States of Matter

Solids, liquids and gases and the kinetic particle theory, changes of state and heating and cooling curves, the effect of temperature and pressure on a gas, and diffusion.

1.1 Solids, liquids and gases

All matter is made of tiny **particles** (atoms, molecules or ions) that are always moving. The **kinetic particle theory** explains the three states of matter by how far apart the particles are, how they are arranged, and how they move.

	Solid	Liquid	Gas
shape	fixed shape	takes the shape of the bottom of its container	fills its container completely
volume	fixed	fixed	not fixed, it expands to fill the container
can it be squashed?	no	no (almost incompressible)	yes, easily
can it flow?	no	yes	yes
particle arrangement	closely packed in a regular pattern	closely packed but irregular	far apart and random
particle motion	vibrate about fixed positions	slide past each other	move quickly and randomly in all directions
forces between particles	strong	weaker than in a solid	almost none

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Changes of state

A change of state is a **physical change**: no new substance is made, and the particles themselves do not change. Only their energy, spacing and arrangement change.

Change	From → to	What happens to the particles
melting	solid → liquid	they gain energy and vibrate more until they break free of their fixed positions
freezing	liquid → solid	they lose energy, slow down and settle into a fixed pattern
boiling	liquid → gas	they gain enough energy to overcome the forces between them and escape throughout the liquid
evaporating	liquid → gas	the fastest particles at the surface escape, at any temperature below the boiling point
condensing	gas → liquid	they lose energy, slow down and come together

NOTE

Boiling happens at one temperature (the boiling point) and bubbles form throughout the liquid. **Evaporation** happens at any temperature, and only at the surface.

When a solid melts or a liquid boils, the thermal energy supplied is used to **overcome the forces between the particles**, not to make them move faster. That is why the temperature stays constant while the change of state happens.

Heating and cooling curves

A heating curve plots temperature against time as a substance is heated steadily.

- **A sloping part:** the temperature is rising. The particles gain kinetic energy and move or vibrate faster, in one state only.
- **A flat part:** a change of state is happening. The energy supplied is used to overcome the forces between the particles, so the temperature stays constant. The first flat part is **melting** and the second is **boiling**.
- The flat parts are at the **melting point** and the **boiling point**. A **pure** substance has a **sharp** melting point and boiling point, but an impure substance melts over a range of temperatures.

A **cooling curve** is the reverse: the flat parts are at the **freezing point** (the same temperature as the melting point) and the **condensing** point.

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A substance is heated steadily from $-20\,^{\circ}\mathrm{C}$. The temperature stays constant at $0\,^{\circ}\mathrm{C}$ and at $100\,^{\circ}\mathrm{C}$ for a while. What is the substance, and what is happening at each flat part?

It is **water**. At $0\,^{\circ}\mathrm{C}$ the ice is **melting**. At $100\,^{\circ}\mathrm{C}$ the water is **boiling**. The energy supplied is used to overcome the forces between the particles, so the temperature does not rise.

Gases: temperature, pressure and volume

A gas exerts **pressure** because its particles are constantly hitting the walls of the container. The more often and the harder they hit, the greater the pressure.

- **Temperature.** If the temperature rises, the particles move faster. At constant pressure the gas **expands** (the volume increases). In a sealed container of fixed volume, the faster particles hit the walls more often and harder, so the **pressure increases**.
- **Pressure.** If the pressure on a gas is increased at constant temperature, the **volume decreases**. The same number of particles are in a smaller space, so they hit the walls more often, and the pressure rises to match.

NOTE

In an exam answer, use the words **particles**, **collide** (or **hit the walls**), **more often** and **faster**. Say that the particles move faster, not that they "expand" or "get hotter".

1.2 Diffusion

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, until they are evenly spread. It is caused by the random motion of the particles.

Diffusion happens in gases and liquids, because their particles move freely. It does not happen in solids, where the particles only vibrate about fixed positions. It is fastest in gases and slower in liquids.

Examples. The smell of cooking spreads through a house. A drop of coloured ink spreads through water, even without stirring. Bromine vapour spreads through a jar of air until the colour is even.

The effect of relative molecular mass

At the same temperature, the particles of a gas with a **lower relative molecular mass** (M_r) move **faster**, so the gas **diffuses faster**. The effect is shown by the experiment with ammonia and hydrogen chloride.

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Cotton wool soaked in concentrated ammonia solution is put in one end of a long tube, and cotton wool soaked in concentrated hydrochloric acid is put in the other end, at the same time. The gases diffuse along the tube and a **white ring of ammonium chloride** forms where they meet:

$$\mathrm{NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)}$$

The ring forms **nearer the hydrochloric acid end**. Ammonia ($M_\mathrm{r} = 17$) is lighter than hydrogen chloride ($M_\mathrm{r} = 36.5$), so its particles travel faster and cover more of the distance before they meet.

> **TRY IT**
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> Gas X has $M_\mathrm{r} = 4$ and gas Y has $M_\mathrm{r} = 64$. Which diffuses faster, and why?

Gas **X** diffuses faster. Its particles have a lower relative molecular mass, so at the same temperature they move faster.

Diffusion is also faster at a **higher temperature**, because the particles have more kinetic energy.

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