using the kinetic particle theory; interpret cooling curves and heating curves.**

The *physical state* (solid, liquid or gas) can be deduced from melting and boiling point data.

**Exam tip**

**Watch out**

Take care with negative values: −20 °C is a lower temperature than −10 °C.

**Worked example**

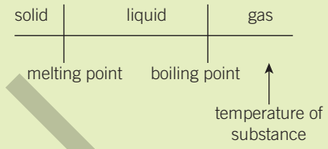
Bromine melts at −7 °C and boils at 59 °C. Deduce the physical state of bromine at 5 °C. Give a reason for your answer. [2]

Liquid ✓ because 5 °C is above the melting point and below the boiling point. ✓



**Exam tip**

When answering questions about the physical state of a substance given the melting and boiling points, it may help you to draw a diagram like this.



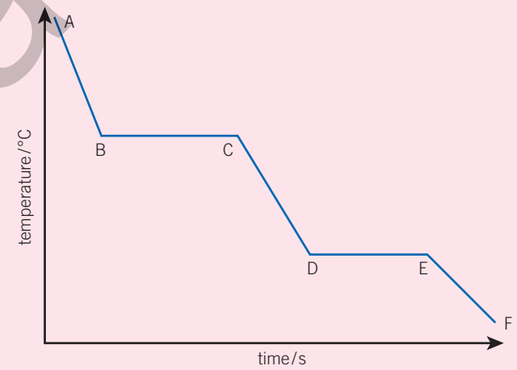

▲ **Physical state change**

*Energy changes* take place when there is a change of state.

A **cooling curve** shows how the temperature changes with time when a gas is slowly cooled to form a liquid or a liquid is slowly cooled to form a solid.

**Worked example**

The temperature of gas **X** decreases as it cools. The cooling curve for gas **X** is shown.




Deduce where **X** is freezing and explain using the kinetic particle theory the shape of the cooling curve between the points **A**, **B** and **C**. [5]

**X** freezes between **D** and **E**. ✓

Between **A** and **B** the temperature of the *gas* is decreasing ✓ because the particles are losing kinetic energy. ✓ Between **B** and **C** the gas is condensing ✓ so energy is being given out. ✓ The temperature remains constant because the decrease in energy of the molecules is balanced by the energy given out. ✓

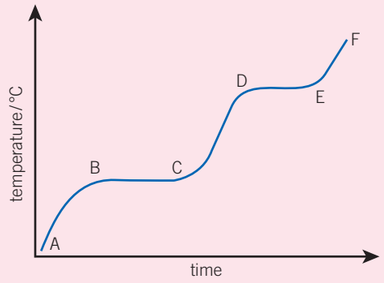
(Note that there are more marking points than marks given for the question)

**Recap**

The flat parts of a cooling curve or **heating curve** are where there is a change of state. For example, solid to liquid or gas to liquid.

## Apply

3. A pure liquid with a melting point of 45 °C is cooled from 60 °C to 30 °C. Describe and explain the cooling curve in terms of the kinetic particle theory.
4. The diagram shows a heating curve starting with a solid.



# 1.4 Solvents, solutes and solutions

**You need to:**

- Define the terms solvent, solute, solution and saturated solution; state that concentration can be measured in g/dm³ or mol/dm³.
- Describe the chemical tests for water; state the meaning of the terms hydrated, anhydrous and water of crystallisation; explain why distilled water is used in practical chemistry.

**Key skills**

You are expected to know the definitions for chemical terms such as saturated solution which appear in the syllabus.

A **solvent** is a substance which dissolves other substances.

A **solute** is a substance which dissolves in a solvent.

A **solution** is a mixture in which a solute is spread evenly throughout the solvent.

A **saturated solution** contains the maximum concentration of solute dissolved in a solvent at a particular temperature.

**Aqueous** means dissolved in water.

*Distilled water* is used in practical chemistry because it does not contain dissolved substances which react with added solutes.

**Worked example**

A student wants to do some experiments using sodium chloride solution. The sodium chloride is dissolved in distilled water until no more salt can dissolve at a particular temperature.

State the name of the type of solution formed when no more solute can dissolve. [1]

saturated solution. ✓

Suggest why distilled water is used instead of tap water. [1]

Substances present in tap water may interfere with the experiments. ✓

Give the chemical name for the solution formed when sodium chloride dissolves in water. [1]

aqueous sodium chloride. ✓

**Exam tip**

**Watch out**

Make sure that you include key words in definitions. For example, in defining a saturated solution, the words 'maximum' and 'at a particular temperature' are important.

**Concentration** is mass (in grams) or moles of substance divided by volume of solution (in dm³).

*Concentration is measured* in g/dm³ or mol/dm³ (for the meaning of mol see Chapter 6).

**Exam tip**

**Watch out**

Make sure that you are working with the correct units of volume (cm³ or dm³) when answering questions about concentration.

**Key skills**

You need to be able to convert dm³ (**decimetres cubed**) to cm³ (centimetres cubed) by multiplying volume in cm³ by 1000.

You need to be able to convert cm³ to dm³ by dividing volume in dm³ by 1000.

**Worked example**

Calculate the concentration of aqueous sodium chloride in g/dm³ when 15 g of sodium chloride is dissolved to make 200 cm³ of solution. [2]

$$200\ cm^3 = \frac{200}{1000} = 0.20\ dm^3 \checkmark$$

$$\text{concentration} = \frac{\text{mass}}{\text{volume in dm}^3}$$

$$\text{concentration} = \frac{15}{0.2} = 75\ g/dm^3 \checkmark$$

## Apply

5. Calculate the concentrations in g/dm³ or mol/dm³ of:
   a. 24 g sodium chloride in 200 cm³ of solution
   b. 56 g sodium hydroxide in 400 cm³ of solution
   c. 0.50 g magnesium nitrate in 4 dm³ of solution
   d. 0.20 mol sodium chloride in 250 cm³ of solution

An **anhydrous solid** does not contain water.

A **hydrated solid** contains water.

**Water of crystallisation** is the water chemically combined in the structure of a crystal.

*Anhydrous copper(II) sulfate* turns from white to blue when water is added.

*Anhydrous cobalt(II) chloride* turns from blue to pink when water is added.

**Worked example**

The equation shows the reaction of anhydrous copper(II) sulfate with water.

$$CuSO_4 + 5H_2O \rightleftharpoons CuSO_4 \cdot 5H_2O$$

State the meaning of the term anhydrous. [1]

A solid which does not contain water. ✓

State the colour change when water is added to anhydrous copper(II) sulfate. [2]

From white ✓ to blue. ✓

State the name given to the water present in the structure of $CuSO_4 \cdot 5H_2O$. [1]

Water of crystallisation. ✓

**Recap**

- Hydrated crystals contain water of crystallisation.
- Solids without water of crystallisation are anhydrous.

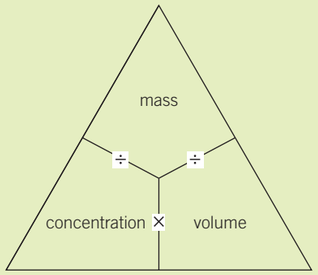
**Recap**

concentration

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

**Exam tip**

The equation triangle may help you rearrange the equation for concentration. Cover the quantity you want to find. You will then see the form of equation to use.




▲ Equation triangle

**Exam tip**

When making up solutions accurately, you dissolve the solid in a small amount of solvent then make it up to the volume required. You do not add the solid to the volume of solvent required.

**Key skills**

You need to be able to rearrange equations. For example, rearrange

$$\text{concentration} = \frac{\text{mass}}{\text{volume}}$$

to make mass the subject:

mass = concentration × volume

You need to memorise the colour changes of particular reactions stated in the syllabus.

# 1.5 Diffusion

**You need to:**

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

### Exam tip

**Watch out**

Make sure that you include the word particles when writing answers to questions about diffusion. Writing 'the gas moves' or 'the ink moves' will not get you the marks.

### Exam tip

It is better to write that the particles diffuse by random movement or random collisions rather than they '*move from a higher to a lower concentration*'. The words in italics suggest that movement only takes place in one direction rather than in all directions.

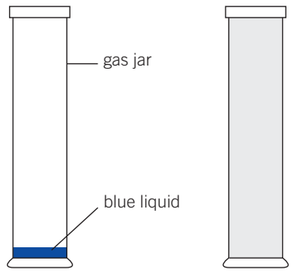
### Recap

Diffusion is the spreading out and mixing of different particles because of their random movement.

**Diffusion** is the spreading out and mixing of different particles because of their random movement.

#### Worked example

A gas jar contains a blue liquid which easily turns into a gas at room temperature. After 1 hour, the blue colour of the gas has spread throughout the gas jar. Explain this using the kinetic particle theory. [3]




The particles of gas have moved ✓ randomly ✓ by diffusion ✓ so they have spread throughout the jar.

## Apply

6. Explain using the kinetic particle theory why it takes time for a smelly gas 20 m distant from you to reach your nose by diffusion.

The rate of diffusion is faster the lower the relative molecular mass of a substance. S

#### Worked example

A dish containing a substance, **A**, that has a strong smell is placed at the front of a classroom. A student at the back of the room does not smell substance **A** at first. After 10 seconds the student can smell substance **A**. The experiment is repeated using a different substance **B** which has twice the relative molecular mass of **A** and a similar smell. Suggest how long it takes for the student to smell substance **B**. Explain your answer. [2]

**B** takes 15–20 seconds – it will be more than 10 seconds. ✓ Because the higher the molecular mass, the lower the rate of diffusion. ✓





## Questions

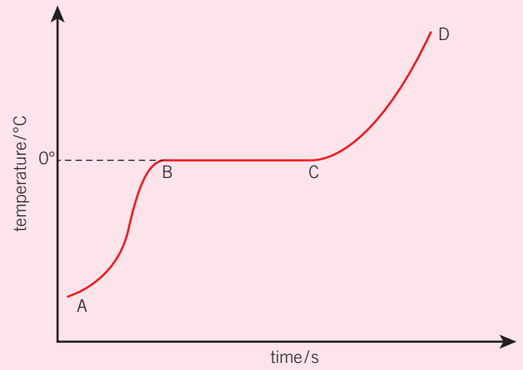
1. Describe the motion and separation of the particles in liquid bromine and bromine gas. [4]
2. Draw a sketch graph to show the effect of increasing pressure on the volume of gas in a syringe at constant temperature. [2]
3. State the names of these changes of physical state.
   - **a.** solid to liquid
   - **b.** gas to liquid
   - **c.** liquid to gas below the boiling point [3]
4. Iodine melts at 114 °C and boils at 184 °C. Deduce the physical state of iodine at 100 °C. Give a reason for your answer. [2]
5. The equation shows the reaction of anhydrous cobalt(II) chloride with water.

   $$CoCl_2 + 6H_2O \rightleftharpoons CoCl_2 \cdot 6H_2O$$

   - **a.** State the meaning of the term anhydrous. [1]
   - **b.** State the colour change in this reaction. [2]
   - **c.** Give the chemical name of $CoCl_2 \cdot 6H_2O$. [1]
6. Choose words from the list to complete the following sentence.

   amount maximum minimum solute solution solvent volume water

   A saturated solution contains the ..... concentration of ..... dissolved in a ..... at a particular temperature. [3]
7. Calculate:
   - **a.** The concentration, in g/dm$^3$, of 4 dm$^3$ of a solution containing 20 g of solid. [1]
   - **b.** The concentration, in mol/dm$^3$, of 50 cm$^3$ of solution containing 2 mol of solid. [2]
   - **c.** The mass of solid in 0.20 dm$^3$ of a solution of concentration 30 g/dm$^3$. [2]
   - **d.** The volume of a solution, in cm$^3$, of concentration 12.5 g/dm$^3$ that contains 0.50 g of solute. [3]
8. Explain in terms of the kinetic particle theory why a drop of ink placed in water gradually spreads throughout the water. [3]
9. S Use the kinetic particle theory to explain why the volume of gas in a syringe increases as the temperature increases. [3]
10. Part of a heating curve for water is shown.



Raise your grade

**a.** State which part of the curve shows ice being heated. Give a reason for your answer. [2]

**b.** Explain the shape of this curve in terms of kinetic particle theory. [4]

**11.** The rate of diffusion of two gases methane, $CH_4$, and ethane, $C_2H_6$ are compared. State and explain which of these gases diffuses faster. [2]

## Sample question

This question is about solids, liquids, gases and solutions.

**1. a.** Define the term solute. [1]

**b.** Iodine is soluble in hexane.

**(i)** State the meaning of the term soluble. [1]

**(ii)** Calculate the concentration of iodine in 150 $cm^3$ of a solution of iodine in hexane which contains 1.2 g of iodine. Give your answer in $g/dm^3$. [1]

**(iii)** A crystal of iodine is dropped into a beaker of hexane. After an hour the colour of the iodine has spread throughout the hexane. Explain this using the kinetic particle theory. [3]

**c.** Bromine melts at −7 °C and boils at 59 °C.

**(i)** Deduce the physical state of bromine at −15 °C. Give a reason for your answer. [2]

**(ii)** State the name of the change of state when liquid bromine changes to bromine gas. [1]

**(iii)** Describe the arrangement and motion of the particles in bromine gas. [2]

**(iv)** State two characteristics of a gas. [2]

S **d.** Hydrogen chloride (relative molecular mass 36.5) and hydrogen bromide (relative molecular mass 81) are both gases.

**(i)** Which of these compounds diffuses faster at the same temperature? Explain your answer using the kinetic particle theory. [2]

**(ii)** Describe and explain what happens when the volume of a sample of hydrogen chloride in a gas syringe is decreased at constant temperature. [3]

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**email** schools.enquiries.uk@oup.com
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