Cambridge (CIE) IGCSE Chemistry

Your notes

Solids, liquids & gases

Contents

Solids, liquids & gases

- The properties of solids, liquids, and gases can be explained by the **kinetic theory of matter**
- This model describes matter as consisting of tiny particles that are in constant motion
- The arrangement and movement of these particles are different in each state of matter
    - This leads to their different physical properties

Solids

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

Liquids

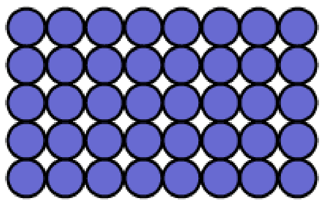
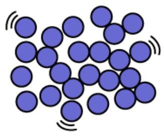
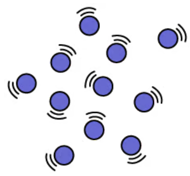
- Liquids also have a fixed volume but adopt the shape of the container
- They are generally less dense than solids (an exception is water), but much denser than gases
- The particles are still close together but are arranged randomly
- The particles **move** and **slide** past each other which is why liquids adopt the shape of the container and 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
- The particles are far apart and move randomly and quickly (around 500 m/s) in all directions.
- Since there is a lot of space between the particles, gases can be easily compressed.
- 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

	Solid	Liquid	Gas

Diagram			
Arrangement of particles	Regular arrangement	Randomly arranged	Randomly arranged
Movement of particles	Vibrate about a fixed position	Move around each other	Move quickly in all directions
Closeness of particles	Very close	Close	Far apart
Density	High	Medium	Low
Energy of particles	Low energy	Greater energy	Highest energy

Your notes

Examiner Tips and Tricks

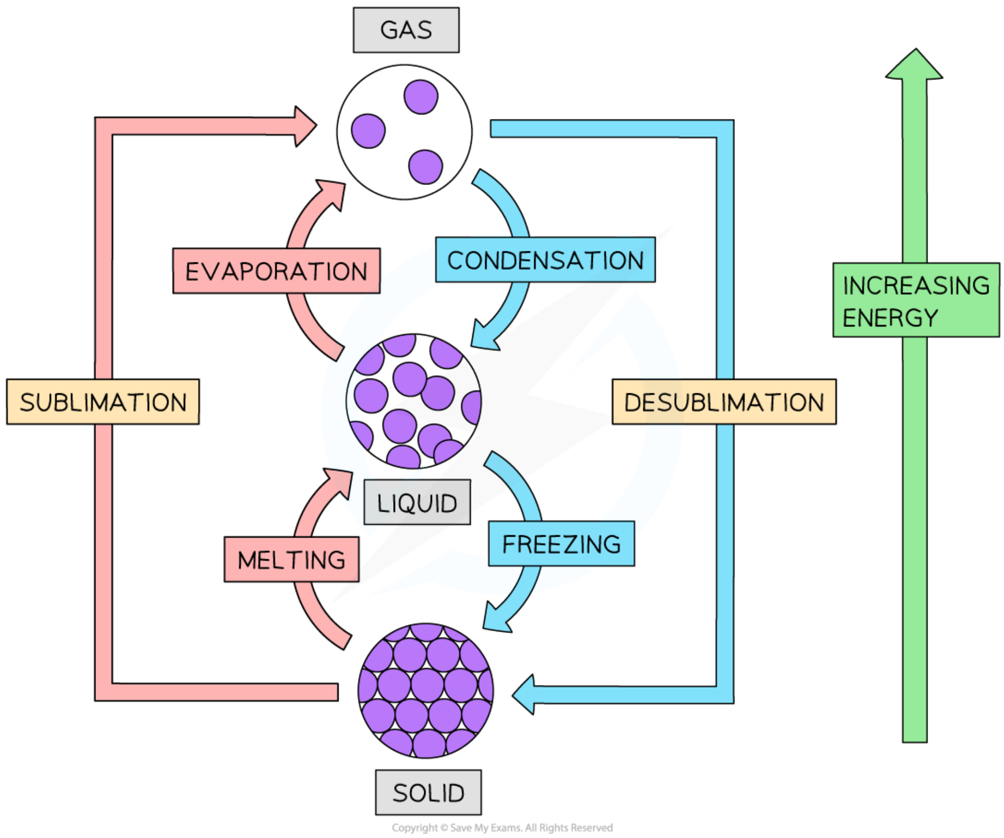
In your exam, you will need to apply the **kinetic theory of matter** to explain the properties of solids, liquids, and gases.

This means focusing on the key differences in particle **arrangement**, **movement**, and the **energy** of the particles in each state.

State changes

- **State changes** occur when:
    - Solids become liquids
    - Liquids become gases
    - Gases become liquids
    - Liquids become solids
- Each state change requires a change in the energy, arrangement and movement of the particles

The state changes



The inter-conversions / state changes are shown in relation to energy

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.)

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 °C
- Requires a significant decrease in temperature (or loss of thermal energy) and occurs at a specific temperature

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.)

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

Examiner Tips and Tricks

Questions on the particle theory of matter show interconversion of states with a reversible arrow: $\rightleftharpoons$, which means that the process can go forwards and backwards.

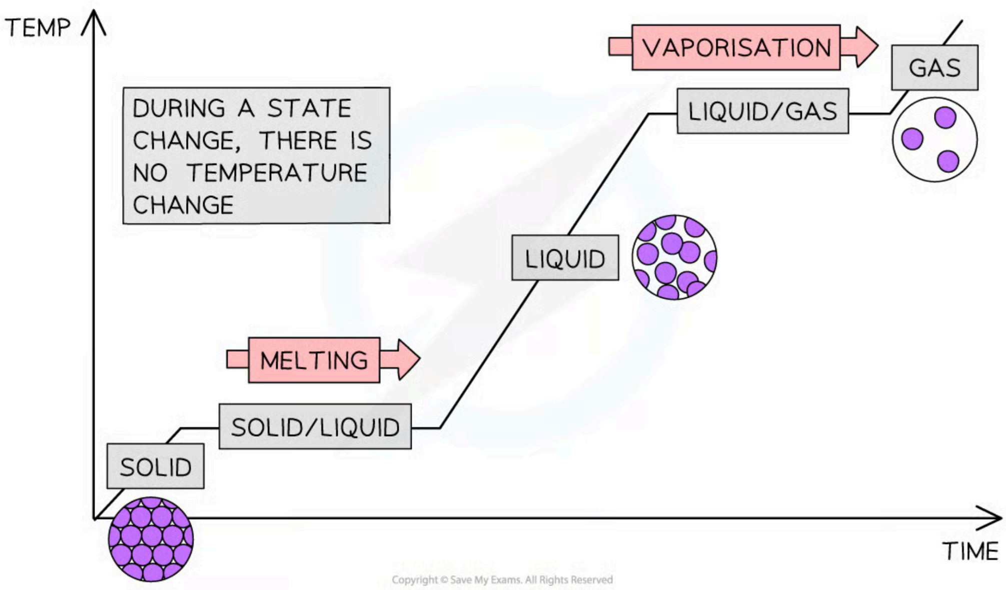
Read the question carefully and pick the direction of the change in state that the question refers to.

State changes & kinetic theory

Your notes

Extended tier only

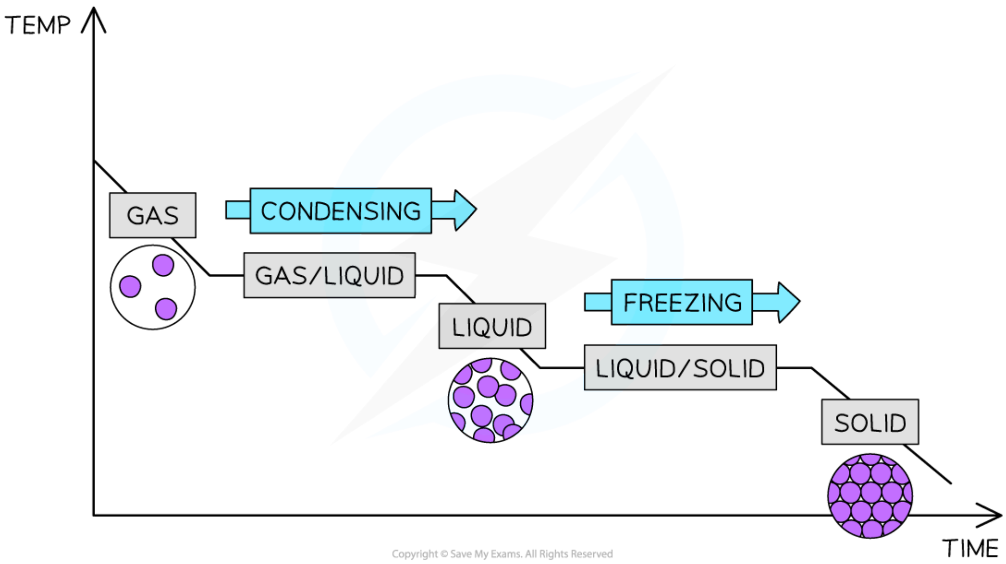
- When substances are heated, the particles **absorb** thermal energy which is converted into kinetic energy
  - This is the basis of the kinetic theory of matter
- Heating a solid causes its particles to vibrate more
  - As the temperature increases, the particles vibrate so much that the solid **expands** until the structure breaks
  - This is when the solid **melts** into a liquid
- Heating a liquid causes its particles to move more and spread out
  - Some particles at the surface gain sufficient energy to overcome the intermolecular forces
  - This is when a liquid starts to **evaporate**
  - When the boiling point is reached, all of the particles gain enough energy to escape and the liquids **boils** into a gas
- These changes in state can be shown on a graph called a **heating curve**:



A heating curve showing the states, state changes and temperature changes as time progresses

- Cooling down a gas has the reverse effect and this would be called a **cooling curve**:

Your notes



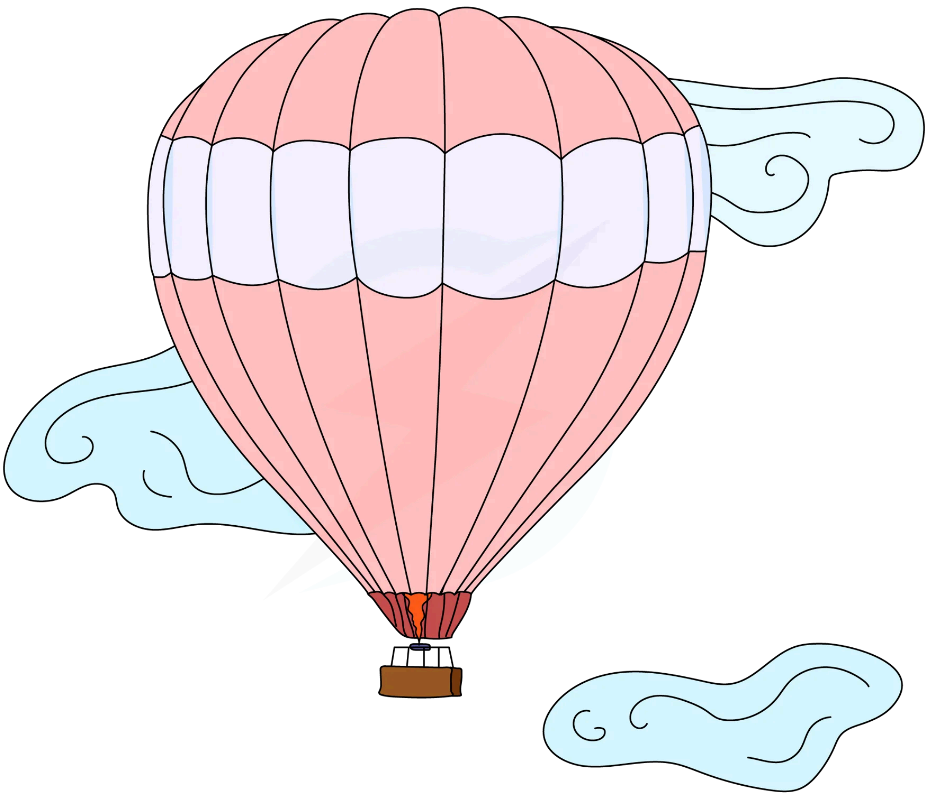
A cooling curve is like a heating curve, but is the mirror image

- Heating and cooling curves are used to show how changes in temperature affect changes of state
- The horizontal sections occur when there is a change of state but there is no change in temperature

Your notes

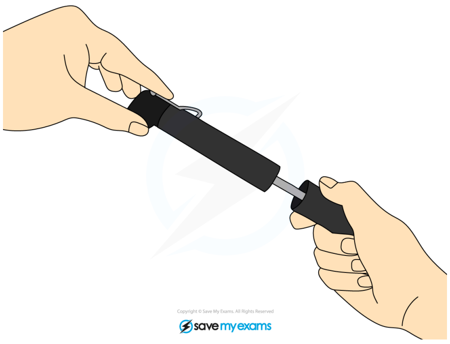
Pressure & temperature in gases

- A change in temperature or pressure affects the volume of gases
- As the air inside a hot air balloon is heated up, it expands and the balloon gets bigger
- This is because the volume of a gas increases as temperature increases



As temperature increases gas volume increases. The density decreases as the volume increases so the balloon rises.

- If you have a gas stored inside a container that is squeezed, the pressure increases as you decrease the volume
- This is what happens in a bicycle pump



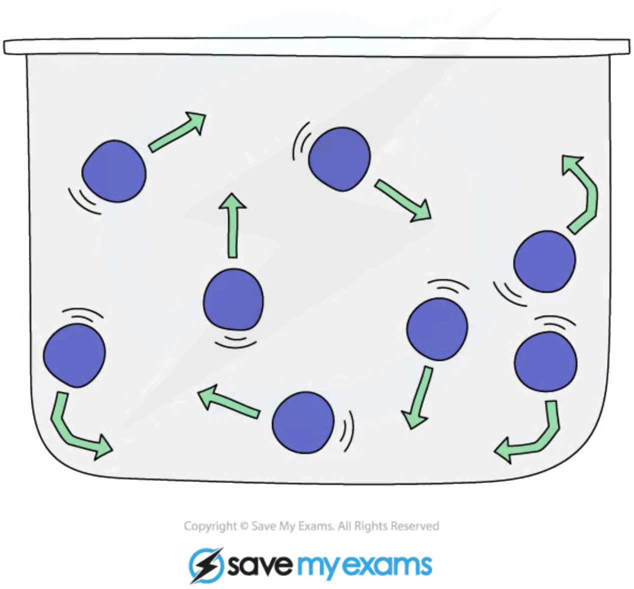
Pressure increases as volume decreases in a bicycle pump

- As you compress the bicycle pump, the high pressure allows you to inflate a tyre
- You can feel the force of the high pressure if you put your finger on the end of the pump

Gases & kinetic theory

Extended tier only

- Gaseous particles are in constant and **random motion**
- The pressure that a gas creates inside a closed container is produced by the gaseous particles hitting the inside walls of the container:



Moving particles of gas colliding with each other and the container walls

How does temperature affect the volume of a gas?

- Increasing the temperature increases the **kinetic** energy of each particle

Your notes

- **Remember:** The thermal energy from increasing the temperature is converted to kinetic energy in the particles
- As the temperature increases, the particles in the gas **move faster** and **spread out more**
- If the gas particles are inside a container, they will collide with the container walls more **frequently**
  - If the container walls are flexible and stretchy then the container will get bigger and bigger, just like the hot air balloon!

Examiner Tips and Tricks

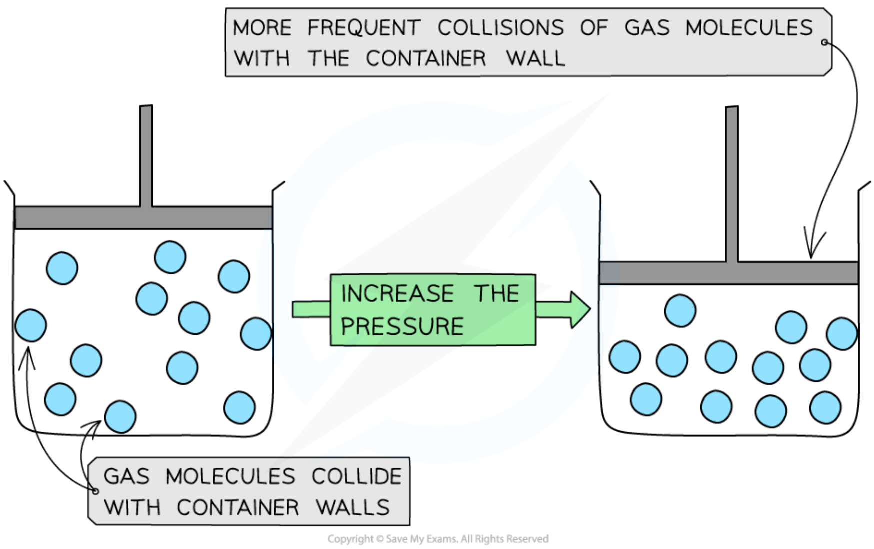
If you are talking about the particles, then make sure that you talk about them spreading out.

If you are talking about the material, then you can use the word expand.

You will lose a mark in an exam if you talk about particles expanding!

How does pressure affect the volume of a gas?

- Pressure is about the number of particles in a given volume
- Increasing the pressure means that there are the same number of particles but in a smaller volume
  - Conversely, decreasing the pressure means that there are the same number of particles but in a larger volume



When the pressure increases, the volume decreases. This means that the molecules collide with the container walls more frequently

- Since the volume is decreased, the gas particles hit the container walls more frequently

- If the pressure is too high, this can result in the container leaking gas or exploding

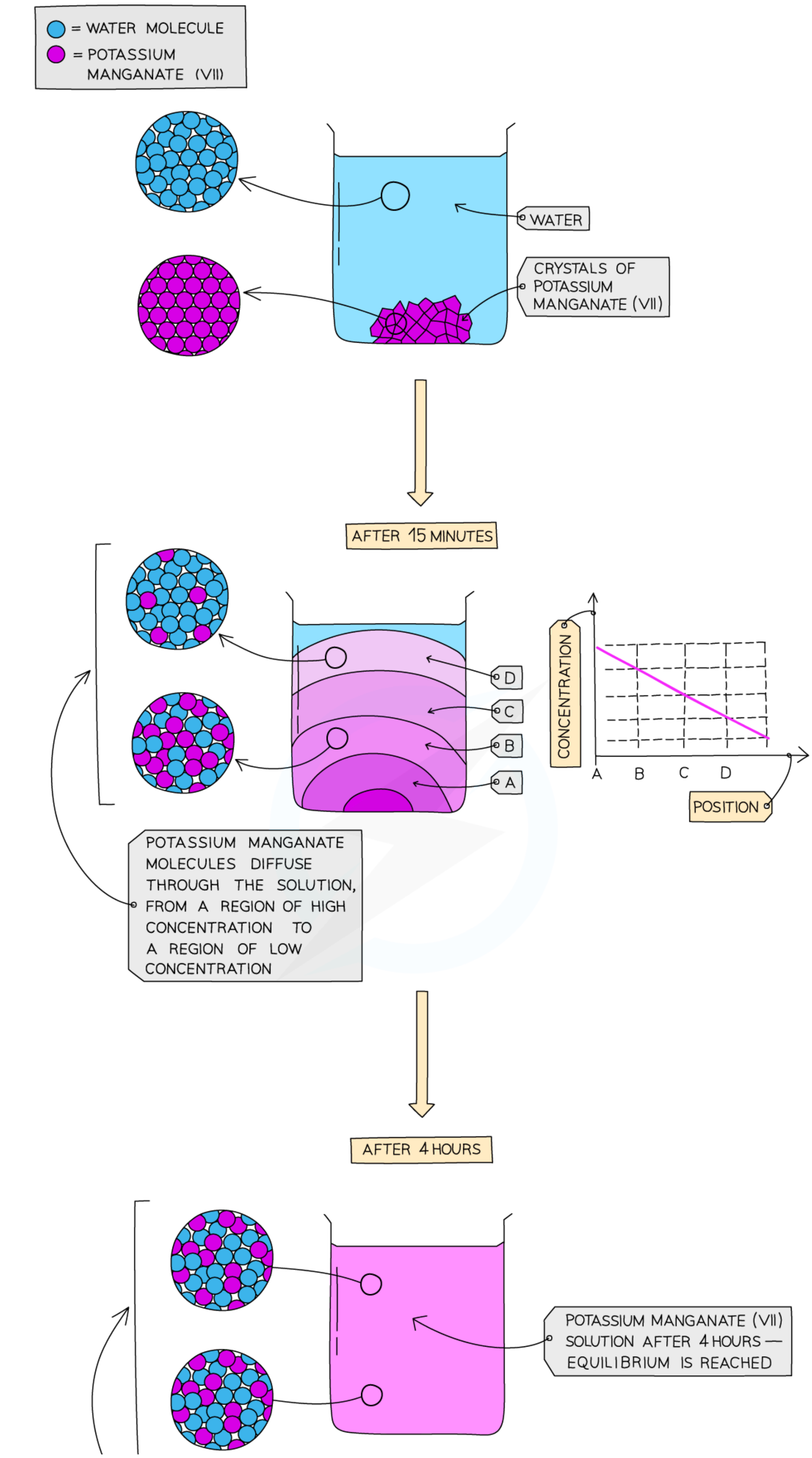
Your notes

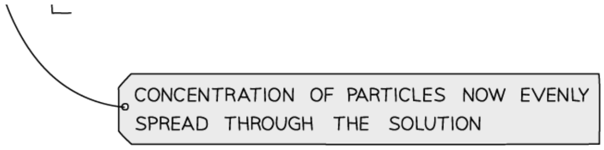
Diffusion

- Diffusion occurs in gases and liquids, due to the random motion of their particles
- It is where particles move from an area of **high concentration** to an area of **low concentration**
- Eventually the concentration of particles is **even** as the particles are evenly spread throughout the available space
- Diffusion happens on its own and no energy input is required
  - Although, it occurs faster at higher temperatures because the particles have more kinetic energy

Diffusion in liquids

- Potassium manganate(VII), $KMnO_4$, in water is a typical demonstration of diffusion in liquids:

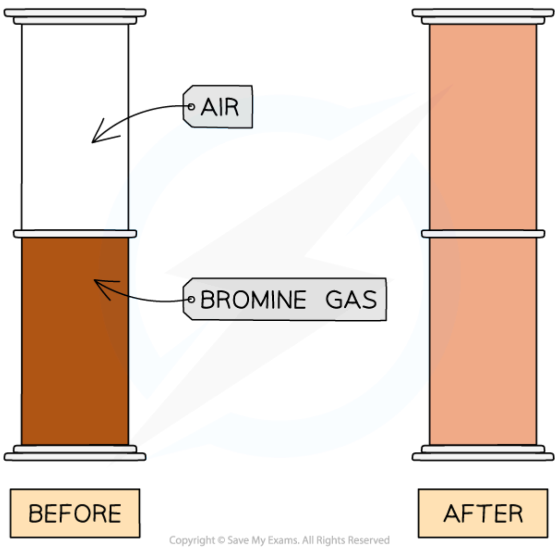

= WATER MOLECULE
= POTASSIUM MANGANATE (VII)
WATER
CRYSTALS OF POTASSIUM MANGANATE (VII)
AFTER 15 MINUTES
D
C
B
A
CONCENTRATION
A B C D
POSITION
POTASSIUM MANGANATE MOLECULES DIFFUSE THROUGH THE SOLUTION, FROM A REGION OF HIGH CONCENTRATION TO A REGION OF LOW CONCENTRATION
AFTER 4 HOURS
POTASSIUM MANGANATE (VII) SOLUTION AFTER 4 HOURS — EQUILIBRIUM IS REACHED



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

Diffusion in gases

- Diffusion is **faster** in gases than in liquids
  - This is because gaseous particles have more energy and move quicker than liquid particles
- For example, the diffusion of bromine gas and air:



Bromine diffuses until it is evenly spread throughout the container

- At the start, the **orange-brown** bromine gas is an area of high concentration
- It diffuses from a high to low concentration
- After 5 minutes, the bromine gas will have diffused from the bottom jar until it is **evenly spread** throughout both jars
  - The same can be said for the air, although it is less obvious as it is colourless

Examiner Tips and Tricks

When you are talking about diffusion, you should (where appropriate) include:

Your notes

- Ideas about areas of high and low concentration
- The energy / movement of the particles

Your notes

Diffusion & molecular mass

Extended tier only

How molecular mass affects diffusion

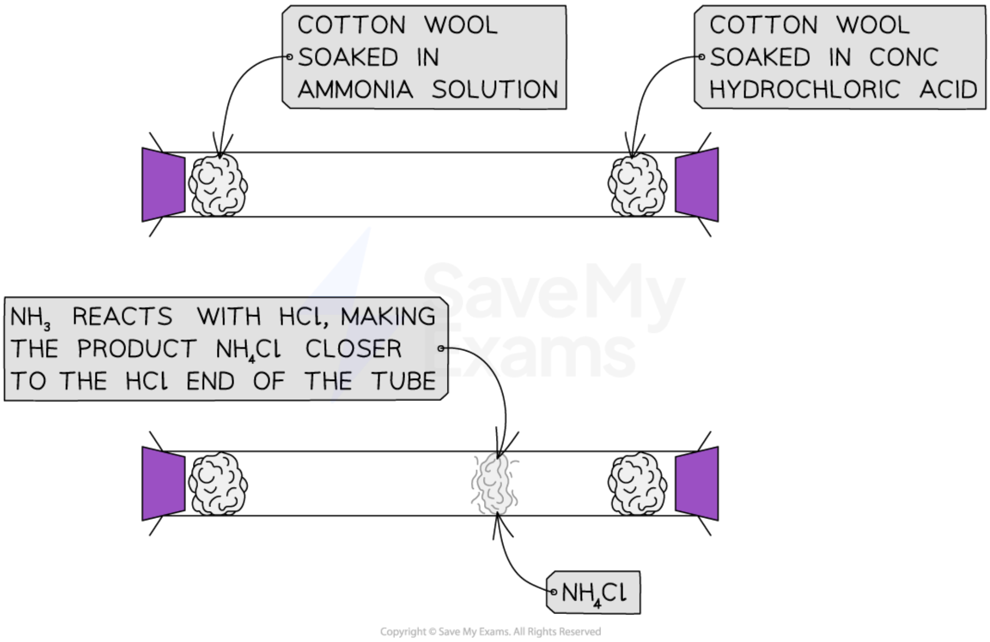
- At the same temperature, different gases do not diffuse at the same rate.
- This is due to the difference in their **relative molecular masses**
- Gases with a lower relative molecular mass are "lighter" which means that they:
  - Travel faster
  - Travel further in the same amount of time
- The reverse argument is true for gases with a high relative molecular mass, they:
  - Travel slower
  - Do not travel as far in the same amount of time
- For example, the reaction between ammonia and hydrogen chloride

Diffusion of ammonia and hydrogen chloride

- Ammonia gas and hydrogen chloride gas react together to form solid ammonium chloride

$$NH_3\,(g) + HCl\,(g) \rightarrow NH_4Cl\,(s)$$

- The M_r of ammonia is 17, while the M_r of hydrogen chloride is 36.5
  - This means that ammonia will travel faster and further than hydrogen chloride
  - Therefore, the ammonium chloride will form nearer to the hydrogen chloride
    - This is seen as a white "smoke" ring inside the gas tube



Ammonia molecules have less mass than HCl molecules so they diffuse faster and the product forms closer to the HCl end

Your notes