

States of Matter

Kinetic Theory

Solids, Liquids & Gases

Solids

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

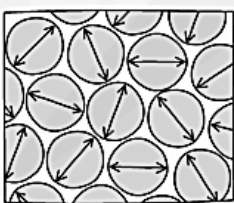
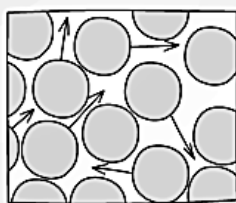
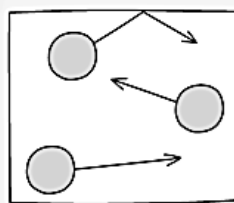
Liquids

1. Liquids also have a fixed volume but adopt the shape of the container
2. They are generally less dense than solids (an exception is water), but much denser than gases
3. 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

1. Gases do not have a fixed volume, and, like liquids, take up the shape of the container
2. Gases have a very low density
3. Since there is a lot of space between the particles, gases can be compressed into a much smaller volume
4. The particles are far apart and move randomly and quickly (around 500 m/s) in all directions
5. 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

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			

States of Matter

State Changes

Melting

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

Boiling

1. Boiling is when a liquid changes into a gas
2. 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
3. Occurs at a specific temperature known as the **boiling point** (b.p.)

Freezing

1. Freezing is when a liquid changes into a solid
2. 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

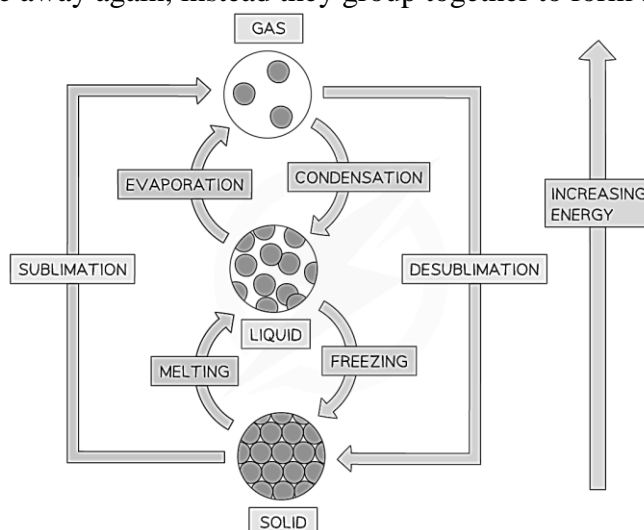
- Requires a significant decrease in temperature (or loss of thermal energy) and occurs at a specific temperature

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

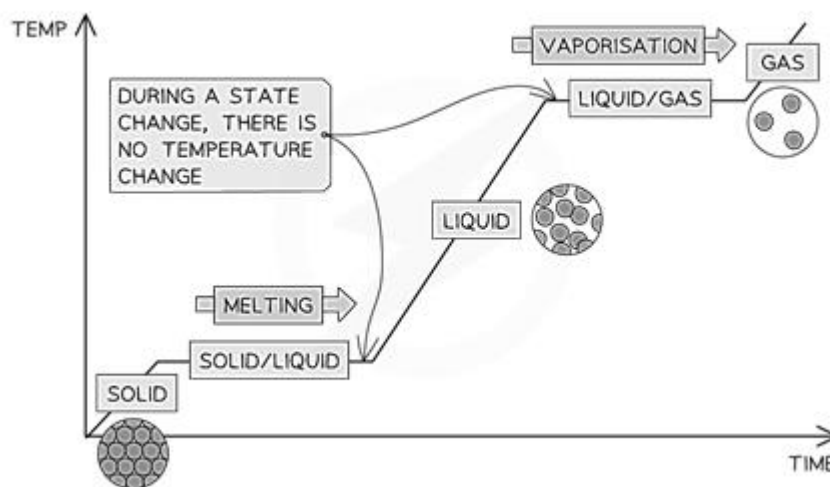


Interconversion of solids, liquids and gases

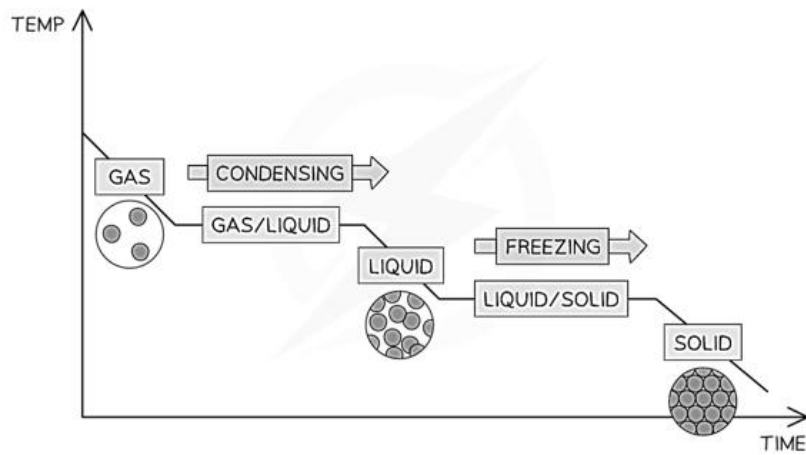
State Changes & Kinetic Theory

EXTENDED

- 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



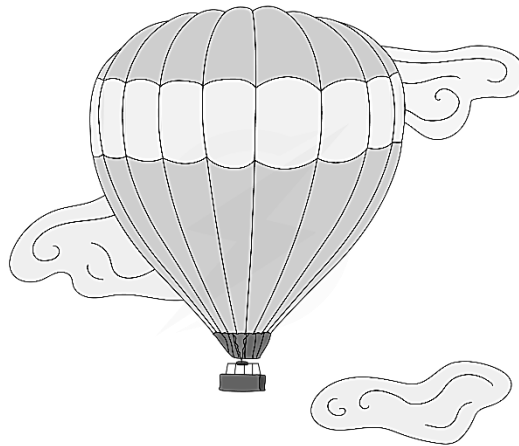
A heating curve showing the states, state changes and temperature changes as time progresses



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

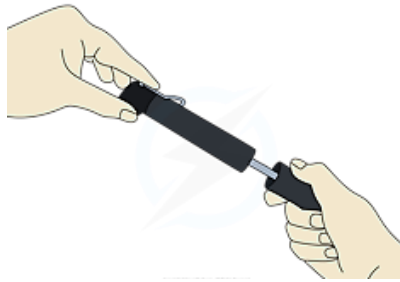
Pressure & Temperature in Gases

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



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

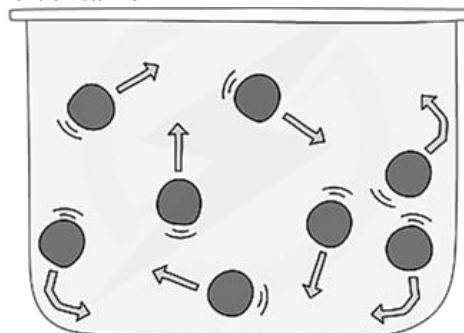
4. If you have a gas stored inside a container that is squeezed, the pressure increases as you decrease the volume
5. This is what happens in a bicycle pump
6. As you compress the bicycle pump the high pressure allows you to inflate a tire
7. You can feel the force of the high pressure if you put your finger on the end of the pump



Pressure increases as volume decreases in a bicycle pump

Gases & Kinetic Theory

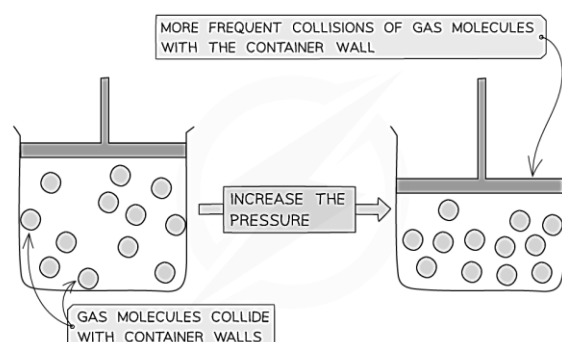
1. Gaseous particles are in constant and **random motion**
2. The pressure that gas creates inside a closed container is produced by the gaseous particles hitting the inside walls of the container



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

3. An increase in temperature increases the **kinetic** energy of each particle, as the heat energy is transformed to kinetic energy, so they move faster

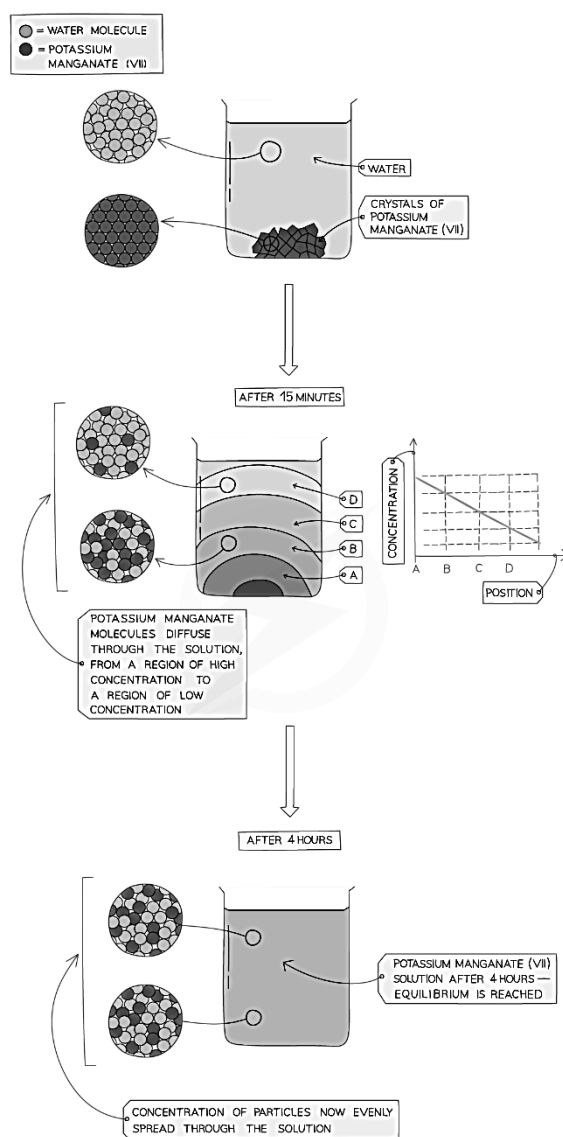
- As the temperature increases, the particles in the gas move faster, impacting the container's walls more **frequently**
- If the container walls are flexible and stretchy then the container will get bigger and bigger, just like the hot air balloon!
- If the container is made smaller, then the gas particles hit the wall more frequently
- So when there is a **decrease in volume** this causes an **increase in gas pressure**



Molecules collide more frequently with the container walls when the pressure is increased

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

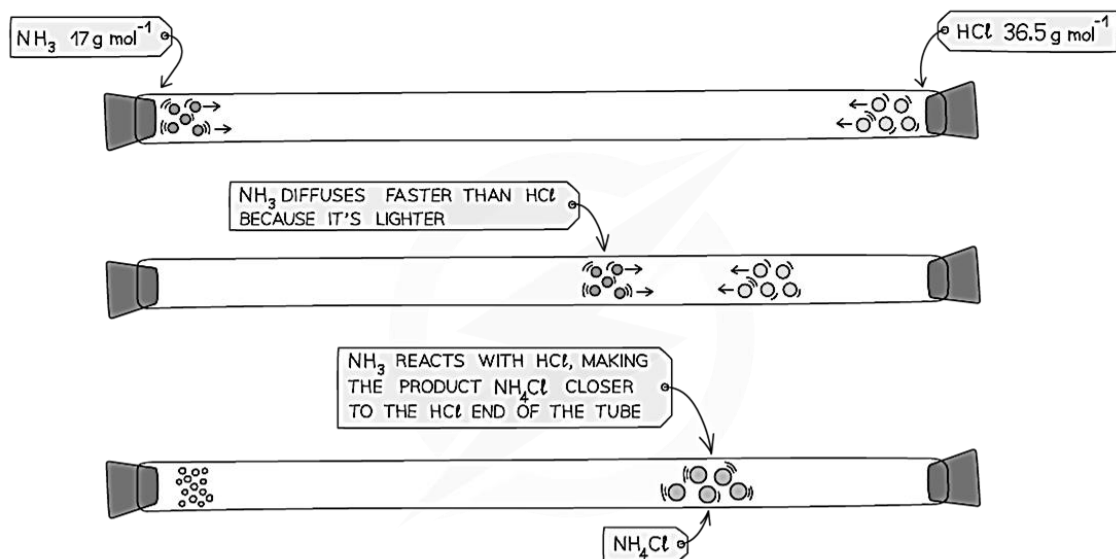


Diffusion of potassium manganate (VII), $KMnO_4$, in water. After a few hours the concentration of $KMnO_4$ is the same throughout the solution

Diffusion & Molecular Mass

- 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



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