Unit-I

# STATES OF MATTER

↳ The matter can exist in either gaseous state, solid state or liquid state. These different states in which the matter Exists are referred to as 'states of matter' also termed as 'states of phases'.

↳ changes in the states of matter occur due to changes in the intermolecular forces, intensity, pressure and temperature. These are considered to be the determinant factors in the states of matter.

→ characteristics of States of matter :-
    ↳ * solid state      ↳ * liquidstate    ↳* Gaseous state

↳ * solid state :- ⓐ shape and volume :-↳ The Molecules of Solid state are stable in nature and possess definite shape.
    ↳ changes in the shape of solid molecules can be brought about by exerting an External force [like temperature, pressure Etc...]

ⓑ Arrangement :- Solids tend to acquire a packed arrangement because of the strong intermolecular forces of attraction operating between their molecules.
↳ Thus, the Molecules of solids are not allowed to undergo free movement, but can undergo vibrations

at fixed positions.

© Energy :- Solid molecules generally possess low kinetic Energy at low temp. But on increasing the temp, Energy is acquired by the molecules which is sufficient Enough to break their ~~and~~ orderly ~~att~~ arrangement, thus converting them to liquid state

Eg :- Conversion of ice to water.

→ ② Liquid state :- ⓐ shape and volume :-

unlike the molecules of solid, molecules of liquid do not have a definite shape. They acquire the shape of the container in which they are poured.

ⓑ Arrangement :- The molecules of liquid state are not orderly arranged like in solids. Instead, they move about freely and can even move against one another.

© Energy :- liquid molecules possess high kinetic Energy Even at room temp when compared to solids. An increase in temp increases their kinetic Energy which enables the liquid molecules to Enter the gaseous state. Such conversion of liquid state to gaseous state is referred to as Evaporation

Eg :- Conversion of water to water vapour.

③ Gaseous state :-

ⓐ Shape and Volume :- The molucules of gas are randomly arranged. Hence, gas is devoid of any particular shape and also tends to occupy the entire space of the container.

ⓑ Arrangement :- Molucules of gaseous state move freely than the liquid molecules and slide past one another. Such property is affected due to the weak intermolecular forces of attraction between the gas molecules. The molecules of gas can be easily compressed because of increased space between them.

ⓒ Upon cooling, the gaseous state gets converted to liquid state, Such conversion is known as condensation.

Eg :- Conversion of cloud to rain.

⇒ Factors Influencing the states of matter :-
  ① Intermolecular forces
  ② Temperature
  ③ pressure

# Solid and crystalline state :-

↳ Solids are formed when liquids are cooled. Solids consist of ions, atoms and molecules, which are held in fixed positions and closely packed. The inter-particle attractions in solids are stronger than in liquids.

## classification

↳ Based on the nature of bonds

* Metallic :- Eg :- Magnesium, copper

* Ionic :- Electro static forces of attraction
Eg :- Sodium chloride

* Valence (or atomic) :- covalent bonding,
Eg :- diamond

* Molecular :- weak van der waals forces
Eg :- Naphthalene

↳ Based on the structure :

* Crystalline :- Atoms, ions & molecules are arranged in a regularly repeated pattern.
Eg :- Metals, alloys, rocks & minerals.

* Non- Crystalline :- [or amorphous] :- They do not have the characteristic regularity.
Eg :- glass, wood, plastics.

* Anisotropic :- A phenomenon of having physical properties different in different directions is known as anisotropy

* <u>Isotropic</u> :- (iso = same) :- A phenomenon of having same physical properties in all directions is known as isotropy.

⇒ <u>Crystals</u> :- Most pharmaceutical solids have crystals in the size (diameter) range of 0.5-300 μm.

<u>Types of Solids</u> :- 2 Types

↳① Crystalline (True) Solids

↳② Amorphous solids / Super-cooled liquids / non-laltice like solids.

① <u>Crystalline Solids</u> :- → Solids that have definite arrangement patterny (lattices) of individual units are known as Crystalline Solids.

Crystalline Solids
↓ Based on

Crystal composition                                    arrangement

molecular    Ionic    covalent    Metallic
crystals     crystals

Cubic           Tetagonal      Hexagonal        Rhombic
Eg: Nacl        Eg:- urea      Eg:- Ialobroon   Eg:- Iodine


c
b
a   90°
cubic


c
a  90
Tetragonal


c
b
a  120°
Hexagonal


c
a        b
Rhombic

                                    Monoclinic
                                    Eg: Sucrose

                                    Triclinic
                                    Eg:- Boric acid


b
a  90°
monoclinic


c
b
a
Triclinic
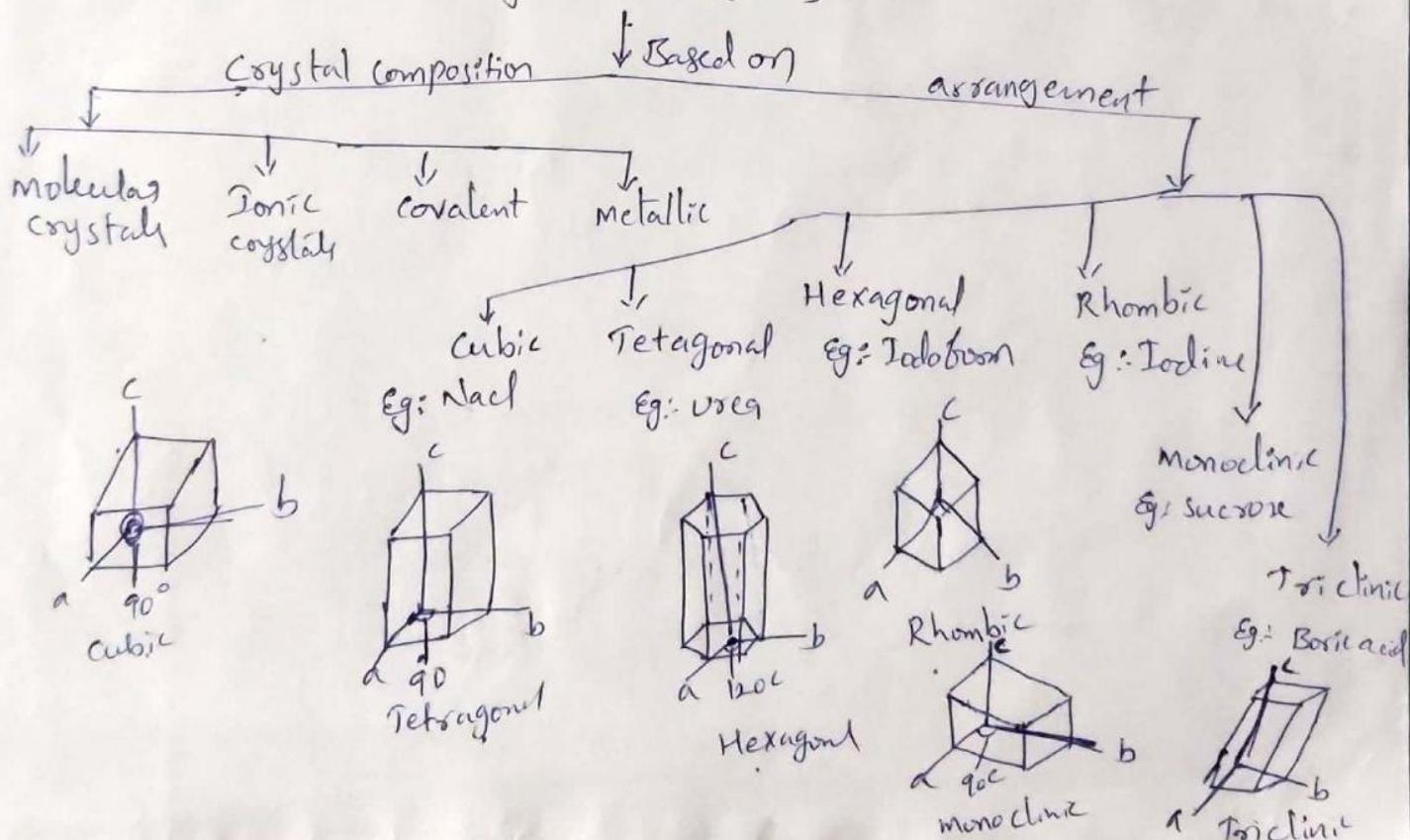
ⓐ Molecular Crystals :- Molecular crystals are the crystals, in which the crystal lattice is made up of molecules. These molecular crystals are held together either by dipole-dipole forces of attraction. Because of of these weak forces of attraction, low melting point

Eg :- Carbon dioxide, hydrogen chlorides, naphthalene

ⓑ Ionic Crystals :- Crystals in which the crystal-lattice is made up of ions, are referred to as ionic crystals. The ions in these crystals are bound by strong electrostatic forces of attraction. Because of these strong intermolecular forces of attraction, the ionic crystals show high melting point & hard in nature

Eg :- NaCl, $KNO_3$, $Na_2SO_4$.

ⓒ Covalent Crystals :- The crystal lattice of Covalent crystals is made up of atoms. Covalent bonds are the forces of attraction that bound these atoms. These crystals are high melting points because of the presence of strong Covalent bonds

Eg :- Diamond.

ⓓ Metallic Crystals :- The crystal lattice in metallic crystals is made up of free moving electrons interspersed with positively charged ions. metallic crystals are either extremely soft (like sodium & potassium) (or) extremely hard (like osmium). They high melting point because of presence of strong electrostatic attractions between the

positively charged ions & negatively charged electrons.

   Eg: Sodium, Copper.

② Amorphous Solids :- Solids that do not have any specific molecular or ionic or atomic arrangement are referred to as amorphous solids. Arrangement of such disordered particles in amorphous solids is some what similar to liquids.

⤷ These solids also tend to show ~~has a great impact on the absorption of~~ movement upon application of pressure for prolonged periods.

  ⤷ Certain materials contain both amorphous & Crystalline forms.

    Eg:- petrolatum.

  ⤷ Certain amorphous & crystalline form on heating & cooling
    Eg:- Beeswax and paraffin.

POLYMORPHISM :- is the ability of a compound to Crystallise as more than one distinct crystalline species with different internal lattices.

⤷ polymorphism is exhibited by 63% of barbiturates, 76% of steroids and 40% of sulphonamides.

  ⤷ different shapes & properties.
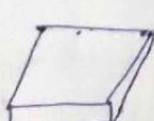


plate :- Eg: Naphthalene
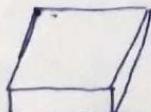
Tabular
Eg: Tolbutamide
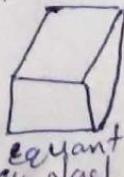
Equant
Eg: NaCl
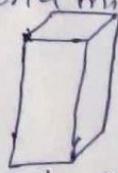
Columnar
Eg: Fluorocortisone acetate

↳ ◨ polymorphs are structurally not different, but exhibit differences in their physicochemical and biological properties.

  ↳ melting point
  ↳ solubility
  ↳ Dissolution
  ↳ Bioabsorption.

↳ There fore, the performance of different drugs depends on habit and crystalline modifications of the active drugs.

Applications:- ① Enhanced Solubility :- Metastable forms have low melting points and high solubilities.

↳ There fore, they exhibit greater dissolution. ~~free~~

Eg:-

| Form Riboflavin | melting point °C | aqueous solubility mg/ml |
|---|---|---|
| Form I (stable | 291 | 60 |
| Riboflavin Form-II | 278 | 80 |

② Improved dissolution:- If solubility is enhanced, the dissolution rate also increases. metastable polymorph of methyl prednisolone (Form II) has 1.4 times higher rate of dissolution than stable form (Form-I)

③ Enhanced absorption:- As solubility & dissolution are Enhanced, the rate of absorption of metastable polymorph also increases

  ↳ Form II (methyl prednisolone) has 1.7 time higher rate of absorption than a stable crystal (Form I)

④ manufacture of dosage forms:- In the manufacture of suppositories, cocoa butter is used.

4 It is available in 6 different polymorphic forms.

Gamma (γ) form
Cocoa butter

Alpha (α) form

Beta prime (β') form

Beta (β) form

M.P - 18°C

MP - 22°C

MP - 28°C

MP - 34.5°C

## Characterisation of crystals :-

① melting point or Fusion Temp

② X-Ray Diffraction (X-RD)

③ Differential Scanning calorimetry (DSC).

## Melting point (or) Fusion Temp:-

The Temp at which a liquid passes into a Solid state is know as freezing point.

It is also known as melting point (or) fusion temp. Crystalline solids have definite (sharp) melting point. Amorphous solids exhibit melting range. The determination of melting point normally involves the conversion of solid into liquid.

The heat absorbed when one mole of solid melts or heat liberated when one mole of liquid freezes is called as Molar heat of fusion.
defined

↳ Heat is used to break the intermolecular attractions.

↳ melting point & heat of fusion roughly express the nature of intermolecular forces as like as

| Substance | melting point | Molar heat fusion | Nature of interaction |
|-----------|---------------|-------------------|-----------------------|
| water | 273.16 | 6.004 | dipolar |
| Ethane | 90 | 2.856 | nonpolar |

↳ The melting points are obtained at normal atmospheric pressure

↳ These values alter with changing of pressures. This relationship is expressed by classius-clapeyron equation

Conclusions Canbe drawn regarding melting point

↳ As the melting point increases molar heat of fusion also increases

↳ * As the number of Carbons increase, melting point also increases because of increase in molecular mass.

↳ * The melting points of alkanes with even number Carbons are higher than the hydrocarbons with odd number Carbons. This is due to less efficient packing of odd carbon alkane chains in the crystal.

② X-ray Diffraction :- (X-RD)

By using diffraction patterns of x-rays we can determine the structure of crystals. when X-rays are passed through the crystal layers that are equidistant to one another, diffraction occurs.

↳ This diffraction is due to passage of X-rays having wavelengths similar to the interatomic distances between the layers of Crystal.

↳ Hence, these Crystals act as gratings (it converts polychromatic light to monochromatic light) to the incident X-rays.

↳ when the resultant diffraction patterns were developed on a sensitive plate or a detector the structure of crystals can be determined.

⓵ To determine the interatomic distances in a crystal.

Bragg's Equation is applied.

↳ Consider that the atomic layers of a crystal is separated by a distance 'd', represented as parallel horizontal layers. When X-rays are allowed to pass through these layers at an angel θ, Some of the rays get reflected at the same angle, while others get absorbed and then get reflected.

↳ These reflected rays coincide, when the difference in path lengths of reflected rays is equal to the integral members of wavelength

$$n\lambda = QS + SR$$
$$QS = SR = PS \sin\theta$$
$$\therefore n\lambda = 2PS \sin\theta$$

↳ The path difference is an integral multiple of wave length

$$\boxed{2d\sin\theta = n\lambda}$$


Incident rays
Reflected rays

In △ OAB, $\sin\theta = \dfrac{AB}{OB}$

$\sin\theta = \dfrac{AB}{d}$

$\boxed{AB = d\sin\theta}$

In △ OBC, $\sin\theta = \dfrac{BC}{d}$

$\boxed{BC = d\sin\theta}$

path diffⁿ = AB + BC
= d sinθ + d sinθ
= 2d sinθ

$\boxed{2d\sin\theta = n\lambda}$
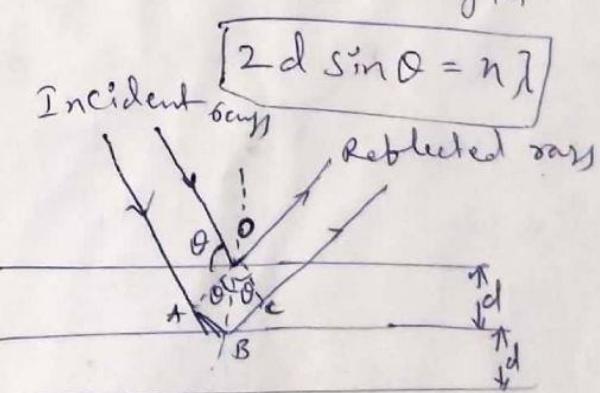
# Applications of XRD:-

* Identification of materials
* Quantitative analysis of drugs and Impurities
* physical & chemical stability studies of drugs
* structural determination
* Differentiation of amorphous and crystalline substance
* Identification of polymorphic forms
* Differentiation of drug pseudomorph

③ **Differential scanning calorimetry (DSC):**

⌐ DSC instrument is used to quantify crystalline transitions, fusion, evaporation and sublimation.

⌐ In this technique, the sample and reference substance are heated separately as per a controlled temperature program. The Energy inputs are maintained at the same level.



Individual heaters
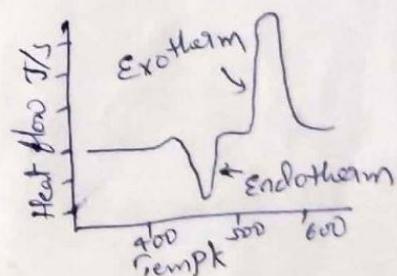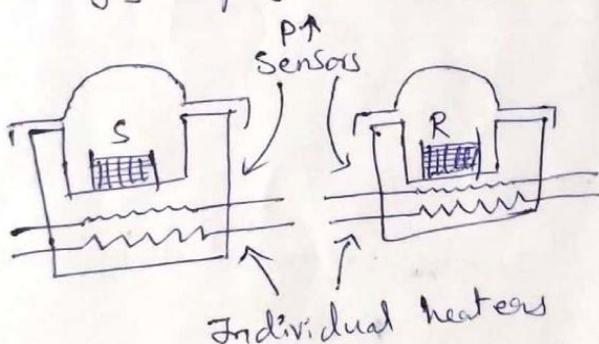
⌐ All dynamic DSC studies are carried on thermal analyser with DSC module.

⌐ calorimetric measurements are made with Empty cell (high-purity alpha alumina disc) as the reference. The instrument is calibrated using high purity indium metal as standard.

Applications → Elimination of an Endothermic & Exothermic peaks
→ Appearance of a new endothermic peak or exothermic peak
→ change in peak shape & peak onset
→ peak maximum temp

→ Identification of chemicals
→ purity of chemicals
→ Incompatibilities of drug-drug & drug-Excipients in a mixture
→ Deciding polymorphic changes
→ characterisation of pseudomorphy

→ ## properties of Solids :-

↳* Melting point and Heat of Fusion

↳* Sublimation

↳* polymorphism.

① Melting point & Heat of Fusion :-

Melting point :- A particular temp at which conversion of Solid to liquid occury is known as the melting point.

Freezing point :- A particular temp at which conversion of liquid to Solid occurs is known as the freezing point

$$\text{Solid} \underset{\text{Freezing.}}{\overset{\text{melting}}{\rightleftharpoons}} \text{liquid}$$
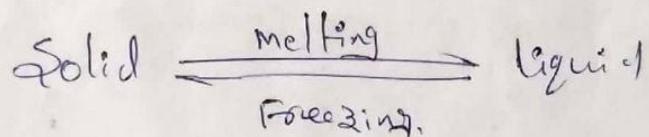
↳ melting and Freezing points vary accordingly with the pressure which can be represented by Clapeyron Equation as.

$$\Delta T/\Delta p = T \frac{V_L - V_s}{\Delta H_f}$$

where,  $V_L$ = Liquid's molar volume

$V_s$ = Solid's molar volume

$\Delta H_f$ = Molar heat of fusion

$\Delta T$ = change in melting or freezing point

$\Delta p$ = change in pressure

② Sublimation :-

By increasing the temp and decreasing pressure, Solids get converted to liquids, which upon further increase in temperature and decrease in pressure, convert to gaseous state. But certain compounds directly convert from solid to gaseous state without converting into liquid. This process of direct conversion of solid to gaseous state is known as Sublimation.
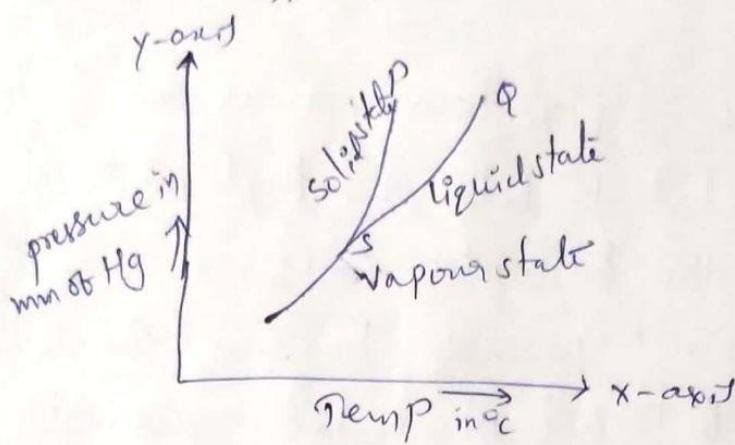


P.S = Melting point curve
QS = Vapour pressure curve
RS = Sublimation curve
S = Triple point of water

↳ The phase diagram of water includes three different curves and a point known as triple point where all the three curves coincide.

ⓐ melting point curve (PS :- This curve depicts the melting point of a solid. Compounds that contain values, on the length of this curve contain solid and liquid phases existing in equilibrium.

ⓑ Vapour pressure curve (QS):- This curve depicts the vapour pressure of a liquid. Compounds whose values lie above this curve exist liquid state only and whose values lie below this curve are present only in gaseous state.

© Sublimation Curve (RS):- This curve depicts vapour pressure of a solid. Compounds exists in solid form when the values fall to the left side of this curve whereas whose values fall to the right side of this curve, exist only in gaseous state.

④ Triple point:- The point where all these three curves coincide is known as triple point. At this particular point all the three phases. i.e., Solid, liquid and gas are in an Equilibrium state.

↳ The process of Sublimation occurs only when the pressure exerted lie below the triple point. At pressures above the triple point, conversion of solid to gaseous state is not possible because the solid has to convert to liquid phase before converting into gaseous state.

③ polymorphism:-

Existence of a substance in different crystalline forms is known as polymorphism and the substance exhibiting this phenomenon are known as polymorphs. Existence of Element in different crystalline forms is known as allotropy.

→ **LATENT HEAT :-**

When change in the state of matter occurs, temperature does not rise, it remains constant but heat get absorbed or liberated. Thus, the heat which results in the change of matter, without change in the temperature is called the latent heat.

Two types :- ① Latent heat of Fusion
② Latent heat of Vaporization.

① **Latent heat of Fusion :-** This heat is latent because it is not associated with the change in temp. Latent heat of fusion is associated with the solid-liquid transition without change in the temp.

For Example, ice (at 0°c or 32° F) converts to water with the Latent heat of fusion.

$$\text{Solid (ice)} \xrightarrow[\text{} ]{\text{Latent heat of fusion} \atop +\Delta (80\ \text{calories})} \text{Liquid (water)}$$

Temperature ←———————————— Temperature
(0°c)                          $-\Delta$                    (0°c)
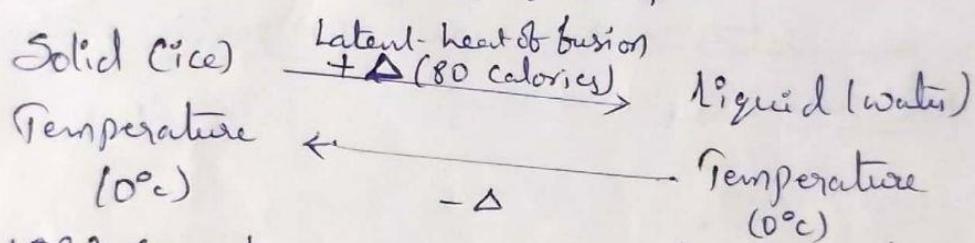
↳ Ice (at 0°c) converts to water with the latent heat of fusion. The heat of fusion for water at 0°c is approximately 80 calories per gram of ice.

② **Latent heat of Vaporization :-** Latent heat of vaporization is associated with liquid-vapour transition. The amount of heat required to convert unit mass of a liquid into the vapour without a change in temp

$$\text{Liquid (water)} \xrightarrow[\text{}]{\text{Latent heat of Vaporisah} \atop +\Delta (533\ \text{calories})} \text{Gas}$$
Temp (100°c                                      Temp (100°c)
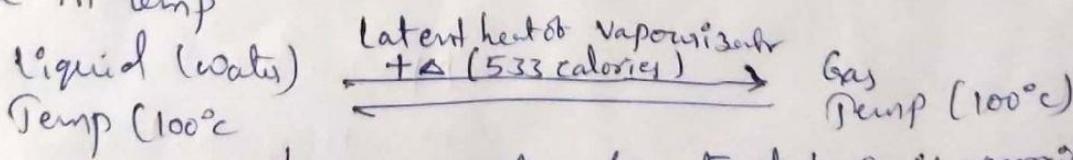
↳ The Latent heat of vaporization of water at 100°c is approximately 533 calories per gram of liquid.

# Gaseous state

Matter is made of molecules, atoms, and ions. Matter exist in one of the three states, viz., gas, liquid & solid.

↳ In gases, the intermolecular forces are the weakest compared to that of liquids and solids. Therefore, the behaviour of gases is comparatively very simple & predictable.

↳ Moreover, the gas molecules usually occupy entire volume of the container in which they are placed.

Applications:-

ⓐ Anaesthetic gases :- Eg: Cyclopropane
ⓑ Sterilisation gases :- Eg:- Ethylene oxide
ⓒ Fuel gases :- Eg:- Butane & propane
ⓓ Gases in chemical processes: Eg:- hydrogen & nitrogen
ⓔ Refrigeration gases :- Eg:- fluorochlorohydrocarbons

## characteristics (or) Measurable properties of Gases:

① pressure :- Units of pressure :- Pascal (Pa)

② Temp :- units $k = °C + 273$ (or) $°C = k - 273$

③ Volume: $1 \, lit = 1000 \, ml$

$$1 \, ml = 10^{-3} \, lit$$

④ moles of a gas :- $n = \dfrac{m}{M}$

where: n = moles of the gas

M = molecular weight

m = mass of the gas

# Law's Involved in Gaseous

① **Ideal Gas Equation :-** ⓐ Boyle's law

ⓑ charles law

ⓒ Avogadro's law

② **Real Gases :-** Van Der Waals Equation.

③ **Dalton's law of partial pressures**

④ **Graham's law of Diffusion of Gases**

① **Boyle's Law :-** For a given mass of gas at

Constant temp (T), the pressure (P) is inversely -

- proportional to the volume (V)

Boyle's law :- $P \propto \dfrac{1}{V}$ (when T & n are Constant)

$$V = k \times \dfrac{1}{P}$$

where

$P_1$ = Initial pressure of the gas

$V_1$ = " Volume " "

$P_2$ = Final Pres of the gas

$V_2$ = " Volume of gas

$$\boxed{PV = k}$$ k = proportionality constant

$$P_1 V_1 = P_2 V_2$$

② **charles' law :-** For a given mass of gas at Constant-

- pressure (P), the volume (V) is directly proportional

to the absolute temp (T).

charles' law :- $V \propto T$ (when P & n are Constant)

$$V = kT \quad i.e., \quad \dfrac{V}{T} = k \Rightarrow \dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$$

where: k = proportionality Constant

$V_1$ = Initial volume of the gas    $T_1$ = Initial temp of gas

$V_2$ = Final " "    $T_2$ = Final " " "

① **Avogadro's law:-** The conditions of constant pressure and temp, the Volume of a gas is directly proportional to the number of moles.

$$V \propto n \quad \text{(when T and P are constant)}$$

$$V = in \quad \text{or} \quad V = kn \implies = \frac{V}{n} = i \text{ or } k \implies \frac{V_1}{n_1} = \frac{V_2}{n_2}$$

where:- $k = $ ~~p.p~~ i or $k = $ proportionality constant

$V_1 = $ Initial Volume of gas

$n_1 = $ Number of moles

$V_2 = $ final Volum of the gas

$n_2 = $ Number of moles

② **Real Gases- Van Der Waals Equation:-**

↳ Real gases are those which deviate from the ideal gas Equations. These are also known as actual gases Some gases Exhibit deviations from ideal gas Equation for the following reasons.

ⓐ The kinetic Molecular theory postulates that the molecules of a gas are simply 'point masses' The actual volume occupied by the gas molecule is negligible as compared to the total Volume of gas

(fig:1)

↳ In real gases, the molecules do have a Volume particularly at high pressure and low temp (fig:2)

ⓑ According to theory, intermolecular attractions are completely absent in gases. This is particularly true at low pressures and high temp (fig-3).

↳ In real gases, intermolecular attractions do Exist though they are weak. This is true

particularly at high pressures and low tem (fig 4)
Therefore, pressure correction is required in the ideal
gas Equation
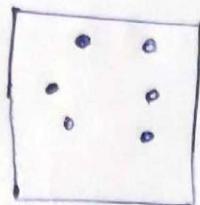


fig-1:- Volume of the gas molecules is
negligible compared to the total volume
of the gas
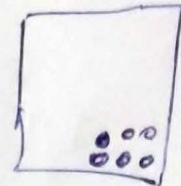
fig-2:- Volume of gas molecule
and their interactions cannot
be ignored at high pressure

→ fige ① &② → Influence of volume of gas molecules
compared to the volume of the container.



Wall of the
Container

Gas molecules

Wall of the
container

O ← Gas molecule
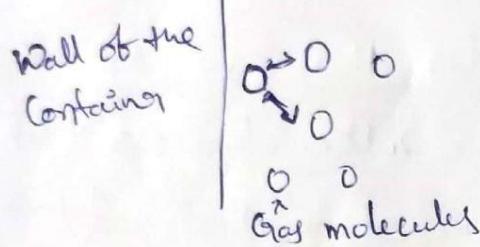
③ Gas at low density intermolecular
attractions are absent
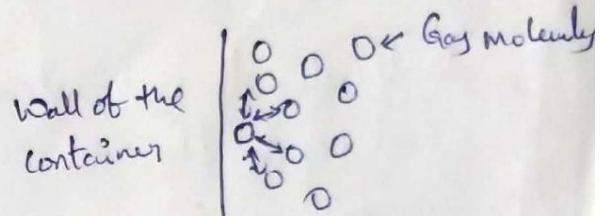
④ Gas at high density
intermolecular attractions are
appreciable

→ fig ③ &④ → Intermolecular forces on a molecule
are greater when the gas has higher density.

Van Der waals Equation:-

$$\left(P + \dfrac{a}{V^2}\right)(V-b) = RT \quad —①$$

where:- P = Pressure of the gas, kPa
V = Volume of the gas, m²
R = Ideal gas constant, kJ/kmol.k.
T = absolute temp, k
a = Van der waals constant, m⁶. kPa/kmol²
b: $\quad$ ° $\quad$ ° $\quad$ ° $\quad$ , m³/kmol

For n moles of gas, Equation ① changes to:

$$\left(P + \frac{na}{V^2}\right)(V - nb) = nRT \quad — ②$$

## Applications:-

① The term $a/V^2$ is known as Internal pressure per kilomole resulting from intermolecular forces of attraction

② The term 'b' accounts for incompressibility of the molecules.

## ③ Dalton's law of partial pressures:-

↳ According to the kinetic theory of gases, the forces of attractions between the molecules are negligible. As the molecules do not interact with other, they exert pressure independently. This is the basis for Dalton's law of partial pressures.

↳ Dalton's law of partial pressures states that the total pressure exerted by a mixture of ideal gases may be considered as sum of the partial vapour pressures exerted by each of the ideal gases, if alone were present and occupied the total volume.

law:-     $P = P_1 + P_2 + P_3 + \cdots$

where   $P$ = total pressure of the mixture of gases, $kP_a$

$P_1, P_2, P_3 \cdots$ etc = partial pressures of the gases 1, 2, 3... etc.
respectively, $kP_a$

↳ The partial pressure of a component gas is defined as the pressure that would be exerted by that component gas if it alone were present in the same volume and at the same temp of the mixture

applications:- laws of mixtures of ideal gases can be put as follows
                    volume (%) = pressure (%) = kilomoles (%)
→ miscible liquids are classified. It is used in theory and practice of distillation.
→ In aerosols, a mixture of propellants is introduced into the pressure packs.

⓪ Graham's law of Diffusion :-

↳ Diffusion in terms of gases may be defined as the random movement of different molecules of gases, resulting in their mixing. However, diffusion is a slow process because the movement of gas molecules result from the collisions with other gas molecules rather than their direct transfer.

↳ The Graham's law states that under definite conditions of temp and pressure, the rate of diffusion of gases bear an inverse relationship with the square root of their molecular masses.

$$\frac{\mu_A}{\mu_B} = \sqrt{\frac{M_B}{M_A}}$$

Where :- $\mu_A$ & $\mu_B$ are the rates of diffusion of gases A and B respectively

$M_A$ & $M_B$ are the molecular masses of gases A and B respectively

The units of rate of diffusion is m/sec.

↳ The relation between rate of diffusion and density of the gases is given as:

$$\frac{\mu_A}{\mu_B} = \sqrt{\frac{d_B}{d_A}}$$

where :- $d_A$ & $d_B$ are densities of gases A & B respectively

↳ other mathematical relations expressing diffusion may be given as

where:

$$\mu = \sqrt{\frac{3RT}{M}} \quad or \quad \mu = \sqrt{\frac{3P}{d}}$$

where:-

$\mu$ = Rate of diffusion

R = Gas Constant

T = Temperature

M = Molecular mass of the gas

P = pressure

d = Density

Applications!

① separation of gaseous mixtures. In principle of diffusion, a heavier gas can be separated from a lighter gas.

② Dispersion of foul gases:- The effect of poisonous and the foul gases by diffusion into air

③ Detection of marsh gas in mines:- It can be detected using a simple apparatus that works on the principle of diffusion.