Cambridge IGCSE · Chemistry 0620 · Notes

States of matter

Read online at **pastopic.com/cambridge/chemistry-0620/notes/states-of-matter**

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What you need to know

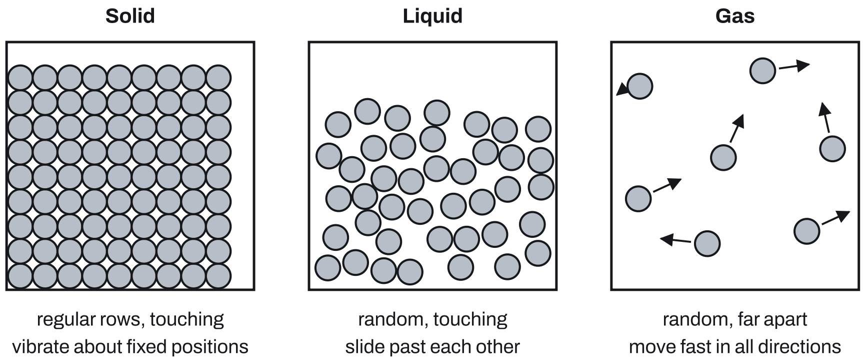
By the end of this topic you should be able to:

1. **State the properties that tell solids, liquids and gases apart**: whether they have a fixed shape, a fixed volume, and whether they can be squashed (compressed) or poured.
2. **Describe the particles in each state** using three words: **separation** (how far apart they are), **arrangement** (regular or random) and **motion** (how they move).
3. **Name the changes of state**: melting, freezing, boiling, evaporating and condensing.
4. **Describe how temperature and pressure change the volume of a gas.**
5. **Extended only:** explain changes of state with the kinetic particle theory (what happens to the particles and their energy), and read heating and cooling curves.
6. **Extended only:** explain, with the kinetic particle theory, why temperature and pressure change the volume of a gas.
7. **Describe and explain diffusion** in terms of moving particles.
8. **Extended only:** describe and explain how the relative molecular mass, M_r, of a gas affects how fast it diffuses.

Understand it

Everything is made of moving particles

The **kinetic particle theory** says that all matter is made of tiny particles (atoms, molecules or ions) that are always moving. "Kinetic" means "to do with movement". The hotter a substance is, the more kinetic energy its particles have and the faster they move. The particles also attract each other. Which state a substance is in depends on the contest between these two things: the attractions pulling the particles together and the movement shaking them apart.



Solids

In a solid the attractions win. The particles are **close together (touching)**, in a **regular arrangement** (neat rows, a lattice), and they can only **vibrate about fixed positions**. They cannot swap places.

So a solid has a **fixed shape** and a **fixed volume**, and it **cannot be compressed**: the particles are already touching, so there is no space to push them into.

Liquids

In a liquid the particles have more energy. They are still **close together (touching)**, but the arrangement is **random** (irregular), and they **move around, sliding past each other**.

So a liquid has a **fixed volume** but **no fixed shape**: it flows and takes the shape of its container. It **cannot be compressed**, for the same reason as a solid.

Gases

In a gas the particles have so much energy that they have broken away from each other. They are **far apart**, in a **random arrangement**, and they **move quickly and randomly in all directions**, in straight lines until they hit another particle or the container wall.

So a gas has **no fixed shape and no fixed volume**: it spreads out to fill whatever container it is in. It **can be compressed easily**, because there is lots of empty space between the particles.

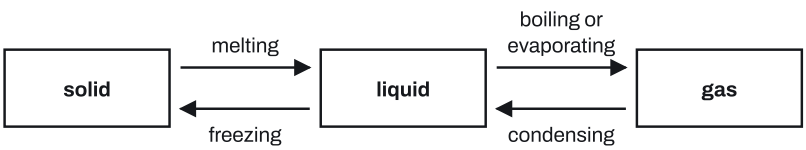
	Solid	Liquid	Gas
Separation	touching (close together)	touching (close together)	far apart
Arrangement	regular	random	random
Motion	vibrate about fixed positions	slide past each other	move fast, in all directions
Shape	fixed	takes the shape of the container	fills the container
Volume	fixed	fixed	not fixed
Compress?	no	no	yes, easily

The particles in a solid are packed most closely, so the same volume of solid holds the most particles. A liquid of the same substance holds slightly fewer (its particles are touching but with a few gaps), and a gas holds far fewer. (Water is the usual exception: ice floats because its particles are slightly further apart than in liquid water.)

Changes of state

When you heat a substance its particles gain energy; when you cool it they lose energy. At certain temperatures this makes the substance change state.

left to right: energy taken in, particles move faster and further apart



right to left: energy given out, particles slow down and move closer

- **Melting**: solid → liquid, at the **melting point**.
- **Freezing**: liquid → solid, at the same temperature (the melting point and freezing point of a pure substance are equal).
- **Boiling**: liquid → gas, at the **boiling point**, all through the liquid (you see bubbles of gas forming inside it).
- **Evaporating**: liquid → gas, **below** the boiling point, only from the **surface**. Puddles dry up and wet washing dries this way. The fastest particles at the surface have enough energy to escape.
- **Condensing** (condensation): gas → liquid, for example steam turning to water droplets on a cold window.

Past papers sometimes also use **sublimation** for a solid turning straight into a gas (and the change back), for example solid carbon dioxide or iodine. It is not on the syllabus list, but it helps to recognise the word.

Melting, boiling and evaporating **take in** energy (they are endothermic). Freezing and condensing **give out** energy (exothermic). These are all **physical changes**: no new substance is made, and the change can be reversed.

Using melting and boiling points

Compare the temperature with the melting point (m.p.) and boiling point (b.p.):

- below the melting point: **solid**;
- between the melting point and the boiling point: **liquid**;
- above the boiling point: **gas**.

For example, bromine melts at -7 °C and boils at 59 °C, so at room temperature (25 °C) it is a liquid. Oxygen boils at -183 °C, so it is a gas at room temperature. "Room temperature" means about 20–25 °C.

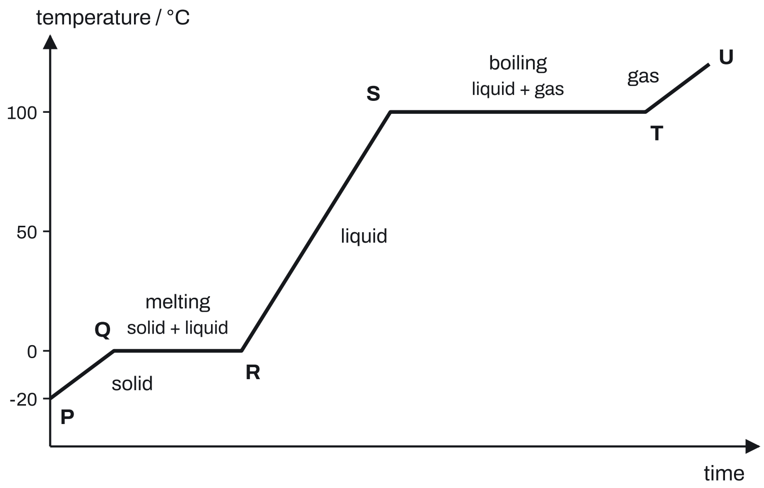
Explaining changes of state (Extended)

Extended only: when a solid is heated, its particles vibrate more and more strongly. At the melting point they have enough energy to **overcome some of the attractive forces** holding them in place, so they leave their fixed positions and start to slide past each other: the solid melts. Heating the liquid makes the particles move faster; at the boiling point they have enough energy to **overcome the remaining attractive forces**, escape from the liquid and move far apart: it boils.

Cooling does the reverse. The particles lose energy and slow down; the attractions pull them closer together (condensing), then into fixed positions in a regular arrangement (freezing). As the attractions form, energy is **released** to the surroundings.

Heating and cooling curves (Extended)

Extended only: if you heat a solid steadily and plot its temperature against time, you get a **heating curve**.



flat parts: the state changes, so the temperature stays the same

- **Sloping parts**: one state is being heated. The energy makes the particles move faster (more kinetic energy), so the temperature rises.
- **Flat parts**: the state is changing. The energy is being used to **overcome the attractive forces between particles**, not to make them move faster, so the **temperature stays the same** even though heating continues. The first flat part is at the melting point (solid and liquid both present); the second is at the boiling point (liquid and gas both present).
- Boiling usually takes longer than melting, because the particles must be separated completely.

A **cooling curve** is the same idea in reverse, from a gas or a liquid down to a solid. The flat parts are now condensing (at the boiling point) and freezing (at the melting point). The temperature stays constant there because the energy **released** as the particles are pulled together makes up for the heat being lost to the surroundings. A cooling curve often ends with a flat line at room temperature: that is not a change of state, just the substance having cooled as far as it can.

How temperature and pressure change a gas's volume

Think of a fixed amount of gas in a sealed syringe whose plunger can move freely.

- **Temperature up** → **volume up** (at constant pressure). Temperature down → volume down.
- **Pressure up** → **volume down** (at constant temperature). Pressure down → volume up.

Extended only: the pressure of a gas is caused by its **particles colliding with the walls** of the container.

- **Heating** gives the particles more kinetic energy, so they move faster and hit the walls **more often and harder**. In a container that can expand (a syringe, a balloon), the gas pushes outwards and expands until the pressure is back to what it was: the particles end up further apart. In a container that cannot expand (a sealed can), the volume stays the same and the **pressure rises** instead.
- **Increasing the pressure** at constant temperature pushes the particles **closer together**, into a smaller volume. There is room to do this because gas particles are far apart. The particles' speed does not change, because the temperature has not.
- Squeezing the same gas into a smaller volume, or putting more particles into the same volume, means more collisions with the walls per second, so a higher pressure.

The size of the particles never changes: only their speed and how far apart they are.

Diffusion

Diffusion is the net movement of particles from where they are at a **high concentration** to where they are at a **low concentration**, caused by their **random movement**. Nobody stirs the mixture: the particles' own motion mixes them until they are evenly spread.

- Open a bottle of perfume and after a while it can be smelled across the room. The gas particles move randomly, colliding with air particles, and spread out.
- A drop of bromine in a gas jar: the brown colour gradually fills the whole jar.
- A coloured crystal at the bottom of a beaker of water first **dissolves** (its particles separate and mix with the water), then the particles **diffuse**, until the colour is the same everywhere. Two processes: dissolving **and** diffusion.

Diffusion happens easily in **gases**, more slowly in **liquids** (the particles move more slowly and keep bumping into their close neighbours), and not in solids, where the particles cannot move from their places.

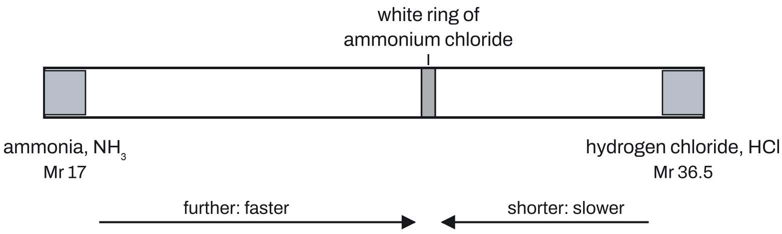
Many questions use a **long tube**: cotton wool soaked in a solution that gives off a gas at one end, and damp indicator paper at the other. The paper changes colour only after a short time, because the gas particles have to diffuse along the tube, colliding with air particles on the way. At first there are none at the far end; after a while enough have arrived to change the paper.

Diffusion and relative molecular mass (Extended)

Extended only: at the same temperature, **lighter particles move faster** than heavier ones. So a gas with a **lower relative molecular mass** diffuses **faster**.

To compare gases, work out each M_r by adding the relative atomic masses (from the Periodic Table). The smallest M_r diffuses fastest; the largest diffuses slowest. Two gases with the same M_r (such as carbon monoxide, CO, and nitrogen, N_2, both 28) diffuse at the same rate.

The classic experiment puts ammonia at one end of a long tube and hydrogen chloride at the other. Where they meet they react to make a white ring of solid ammonium chloride.



Ammonia ($M_r = 14 + 3 = 17$) is lighter than hydrogen chloride ($M_r = 1 + 35.5 = 36.5$), so ammonia molecules move faster and travel further in the same time. The ring forms **nearer the hydrogen chloride end**. With a heavier gas instead of hydrogen chloride, such as hydrogen bromide ($M_r = 81$), the ring forms even nearer that end.

Key facts and formulas

There are no formulas to use in this topic; these are the facts to learn. The syllabus's own formula list has nothing for it, so everything here is **Learn it**.

Formula	Status
Solid: touching, regular, vibrate about fixed positions; fixed shape and volume; not compressible	Learn it
Particles in the same volume: solid most, liquid slightly fewer, gas far fewer	Learn it
Liquid: touching, random, slide past each other; fixed volume, takes the container's shape; not compressible	Learn it
Gas: far apart, random, move fast in all directions; fills the container; easily compressed	Learn it
Melting (s → l), freezing (l → s), boiling and evaporating (l → g), condensing (g → l)	Learn it
Evaporating: below the boiling point, from the surface only; boiling: at the boiling point, throughout the liquid	Learn it
Below m.p. solid; between m.p. and b.p. liquid; above b.p. gas	Learn it

Formula	Status
Gas at constant pressure: temperature up, volume up	Learn it
Gas at constant temperature: pressure up, volume down	Learn it
Diffusion: net movement from high to low concentration, by the random movement of particles	Learn it
Extended only: lower M_r → faster diffusion; M_r = sum of the relative atomic masses	Learn it
Extended only: flat parts of a heating or cooling curve = change of state, temperature constant	Learn it
Extended only: gas pressure comes from particles colliding with the container walls	Learn it

How to do it

In the questions we have tagged for this topic (157 questions, 2021–2025, on Papers 1–4), the types came up this often. 23 of the 157 questions mix types, so the counts add up to more than 157.

Question type	Questions
Particles in solids, liquids and gases	45
Changes of state	38
Gas volume, temperature and pressure	27
Rate of diffusion and relative molecular mass	27
Explaining diffusion	24
State at a given temperature	15
Heating and cooling curves	10

1. Particles in solids, liquids and gases (45 questions)

1. **Read which words the question asks for**: arrangement, separation, motion, or two of them. Answer only those, one line each, and put each under its own heading.
2. **Use the exact words from the table** in "Understand it":
    - arrangement: **regular** (solid) or **random** (liquid, gas);
    - separation: **touching** or **close together** (solid, liquid) or **far apart** (gas);
    - motion: **vibrate** about fixed positions (solid), **slide past each other** (liquid), **move fast and randomly** (gas).

3. **Say something about the particles**, not the bulk substance. "It flows" is a property of a liquid; "the particles slide past each other" is its motion.

Variations you will meet:

- **"State two general properties of a gas (or a solid, or a liquid)."** These are the bulk properties: shape, volume, and whether it can be compressed. For a gas: no fixed shape, no fixed volume (fills its container), easily compressed.
- **Match descriptions to states**, for example "particles far apart, rapid motion in straight lines" is a gas.
- **"In which states are the particles a similar distance apart?"** Solid and liquid.
- **"Which can be compressed to half its volume?"** Only a gas.
- **Which state has the most particles in 1 dm^3?** The **solid**: its particles are packed most closely. A liquid holds slightly fewer and a gas far fewer (a hotter gas even fewer).
- **"Which state takes the shape of its container?"** Liquid or gas.
- **Describe the particles in a named substance at a stated temperature** (for example molten sodium chloride at 900 °C, or solid zinc). First decide the state, then describe that state. Molten or "liquid" means use the liquid description even for an ionic compound or a metal.

2. Changes of state (38 questions)

1. **Identify the start and end state**, then give the name from the diagram in "Understand it". Arrows in a solid–liquid–gas diagram are often labelled with letters: read which way each arrow points.
2. **Say whether energy is taken in or given out** if asked: taken in going solid → liquid → gas; given out going the other way.
3. **Describe what the particles do** if asked: moving to the right (towards gas) they speed up and move further apart; moving to the left they slow down and move closer together.

Variations you will meet:

- **Boiling vs evaporation.** Evaporation happens at any temperature below the boiling point and only at the surface; boiling happens at the boiling point and throughout the liquid. A liquid left in an open dish below its boiling point, which disappears over time, has **evaporated**.
- **Which changes happen when the temperature is lowered?** Condensing and freezing.
- **"Which change is exothermic?"** Condensing (or freezing).
- **"In which changes do the particles move further apart?"** Evaporating and boiling (liquid → gas), and any change towards a gas.
- **Changing ice into steam** needs two changes: melting, then boiling.
- **Solid to aqueous** (a solid going into solution) is **dissolving**, which is not a change of state.
- **Sublimation**, where it appears in older questions, is solid → gas directly.

3. Gas volume, temperature and pressure (27 questions)

1. **Identify what changes** (temperature or pressure) and what is kept constant.

2. **Give the effect on the volume**: temperature up → volume increases; pressure up → volume decreases. Reverse both for "down".
3. **Extended only: explain with particles**:
   - temperature up: particles gain kinetic energy, move faster, collide with the walls more often and with more force, so the gas expands and the particles move further apart;
   - pressure up: the particles are pushed closer together, so the volume is smaller.

Variations you will meet:

- **A sealed syringe with a free plunger, and a table to fill in** with "increases", "decreases" or "no change". Just the word; no explanation is needed unless asked.
- **A rigid container (fixed volume) heated**: the volume cannot change, so the pressure increases, the particles move faster and hit the walls more often and harder.
- **A balloon that expands slightly when heated**: its particles move faster **and** further apart.
- **Pressure decreased at constant temperature**: the particles' speed does not change; they spread out, so they collide less often.
- **Fastest and furthest apart**: high temperature and low pressure. **Most frequent collisions**: high pressure and high temperature.
- **Which container has the highest pressure?** The one with the most particles in the same volume (at the same temperature).
- **Combined changes**: if the temperature and pressure both rise but the volume stays the same, the particles move faster but their average distance apart does not change.
- **Heating a gas** never makes the particles themselves bigger.

4. Rate of diffusion and relative molecular mass (27 questions)

Extended only.

1. **Work out the M_r of each gas** from the formula, using the Periodic Table: for example $CH_4 = 12 + 4 = 16$; $SO_2 = 32 + 32 = 64$.
2. **Lowest M_r = fastest diffusion**; highest M_r = slowest.
3. **Explain** in the form "X has a lower relative molecular mass, so its molecules move faster (at the same temperature)". Say **relative molecular mass**, not "lighter gas" or "relative atomic mass".

Variations you will meet:

- **Put gases in order** of rate: sort by M_r.
- **Gases named, not given as formulae**, for example "the gas that makes up 78% of the air" (nitrogen) or "the gas made when a carbonate reacts with an acid" (carbon dioxide). Identify the gas first, then find its M_r.
- **Two gases diffuse at the same rate** only if they have the same M_r: CO and N_2 (both 28).
- **Where the white ring forms** in a tube with ammonia at one end and an acidic gas at the other: nearer the end of the gas with the **higher** M_r (it travels a shorter distance).

- **A time for one gas, predict another.** If a gas with a higher M_r replaces it, it diffuses more slowly, so the time is **longer**; with a lower M_r the time is shorter. Look for the one option that fits (and check whether the indicator changes to the right colour: acidic gases turn damp blue litmus or universal indicator red, ammonia turns damp red litmus blue).
- **Name an element** (from a list or a part of the Periodic Table) with the fastest or slowest rate of diffusion. Only consider the elements that are gases, and remember how they exist: nitrogen, oxygen, fluorine, chlorine and hydrogen are diatomic ($N_2 = 28$, $O_2 = 32$, $F_2 = 38$, $Cl_2 = 71$, $H_2 = 2$), while noble gases are single atoms ($Ne = 20$, $Ar = 40$). Among neon, nitrogen, oxygen and fluorine, neon diffuses fastest.

5. Explaining diffusion (24 questions)

These are usually the long-tube or gas-jar questions: "At first the paper does not change colour. After a short time it does. Explain these results in terms of the kinetic particle theory."

1. **Name the process: diffusion.**
2. **Mention particles (or molecules) and their random movement**: "the gas particles move randomly and collide with air particles".
3. **Say where they go**: they spread out from high concentration to low concentration, so after a while they reach the paper and react with it.

For example: "The hydrogen chloride particles diffuse along the tube by random movement. At first none have reached the paper, so it does not change. After a short time enough particles have spread to the other end to turn the paper red."

Variations you will meet:

- **If the gas comes from a liquid**, add "the liquid evaporates" first.
- **A crystal in water** whose colour spreads through the beaker: **dissolving** and then **diffusion**. It is not a chemical reaction.
- **"Describe why gases diffuse"** (not what they do): because their particles are in constant random motion.
- **In which states does diffusion happen readily?** Gases and liquids. Diffusion in a liquid is **very slow**.
- **"Which process is caused by gas particles colliding and moving randomly?"** Diffusion.
- **Aqueous ions can diffuse** in water; diffusion is not only for gases.

6. State at a given temperature (15 questions)

1. **Read off the melting point and boiling point.**
2. **Compare**: below the melting point, solid; between, liquid; above the boiling point, gas. Room temperature is about 25 °C.
3. **Give the reason using the numbers**, for example "liquid, because -75 °C is between its melting point (-101 °C) and boiling point (-35 °C)".

Variations you will meet:

- **A table of several substances**: pick the one that is a gas at 25 °C (boiling point below 25 °C), a liquid at 25 °C (melting point below and boiling point above), and so on. With negative numbers, -183 is **lower** than -35.
- **"In which elements do the particles vibrate about fixed positions at 0 °C?"** The solids at 0 °C: melting point above 0 °C.
- **Samples at a very low temperature**, such as -200 °C: check each one's melting and boiling points against it.
- **Match substances to data**, for example ethanol, sulfur and chlorine: chlorine is the gas (boiling point below room temperature), sulfur the solid, ethanol the liquid.
- **A pure substance melts and boils at one exact temperature**, so a boiling point given as a range (such as "107 °C to 117 °C") is not for a pure substance.
- **Predict the state** from a trend in a table (for example the halogens, where the missing value fits the pattern), then compare as usual.

7. Heating and cooling curves (10 questions)

Extended only.

1. **Find the flat parts.** Each is a change of state; its temperature is the melting (freezing) point or the boiling (condensing) point. The lower flat part is melting/freezing, the higher one is boiling/condensing.
2. **Name the state(s) on each part**: sloping parts are one state; a flat part has two states present.
3. **Explain the flat part**: the temperature stays constant because the energy is used to overcome the attractive forces between the particles (heating), or is released as the particles are pulled together (cooling), rather than changing their speed.
4. **Explain the sloping part**: the particles gain (or lose) kinetic energy, so the temperature rises (or falls).

Variations you will meet:

- **"Between which points do the particles change from fixed positions to being mobile?"** The melting flat part.
- **"Between which points is the substance freezing?"** The lower flat part on a cooling curve.
- **Draw the cooling curve** for a gas cooling from above its boiling point to below its melting point: slope down, flat at the boiling point, slope down, flat at the melting point, slope down.
- **A flat part at room temperature** at the end of a cooling curve is not a change of state.
- **Energy is absorbed on every part** of a heating curve, including the flat parts.
- **Ice melting in water**: the temperature stays the same, and the energy is used to overcome the attractive forces.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

Gallium is a metal. Its melting point is 30 °C and its boiling point is 2400 °C.

(a) State the physical state of gallium at 20 °C and at 50 °C. **[2]**

(b) Describe the arrangement and motion of the particles in gallium at 20 °C. **[2]**

(c) Liquid gallium is poured into a mould and left to cool. Name the change of state that happens. **[1]**

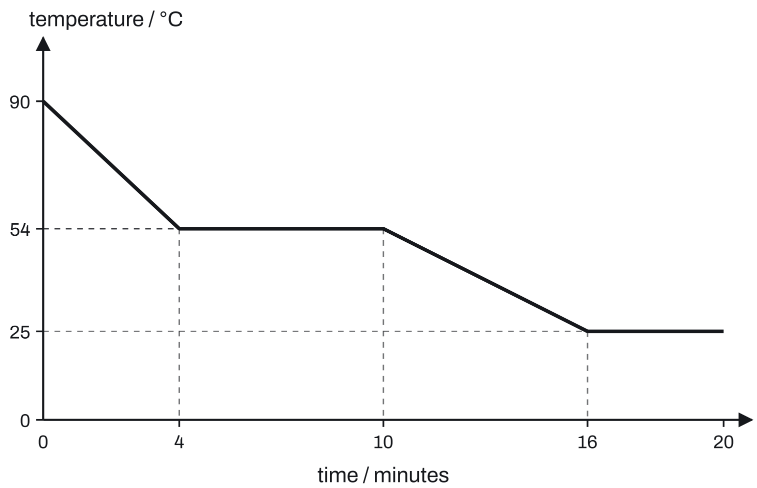
(a) 20 °C is below the melting point, so gallium is a **solid**. **B1** 50 °C is between the melting point and the boiling point, so it is a **liquid**. **B1**

(b) At 20 °C it is a solid. Arrangement: **regular** (in rows). **B1** Motion: the particles **vibrate about fixed positions**. **B1**

(c) Liquid to solid: **freezing**. **B1**

Example 2

Extended. Liquid Z is cooled from 90 °C. Its cooling curve is shown.



(a) State the freezing point of Z. **[1]**

(b) Name the physical state or states of Z between 4 and 10 minutes. **[1]**

(c) Explain, in terms of particles, why the temperature stays the same between 4 and 10 minutes. **[2]**

(d) Describe how the motion of the particles changes between 0 and 4 minutes. **[1]**

(e) Explain why the temperature stays the same between 16 and 20 minutes. **[1]**

(a) The first flat part is at 54 °C, so the freezing point is 54 **°C**. **B1**

(b) Z is freezing: **liquid and solid**. **B1**

(c) The particles are being pulled into fixed positions as attractive forces form between them. **M1** This **releases energy**, which balances the heat lost to the surroundings, so the temperature does not fall. **A1**

(d) The particles **lose kinetic energy, so they move more slowly** (still sliding past each other). **B1**

(e) Z has cooled to **room temperature** $(25$ °C), so it cannot lose any more heat to the surroundings; this is not a change of state. **B1**

Example 3

A long glass tube has cotton wool soaked in concentrated ammonia solution at one end and cotton wool soaked in concentrated hydrochloric acid at the other. Both ends are closed. After a few minutes a white ring of ammonium chloride forms inside the tube.

(a) Explain, in terms of the kinetic particle theory, how the two gases reach each other. **[2]**

(b) **Extended.** Calculate the relative molecular masses of ammonia, NH_3, and hydrogen chloride, HCl. Use them to explain whether the white ring forms nearer the ammonia end or the hydrochloric acid end. **[3]**

(c) **Extended.** The experiment is repeated with hydrogen bromide, HBr, in place of hydrogen chloride. Suggest how the position of the ring changes. **[1]**

(a) The ammonia and hydrogen chloride molecules **move randomly** and collide with air molecules. **M1** They **diffuse**, spreading from high concentration (at the cotton wool) to low concentration along the tube, until they meet. **A1**

(b) NH_3: $14 + 3 \times 1 = 17$. HCl: $1 + 35.5 = 36.5$. **B1** Ammonia has the lower relative molecular mass, so its molecules move faster and diffuse further in the same time. **M1** The ring forms **nearer the hydrochloric acid end**. **A1**

(c) HBr has $M_r = 1 + 80 = 81$, higher than HCl, so it diffuses even more slowly: the ring forms **even nearer the hydrogen bromide end**. **B1**

Example 4

A sealed gas syringe with a plunger that moves freely contains 60 cm³ of argon gas.

(a) The syringe is warmed and the pressure stays constant. State and explain the effect on the volume of the gas. **[3]**

(b) The plunger is pushed in, increasing the pressure, and the temperature stays constant. State the effect on the volume and on the separation of the particles. **[2]**

(a) The volume **increases**. **B1** The particles gain kinetic energy and move faster, **M1** so they collide with the walls and plunger more often and with more force, pushing the plunger out until they are further apart. **A1** (The explanation is Extended.)

(b) The volume **decreases**. **B1** The particles are pushed **closer together**. **B1** Their speed does not change, because the temperature is constant.

Common mistakes

- **Mixing up arrangement, separation and motion.** Examiners say this every year. Arrangement is regular or random; separation is touching or far apart; motion is vibrating, sliding or moving fast. Writing "the particles move freely" when asked for arrangement scores nothing.
- **Writing about the substance, not the particles.** "Liquids flow" or "gases fill the container" does not describe the particles. Start every line with "the particles ...".
- **Vague answers.** "The particles are a little apart" could mean a liquid or a gas; "they are separated" just repeats the question. Use **touching** or **far apart**.
- **"The particles in a liquid only vibrate"** or "they collide with each other". Vibrating is a solid; colliding happens in a gas too. For a liquid, say they **slide past each other**.
- **Confusing boiling and evaporation.** A liquid that disappears from an open dish below its boiling point has evaporated, not boiled.
- **Explaining diffusion without particles.** "The gas spreads out" or "the acid moves along the tube" is not enough. Name diffusion **and** say the particles (or molecules) move **randomly**.
- **Confusing diffusion with other processes**, such as the cotton wool moving, or the gas "reacting its way" along the tube.
- **Using the wrong reason for faster diffusion.** Say "lower **relative molecular mass**", not "fewer atoms", "lighter gas" or "lower relative atomic mass". Carbon monoxide (Mr 28) is not faster than methane (Mr 16) just because it has fewer atoms.
- **Explaining when asked to state.** "State the effect on the volume" needs one word: increases or decreases. Also, questions about gas volume are not about rates of reaction.
- **Getting heating curves wrong.** The temperature does **not** change during a change of state, and a flat part at the end of a cooling curve can just be room temperature.
- **Writing about the particles getting bigger** when a gas is heated. The particles stay the same size; they move faster and further apart.

How to get the marks

- **One mark per word asked for.** When a question asks for arrangement **and** motion, each is a separate mark. Label your two lines and use the key words: regular / random; touching / far apart; vibrate / slide past each other / move fast and randomly.
- **Mark schemes accept a few set words.** For a solid, "regular" or "in rows"; for a liquid, "random" or "irregular" and "slide past each other"; for a gas, "far apart" and "random" or "fast". Stick to these.
- **"Describe"** means say what the particles are like or what happens. **"Explain"** means give the reason too, in terms of particles and energy.
- **"In terms of the kinetic particle theory"** means you must mention **particles** (or molecules) and their **movement**. For diffusion: particles, random movement, and the word diffusion.
- **"State"** needs a short answer with no explanation, such as a name (condensing) or a word in a table (decreases).
- **Names must be exact**: melting, freezing, boiling, evaporating (or evaporation), condensing (or condensation). Use these words, not everyday ones.
- **Relative molecular mass explanations** need the comparison: "lowest M_r so it diffuses fastest".
- **State at a temperature** needs the reason with the numbers from the table, not just the state.
- **Multiple-choice questions** often turn on one word: "only", "fixed", "all", "same". Check every part of an option, both columns of a table row.

Quick check

1. Substance Q melts at -23 °C and boils at 77 °C. State its physical state at -50 °C, 25 °C and 100 °C.
2. Name the change of state: (a) water droplets forming on a cold window from steam; (b) molten wax turning solid as it cools.
3. **Extended.** Put these gases in order of rate of diffusion, fastest first: sulfur dioxide, SO_2; nitrogen, N_2; hydrogen, H_2; carbon dioxide, CO_2.
4. **Extended.** A sealed metal can of gas, which cannot change its volume, is heated. Explain what happens to the pressure inside the can.
5. **Extended.** On a heating curve, explain why the temperature stays the same while a solid melts.

Answers

1. -50 °C is below the melting point: **solid**. 25 °C is between -23 °C and 77 °C: **liquid**. 100 °C is above the boiling point: **gas**.
2. (a) Gas to liquid: **condensing**. (b) Liquid to solid: **freezing**.
3. M_r: $H_2 = 2$, $N_2 = 28$, $CO_2 = 12 + 32 = 44$, $SO_2 = 32 + 32 = 64$. The lowest M_r diffuses fastest: **H_2, N_2, CO_2, SO_2**.
4. The particles gain kinetic energy and move faster. They hit the walls of the can **more often and with more force**, so the **pressure increases**. (The volume cannot change, so the particles stay the same distance apart.)
5. The energy taken in is used to **overcome the attractive forces between the particles**, so they can leave their fixed positions. It does not make them move faster, so the temperature does not rise until all the solid has melted.

Past questions to try

- **0620/42/O/N/25 Q1**: parts (a)–(c) on particles, changes of state and why gases diffuse.
- **0620/33/O/N/23 Q4**: properties, changes of state, particles and a gas syringe.
- **0620/31/M/J/24 Q6**: part (f) explains a long-tube diffusion result.
- **0620/42/O/N/21 Q1**: particles, boiling and evaporation, and drawing a cooling curve.