

States of matter

IGCSE Chemistry

The three states of matter

Everything around you is made of tiny **particles** 粒子—these can be **atoms** 原子, **molecules** 分子, or **ions** 离子. The **kinetic particle theory** 粒子动理论 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** 固体, a **liquid** 液体, or a **gas** 气体.

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** 体积. It does not flow and you cannot **compress** 压缩 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** 密度 means how much **mass** 质量 is packed into a given volume.

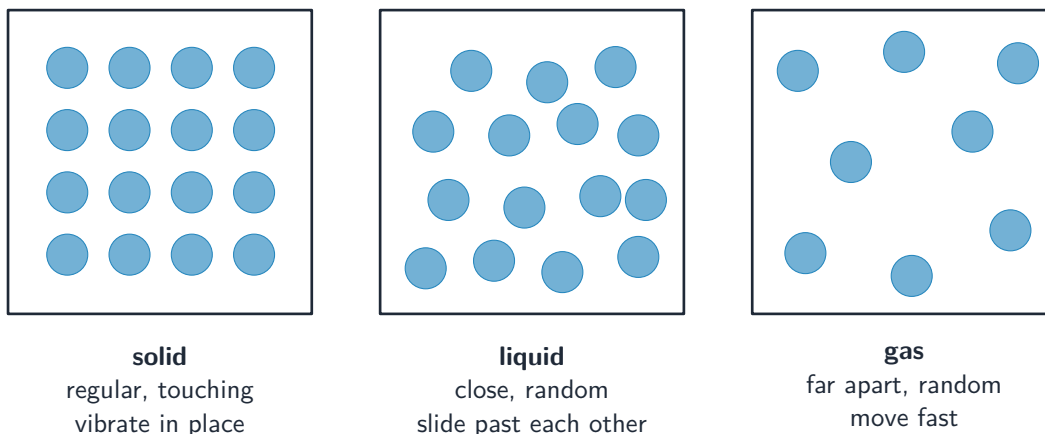
Property	Solid	Liquid	Gas
Shape	fixed	takes the shape of the container	fills the whole container
Volume	fixed	fixed	fills the whole container
Can it be compressed?	no	almost none	yes, easily
Does it flow?	no	yes	yes
Density	high	high	low

The particle picture

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

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

Strong **forces of attraction** 引力 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. In a gas the particles move so fast that the forces hardly act at all, so the gas spreads out.



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

Changes of state



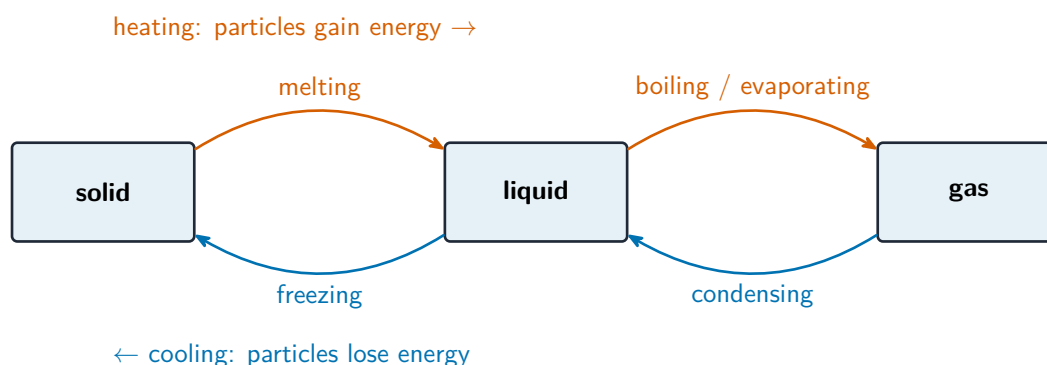
Ice melting to water: a change of state as the solid warms.

Image: Darren Hester, CC BY-SA 2.5 (commons.wikimedia.org)

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 融化	melting
liquid → solid	freezing 凝固	freezing
liquid → gas (at the surface, below the boiling point)	evaporating 蒸发	evaporation
liquid → gas (all through the liquid)	boiling 沸腾	boiling
gas → liquid	condensing 凝结	condensation

A pure solid melts at one fixed temperature, the **melting point** 熔点. A pure liquid boils at one fixed temperature, the **boiling point** 沸点. 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** 升华. 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)

Image: Kate7234, CC0 (commons.wikimedia.org)

Explaining changes of state with the particle theory

Each change of state is really a change in the **energy** 能量 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 a change of state the energy goes into breaking the forces of attraction, not into making the particles move faster. This is why the temperature stays the same while a substance is melting or boiling.

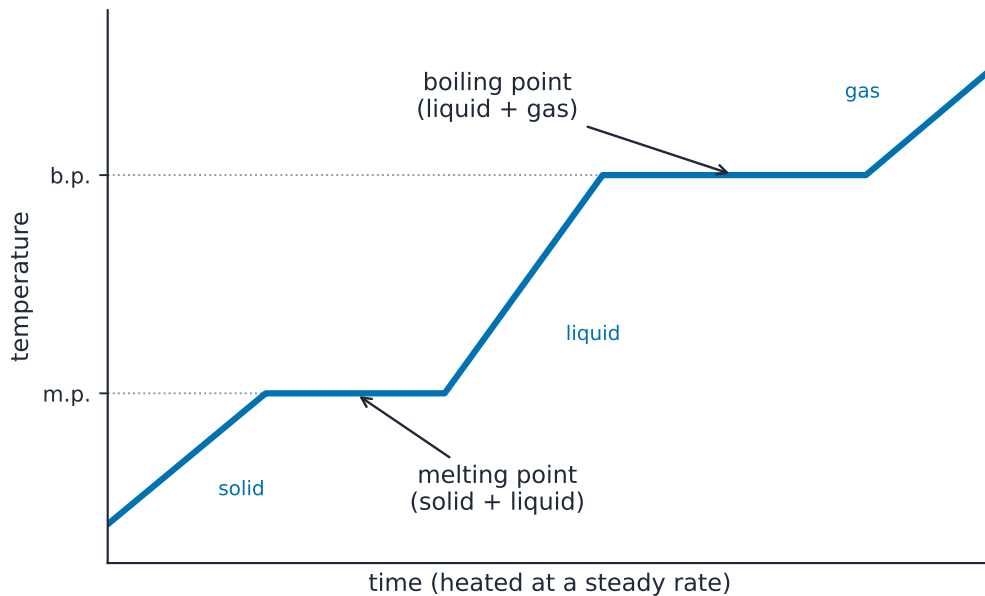
Heating and cooling curves

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

On a heating curve there are two flat (level) parts:

- The first flat part is at the **melting point**. Here solid and liquid are both present. The heat energy breaks the forces holding the solid together, 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). As the particles slow down, **thermal energy** 热能 is released to the surroundings.



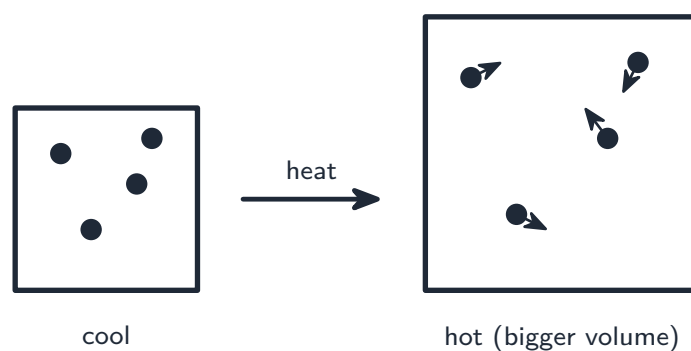
Temperature stays constant at the melting and boiling points while forces of attraction are broken

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** 压强 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.



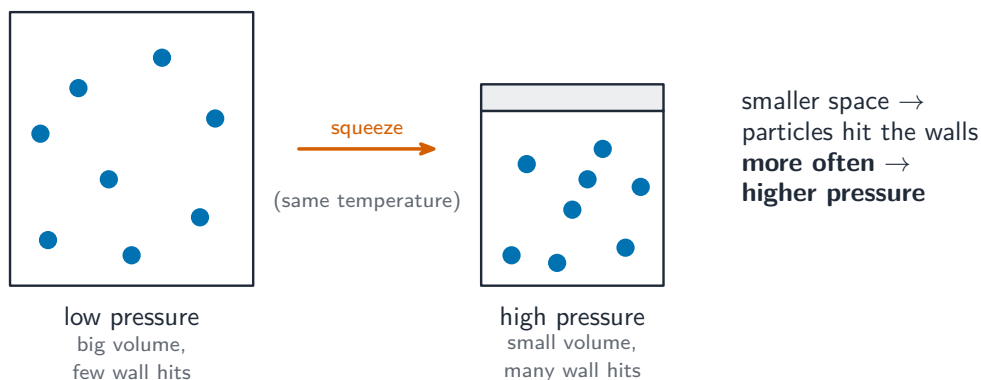
A heated gas: faster particles spread out and take up more space

Using the particle theory: heating gives the particles more **kinetic energy** 动能, 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** 碰撞 with the walls harder and more often.

Effect of pressure

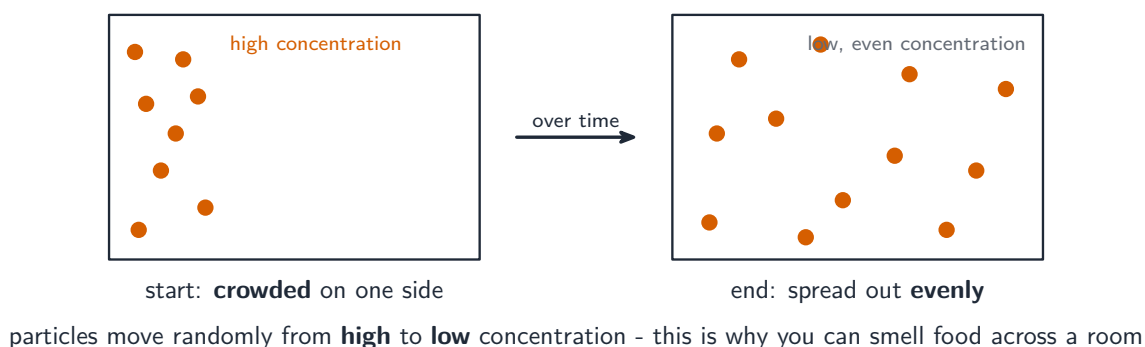
If you increase the pressure on a fixed mass of gas while keeping the temperature the same, its volume decreases. Squeezing the gas into a smaller space means the particles hit the walls more often, which is what a higher pressure means.



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

Diffusion

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



Particles diffuse from high to low concentration until they are spread out evenly

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.

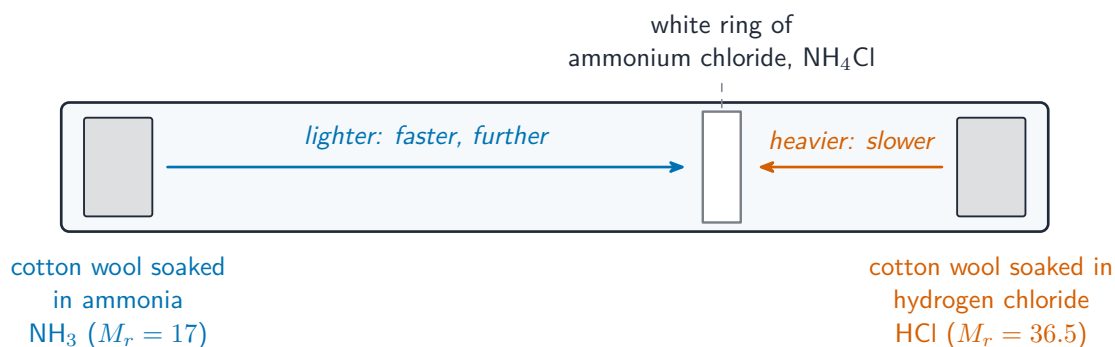
Rate of diffusion and molecular mass

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

A classic experiment shows this. Cotton wool soaked in **ammonia** 氨气 (NH_3) is put at one end of a long glass tube. Cotton wool soaked in **hydrogen chloride** 氯化氢 (HCl) is put at the other end. Both gases diffuse along the tube and meet to form a white ring of **ammonium chloride** 氯化铵 (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. Bromine ($M_r = 160$) and ammonia ($M_r = 17$) are released at the same moment from opposite ends of a long tube. Which travels further before they meet? Compare the relative molecular masses. Ammonia's M_r is far smaller, so its molecules move faster at the same temperature and it diffuses more quickly. Ammonia therefore travels the greater distance, and the two gases meet nearer the **bromine** end. The rule is always "lighter means faster" - argue from M_r , never from how big the formula looks on paper.

Exam tips

- During **melting** and **boiling** the temperature stays constant (the flat parts of a heating curve), because the energy breaks the forces between particles instead of making them move faster.
- **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** is faster for lighter particles (smaller M_r) and cannot happen in solids. In the ammonia/hydrogen chloride tube the lighter ammonia travels further, so the white ring forms nearer the HCl end.