States of matter

IGCSE Chemistry

The three states of matter

Everything around you is made of tiny **particles** – these can be **atoms**, **molecules**, or **ions**. The **kinetic particle theory** says these particles are always moving. How close the particles are, how they are arranged, and how they move decides whether matter is a **solid**, a **liquid**, or a **gas**.

Properties you can observe

You do not need a microscope to tell the three states apart. They behave in different ways:

- A solid has a fixed shape and a fixed **volume**. It does not flow and you cannot **compress** it (squeeze it smaller).
- A liquid has a fixed volume but no fixed shape. It flows and takes the shape of its container. It is almost impossible to compress.
- A gas has no fixed shape and no fixed volume. It flows and spreads out to fill the whole container. A gas is easy to compress.

The table below sums up these properties. **Density** means how much **mass** is packed into a given volume.

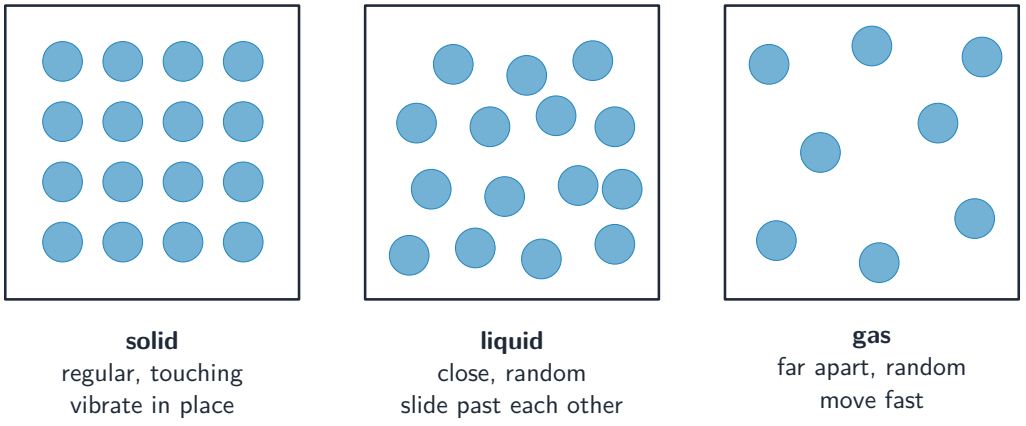
Property	Solid	Liquid	Gas
Shape	fixed	takes the shape of the container	fills the whole container
Volume	fixed	fixed	fills the whole container
Can it be compressed?	no	almost none	yes, easily
Does it flow?	no	yes	yes
Density	high	high	low

The particle picture

The kinetic particle theory explains these properties by looking at three things: the **separation** of the particles (how far apart they are), their **arrangement** (the pattern), and their **motion** (how they move).

	Solid	Liquid	Gas
Separation	touching, very close	close together	far apart
Arrangement	**regular** pattern	random, no pattern	random, no pattern
Motion	**vibrate** about fixed positions	move and slide past each other	move quickly in all directions

Strong **forces of attraction** hold the particles together. In a solid these forces are strong enough to hold every particle in place, so a solid keeps its shape. In a liquid the forces are weaker, so particles can move around. Gas particles are far apart and move randomly; attractions have little effect in this simple model, so the gas spreads through its container.



Particles are packed and regular in a solid, close and random in a liquid, and far apart in a gas

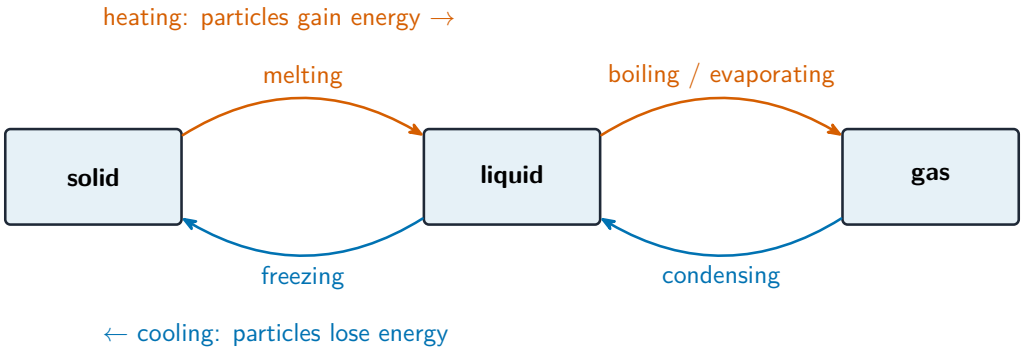
Changes of state

Ice melting to water: a change of state as the solid warms.

When you heat or cool a substance, it can change from one state to another. You must know the name of each change.

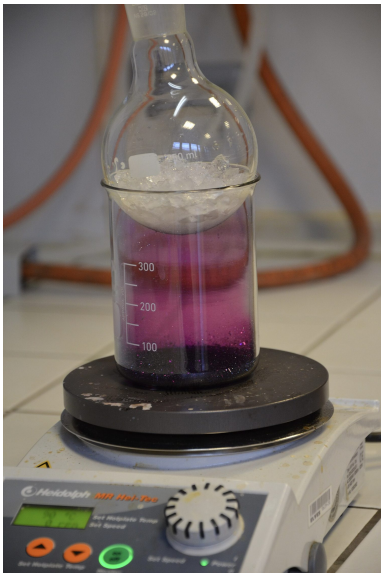
Change	**What happens**	**Name**
solid → liquid	**melting**	melting
liquid → solid	**freezing**	freezing
liquid → gas (at the surface, below the boiling point)	**evaporating**	evaporation
liquid → gas (all through the liquid)	**boiling**	boiling
gas → liquid	**condensing**	condensation

At a fixed pressure, a pure solid melts at one fixed temperature, the **melting point** . At a fixed pressure, a pure liquid boils at one fixed temperature, the **boiling point** . The same substance freezes at its melting point and condenses at its boiling point.



Heating: solid → liquid → gas; cooling reverses each change

A few substances change straight from solid to gas without melting first. This is called **sublimation** . In the photo below, warmed solid iodine in a beaker turns directly into a purple gas; the gas then cools on the round flask of ice above and turns back into a solid.



Warmed solid iodine turns straight into a purple gas (sublimation)

The everyday example: dry ice is solid carbon dioxide, and it sublimes too – it never leaves a puddle

Explaining changes of state with the particle theory

Each change of state is really a change in the **energy** of the particles.

- When you heat a solid, the particles gain energy and **vibrate** faster. At the melting point the particles have enough energy to break away from their fixed places and slide around – the solid melts.
- When you heat a liquid, the particles move faster. At the boiling point they have enough energy to fully escape the forces of attraction and become a gas.
- Cooling does the opposite. The particles lose energy, move more slowly, and the forces of attraction pull them back together.

During melting or boiling of a pure substance at fixed pressure, supplied energy overcomes forces of attraction between particles rather than increasing their average kinetic energy. Temperature stays constant during the change. This does not mean bonds within molecules break: melting ice still gives water, not hydrogen and oxygen.

Heating and cooling curves

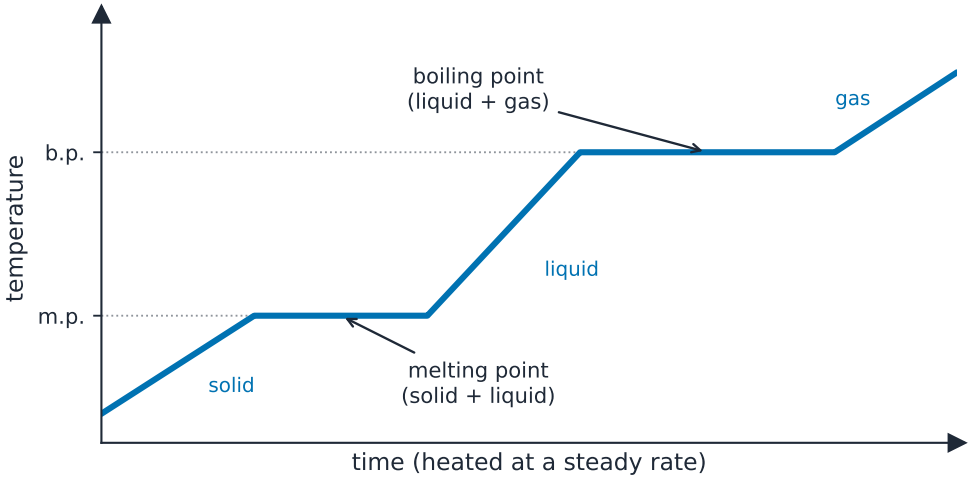
A **heating curve** is a graph of temperature against time as you heat a substance steadily. A **cooling curve** is the same graph as the substance cools.

For a pure substance heated from solid through liquid to gas at fixed pressure, the ideal heating curve has two flat parts:

- The first flat part is at the **melting point**. Here solid and liquid are both present. The supplied energy overcomes the forces holding particles in fixed positions, so the temperature does not rise.

- The second flat part is at the **boiling point**. Here liquid and gas are both present, and the temperature again stays constant.

A cooling curve is the reverse. It has a flat part at the boiling point (the gas condenses) and a flat part at the melting point (the liquid freezes). On falling single-state sections, average kinetic energy decreases. During the freezing and condensing plateaux, temperature stays constant while **thermal energy** is transferred to the surroundings.



plateau: attractions overcome; temperature constant

Temperature stays constant at the melting and boiling points while forces of attraction are overcome

Worked original curves: on 0620/22 November 2025 Q2, **Q–R** is melting: particles leave fixed positions and become mobile (option B). P–Q warms solid; S–T is boiling. On 0620/22 March 2025 Q2, **W–X** is liquid cooling: particles are close and randomly arranged (option C). V–W is condensation and X–Y is freezing. Cooling transfers energy out, including during the plateaux; a flat section does not mean no energy transfer.

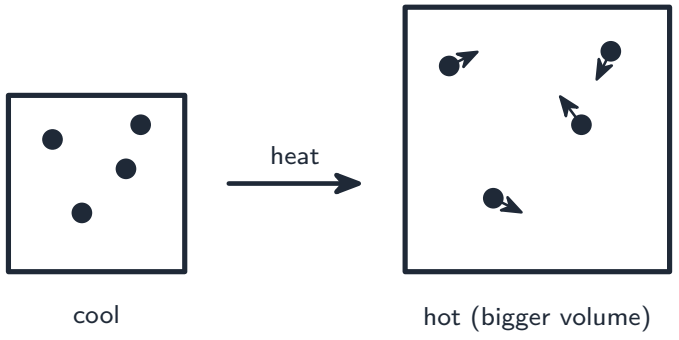
Melting is different from dissolving: ice becoming liquid water is melting. A soluble solid added to water becomes an aqueous solution by **dissolving**, the third physical change in 0620/42 November 2025 Q1(b). Heating the solid is not required for dissolving. Gas becoming liquid is condensation.

Gases: temperature, pressure and volume

A gas pushes on the walls of its container. This push, spread over the area of the wall, is the **pressure** of the gas. Pressure comes from the gas particles hitting the walls.

Effect of temperature

If you heat a fixed mass of gas while keeping the pressure the same, its volume increases.



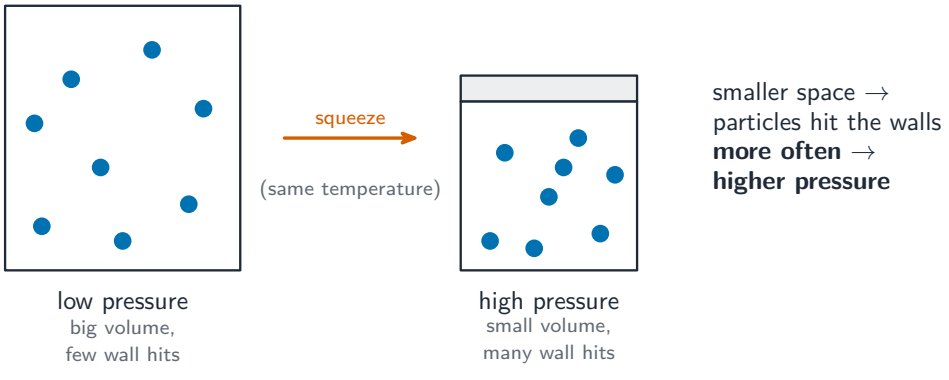
At constant pressure, heating a fixed mass of gas increases its volume; particles do not grow

Using the particle theory: heating gives the particles more **kinetic energy** , so they move faster. They hit the walls harder and more often. To keep the pressure the same, the gas must take up more space, so the volume gets bigger.

If instead the volume is fixed (a sealed, rigid container), heating the gas makes the pressure rise, because the faster particles **collide** with the walls harder and more often.

Effect of pressure

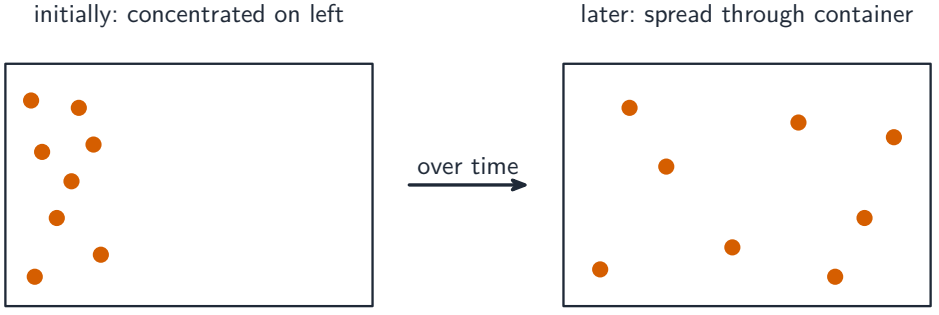
If you increase the pressure on a fixed mass of gas while keeping the temperature the same, its volume decreases. Squeezing the gas into a smaller space means the particles hit the walls more often, which is what a higher pressure means.



Squeezing a gas into a smaller volume makes the particles hit the walls more often, so the pressure rises

Diffusion

Diffusion is the net spreading of particles from a region where they are crowded to a region where they are spread out – that is, from high **concentration** to low concentration. It happens because particles are always moving in random directions.



Particles move randomly in all directions.
Net spreading: higher to lower concentration.

Net spreading is from higher to lower concentration; particles keep moving randomly after mixing

Diffusion explains why you can smell food from across a room: the smell particles move and mix with the air until they reach your nose. Diffusion happens in gases and in liquids, but not in solids, because solid particles cannot move from place to place.

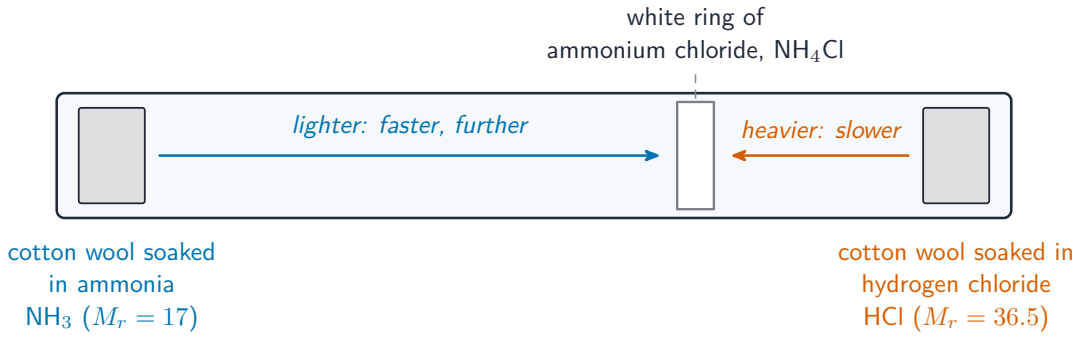
■ Rate of diffusion and molecular mass

Lighter gas particles move faster than heavier ones at the same temperature. So a gas with a smaller **relative molecular mass** (a smaller mass for each molecule) has a faster **rate** of diffusion.

A classic experiment shows this. Cotton wool soaked in **ammonia** (NH_3) is put at one end of a long glass tube. Cotton wool soaked in **hydrogen chloride** (HCl) is put at the other end. Both gases diffuse along the tube and meet to form a white ring of **ammonium chloride** (NH_4Cl).

$$NH_3 + HCl \rightarrow NH_4Cl$$

Ammonia has $M_r = 17$ and hydrogen chloride has $M_r = 36.5$. Ammonia is lighter, so it diffuses faster and travels further along the tube. The white ring forms nearer the hydrogen chloride end.



Ammonia ($M_r = 17$) is lighter, so it diffuses faster and further; the white ring forms nearer the HCl end

> **Worked example.** Nitrogen N_2 ($M_r = 28$) and carbon dioxide CO_2 ($M_r = 44$) diffuse at the same temperature under comparable conditions. Which diffuses faster? Nitrogen has the smaller relative molecular mass, so its molecules move faster on average and it diffuses faster. Compare molecular masses, rather than the length of the formula or the number of atoms. The ammonia/hydrogen chloride ring is a separate example in which diffusion is followed by a chemical reaction; do not assume that any two gases will produce such a ring.

A reaction is not just deposition: ammonia and hydrogen chloride form a new substance, solid ammonium chloride: $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$. This is a chemical reaction. Gas becoming solid is a physical change only when the substance stays the same, for example iodine vapour forming solid iodine. Ammonia and bromine do not provide chlorine atoms and cannot form ammonium chloride.

Common mistakes.

- Saying the particles themselves expand, melt or get hotter. The particles stay the same size; what changes is how fast they move and how far apart they are.
- Saying the temperature stays the same during melting because "no energy is going in". Energy is still being supplied; it is used to **overcome the forces of attraction** between particles, not to raise their speed.
- Saying boiling breaks the bonds inside the molecules. Boiling water gives steam (H_2O gas), not hydrogen and oxygen; only the forces **between** molecules are overcome.
- Saying the white ring in the diffusion tube forms in the middle, or nearer the ammonia end. Ammonia is **lighter** (M_r 17 against 36.5), so it travels further, and the ring forms **nearer the hydrogen chloride** end.
- Saying a heavier gas diffuses faster because it has more energy. At the same temperature, lighter particles move **faster**.

Exam tips

- During **melting** and **boiling** the temperature stays constant (the flat parts of a heating curve), because the energy overcomes attractions between particles instead of increasing their average kinetic energy. For a pure substance, compare at fixed pressure.
- **Evaporation** happens only at the surface and at any temperature; **boiling** happens throughout the liquid at one fixed temperature.
- Explain gas behaviour with the particle theory: heating a gas at fixed volume raises the pressure because the particles hit the walls harder and more often – the particles themselves do not get bigger.
- **Diffusion** in gases is faster for lighter particles (smaller M_r) at the same temperature. In the solid particle model, particles vibrate about fixed positions rather than moving through the solid. In the ammonia/hydrogen chloride tube the lighter ammonia travels further, so the white ring forms nearer the HCl end.