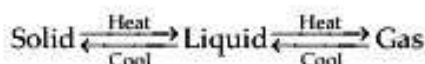


Chemistry : States Of Matter

INTRODUCTION

- ☐ Solid, liquid and gas are three stable states of matter. They are inter-convertible by exchange of heat between them



- ☐ Characteristics properties of solid, liquid and gas are as follows:

• **Types of intermolecular forces**

1) **Dipole-dipole interaction**

- ☐ Force of attraction between two permanent dipole moment molecules.
- ☐ Polar molecules like HF; HCl, HBr, H₂O etc. possess the dipole moment.
- ☐ Due to difference in electronegativity of two atoms, one atom acquire partial positive and other atom acquire partial negative charge.

Solid	Liquid	Gas
i) Particles or atoms are tightly bounded together.	i) Particles or atoms are loosely bounded together.	i) Particles or atoms are more loosely bounded together.
ii) They have regular arrangements of atom or molecules.	ii) They have irregular arrangements of particles.	ii) Particles have a random motion.
iii) Solids have definite shape, size and volume.	iii) Liquid takes a shape of container but definite volume.	iii) Gas have shape and volume as a container or indefinite.
iv) Intermolecular space is very small.	iv) Intermolecular space is moderate.	iv) Large Intermolecular space.
v) No compressibility.	v) Less compressibility.	v) Compressible.
vi) High densities.	vi) Low densities.	vi) Very low densities.
vii) Effect of temperature is small on volume.	vii) Moderate effect of temperature on volume change.	vii) Significantly volume changes by change in temperature.

INTERMOLECULAR FORCES

- ☐ Physical states of the substance depends on intermolecular force of attraction and kinetic energy. Intermolecular force keep the molecules together and kinetic energy separate the molecules from each other.
- ☐ Kinetic energy i.e. temperature and intermolecular force as a pressure decides the states of matter and their physical properties such as melting point, boiling point, vapour pressure, viscosity, surface tension, solubility, etc.
- ☐ **Dipole moment:** It is a product of magnitude of the two charges and distance separated between them.

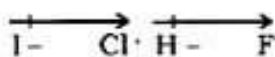
$$\mu_v = Qd$$

Dipole moment = Charge \times Distance

- It is expressed as (D) debye.

$$1 \text{ D} = 3.33564 \times 10^{-30} \text{ CM}$$

Dipole moment is a vector quantity and represented by arrow \longrightarrow



- Partial charges are weaker than Coulombic charge ($1.603 \times 10^{-19} \text{ C}$)
- Negative end of one molecule attract to positive end of other molecule.
e.g. $\text{H}^{\delta+} \dots \text{Cl}^{\delta-} \dots \text{H}^{\delta+} \dots \text{Cl}^{\delta-}$
- Strength of dipole-dipole interaction directly proportional to dipole moment of polar molecule.

- Interaction energy inversely proportional to $\frac{1}{r^3}$ for stationary state and $\frac{1}{r^6}$ for rotating molecule.
- Stronger the interaction force higher the boiling point of liquid.

Compound	Molar mass amu.	Dipole moment (D)	B.P.(K)
C_2H_6	44	0.1	231
$\text{CH}_3\text{-O-CH}_3$	46.07	1.3	248
$\text{CH}_3\text{-Cl}$	50.49	1.9	249
$\text{CH}_3\text{-CN}$	41.05	3.9	355

2) Dipole-Induced dipole interactions

- Force of attraction between polar and non polar molecules i.e. dipole moment and zero dipole molecules.
- Polar molecules induces dipole to non polar molecules, temporary dipole shifted on non polar molecule or by shifting the electron cloud on non polar molecule.
- Interaction energy directly proportional to dipole moment of polar molecules and polarizability of non polar molecules.
- Size of non polar molecule increases polarizability increases.
- Interaction energy inversely proportional to $\frac{1}{r^6}$

r = distance between two atoms.

Polar Non polar

e.g. $\text{NH}_3 \dots \text{C}_6\text{H}_6$

3) Ion-Dipole interaction

- Interaction between ion and opposite end of polar molecules.
- Interaction force depends on
 - Dipole moment of polar molecule.
 - Size of the molecule
 - Charge and size of the ion.
- Smaller the size and larger the charge on cations stronger the attraction.
- Ion dipole interaction increases as $\text{Na}^+ < \text{Mg}^{2+} < \text{Al}^{3+}$ ion.
- Negative end of polar molecule attract the opposite end of ion.

4) Dispersion force or London force

- It is developed due to interaction between two non polar molecules.
- Interaction depends on polarizability of the non polar molecules or atoms.
- Polarizability depends on number of electron surrounded by atoms or molecules.
- Due to instantaneous dipole moment developed on molecule.
- Dispersion force are strong at a low temperature, low kinetic energy and small intermolecular distance.
- As shape, size, mass and No. of electrons in atoms/molecule increases the strength of the London force increases.
e.g. $\text{CH}_4 \dots \text{CH}_4$, $\text{C}_2\text{H}_6 \dots \text{C}_2\text{H}_6$, $\text{C}_6\text{H}_6 \dots \text{C}_6\text{H}_6$ non polar molecules.
- Force present in very short distance about 500 Pm and magnitude depends on polarizability of molecule.

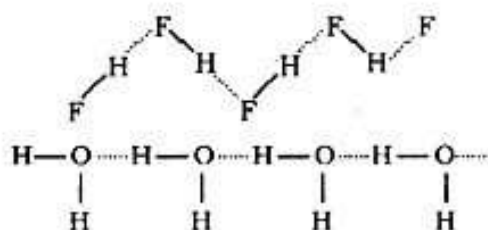
- Interaction energy is proportional to $\frac{1}{r^6}$ where ' r ' is distance between two atoms or molecules.

- It is temporarily dipole, when atoms or molecules are closer instantaneous dipole induces one to another and these molecules attract to each other.

5) Hydrogen bond

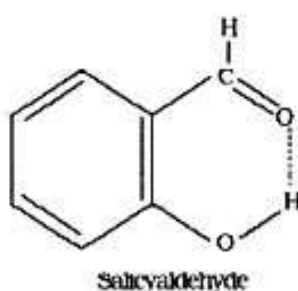
- The bond between hydrogen atom and electronegative elements such as F, Cl, Br, O, N, S, P etc called as hydrogen bond.
- Due to the difference in dipole moment, H acquire the partial positive charge and electronegative element get partial negative charge. Negative end of one molecule attract to positive end of H atoms.
- Hydrogen bonding are of two types.

- i) Intermolecular hydrogen bonding is present in molecules like H_2O , HF , HCl , NH_3 , etc.



- ii) Intramolecular hydrogen bonding is present in within one molecule,

e.g. o-nitrophenol, salicylaldehyde, o-nitrobenzaldehyde



- ❑ Association of molecules due to the hydrogen bonding.
- ❑ H_2O is liquid due to strong hydrogen bonding that of H_2S is gas due to weak hydrogen bonding. Melting and boiling point of compounds are high value due to strong hydrogen bonding.
- ❑ In hydrogen bonding formation of 10-40 kJ energy is released.
- ❑ Hydrogen bonding affects the solubility the substance.
- ❑ ONF Nitrosyl fluoride and H_2O are polar molecules with same dipole moment, but boiling and ONF is -56°C and H_2O is 100°C . Because H_2O have hydrogen bonding.
- ❑ Boiling point increases as molar mass substance increases with exception NH_3 , H_2O and HF have low molar mass but high boiling point values, due to presence of hydrogen bonding in these molecules.

CHARACTERISTICS PROPERTIES OF GASES

- i) Gas molecules are held by weak Vander Waal's force or intermolecular forces.
- ii) They have low densities.
- iii) Gas molecules have a random motion with different directions, with different velocities.

- iv) Gas have indefinite shape, size and volume. Gas are highly compressible.

- v) Gas molecules undergoes diffusion.

• Measurement properties of gases

- 1) **Mass** : It is expressed in g or kg.

a)
$$\text{No. of moles (n)} = \frac{\text{Mass in grams}}{\text{Molar mass in grams}}$$

$$n = \frac{W}{M}$$

b)
$$n = \frac{\text{No. of molecules}}{\text{Avogadro's number}} = \frac{N}{6.023 \times 10^{23}}$$

c)
$$n = \frac{\text{Volume of gas at STP (dm}^3\text{)}}{22.4}$$

- 2) **Volume** : It is measure in litre, ml, cm^3 , dm^3 or M^3 .

$$1 \text{ L} = 1000 \text{ ml} = 1000 \text{ cm}^3 = 1 \text{ dm}^3$$

$$1 \text{ M}^3 = 10^3 \text{ dm}^3 = 10^3 \text{ L} = 10^6 \text{ cm}^3 \text{ or ml.}$$

- 3) **Pressure** : Pressure of gas measured in atm, Pa, N/ m^2 (SI) bar or torr.

$$1 \text{ atm} = 76 \text{ cm Hg} = 760 \text{ mm of Hg} = 760 \text{ torr.}$$

$$= 1.01325 \times 10^5 \text{ or N/m}^2 \text{ or bar or Pa}$$

- 4) **Temperature** : Kelvin (K) is S.I. unit of temperature.

$$T(\text{K}) = t^\circ\text{C} + 273.15$$

$$T^\circ\text{F} = \left(\frac{9}{5} t^\circ\text{C} + 32 \right)$$

$$t^\circ\text{C} = \frac{5}{9} (^\circ\text{F} - 32)$$

- 5) **Density** : It expressed in kg m^{-3} or g cm^{-3} for the gas, relative density with respect to hydrogen gas is

$$\text{Vapour density} = \frac{\text{Molar mass}}{2}$$

- 6) **Diffusion** : Rate of diffusion

$$r = \frac{\text{Volume of gas diffused}}{\text{time}} \quad r = \frac{V}{t}$$

It is expressed in dm^3s^{-1} or cm^3s^{-1}

Graham's law of diffusion gives

$$\frac{r_1}{r_2} = \sqrt{\frac{d_2}{d_1}} \quad \text{or} \quad \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{V_2}{V_1} \times \frac{t_1}{t_2}}$$

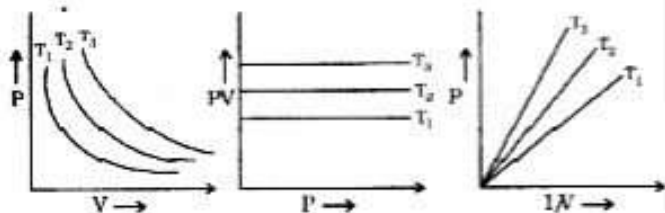
GAS LAWS

1) Boyle's law

- At constant temperature, $P \propto \frac{1}{V}$

i.e. $PV = K(\text{constant})$

- $P_1V_1 = P_2V_2$ at constant temperature.



- Relation between pressure and density of the gas at constant temperature

2) Charles's law

- At constant pressure, $V \propto T$

i.e. $V = KT$ or $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

- Volume of the gas increases or decreases by $\frac{1}{273}$ rd part of initial volume for every degree rise or fall in temperature.

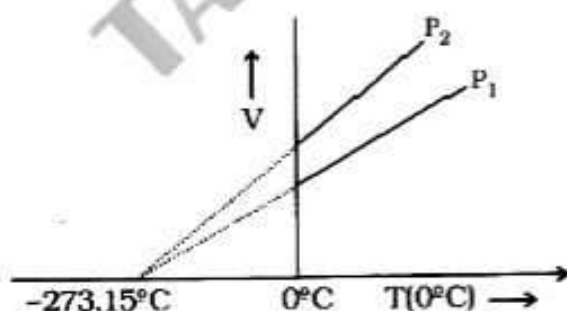
i.e. $V_1 = V_0 + \frac{V_0}{273.15} \times t_1$

V_1 = New volume of gas.

V_0 = Initial volume of gas at temperature $t_1^\circ\text{C}$.

- According to law at $-273.15^\circ\text{C} = 0(\text{K})$ called as absolute zero temperature.

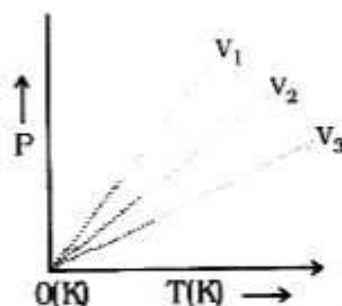
- At this temperature gas is converted into liquid or solid state.



3) Gay-Lussac's law (P-T law)

- At constant volume, $P \propto T$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$



- Graph plotted at

- Constant temperature - Isotherms
- Constant pressure - Isobars
- Constant volume - Isochores

4) Avogadro's law

- $V \propto n$

$\therefore V = kn$ at const., temperature and pressure

$$n = \frac{m}{M} \quad V = K \times \frac{m}{M}$$

$$\therefore M = K \times d$$

$m \propto d$ at const, temperature and pressure.

Applications of Avogadro's law

- $V \propto n$ i.e. $V = Kn$
- Molar mass = $2 \times$ vapour density
- Gram molar volume of any gas at STP or NTP
– 22.4 litre = 22.4 dm³.

5) Dalton's law of partial pressure

- Total pressure exerted by two or more non reacting gases is a sum of partial pressure of each gas in mixture.

$$P_{\text{Total}} = P_1 + P_2 + P_3$$

P_1, P_2, P_3 are the partial pressure of 1, 2, 3 etc. Putting $PV = nRT$,

$$P_1 = \frac{n_1RT}{V} \quad \text{---(i)}$$

$$P_2 = \frac{n_2RT}{V} \text{ etc.}$$

$$P_{\text{Total}} = (n_1 + n_2 + n_3) \frac{RT}{V} \quad \text{---(ii)}$$

From equation (i) and (ii) and mole fractions n_1, n_2, n_3, \dots etc. for 1, 2, 3 gas respectively.

$$P_1 = P_{\text{total}} \times x_1$$

Similarly, $P_2 = P_{\text{total}} \times x_2$ and $P_3 = P_{\text{total}} \times x_3$

IDEAL GAS EQUATION

- Gas which obeys Boyle's law and Charle's law perfectly at all temperature and pressure is an ideal gas.

□ Ideal gas equation is $PV = nRT$.

□ R = gas constant

$$R = 0.0821 \text{ Lit atm K}^{-1} \text{ mol}^{-1}$$

$$= 8.314 \text{ JK}^{-1} \text{ mol}^{-1}$$

$$= 1.987 \approx 2 \text{ cal K}^{-1} \text{ mol}^{-1}$$

- Combined gas law equation,

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

- Relation between molar mass (M) and density (d)

$$M = \frac{dRT}{P} \text{ or } M = \frac{mRT}{PV}, m = \text{mass of the gas}$$

KINETIC MOLECULAR THEORY OF GASES

- **Postulates**

- Gas consists of large number of small tiny particles called as molecules.
- Molecules of the gas are identical in all respects like mass, volume, shape, size etc.
- Gas molecules are perfectly elastic. There is no loss of kinetic energy due to the collision of gas molecules.
- Volume of a single molecule is negligible compared to total volume of the gas.
- There is no force of attraction or repulsion between the gas molecules.
- Gas molecules exerts pressure when they are collides on each other or collides on wall of the container.
- Average kinetic energy of the gas molecule is directly proportional to the absolute temperature.

□ Kinetic gas equation = $PV = \frac{1}{3} mnU^2$

\bar{U} = R.M.S. velocity of the gas molecules

$$\bar{U} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3PV}{M}} = \sqrt{\frac{3P}{d}}$$

$$\bar{U} = \sqrt{\frac{u_1^2 + u_2^2 + u_3^2}{n}}, n = \text{No. of gas molecules}$$

- **RMS velocity (\bar{U})** : It is defined as square root of mean square velocities on number of molecules of the gas.

$$\bar{U} = \text{Average velocity} = U_{\text{av}} = \sqrt{\frac{3RT}{\pi M}}$$

$$\text{Most probable velocity} = U_{\text{MP}} = \sqrt{\frac{2RT}{M}}$$

$$\text{Average velocity} = 0.9213 \times U_{\text{RMS}}$$

$$U_{\text{MP}} = 0.816 \times U_{\text{RMS}}$$

$$\begin{array}{ccc} U_{\text{MP}} & : & U_{\text{av}} & : & U_{\text{RMS}} \\ 1 & : & 1.128 & : & 1.224 \end{array}$$

DEVIATION FROM IDEAL BEHAVIOUR OF GASES

- **Compressibility factor (Z)**
- It is a ratio of volume for real gas to a volume of an ideal gas.

$$Z = \frac{V_{\text{real}}}{V_{\text{ideal}}} \quad \therefore \quad Z = \frac{PV}{nRT}$$

- $Z = 1$ Ideal gas no with deviation.

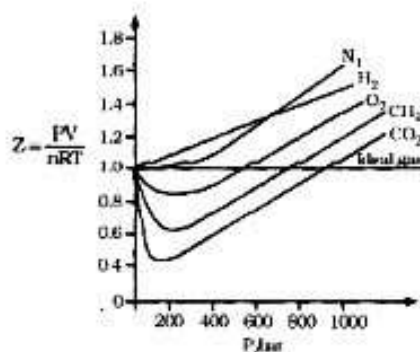
- $Z > 1$ Gas shows positive deviation.

Volume of the gas is greater than 22.4 dm^3 . Low compressibility and gas cannot liquefied easily, e.g. H_2 , He , N_2 etc.

- $Z < 1$ Gas shows negative deviations.

Volume of gas is less than 22.4 dm^3 .

Gas have high compressibility and gas liquefied easily, e.g. CH_4 , CO etc.



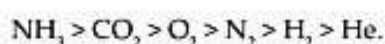
• **Difference between Ideal and Real gas**

Ideal gas	Real gas
i) It obeys Boyle's law, Charles's law at all temperature and pressure.	i) It shows deviations from Boyle's law and Charles's law at high temperature and pressure and obeys these laws at low pressure and high temperature.
ii) $Z = \frac{PV}{nRT}$	ii) $Z \neq 1$
iii) Molecules are perfectly elastic in nature.	iii) Molecules are not perfectly elastic.
iv) There is no attraction or repulsion between gas molecules.	iv) Intermolecular force of attraction is observed.
v) No loss of kinetic energy of molecules.	v) Kinetic energy lost due to the collision of the gas molecules.
vi) Volume of single molecule is negligible as compared to total volume of the gas.	vi) Volume of single molecule is considerable at high pressure and low temperature.
vii) Gas can not liquefied easily.	vii) Gas can be liquefied at low temperature and high pressure.
viii) There is no any ideal gas exists.	viii) The existence of gases like H_2 , O_2 , CO_2 , N_2 etc as a real behaviour.

LIQUEFACTION OF GASES AND CRITICAL CONSTANTS

- ❑ Liquefaction of CO_2 gas explained by Andrew's isotherms.
- ❑ At about $50^\circ C$, CO_2 gas behaves as an ideal gas. It obeys Boyle's law.
- ❑ As temperature decreases CO_2 gas shows deviations from ideal behaviour.
- ❑ At low temperature and high pressure gas can be liquefied.
- ❑ CO_2 gas liquefied at $30.98^\circ C$ and 73 atm pressure.
- ❑ $30.98^\circ C$ is critical temperature above which CO_2 gas can not liquefied.
- ❑ Volume of gas at this temperature called critical volume i.e. 95.6 ml and critical pressure for CO_2 gas is 73 atm.
- ❑ Greater the critical temperature, easier the liquefaction of the gases.

Liquefaction tendency is in order of



Gas	T_c/K	P_c/bar	$V_c(\text{dm}^3\text{mol}^{-1})$
H_2	33.2	12.97	0.0650
He	5.3	2.29	0.0577
N_2	126.0	33.9	0.0900
O_2	154.3	50.4	0.0744
CO_2	304.10	73.9	0.0956
H_2O	647.1	220.6	0.0450
NH_3	405.5	113.0	0.0723

LIQUID STATE

- ❑ It is an intermediate state of matter.
 - ❑ Intermolecular force in liquid molecules are stronger than gas but weaker than solid.
 - ❑ Liquid have indefinite shape and size but definite volume.
 - ❑ They have boiling point, freezing point, surface tension, viscosity, vapour pressure, evaporation, condensation etc. typical properties.
 - ❑ Liquid have a fluidity. They have an intermediate density values than solid and gas.
- 1) Vapour pressure**
- ❑ Pressure exerted by liquid vapours on the surface of liquid at equilibrium is a vapour pressure.

- ☐ At equilibrium, rate of evaporation and the rate of condensation are equal.
- ☐ Vapour pressure of water is called as aqueous tension.
- ☐ Vapour pressure of a liquid depends upon
 - i) **Temperature** - Temperature \propto Vapour pressure.
 - ii) Intermolecular force in liquid molecules increases vapour pressure decreases.
- ☐ It is expressed in atm, N/m², Pa, mmHg, bar, torr etc.
- ☐ Vapour pressure of ether > acetone > ethyl alcohol > water.
- 2) **Surface tension**
 - ☐ The force acted per unit length perpendicular to the surface of liquid is called as surface tension.
 - ☐ It is expressed in Nm⁻¹ or kg/s²
 - ☐ Surface tension of liquid depends upon
 - i) Temperature $\propto \frac{1}{\text{Surface tension}}$
 - ii) Intermolecular force oc Surface tension
 - ☐ Due to surface tension, drop of liquid is spherical in nature, liquid rises in capillary tube.
 - ☐ Soap, detergent, hot water used for the washing of cloth, it decreases the surface tension of water.
- 3) **Viscosity**
 - ☐ Resistance to flow of liquid is called as viscosity.
 - ☐ Internal resistance to flow of liquid offered by one layer to another layer of the liquid is a viscosity.
 - ☐ It is expressed in Nsm⁻² or poise or kg m⁻¹ s⁻¹
poise = 1 gm cm⁻¹ s⁻¹ = 10 kg m⁻¹ s⁻¹
 - ☐ Viscosity of liquid is depends upon
 - i) Temperature $\propto \frac{1}{\text{viscosity}}$
 - ii) Intermolecular force \propto Viscosity
 - iii) Molar mass of liquid increases viscosity increases.
 - ☐ Viscosity mostly expressed in poise.

$$F = \eta A \frac{du}{dx}$$

η = coefficient of viscosity in poise.

F = force on liquid

A = surface area of liquid

$\frac{du}{dx}$ = velocity gradient.

- ☐ Oil is more viscous than another liquid hence it is used as lubricant.