IGCSE Chemistry CIE

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1. The Particulate Nature of Matter

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1.1 The Particulate Nature of Matter

1.1.1 Kinetic Theory

Solids, Liquids & Gases

Solids

- Solids have a **fixed** volume and shape and they have a high density
- The atoms **vibrate** in position but can't change location
- The particles are packed very closely together in a fixed and regular pattern

Liquids

- Liquids also have a fixed volume but adopt the shape of the container
- They are generally less dense than solids (an exception is water), but much denser than gases
- The particles **move** and **slide** past each other which is why liquids adopt the shape of the container and also why they are able to flow freely

Gases

- Gases do not have a fixed volume, and, like liquids, take up the shape of the container
- Gases have a very low density
- Since there is a lot of space between the particles, gases can be compressed into a much smaller volume
- The particles are far apart and move randomly and quickly (around 500 m/s) in all directions
- They **collide** with each other and with the sides of the container (this is how **pressure** is created inside a can of gas)

Summary of the Properties of Solids, Liquids and Gases

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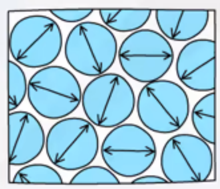
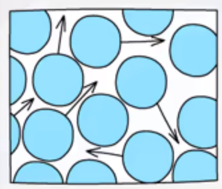
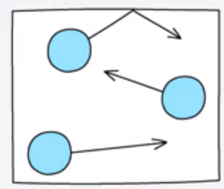
State	Solid	Liquid	Gas
Density	High	Medium	Low
Arrangement of particles	Regular pattern	Randomly arranged	Randomly arranged
Movement of particles	Vibrate around a fixed position	Move around each other	Move quickly in all directions
Energy of particles	Low energy	Greater energy	Highest energy
2D diagram			

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Exam Tip

You can explain the differences in the physical properties of solids, liquids and gases by referring to the arrangement and motion of particles. This is called the kinetic theory of matter.

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State Changes

Melting

- Melting is when a solid changes into a liquid
- Requires heat energy which transforms into **kinetic** energy, allowing the particles to move
- Occurs at a specific temperature known as the melting point (m.p.)

Boiling

- Boiling is when a liquid changes into a gas
- Requires heat which causes bubbles of gas to form **below** the surface of a liquid, allowing for liquid particles to escape from the surface and within the liquid
- Occurs at a specific temperature known as the boiling point (b.p.)

Freezing

- Freezing is when a liquid changes into a solid
- This is the reverse of melting and occurs at exactly the **same temperature** as melting, hence the melting point and freezing point of a pure substance are the same. Water, for example, freezes and melts at 0 ºC
- Requires a significant decrease in temperature (or loss of thermal energy) and occurs at a specific temperature

Evaporation

- Evaporation occurs when a liquid changes into a gas and occurs over a **range** of temperatures
- Evaporation occurs only at the **surface** of liquids where high energy particles can escape from the liquid's surface at **low** temperatures, below the b.p. of the liquid
- The larger the surface area and the warmer the liquid surface, the more quickly a liquid can evaporate

Condensation

- Condensation occurs when a gas changes into a liquid on cooling and it takes place over a **range** of temperatures
- When a gas is cooled its particles lose energy and when they bump into each other they lack the energy to bounce away again, instead they group together to form a liquid

Sublimation

- When a solid changes directly into a gas, without going through the liquid stage
- This happens to only a few solids such as iodine or solid carbon dioxide
- The reverse reaction also happens and is called deposition or desublimation

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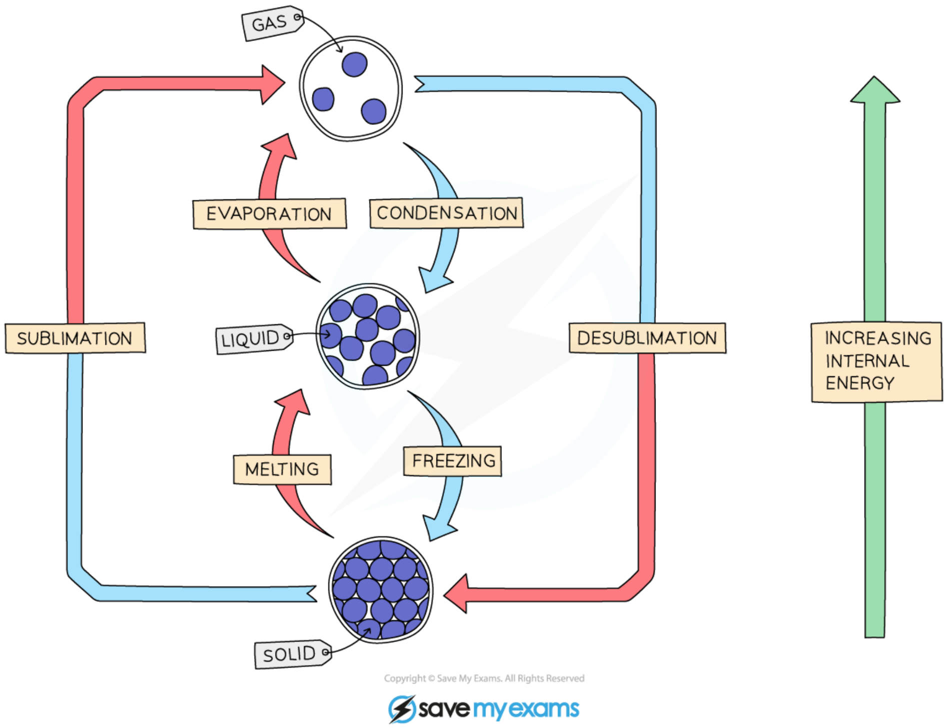

Interconversion of solids, liquids and gases

Exam Tip

Questions on the particle theory of matter show interconversion of states with a reversible arrow: ⇌, which means that the process can go forwards and backwards. Read the question carefully and pick the direction of the change in state that the question refers to.

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Changes in State & Kinetic Theory

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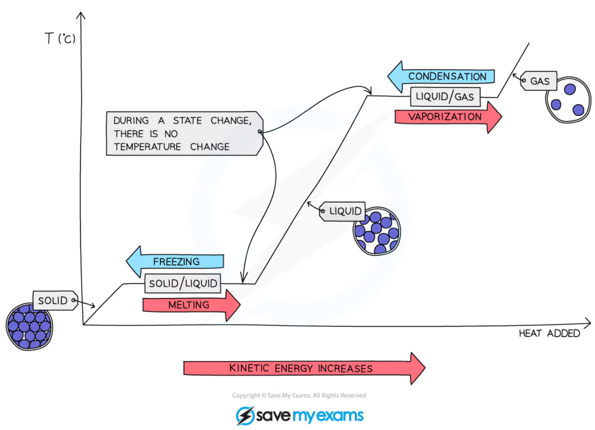
- When substances are heated, the particles **absorb** thermal energy which is converted into kinetic energy. This is the basis of the kinetic theory of matter
- Heating a solid causes its particles to vibrate more and as the temperature increases, they vibrate so much that the solid **expands** until the structure breaks and the solid melts
- On further heating, the now liquid substance expands more and some particles at the surface gain sufficient energy to overcome the intermolecular forces and **evaporate**
- When the b.p. temperature is reached, all the particles gain enough energy to escape and the liquids boils
- These changes in state can be shown on a graph called a **heating curve**
- Cooling down a gas has the reverse effect and this would be called a **cooling curve**
- These curves are used to show how changes in temperature affect changes of state



Heating curve for water with interconversions of state

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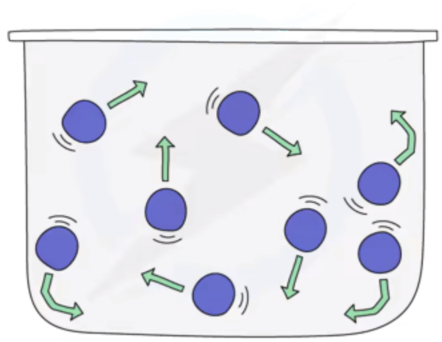
Pressure & Temperature in Gases

- Gaseous particles are in constant and **random motion**
- An increase in temperature increases the **kinetic** energy of each particle, as the heat energy is transformed to kinetic energy, so they move faster
- Decreasing the temperature has the opposite effect, so the particles slow down
- As the temperature increases, the particles in the gas move faster, impacting the container's walls more **frequently**
- The pressure that a gas creates inside a closed container is produced by the gaseous particles hitting the inside walls of the container
- So when there is an **increase in temperature** this also causes an **increase in gas pressure**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Moving particles of gas colliding with each other and the container walls

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1.1.3 Brownian Motion

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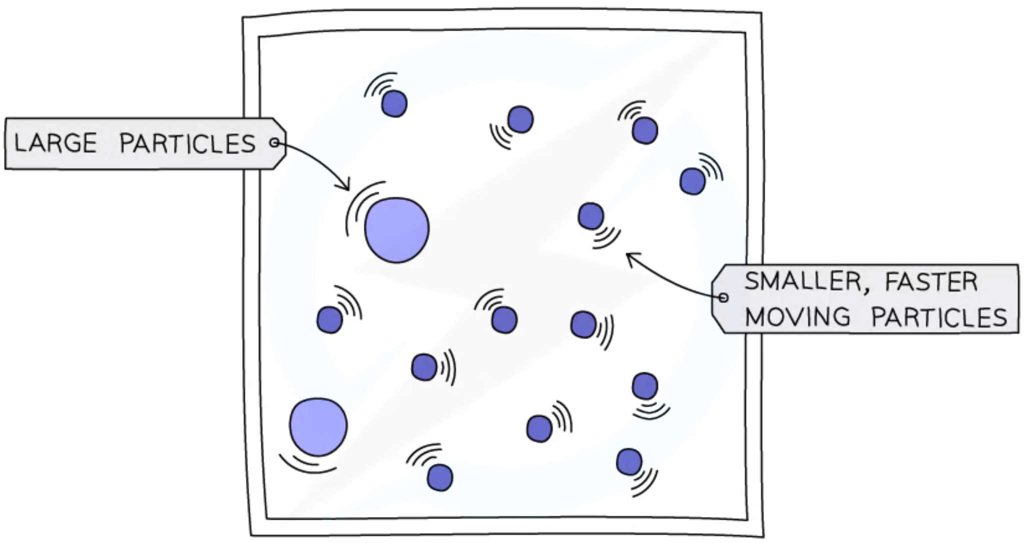
Brownian Motion

- Robert Brown was a Scottish botanist who first observed the random motions of pollen grains in water seen under a microscope
- He first thought it might be due to the pollen grains being alive, so he boiled them and repeated his observations which showed the same effect
- Although he could not provide an explanation for what he saw, it later provided evidence for the existence of particles in motion in the kinetic theory of matter
- Brownian motion is the random movement of particles in a liquid or a gas produced by large numbers of collisions with smaller, often invisible particles



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Large particles show jerky and erratic movement caused by many collisions with smaller particles

Explaining Brownian Motion

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- Almost eighty years after Robert Brown's observations, the physicist Albert Einstein explained that the jiggly movement of pollen grains in water were being caused by individual **water molecules**
- He was able to model the effect in one of his first scientific contributions
- The force of the bombardment is constantly changing as water molecules hit the pollens grains randomly from different directions
- The effect can also be seen in smoke particles under a microscope where their jerky and erratic motion is due to being hit by the unseen molecules in the air
- In all cases, larger and visible particles are caused to move by the random bombardment of smaller, invisible particles

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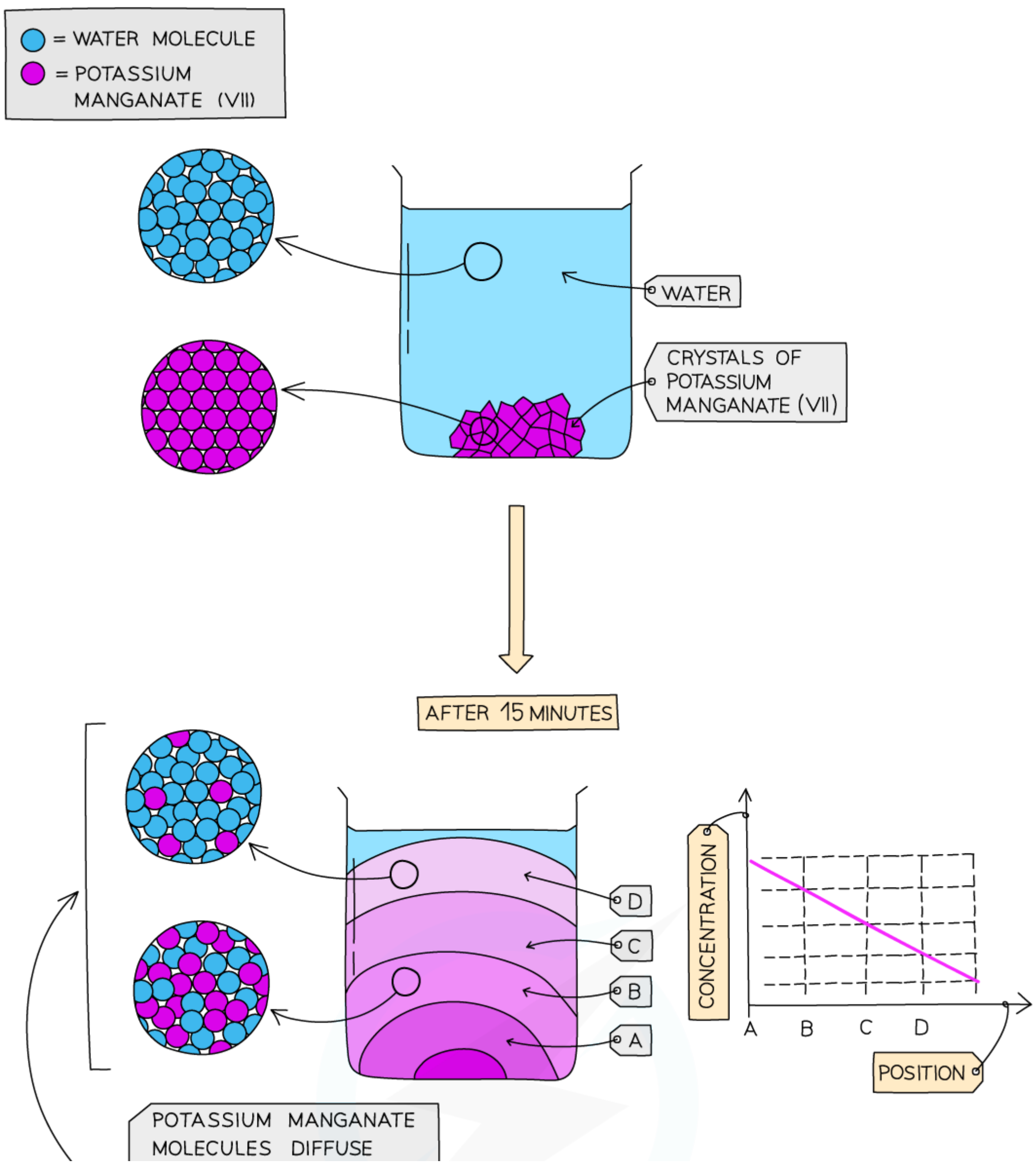
Diffusion

Diffusion

- This is the process by which different gases or different liquids mix and is due to the random motion of their particles
- Diffusing particles move from an area of **high concentration** to an area of **low concentration**
- Eventually the concentration of particles is **even** as they spread out to occupy all of the available space
- Diffusion happens on its own and no energy input is required although it occurs faster at higher temperatures



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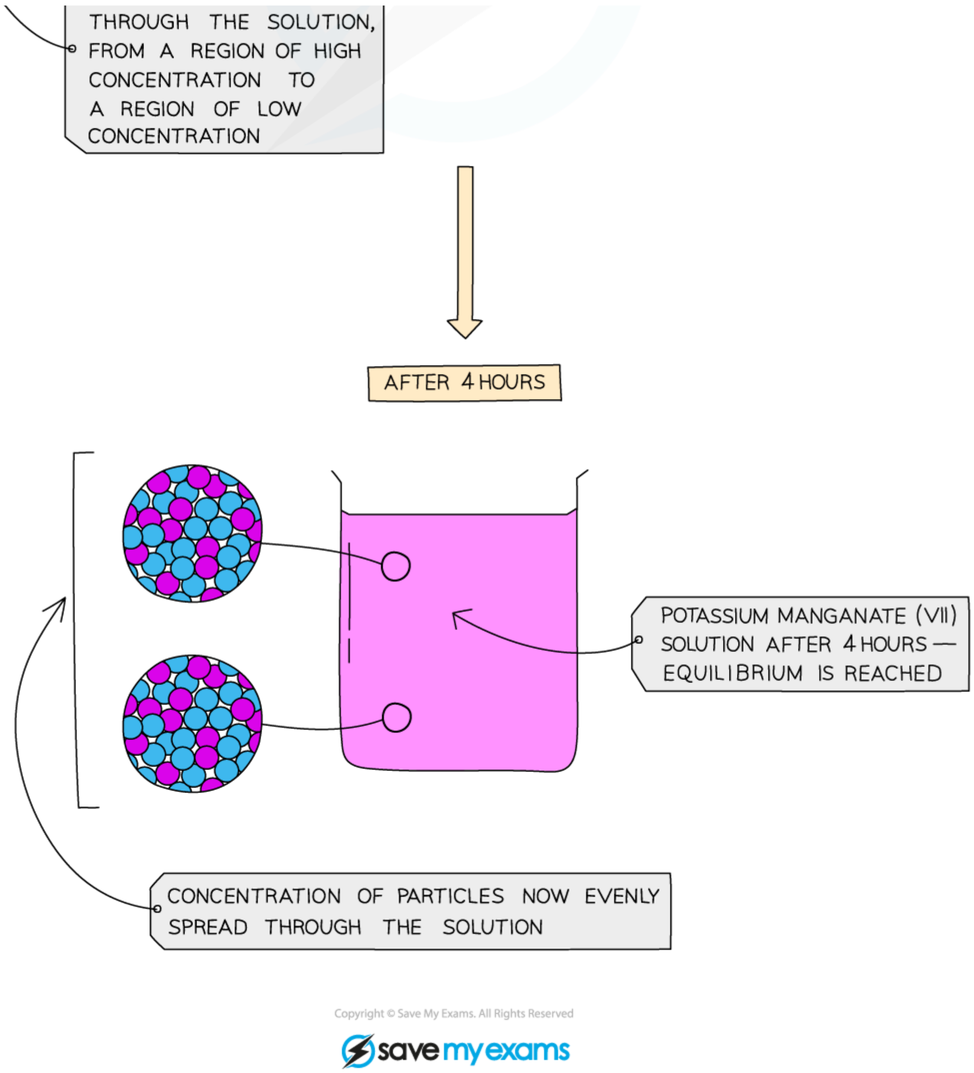

Diffusion of potassium manganate(VII), $KMnO_4$, in water. After a few hours the concentration of $KMnO_4$ is the same throughout the solution

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Diffusion & Molecular Mass

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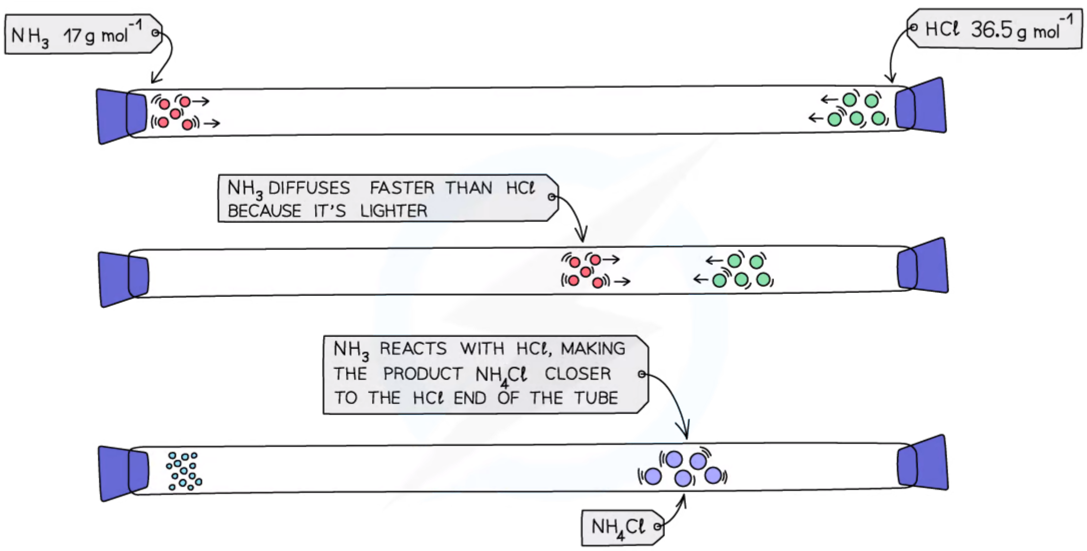
- Diffusion occurs much **faster** in gases than in liquids as gaseous particles move much quicker than liquid particles
- At the same temperature, different gases do not diffuse at the same rate.
- This is due to the difference in their relative molecular masses
- Lighter gas particles can travel faster and hence further, therefore the lower its relative mass the faster a gas will diffuse
- This can be demonstrated in the reaction between ammonia, NH_3, and hydrogen chloride gas, HCl, inside a long glass tube
- Where the two gases meet a white smoke of ammonium chloride, NH_4Cl, is formed
- This does not occur in the middle of the tube as you might expect, but much closer to the end with the hydrogen chloride (M_r = 36.5) and the ammonia (M_r = 17) molecules are smaller and lighter



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NH_3 molecules have less mass than the HCl molecule, so diffuse faster, hence the product (a white smoke of NH_4Cl) forms closer to the end where the HCl is

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