IGCSE CHEMISTRY 0620 · CHAPTER 1 NOTES · ~12 MIN READ

States of matter

Why solids keep their shape, why gases fill a room, and what really happens to the particles when you heat, cool or squash a substance — plus diffusion, explained properly.

Solids, liquids, gases | Changes of state | Heating curves | Gas pressure | Diffusion

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- Everything is made of **tiny particles**. The state — solid, liquid or gas — depends on how close the particles are and how freely they move.
- **Heating gives particles energy.** Enough energy and they break free of their neighbours: melting, then boiling.
- **Gas pressure** is particles hitting the walls of the container. Faster or more crowded particles = more hits = more pressure.
- **Diffusion** is the spreading of particles from where there are many to where there are few. Lighter particles spread faster. EXT

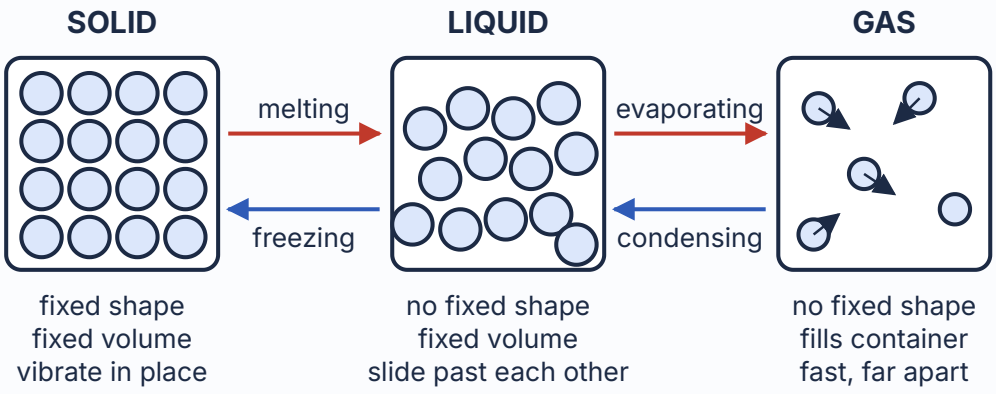
BY THE END YOU CAN

- Describe the arrangement, spacing and movement of particles in a solid, a liquid and a gas.
- Name the changes of state and say what happens to the particles in each.
- Explain heating and cooling curves with the particle model. EXT
- Describe how temperature and pressure change the volume of a gas, and explain it with particle theory. EXT
- Explain diffusion, and why light gases diffuse faster than heavy ones. EXT

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1 The three states of matter

Solid, liquid or gas?



red arrow: energy taken in · blue arrow: energy given out
boiling is evaporation throughout the liquid, at the boiling point

The particle model. Particles are drawn as circles. Arrows show movement. The gas has the most room to move; the solid has none.

Property	Solid	Liquid	Gas
arrangement	regular pattern, in rows	random, but touching	random, far apart
movement	vibrate about fixed positions	slide past each other	move quickly in all directions
forces between particles	very strong	strong	almost none
shape	fixed	takes the shape of its container	fills its container
volume	fixed	fixed	not fixed
can be compressed?	no	no (hardly at all)	yes — lots of empty space
density	high	high	very low

Particle model — the idea that all matter is made of tiny particles (atoms, molecules or ions) that are always moving or vibrating.

PICTURE IT

A **solid** is a packed lift: everyone is stuck in place, shuffling a little. A **liquid** is a busy station: people are close together but keep moving past each other. A **gas** is a few people running about in a huge empty hall.

EXAM TIP

When asked to describe a state, always give **three things**: how the particles are **arranged**, how **close** they are, and how they **move**.

COMMON MISTAKE

"Particles in a solid do not move." They do — they vibrate on the spot, but they cannot move from place to place.

COMMON MISTAKE

"The particles in a gas are lighter or smaller." The particles are the **same** particles in all three states. Only the spacing, forces and movement change.

2 Changes of state

The six changes

Change	From → to	Energy
melting	solid → liquid	taken in
freezing	liquid → solid	given out
boiling	liquid → gas	taken in
evaporation	liquid → gas (surface only)	taken in
condensation	gas → liquid	given out
sublimation	solid → gas directly	taken in

- **Sublimation** skips the liquid state. Examples: iodine crystals (purple vapour), solid carbon dioxide ("dry ice"). The reverse change — gas straight to solid — also happens, for example frost forming on a cold window.
- These are **physical changes**: no new substance forms, and the change can be reversed. See physical and chemical changes.

Boiling or evaporation?

	Boiling	Evaporation
temperature	only at the boiling point	at any temperature below the boiling point
where	bubbles form throughout the liquid	only at the surface
speed	fast	slow
particles	all particles have enough energy	only the fastest particles escape

- Evaporation **cools** the liquid left behind: the fastest, most energetic particles escape, so the average energy of the rest falls. That is why sweating cools you down.

What happens to the particles?

- **Melting:** the solid is heated, the particles vibrate more and more until they break out of their fixed positions and can slide past each other.
- **Boiling:** the particles gain enough energy to overcome the forces between them completely and spread far apart.
- **Condensing and freezing:** particles lose energy and slow down. The forces between them pull them closer together, or lock them into a regular pattern.

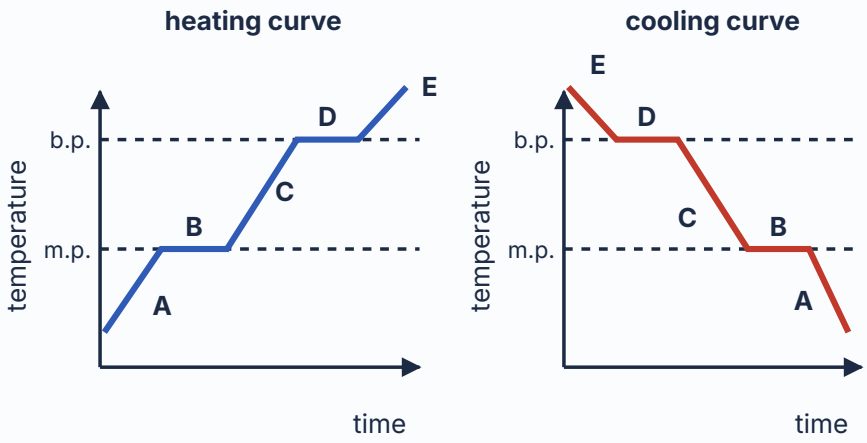
COMMON MISTAKE

"The particles expand when they are heated." The particles do **not** get bigger. They move faster and so move further apart.

Heating and cooling curves

EXTENDED

Kinetic particle theory — the particles in all matter are in constant motion. The higher the temperature, the greater the average kinetic energy of the particles.



A solid warms · B melting · C liquid warms · D boiling · E gas warms
cooling is the reverse: gas → condensing → liquid → freezing → solid
flat parts: the state is changing, so the temperature stays constant

Heating curve for a pure substance. The two flat sections are the changes of state. The sloping sections are the solid, liquid and gas being warmed up.

- **Sloping parts (A, C, E):** the energy supplied makes the particles move faster, so the **temperature rises**.
- **Flat parts (B, D):** the energy supplied is used to **overcome the forces between particles**, not to speed them up. The particles' average kinetic energy stays the same, so the **temperature does not change**.
- A **pure** substance melts and boils at a single, sharp temperature. An **impure** substance melts over a range of temperatures, and at a lower temperature than the pure substance (see testing purity).
- A **cooling curve** is the same picture in reverse: the flat parts are where the particles release energy as the forces pull them together.

WORKED EXAMPLE

EXT **Explain why the temperature stays constant while a liquid is boiling, even though it is still being heated.**

1. The heat energy is taken in by the particles
2. It is used to overcome the forces of attraction between the particles, so they can spread far apart
3. It is **not** used to increase the kinetic energy of the particles
4. **The average kinetic energy stays the same, so the temperature stays constant**

EXAM TIP

In a "describe the curve" question, say what the particles are doing in each section. Flat part = "energy is used to overcome forces of attraction between particles". Sloping part = "particles gain kinetic energy".

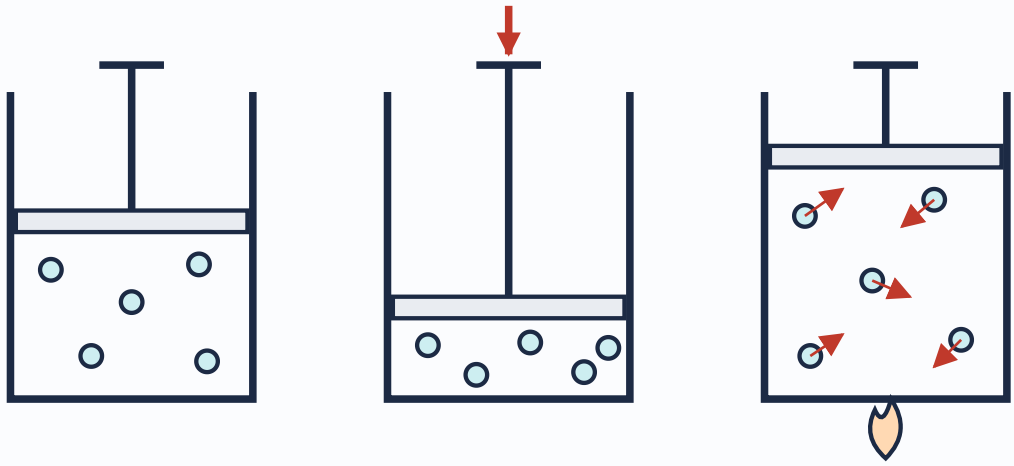
3 Gases: temperature and pressure

Where does gas pressure come from?

Gas pressure — the force per unit area caused by gas particles colliding with the walls of their container.

- Gas particles fly around at random. Billions of them hit the walls every second. Each hit pushes on the wall a tiny bit, and all the pushes together make the pressure.

What changes the volume of a gas?



Left: squeezing a gas into a smaller volume. Right: heating a gas in a container that can expand.

- **Pressure up (temperature fixed):** the volume of the gas **decreases**. The particles are pushed closer together.
- **Temperature up (pressure fixed):** the volume of the gas **increases**. A balloon left in the sun gets bigger.
- **Temperature down (pressure fixed):** the volume **decreases**.

Explaining it with particle theory

EXTENDED

- **Higher temperature:** particles move faster. They hit the walls **harder** and **more often**, so the pressure rises. If the walls can move (a syringe, a balloon) they are pushed outwards until the pressure is balanced again — the volume rises.
- **Smaller volume:** the same number of particles in less space hit the walls **more often**, so the pressure is higher.
- **Lower temperature:** the particles move more slowly and hit the walls less often and less hard, so the pressure falls or the volume shrinks.

PICTURE IT

Imagine a squash court with a few tennis balls bouncing around. Put in more balls (or make the court smaller) and the walls get hit more often. Make the balls move faster and every hit is harder.

COMMON MISTAKE

"The particles hit each other more, so the pressure goes up." Pressure is caused by collisions with the **walls**, not with each other.

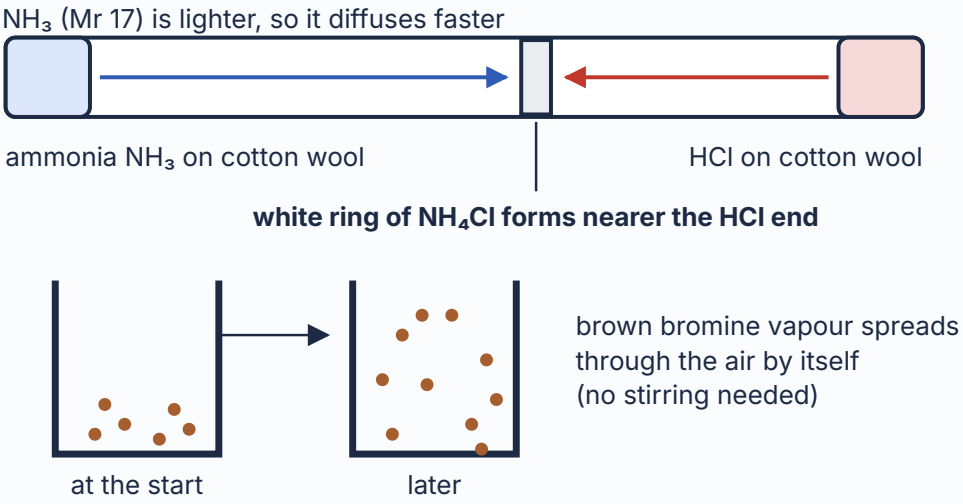
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4 Diffusion

Particles spreading out

Diffusion — the net movement of particles from a region of higher concentration to a region of lower concentration, as a result of their random motion.

- Particles move randomly all the time. In a crowded region, more particles leave than arrive. So there is an overall (**net**) movement from where there are lots of particles to where there are few.
- No stirring, wind or current is needed. Particles keep moving even after they are evenly spread — there is just no net movement any more.
- Examples: the smell of perfume crossing a room; brown bromine vapour spreading through a gas jar; a purple potassium manganate(VII) crystal colouring the water around it.



Top: ammonia and hydrogen chloride gas diffuse towards each other along a tube and meet. Bottom: bromine vapour spreading out through a gas jar of air.

What makes diffusion faster?

Factor	Effect on diffusion	Why
gas, liquid or solid	gases fastest, solids almost none	particles in gases move fastest and have the most room
higher temperature	faster	particles have more kinetic energy
lower relative molecular mass EXT	faster	lighter particles move faster at the same temperature

Ammonia and hydrogen chloride EXTENDED

- Cotton wool soaked in concentrated **ammonia** solution is placed at one end of a long glass tube. Cotton wool soaked in concentrated **hydrochloric acid** is placed at the other end. Both ends are sealed with bungs.
- The two gases diffuse towards each other. Where they meet, they react and form a **white ring of ammonium chloride**: $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$
- The ring forms **closer to the hydrochloric acid end**. Ammonia (Mr = 17) is lighter than hydrogen chloride (Mr = 36.5), so it moves faster and travels further in the same time.

EXAM TIP

Say "**lighter particles diffuse faster**" and use the Mr values. The ring forms where the two gases meet — not "where the stronger one reaches".

COMMON MISTAKE

Writing that the ring forms nearer the ammonia because "ammonia is heavier". It is the **lighter** gas that wins the race.

5 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. List the three states in order of how close the particles are, closest first.
2. What is the difference between evaporation and boiling?
3. Name the change of state in which a solid turns directly into a gas.
4. Why can a gas be compressed but a solid cannot?
5. EXT Why does the temperature stay constant while ice melts?
6. EXT Which diffuses faster, hydrogen (Mr = 2) or oxygen (Mr = 32)?

EXAM-STYLE

7. Use the particle model to explain why a gas fills its container but a liquid does not. [3]
8. EXT A sealed flask of air is heated. Explain why the pressure inside rises. [3]
9. EXT A student sets up the ammonia and hydrogen chloride tube. A white ring forms 14 cm from the ammonia end and 10 cm from the hydrogen chloride end. Explain why. [2]

Show answers

1. solid, liquid, gas
2. evaporation happens at the surface at any temperature below the boiling point; boiling happens throughout the liquid at the boiling point
3. sublimation
4. in a gas the particles are far apart with lots of empty space; in a solid they are already touching
5. the energy is used to overcome forces between particles, not to raise their kinetic energy
6. hydrogen — the lighter particles move faster
7. gas particles are far apart and move quickly in all directions
   there are almost no forces holding them together
   so they spread out until they fill the whole container. Liquid particles are close together with strong forces, so they stay together
8. particles gain kinetic energy and move faster
   they hit the walls of the flask more often
   and each collision is harder, so the force on the walls rises and the pressure increases
9. ammonia has the lower Mr (17 compared with 36.5), so its particles diffuse faster
   so ammonia travels further in the same time and the gases meet closer to the hydrogen chloride end

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