Year 3 Chemistry
Student Notes

Kinetic Particle Theory

(Home-Based Learning topic)

Learning Objectives

- State the kinetic particle theory.
- Describe the solid, liquid and gaseous states of matter.
- Explain the inter-conversion of matter in terms of the kinetic particle theory and energy changes.
- Sketch graphs to show the transition of physical states of substances, e.g. melting, boiling, freezing, condensation processes.
- Describe and explain evidence for the movement of particles in liquids and gases.
- Explain everyday effects of diffusion in terms of particles, e.g. the spread of perfumes and cooking aromas, tea and coffee grains in water.
- State qualitatively the effect of relative molecular mass on the rate of diffusion and explain the dependence of rate of diffusion on temperature.

A. States of Matter

- Matter refers to a substance that **has mass** and **occupies space**.
- There are three physical states of matter – solids, liquids and gases.
- Properties of solids, liquids and gases:

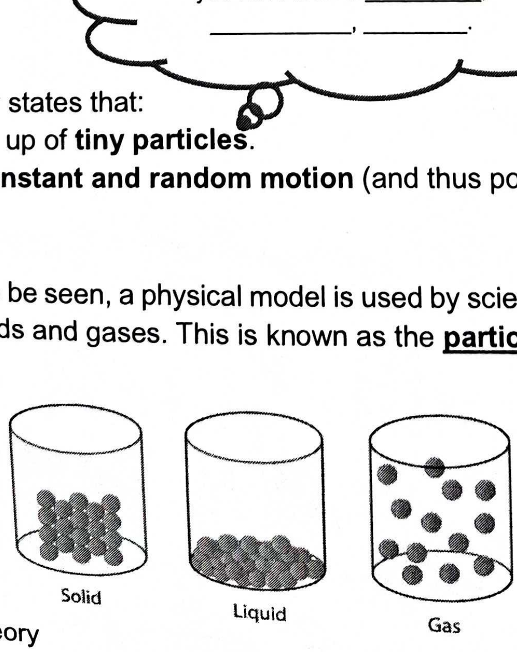
Solid	Liquid	Gas
Fixed shape	No fixed shape • Take the shape of container	No fixed shape • Spread easily to fill any container • Take the shape of container
Fixed volume	Fixed volume	No fixed volume • Take the volume of container
Not compressible	Not compressible	Highly compressible

Some examples of particles that you have learnt: __________, __________, __________.

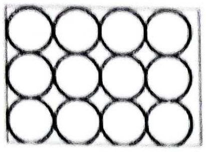
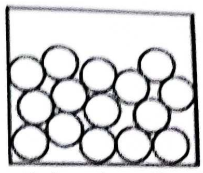
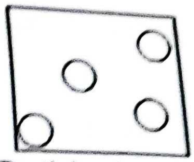
B. Kinetic Particle Theory

- The kinetic particle theory states that:
  - All matter is made up of **tiny particles**.
  - Particles are in **constant and random motion** (and thus possess kinetic energy), colliding with one another.

- As particles are too tiny to be seen, a physical model is used by scientists to show the characteristics of particles in solids, liquids and gases. This is known as the **particulate model of matter**.



- The particulate characteristics for a solid, a liquid and a gas (using the particulate model of matter) are shown in the table below.

	Solid	Liquid	Gas
Arrangement of particles **(Includes Distance between particles)**	**Very closely packed** in a **regular arrangement**  **Particles in a solid**	**Closely packed** in a **random arrangement**  **Particles in a liquid**	**Far apart** and in a **random arrangement**  **Particles in a gas**
Forces of **A**ttraction between particles	Very strong	Strong	Negligible
Movement of particles	Vibrate about fixed positions	Free to move within the liquid by sliding over one another	Move at high speed in all directions
Kinetic **E**nergy of particles	Very low	Low	High

The fundamental difference between solids, liquids and gases is the degree of movement of their particles.

Tip!

Handy Guide to Remember the Particulate Model of Matter

Model – Particulate Model of Matter is used

Arrangement – regular (solids), random (liquids / gases)

Distance – very closely packed (solids), closely packed (liquid), far apart (gases)

Forces of Attraction – very strong (solids), strong (liquids), negligible (gases)

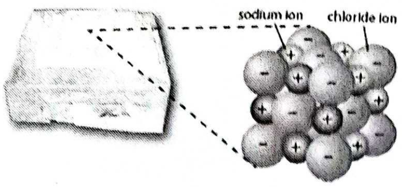
Movement – vibrate about fixed positions (solids), **slide over one another (liquids), move at high speed in all directions (gases)**

Energy (KE) – very low (solids), low (liquids), high (gases)

Note: when answering questions on arrangement of particles, please include the distance between particles in your answer as well.

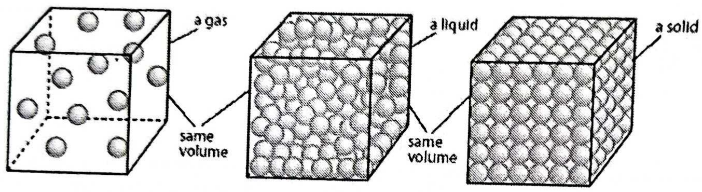
Explanation of Observations in Everyday Life Using the Particulate Model of Matter

Observation 1: Crystals have flat faces, straight edges and sharp points



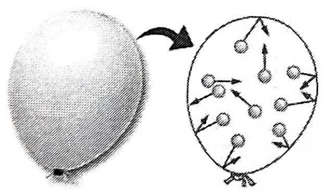
Explanation: The particles in a solid are very closely packed in a fixed positions.

Observation 2: Different states of matter have different densities.



Explanation: For the same substance given the same volume, a gas has less particles than a liquid, which in turn has less particles than a solid. Thus, in general, the density of a solid < liquid < gas.

Observation 3: Gas exerts a pressure on the container.
(Recall that pressure = force / area)



Explanation: As the gas particles are in constant and random motion, they will hit the walls of the container, exerting a force on the walls.

Comparing Properties of Matter with Properties of Particles

- It is important to note that there are differences in the properties of matter and properties of particles:

Matter	Particles
• may be coloured e.g. sulfur is yellow and nitrogen dioxide gas is brown	• are not coloured
• can feel hot or cold. The temperature of a substance depends on the kinetic energy of its particles (temperature increases when particles gain kinetic energy)	• do not get hot or cold
• expands when heated as particles move further apart	• do not expand when heated, they move faster and further apart

Enrichment: Other states of matter

The Fourth State – Plasma

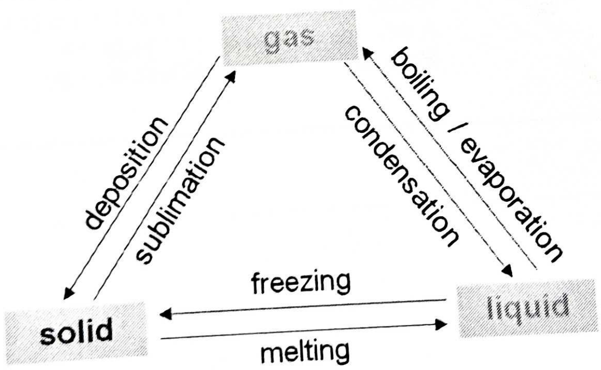
- This state exists only at very high temperatures. The large amounts of energy rip apart gas particles and removing the other electrons of the resulting atoms to give hot ionized gases.
- Plasmas are commonly found in the sun and stars, where the right conditions of temperature exist.

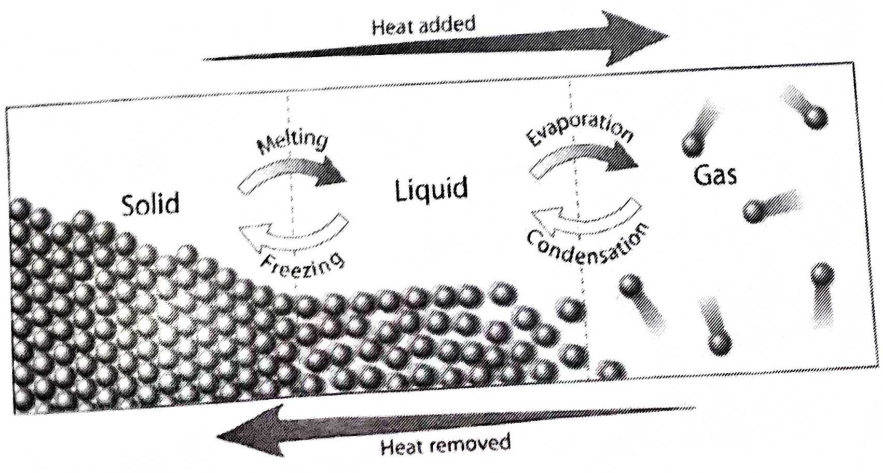
The Fifth State – Bose-Einstein Condensate

- This state exists at temperatures near absolute zero (-273.15°C). As temperature decreases, particles lose kinetic energy. Scientists predict that at absolute zero, particles will reach a point in which all molecular motion stops.
- This gives rise to gaseous superfluids that flow past one another without friction. This represents the fifth state of matter.
- Interestingly, Bose-Eintein condensates are able to 'trap' light and releasing it only when the state breaks down.

C. Changes in State

- Matter can change from one state to another. This is known as **changes of state.**
- Recall: they are **physical changes** as **no new products are formed** in the process.
- Changes in state are **reversible.**
- Processes involved in changes of state:

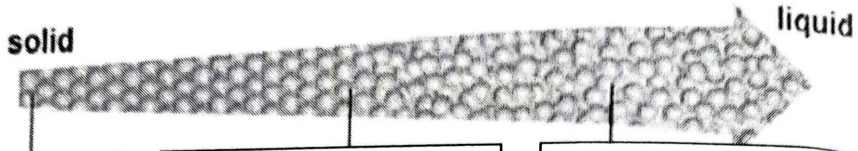




Melting and the Heating Curve

- Melting is the process by which a substance changes from a solid to a liquid.
- The temperature at which a solid melts is its melting point.

When a solid is heated:



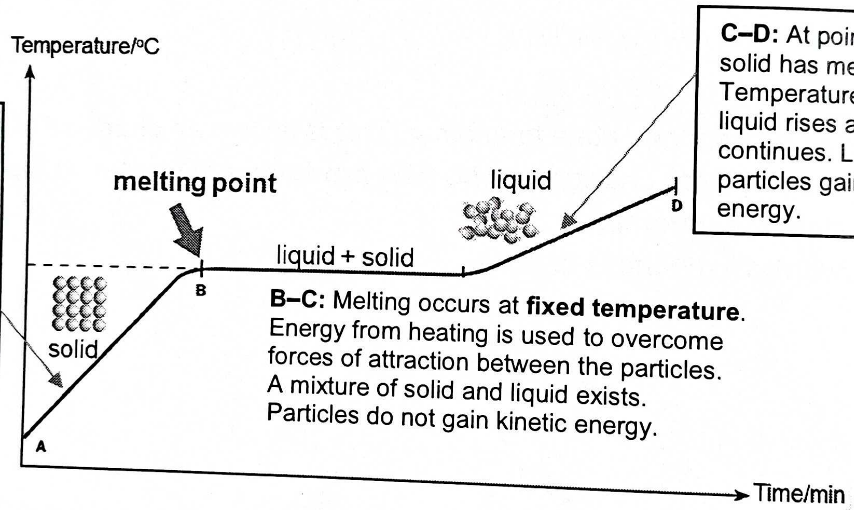
1. Particles gain gain ____ energy and vibrate **faster**.

2. Particles overcome attractive forces ____ between them and **move further apart**.

3. Particles now slide ____ over one another. Solid has melted to liquid.

- The graph below shows the temperature change as a solid is heated:

A–B: As the solid is heated, particles in solid gain kinetic energy, the temperature of the solid increases until it reaches point B, its melting point. At point B, the solid begins to melt.



B–C: Melting occurs at **fixed temperature**. Energy from heating is used to overcome forces of attraction between the particles. A mixture of solid and liquid exists. Particles do not gain kinetic energy.

C–D: At point C, all the solid has melted. Temperature of the liquid rises as heating continues. Liquid particles gain kinetic energy.

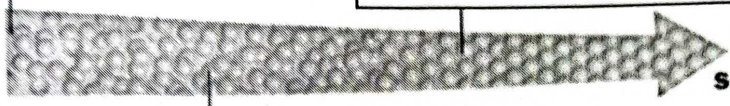
Freezing and the Cooling Curve

- Freezing is the change from a liquid to a solid.
- The temperature at which a liquid freezes is its freezing point.

When a liquid is cooled:

1. Particles lose kinetic energy and **move more slowly**.

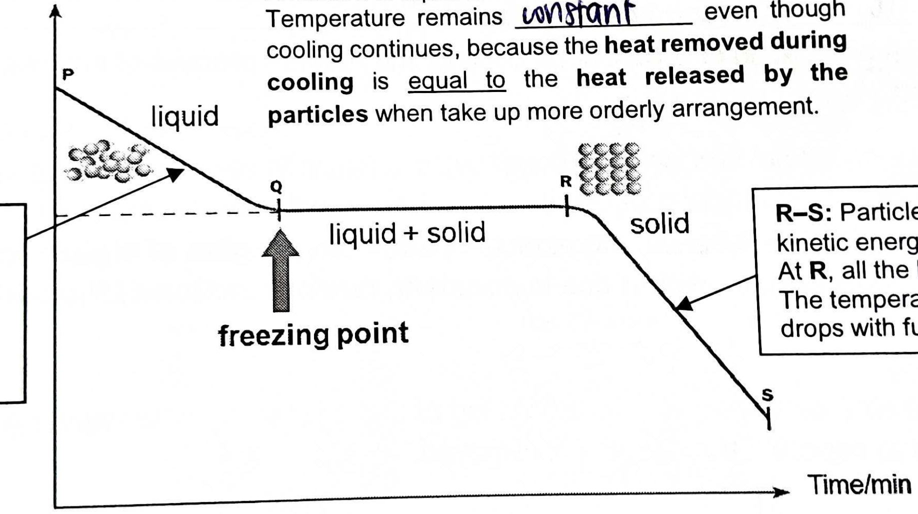
3. All the particles vibrate about fixed and orderly positions. Liquid has frozen into solid.



2. **Forces of attraction** between particles **become stronger** and particles move closer to one another.

- The graph below shows the temperature change as a liquid is cooled.

Q-R: liquid freezes.
A mixture of liquid and solid exists.
Temperature remains constant even though cooling continues, because the **heat removed during cooling** is equal to the **heat released by the particles** when take up more orderly arrangement.



P–Q: Particles in liquid lose kinetic energy. The temperature of the liquid drops to freezing point, Q. At Q, the liquid starts to freeze.

R–S: Particles in solid lose kinetic energy. At **R**, all the liquid has frozen. The temperature of the solid drops with further cooling.

Boiling and Evaporation

- Boiling is the change from a liquid to a gas **at the boiling temperature.**
  - The boiling point is the temperature at which a liquid boils at a particular pressure.
- Evaporation is the change from a liquid to a gas, **below the boiling point** (i.e. without boiling).
  - Particles have enough energy to escape as a gas from the surface of the liquid.
  - Volatile liquids evaporate quickly at room temperature, e.g. dichloromethane, ethanol.
- Differences between boiling and evaporation:

Boiling	Evaporation
Fast process	Slow process
Bubbles are observed	No visible change
Occurs throughout the liquid	Occurs at the exposed surface of the liquid only
Occurs at a fixed temperature	Occurs at all temperatures
Source of energy needed	Energy supplied by the surroundings

Sublimation

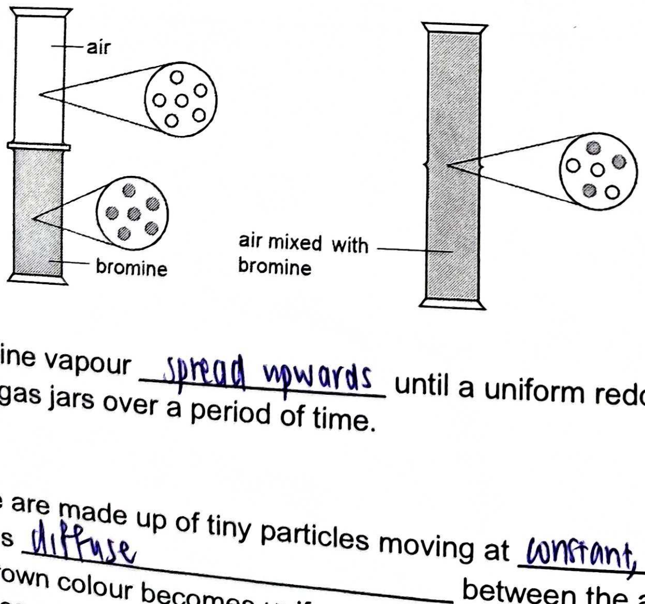
- Sublimation is the change from a **solid to a gas, without melting**.
- The forces of attraction between particles are too weak to remain in the liquid state.
- Substances that sublime include iodine, ammonium chloride, napthalene and dry ice **(solid carbon dioxide).**
- The direct solidification of a vapour by cooling, the reverse process of sublimation is known as **deposition**.

D. Diffusion

- Diffusion is a process whereby the particles move from **a region of higher concentration to a region of lower concentration** due to **constant, random motion of the particles**.

Diffusion in Gases

- A gas jar of air (colourless) is inverted on top of a gas jar of bromine vapour (reddish-brown). A cover used to separate the gas jars is removed.



Observation:

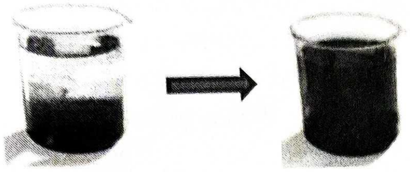
- Reddish-brown bromine vapour spread upwards until a uniform reddish-brown colouration is seen throughout the gas jars over a period of time.

Explanation:

- Both air and bromine are made up of tiny particles moving at constant, random motion.
- The bromine particles diffuse between the air particles, and vice versa.
- When the reddish-brown colour becomes uniform throughout the gas jar, it means that the particles of both gases are evenly spread. A homogeneous mixture of air and bromine is formed.

Diffusion in Liquids

- A small crystal of potassium manganate(VII) is introduced into a beaker of distilled water. A deep purple solution forms at the bottom of the beaker.
- Diffusion slowly takes place until the solution becomes uniformly purple.



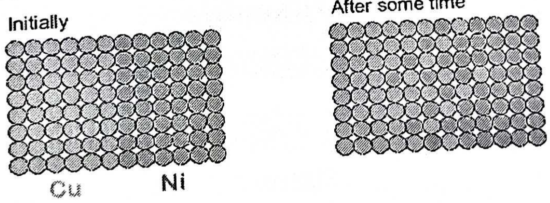
- The process can be sped up by using warm water.
- The solution will become uniformly purple within a shorter time, as **the rate of diffusion** increases **as the temperature of the solution** increase.

Can you explain why?

When the particles in the solution have a higher temperature, they have higher kinetic energy and are able to spread faster.

Diffusion in Solids

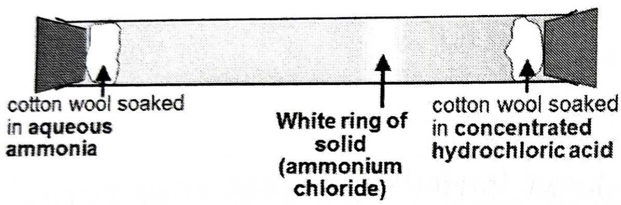
- Diffusion also takes place in solids.
- If a piece of copper and a piece of nickel are tied together firmly and left for an extended period of time, some copper particles will diffuse into the nickel, and vice versa.
- This process, however, is extremely slow, as particles in the solid are held closely together in fixed positions by strong forces of attraction.



E. Effect of Relative Molecular Mass on Rate of Diffusion

- Relative molecular mass (M_r) is the sum of all the relative atomic masses of all the atoms in a molecule.
- Relative molecular mass has **no units** and is **recorded to 1 decimal place.**
- Gas particles diffuse at different speeds, depending on their relative molecular mass.
- Under the same conditions of temperature and pressure, a gas with a **lower relative molecular mass diffuse faster** than a gas with a higher relative molecular mass.

Example 1



Observation:

- A white ring of solid is formed closer to the cotton wool soaked in concentrated hydrochloric acid and further away from the aqueous ammonia.

Explanation:

- M_r of ammonia (NH_3) = 14.0 + 3 x 1.0 = 17.0.
  M_r of hydrogen chloride (HCl) = 1.0 + 35.5 = 36.5.

- Ammonia (from aqueous ammonia) has a lower relative molecular mass than hydrogen chloride (from concentrated hydrochloric acid), and hence diffuses faster. Thus, ammonium chloride is formed further away from the aqueous ammonia.

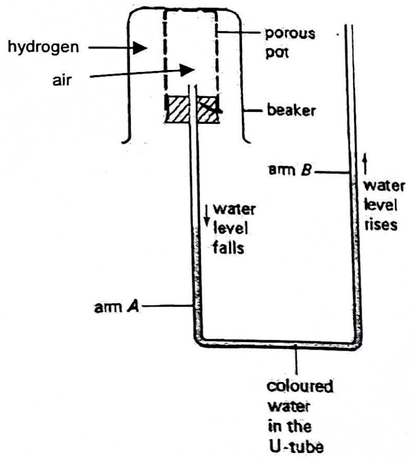
Example 2

Observation:

- A porous pot containing air is covered with a beaker containing hydrogen. The level of water in arm A falls **initially.**

- After sometime, it rises **and returns to the original level.**

Higher Mr → diffuse slower



Explanation:

- M_r of hydrogen (H_2) = 2 x 1.0 = 2.0
  M_r of air ≈ 29.0 **

  regurgitate

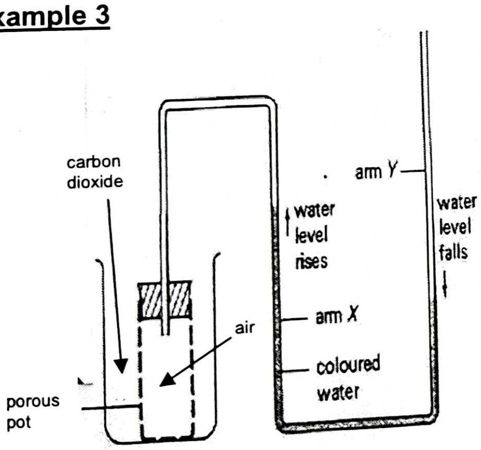
- As the **relative molecular mass of hydrogen is** lower ~~greater~~ **than air,** hydrogen gas **diffuses into the porous pot** ~~slower~~ faster than air can increase diffuse out. This results in an ~~decrease~~ **in the pressure** in the porous pot, causing the **water level at arm A to** ~~rise~~ fall **initially.**

- The water level at A rises to the original level when the concentration of hydrogen and air is the same inside and outside the porous pot, i.e. there is no net diffusion of gases in both directions.

** Consider dry air
% of N_2 ≈ 78, % of O_2 ≈ 21%, % of Ar ≈ 1%

Average M_r of air
= 78 % x (14.0 x 2) + 21% x (16.0 x 2) + 1% x 40.0
= 29.0

Example 3



Observation:

- A porous pot containing air is placed into a beaker containing carbon dioxide. The level of water in arm X falls **initially**.

- After sometime, it rises **and returns to the original level**.

Explanation:

- M_r of carbon dioxide (CO_2) = 12.0 + 2 x 16.0 = 44.0
  M_r of air ≈ 29.0 **

- As the **relative molecular mass of carbon dioxide is** greater **than air,** carbon dioxide gas **diffuses into the porous pot** slower than air can diffuse out. This results in a decrease **in the pressure** in the porous pot causing the **water level at arm X to** fall **initially.**

- The water level at X falls to the original level when the concentration of carbon dioxide and air is the same inside and outside the porous pot, i.e. there is no net diffusion of gases in both directions.