KINETIC PARTICLE THEORY

IMPORTANT DEFINITIONS:

- The mixing process in gases or solutions due to the random motion of particles is called **Diffusion**.
- The process by which a liquid changes into a vapour at any temperature below its boiling point is called **Evaporation**.
- The process by which a solid changes directly into a gas without going through the liquid state is called **Sublimation**.
- The process by which a gas or vapour changes into a liquid or a solid is called **Condensation**.
- The temperature at which a solid changes into a liquid is called **Melting point**.
- The temperature at which a liquid turns rapidly into a gas is called **Boiling point**.
- The temperature at which a liquid becomes a solid is called **Freezing point**.

BASIC CONCEPTS

TEST YOURSELF:

- Describe the properties of the three states of matter solid, liquid and gas .
- Explain the inter conversion of states of matter .

* 1.1 STATES OF MATTER:

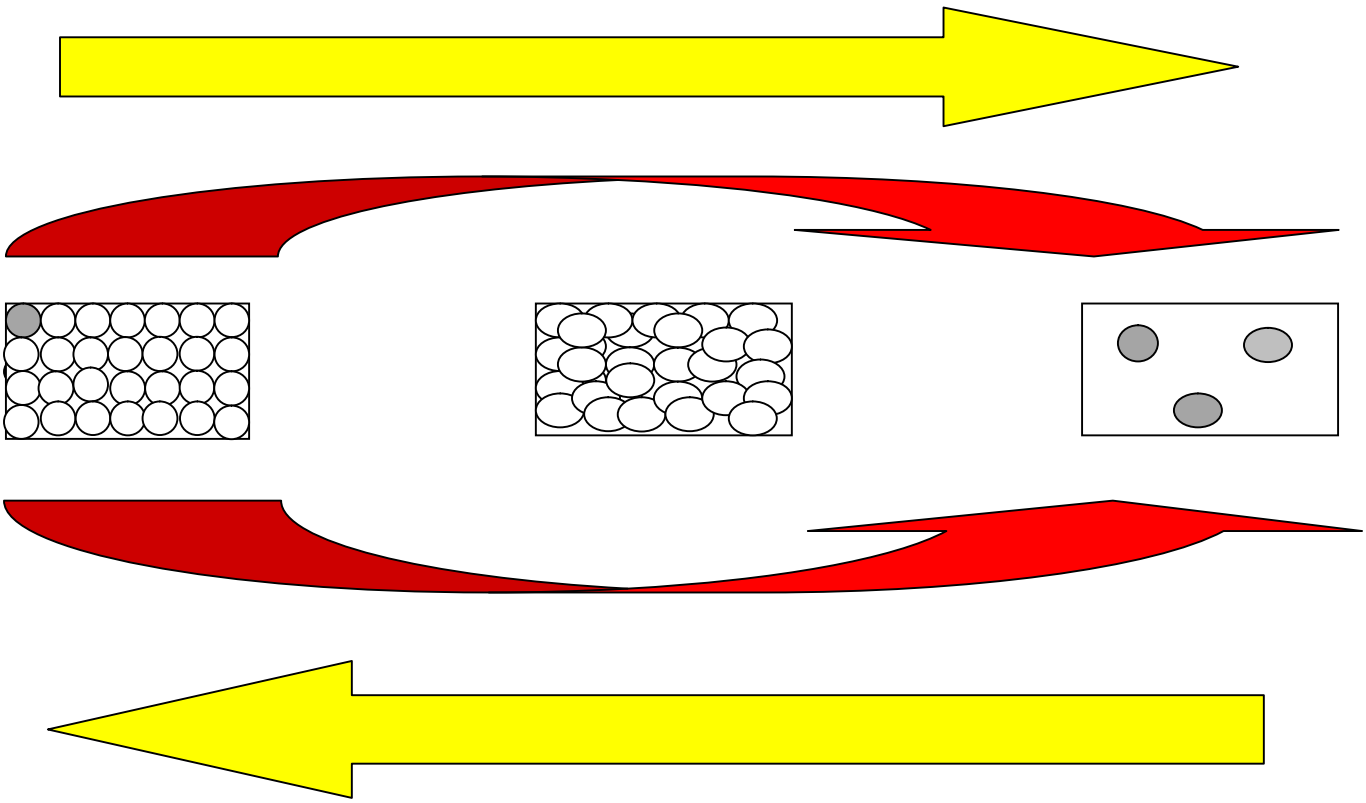
STATES OF MATTER	THEORY
SOLID ➢ Solid has A fixed shape ➢ Solid has A fixed volume ➢ Solid Cannot be compressed	➢ The particles are very closely and orderly packed . ➢ The attractive forces between particles are very strong . ➢ The particles are held tightly together . ➢ The particles can vibrate and rotate about their fixed position, but they cannot move freely .
LIQUID ➢ Liquid has No fixed shape ➢ Liquid has No fixed volume ➢ Liquid Cannot be compressed	➢ The particles are very closely but disorderly packed . There are empty space between the particles . ➢ The attractive forces between particles are strong but the particles are not tightly held together . ➢ The particles can vibrate and rotate and move freely .
GAS ➢ Gas has No fixed shape ➢ Gas has No fixed volume ➢ Gas Can be compressed	➢ Particles are very far from each other . ➢ The attractive forces between particles are weak . ➢ The particles can move rapidly and freely in all directions .

COMMON ERROR	ACTUAL FACTS
✗ Particles in a solid are motionless	✓ Particles in a solid vibrate and rotate about their fixed positions although they do not move from place to place.

* 1.2 KINETIC PARTICLE THEORY AND THE CHANGES OF STATE:

1. The **Kinetic particle theory** states that all matter is made up of tiny particles that are in constant random motion and constantly collide with each other.

2. **Changes of state** occur when particles of substance gain or lose energy.



Tips for students:

Take note that the term '**condensation**' refers to both the change of state from gas to liquid and also the change of state from gas to solid

3. **MELTING**

* When a **SOLID** is heated, heat energy is absorbed by the particles.
* The heat energy is then converted into kinetic energy and the particles being to vibrate faster.
* At the melting point, the particles vibrate vigorously enough to break away from their fixed positions, melting occurs.

4. **BOILING**

* When a **LIQUID** is heated, heat energy is absorbed by the particles .
* The particles gain kinetic energy and start to move faster as the temperature rises .
* Eventually, the particles throughout the liquid have enough energy to overcome the forces holding them together .
* The particles can now spread apart and move rapidly in all direction .
* The substance is now a gas. Hence, boiling occurs.

5. **FREEZING**

* When a **LIQUID** is cooled, the particles lose energy. They move more and slowly.
* At the freezing point, the particles can only vibrate about their fixed positions and a solid is formed.

6. **CONDENSATION**

* When a **GAS** is cooled, the particles lose energy. They move more and more slowly .

* The forces of attraction between the particles will pull the particles closer to each other. Eventually , a liquid is formed .

7. **SUBLIMATION**

* Some substances, such as iodine, ammonium chloride, mothball and dry ice (solid carbon dioxide) sublime on gentle heating.
The solid changes to a gas **without melting**.

* Sublimation occurs because the particles at the **surface of the solid** have enough energy to break away from the solid and escape as a gas.

8. **EVAPORATION**

* ***A Change From The Liquid To The Gaseous State That Occurs At Any Temperature Below The Boiling Point is*** Evaporation .

* Evaporation occurs slowly and takes place **at the surface of the liquid** .

* Evaporation occurs because the particles at the surface of the liquid have enough energy to break away from the liquid and escape as a gas .

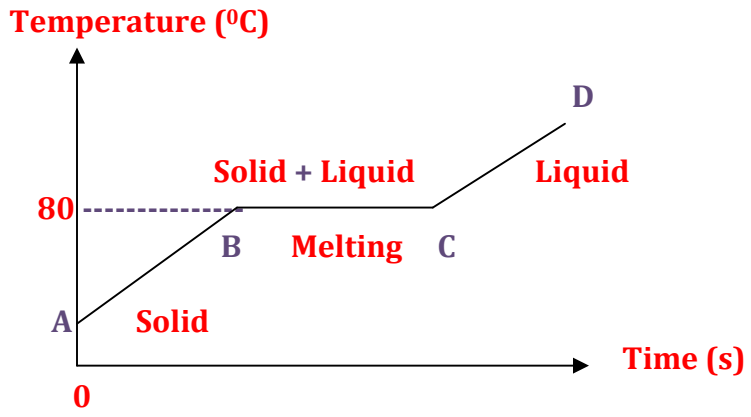
* During evaporation, the particles left behind have lower kinetic energy and therefore cause cooling effect .

9. A **heating curve** shows how the temperature of a solid changes as it is melting point .

EXAMPLE:

Pure solid naphthalene (melting point 80^0 C) is heated . The heating curve and the

changes that occur as naphthalene is heated are shown on the right .



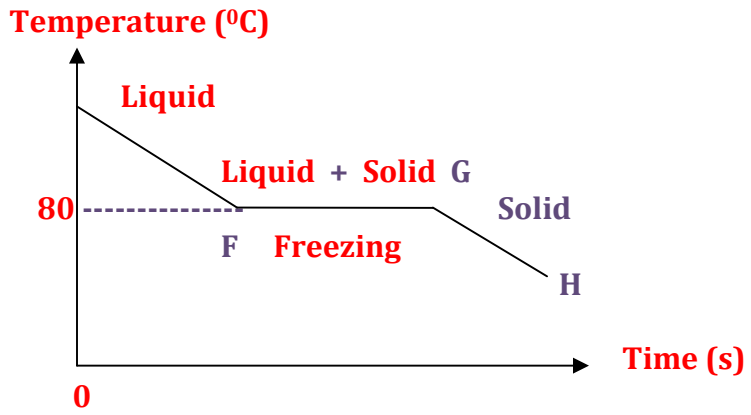
Heating Curves of Naphthalene

STAGE	PHYSICAL STATE	ENERGY AND TEMPERATURE CHANGE
AB	Solid	Kinetic energy of the vibrating molecules increases as temperature increases .
BC	Solid and Liquid	* At B, solid naphthalene beings to melt . * Temperature remains constant at 80^0 C . * Heat supplied is absorbed b y the particles to overcome the forces of attraction holding the solid particles together .
CD	Liquid	* At C, all the solid has melted . * Kinetic energy of the molecules increases as temperature increases .

10. A **Cooling curve** shows how the temperature of a pure liquid changes as it is cooling to its freezing point.

EXAMPLE :

The cooling curve and the changes that occur as naphthalene is cooled are shown below.



Cooling Curves of Naphthalene

STAGE	PHYSICAL STATE	ENERGY AND TEMPERATURE CHANGE
EF	Liquids	* Liquid naphthalene loses heat to the surroundings. * Kinetic energy of the vibrating molecules decreases as temperature decreases.
FG	Liquid and Solid	* At F, Liquid naphthalene beings to freeze (solidify). * The temperature remains constant at 80⁰C. * Heat released during the freezing process is equal to the heat lost to the surroundings.
GH	Solid	* At G, all the solid has melted. * Kinetic energy of the vibrating molecules decreases as temperature decreases.

11. The table below compares the properties of the particles in a substance during heating and cooling.

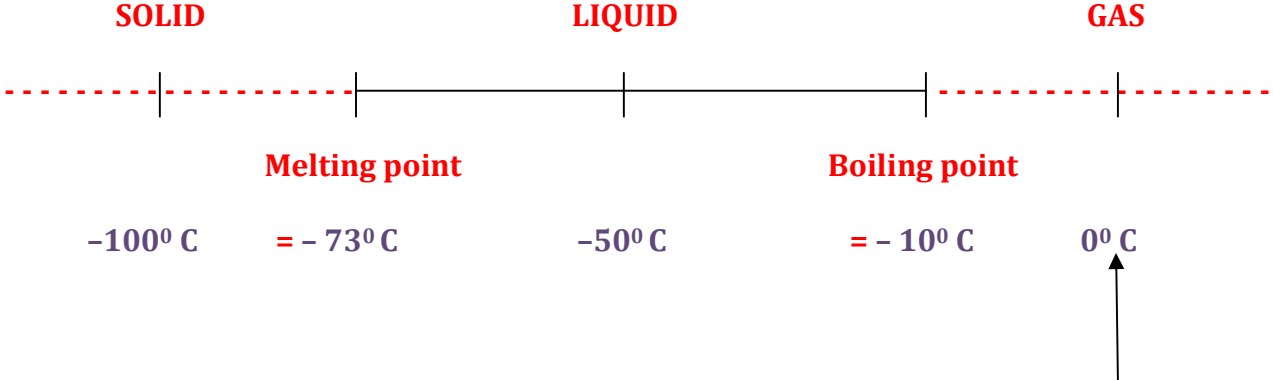
PROPERTY	DURING HEATING	DURING COOLING

Movement of particles	Increases	Decreases
Kinetic energy of particles	Increases	Decreases
Forces of attraction	Decreases	Increases
Distance between particles	Increases	Decreases

12. The physical state of a substance at a given temperature can be predicted if the melting and boiling points are known .

EXAMPLE:

The melting and boiling points of sulfur dioxide are – 73^0 C and – 10^0 C respectively. The physical states of sulfur dioxide at –100^0 C, –50^0 C and 0^0 C can be determined by the following method .



At – 100^0 C (below melting point) sulfur dioxide is a solid .

At – 50^0C (between melting and boiling points), sulfur dioxide is a **Liquid**.

At 0^0 C (above boiling point) , sulfur dioxide is a **Gas** .

Tips for students:

You should be careful with melting point or boiling point with a negative sign, i.e. below 0^0C . For example , the boiling point of sulfur dioxide (-10^0 C) is higher than the boiling point of oxygen (- 183^0C) .

COMMON ERROR	ACTUAL FACT
✘ During melting, the temperature rises because heat is absorbed	✓ During melting the temperature remains constant at the melting point because the heart absorbed is used to overcome the attractive forces between the particles .

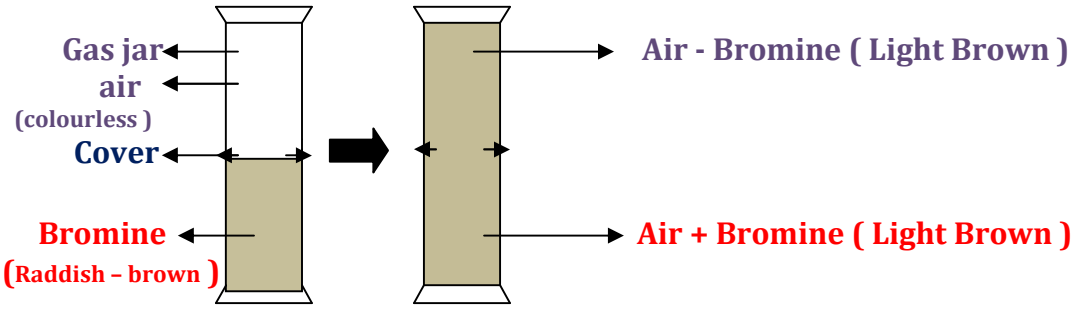
TEST YOURSELF:

- Describe and explain evidence for the movement of particles in liquid and gases
- Describe the effect of temperature and molecular mass on the rate of diffusion

* 1.3 Diffusion:

1. *The process by which particles move freely to fill up any available space is called* **diffusion** .
2. **Diffusion in gases**

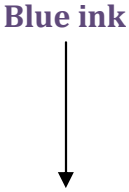
* **Bromine vapour is reddish – brown and is denser than air .**
* **When a jar of air is placed over a jar of bromine vapour, the gas jar at the top will become light brown after a few minutes .**
* **This happen because bromine particles diffuse into the space between the air particles .**
* **At the same time, the air particles also diffuse into the space between the bromine particles .**

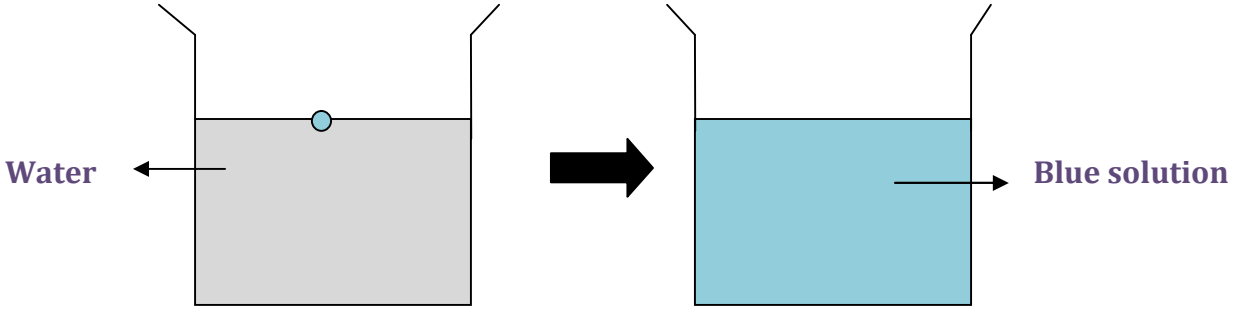


Diffusion of Bromine

3. **Diffusion in gases**

* **If a drop of blue ink placed in a beaker of water, the water slowly turns blue .**
* **This happens because the ink particles diffuse into the , space between the water particles, while the water particles diffuse into the space between the ink particles .**





DIFFUSION OF INK

Tips for students:

Although diffusion occurs in liquid, it does not imply that particles in liquids are well separated. In fact, the particles in the liquid are closely packed.

4. The rate of diffusion depends on two factors:

* **Temperature**
* **Molecular mass of the particles**

5. Effect of temperature on rate of diffusion

* **From the kinetic theory, it can be deduced that the rate of diffusion depends on the speed of the particles. The faster the particles move, the higher is the rate of diffusion .**

  The higher the temperature, the higher the rate of diffusion .

* **Thus, the color of a dye spreads through water more quickly in hot than in cold water .**

6. Effect of molecular mass on the of rate of diffusion

* **Under the same conditions of temperature and pressure, a substance with a lower relative molecular mass (M_r) diffuses faster than a substance with a higher molecular mass .**

  The lower the M_r , the higher the rate of diffusion.

* **The smaller the relative molecular mass of the gas, the lighter the gas. Thus, the lighter the gas, the higher is the rate of diffusion. For example, ammonia gas (M_r = 17) diffuses faster than hydrogen chloride gas (M_r = 36.5).**

COMMON ERROR	ACTUAL FACT
✘ Diffusion does not occur in solids.	✓ Diffusion does occur in solids. In fact, it occurs extremely slowly in solids because the solid particles are less energetic and move with less speed.

STRUCTURAL QUESTIONS AND ANSWERS

1. The kinetic particle theory can be used to account for many properties of matter. Explain the following phenomena using this theory.

   (a) Liquids flow but solids do not.
   (b) The densities of gases are low.
   (c) Gases, unlike solids, can be compressed easily.
   (d) Increasing the pressure on a gas can change it into a liquid.

   Answer:

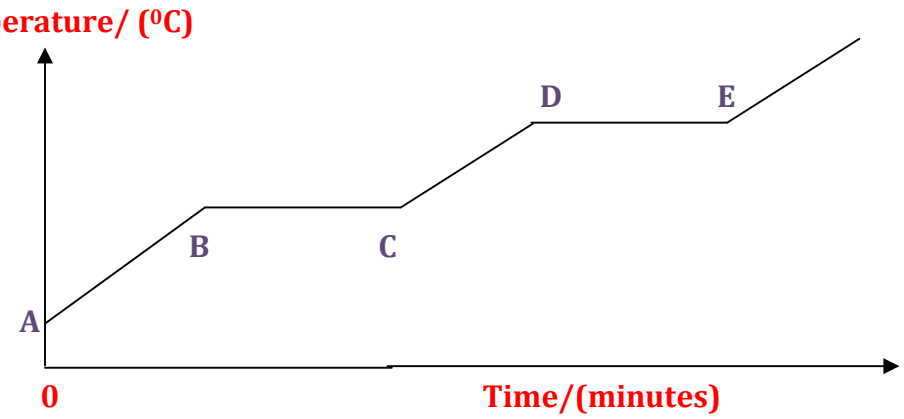
1. **(a)** The attractive forces between particles in liquids are weaker than the attractive forces between particles in solids. Hence, particles in liquids can slide freely around one another while particles in solids are held in fixed positions and cannot move past one another.

(b) The attractive forces between particles in gases are very weak (almost negligible). Hence, the gas particles are widely spaced in any unit volume of gas, and therefore their densities are low.

(c) The attractive forces between particles in solids are very strong while the attractive forces between particles in gases are very weak. Gases can be compressed easily because there are large gaps between the particles in gases. On the other hand, particles in solids are packed very closely together and it is hard for them to move.

(d) the particles in a liquid are packed relatively close together. On the other hand, the particles in a gas are widely spaced. Thus, when pressure is increased, the particles in a gas can be pushed closer to one another such that they become packed quite tightly together and begin to change into a liquid.

2. A white solid **Y** is heated uniformly starting from point **A** in the heating curve below.



(a) Explain in terms of the particles' movements and energies what happens during the periods represented by line segments **AB, BC, CD** and **DE.**

(b) Is **Y** a pre substance? Justify your answer.

Answer:

(2.)(a) Along line segment ***AB,*** the uniform heating causes the kinetic energy of the solid particles to rise. Hence, the solid particles move faster. The temperature of the solid is also raised.

Along line segment ***BC,*** the energy provided by the uniform heating is used to weaken the attractive forces holding the particles together in a fixed orderly arrangement (as in a solid). After the attractive

forces are weakened, the particles become further apart and can move randomly around one another (as in a liquid). Melting is taking place here.
There is no temperature rise because all the heat energy goes into weakening the inter-particle forces and not to raising the kinetic energy of the particles.
Along line segment ***CD,*** the uniform heating causes the kinetic energy of the liquid particles to rise. Hence, the liquid particles move faster. The temperature of the liquid is also raised gradually.
Along line segment ***DE***, the energy provided by the uniform heating is used to overcome the attractive forces holding the particles together (as in a liquid). After the forces are overcome, the particles can move more freely and randomly at high speeds (as in a gas). Boiling is taking place here. There is no temperature rise because all the heat energy goes into weakening the inter-particle forces and not to raising the kinetic energy of the particles.

(c) ***Y*** is a pure substance because it has one fixed melting point and one fixed boiling point. This is clear along line segments ***BC*** and ***DE*** which is horizontal corresponding to melting and boiling respectively.

3. (a) Miss Riva, a chemistry teacher, carried out a simple experiment to demonstrate the effects of diffusion. She first poured some distilled water into a beaker. Next, she poured an equal volume of purple potassium manganate(VII) solution into the beaker using a funnel and a long tube into the bottom of the beaker underneath the distilled water as shown.
   (i) Potassium manganate(VII),like sodium chloride, is a soluble salt. Explain why Miss Riva choose potassium manganate(VII) and not sodium chloride for this.
   (ii) Explain why the potassium manganate(VII) solution remained at the base of the beaker initially.
   (iii) Miss Riva asked her students to check the set-up once a day. Deduce what their observations will be after several days.

(b) A lead and a gold brick placed in contact with each other will be 'glued' together after several years.
(i) Explain why adhesion of the two bricks took place.
(ii) Explain why the adhesion of the two bricks requires several years to take place, unlike the experiment in part (a).

Answer:

3. (a) (i) Potassium manganate(VII) solution is purple while sodium chloride solution is colourless. Potassium managanate(VII) solution is chosen because it can be seen clearly unlikes sodium chloride solution.

(ii) Potassium managanate(VII) Solution is denser than distilled water.

(iii) After several days, all the liquid in the flask would have turned purple. This is due to diffusion of potassium manganate(VII) throughout the mixture.

(b) (i) This adhesion is due to the diffusion of lead and gold atoms. The lead atoms move slowly towards the gold block while the gold atoms move slowly towards the lead block causing the two blocks to adhere.

(ii) The particles in solids are packed closely together. Due to this close packing, the solid particles have limited space to move about and diffusion in solids takes place very slowly. On the other hand, the particles in liquids are not as tightly packed and are free to slide around one another. Hence, the potassium ions, manganate(VII) ions and water molecules move more rapidly and diffusion takes place in a much shorter time.

4. Some properties of three gases are shown in the table below.

Name of gas	**Molecular Formula**	**Relative Molecular mass**	**Smell**	**Colour**
Ammonia	NH_3	17	pungent	colourless
Hydrogen	H_2	2	odourless	colourless
nitrogen dioxide	NO_2	46	pungent	reddish-brown

(a) Gases diffuse more rapidly than liquids.

(i) How does the rate of diffusion of gases vary with temperature?

(ii) At a fixed temperature, which one of the gases listed above diffuses the fastest? Justify your answer.

(b) Mr. Mach conducted a demonstration in class on the phenomenon of diffusion in gases.

(i) Gas **X** is one of the three gases listed in (a). Suggest the identity of gas **X** and explain why Mr Mach choose this gas and not the other two.

(ii) Deduce what will be observed when the tap was opened to release gas **X** into the Pyrex tube.

(iii) Mr Mach used a vacuum pump to extract air from the Pyrex tube and repeated the demonstration. Describe and explain how the observations will differ from that in (ii) when the tap was opened to release gas **X** into the evacuated Pyrex tube.

Answer:

(4.)(a) (i) The rate of diffusion of gases increases with temperature.

(ii) Hydrogen diffuses the fastest. This is because the molecular mass of hydrogen is the smallest. (The rate of diffusion increases with decreasing molecular mass.)

(b) (i) Gas ***X*** is nitrogen dioxide. Nitrogen dioxide is reddish-brown while the other two gases are colourless. Nitrogen dioxide is chosen because it can be seen clearly unlike the other two gases.

(ii) The reddish-brown gas will gradually spread throughout the Pyrex tube due to diffusion through air.

(iii) The reddish-brown gas will spread throughout the Pyrex tube instantly. This is because the nitrogen dioxide molecules will not be colliding with air particles. In the previous case, such collisions slow down the rate of diffusion of nitrogen dioxide molecules.

SUMMARY AND KEY POINTS

1.) The mixing process in gases or solutions due to the random motion of particles is called Diffusion.

2.) The process by which a liquid changes into a vapour at any temperature below its boiling point is called Evaporation.

3.) The process by which a solid changes directly into a gas without going through the liquid state is called Sublimation.

4.) The process by which a gas or vapour changes into a liquid or a solid is called Condensation.

5.) The temperature at which a solid changes into a liquid is called Melting point.

6.) The temperature at which a liquid turns rapidly into a gas is called Boiling point.

7.) The temperature at which a liquid becomes a solid is called Freezing point.

8.) Nature of Solid:

i)Solid has A fixed shape.
ii) Solid has A fixed volume.
iii) Solid cannot be compressed.

Properties:

- **The particles are very closely and orderly packed.**
- **The attractive forces between particles are very strong.**
- **The particles are held tightly together.**
  The particles can vibrate and rotate about their fixed position, but they cannot move t freely.

9.) Nature of LIQUID:

i) it has No fixed shape.
ii)it has No fixed volume.
iii) Liquid cannot be compressed.

Properties**:**

- **The particles are very closely but disorderly packed. There are empty space between the particles.**

- **The attractive forces between particles are strong but the particles are not tightly held together.**
- **The particles can vibrate and rotate and move freely.**

10.) Nature of GAS:

i) it has No fixed shape.
ii) it has No fixed volume.
iii) it Can be compressed.

Properties:

- **Particles are very far from each other.**
- **The attractive forces between particles are weak.**
- **The particles can move rapidly and freely in all directions.**

11.) The **Kinetic particle theory** states that all matter is made up of tiny particles that are in constant random motion and constantly collide with each other.

12.) **Changes of state** occur when particles of substance gain or lose energy.

Key Points:

the term 'condensation' refers to both the change of state from gas to liquid and also the change of state from gas to solid.

13.)**MELTING** is the process that occurs when a Solid is heated, it is converted into a Liquid. **In this process ,** heat energy is absorbed by the particles that is converted into kinetic energy and particles vibrate vigorously enough to break away from their fixed positions and melting occurs.

14.) **BOILING** is the process that occurs when a Liquid is heated, it is converted into a Gas. **In this process**, heat energy is absorbed by the particles gain kinetic energy and the particles can now spread apart and move rapidly in all direction.

15.) **FREEZING is the process that occurs when** a **LIQUID** is cooled,it is converted into a Solid. In this process, particles lose energy.
At the freezing point, the particles can only vibrate about their fixed positions and a solid is formed.

16.) **CONDENSATION** is the process that occurs when a **Gas** is cooled, it is converted into a **Liquid**. In this process, the particles of Gas lose energy. They move more and more slowly.

17.) **SUBLIMATION** is the process by which a **Solid** changes to a **Gas** without melting.

18.) *A Change from the Liquid to the Gaseous State that Occurs at Any Temperature below the Boiling Point is* called the **Evaporation**.

19.) A heating curve shows how the temperature of a solid changes as it is heating to its melting point .

20.) A Cooling curve shows how the temperature of a pure liquid changes as it is cooling to its freezing point.

21.) ***The process by which particles move freely to fill up any available space is called*** **diffusion .**

KEY POINT:

Although diffusion occurs in liquid, it does not imply that particles in liquids are well separated. In fact, the particles in the liquid are closely packed.

22.) The rate of diffusion depends on two factors:

i.)Temperature
ii.)Molecular mass of the particles

23.) From the kinetic theory, it can be deduced that the rate of diffusion depends on the speed of the particles. The faster the particles move, the higher is the rate of diffusion .

The Rate of diffusion increases with the increase of the temperature.

24.) Under the same conditions of temperature and pressure, a substance with a lower relative molecular mass (M_r) diffuses faster than a substance with a higher molecular mass .