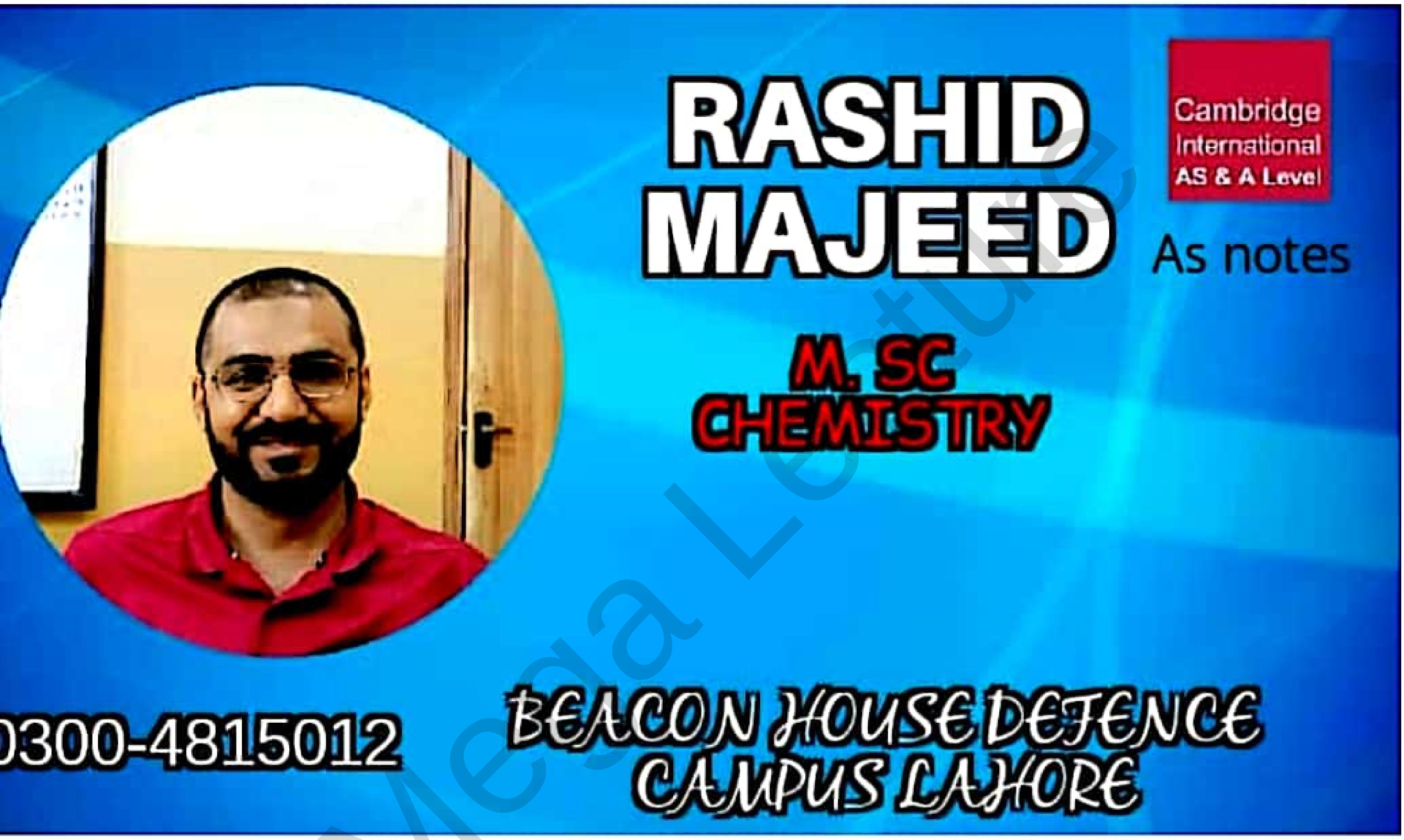
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Kinetic theory of gases

The idea that molecules in gases are in constant movement is called kinetic theory of gases.
Following are the basic assumptions of Kinetic theory of gases.

(i) Gases are made up of small independent molecules which are in a constant radom motion in all possible directions.
(ii) Gas molecules collide with each other and with the walls of the container, the pressure exerted by the gas is due to these collisions.
(iii) The collision of gaseous molecules are perfectly elastic i.e; the total energy of gaseous molecules remains equal before and after collisions.
(iv) There are no forces of attractions or repulsions between gaseous molecules.
(v) Actual volume of the gaseous molecules is negligible of the volume they occupy.
(vi) Kinetic energy of the gaseous molecules is directly proportional to the temperature.

Common gas laws:

Boyle's law: volume of a given mass of a gas is inversely proportional to the applied pressure under constant temperature.

$$V \propto \frac{1}{P}$$

$$V = K \frac{1}{P}$$

$$PV = K$$

If P_1 is the initial pressure and V_1 is the initial volume, so P_2 will be final pressure and V_2 will be the final volume.

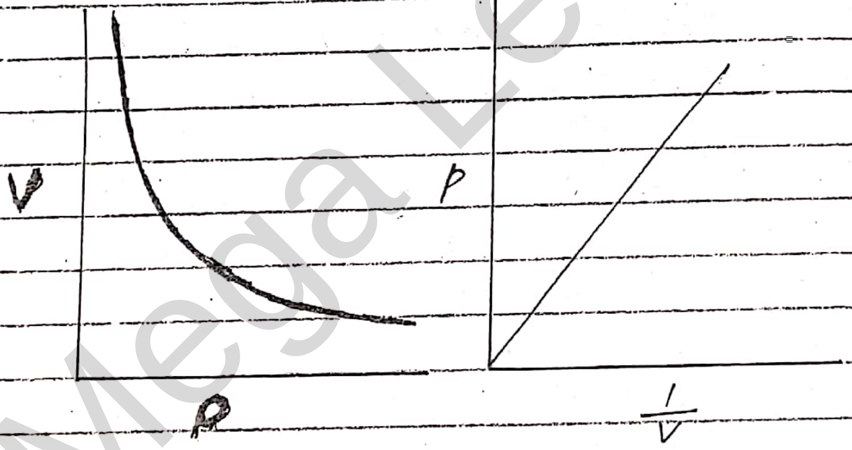
$$P_1V_1 = K \quad — ①$$

$$P_2V_2 = K \quad — ②$$

Putting the value of K in 2nd equation

$$P_1V_1 = P_2V_2$$

Graphical representation of Boyle's law



Boyl's law can also be defined as "the product of pressure and volume remains always constant.

Charle's law:- volume of a given mass of a gas is directly proportional to the temperature at constant pressure.

$$V \propto T$$

$$V = KT$$

$$\frac{V}{T} = K$$

If V_1 is initial volume and T_1 is initial temp then V_2 and T_2 will be the final volume and temperature respectively then

$$\frac{V_1}{T_1} = K \quad — ①$$

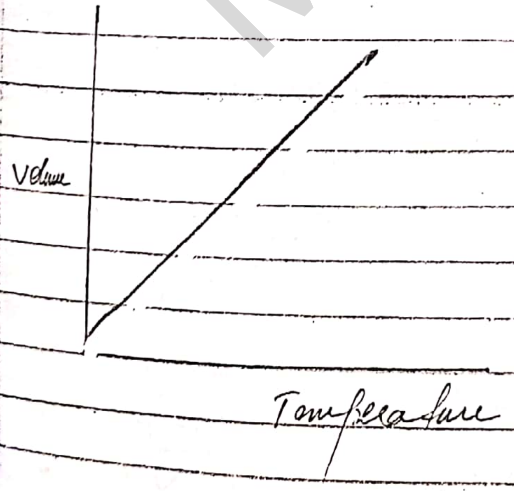
$$\frac{V_2}{T_2} = K \quad — ②$$

Putting the value of K in second equation

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

Ratio of the volume to temperature remains always constant

Graphical representation of Charle's law



Numerical questions based on Boyle's law

Flask A contains 1dm³ of helium at 2kpa pressure and flask B contains 2dm³ of neon at 1 Kpa pressure.
If the flasks are connected at constant temperature, what is the final pressure?

Solution

$p_1 = 2\ \text{Kpa}$ (Higher pressure will be initial pressure)
$V_1 = 2\ \text{dm}^3$ (Higher volume)
$p_2 = ?$
$V_2 = 3\text{dm}^3$ (Sum of the volumes of two containers)

$$p_1 V_1 = p_2 V_2$$

$$p_2 = \frac{p_1 V_1}{V_2}$$

$$p_2 = \frac{2 \times 2}{3} = 1.33\ \text{Kpa}$$

Flask X contains 5dm³ of helium at 12kpa pressure and flask Y contains 10dm³ of neon at 6 Kpa pressure.
If the flasks are connected at constant temperature, what is the final pressure?

Solution

$p_1 = 12\text{Kpa}$
$V_1 = 10\ \text{dm}^3$
$p_2 = ?$
$V_2 = 15\ \text{dm}^3$

$$p_1 V_1 = p_2 V_2$$

$$p_2 = \frac{p_1 V_1}{V_2}$$

$$\frac{12 \times 10}{15}$$

$$8\ \text{Kpa}$$

Avogadro's law:- According to the law, volume of a given mass of a gas is directly proportional to the number of moles / or / molecules under constant temperature and pressure.

$$V \propto n$$

$$V = Kn$$

$$\frac{V}{n} = K$$

Dalton's law of partial pressure

According to the law, the total pressure exerted by the mixture of gases is equal to the sum of the partial pressure of all the gases present in a mixture at same temperature.

$$P_{total} = P_A + P_B + P_C + \dots\dots\dots P_n$$

Let's derive formula for calculating the partial pressure of a gas.

Partial pressure of a gas (A) depends upon its number of moles

$$P_A V = n_A RT$$

$$P_A V = n_A RT \quad \text{—} ①$$

so $P_t V = n_t RT$ — ②

Divide eq ① by eq ②

$$\frac{P_A V}{P_t V} = \frac{n_A RT}{n_t RT}$$

$$\boxed{P_A = \frac{n_A}{n_t} \times P_t}$$

$$\frac{P_A}{P_t} = \frac{n_A}{n_t}$$

General gas equation

By combining the gas laws we can derive general gas equation

$V \propto \frac{1}{p}$ Boyle's law

$V \propto T$ Charle's law

$V \propto n$ Avogadro's law

By combining the three laws

$$V \propto \frac{nT}{p}$$

$$V = \frac{RnT}{p}$$

Standard temp & Pressure
$T = 0°C$ or $273K$
$P = 101325\ Nm^{-2}$ or $101325\ Pa$
$V = 22.4\ dm^3$ or $0.0224\ m^3$
$n = 1$ mole

where R is a gas constant
Rearranging the equation

$$pV = nRT$$

P is the pressure in pascals or Nm^{-2} ($1pa = 1Nm^{-2}$)
V is the volume in cubic metres m^3
$1m^3 = 1000\ dm^3$
n is the number of moles of a gas
R is the gas constant and its value is $8.31\ JK^{-1}mol^{-1}$
T is the temp in kelvin

Determination of Mr using general gas equation

$$pV = nRT \qquad n = \frac{m}{M_r}$$

$$pV = \frac{m}{M_r}RT$$

Determination of density using general gas equation

$$PV = nRT$$

$$PV = \frac{m}{M_r} RT$$

$$PM_r = \frac{m}{V} RT \quad \text{where } \frac{m}{V} = D$$

$$PM_r = DRT$$

$$\boxed{D = \frac{PM_r}{RT}}$$

Combined gas law using general gas equation

For one mole of a gas, the general gas equation is

$$PV = RT \quad \text{or} \quad \frac{PV}{T} = R$$

Hence $\frac{P_1V_1}{T_1} = R$ —①

$\frac{P_2V_2}{T_2} = R$ —②

Putting the value of R in eq ①

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$ Combined gas law or equation

Solved examples from the past papers

Calculate the volume occupied by 0.500 mol of carbon dioxide at a pressure of 150 kpa and a temperature of 19°c.

Solution

$p = 150\ kpa = 150000\ pa$

$T = 19°c + 273 = 292\ K$

$$V = \frac{nRT}{P}$$

$$V = \frac{0.500 \times 8.31 \times 292}{150000}$$

$8.09 \times 10^{-3}\ m^3$

$8.09\ dm^3$

Q: A sample of nitrogen gas is enclosed in a vessel of volume 380 cm^3 at 120°c and pressure of 101325 Nm^{-2}. This gas is transfered to a 10 dm^3 flask and cooled to 27°c. Calculate the pressure in Nm^{-2} exerted by the gas at 27°c.

Solution

As all the three parameters of this gas have been changed, so we can solve this by using combined gas equation.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$V_1 = 380cm^3 = 0.00038\,m^3$

$T_1 = 120°c + 273 = 393k$

$P_1 = 101325\ Nm^{-2}$

$T_2 = 27°c + 273 = 300k$

$V_2 = 10\,dm^3 = 0.01\,m^3$

$P_2 = \ ?$

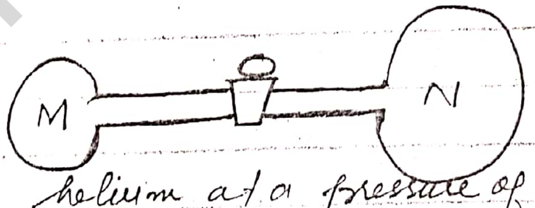
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{101325 \times 0.00038 \times 300}{393 \times 0.01}$$

$$\frac{11551.05}{3.93}$$

$$P_2 = 2939\ Nm^{-2}$$

Two glass vessels M and N are connected by a closed valve



Q: M contains helium at a pressure of 1×10^5 pa. N has been evacuated, and has three times the volume of M. In an experiment the valve is opened and the temperature of the whole apparatus is raised to 100°c. What is the final pressure?

Solution

$V_1 = 1$

$V_2 = 1 + 3 = 4$

$P_1 = 1\times10^5$ pa

$P_2 = ?$

$T_1 = 20+273 = 293k$

$T_2 = 100 + 273 = 373k$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{1\times10^5 \times 1 \times 373}{293 \times 4}$$

$P_2 = 31825$ pa

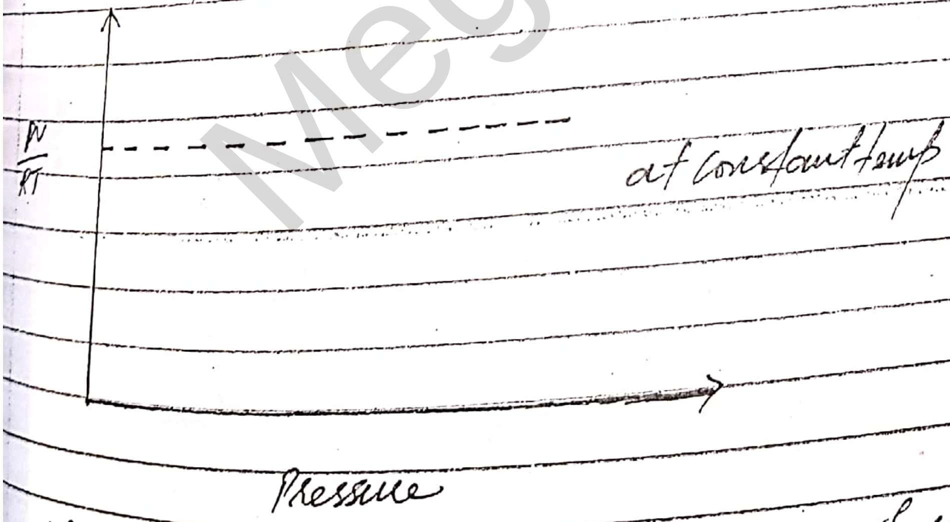
Ideal and Non ideal gases

Ideal gases :- Gases which obey all postulates of kinetic particle theory under all conditions of temperature and pressure are called ideal gases.

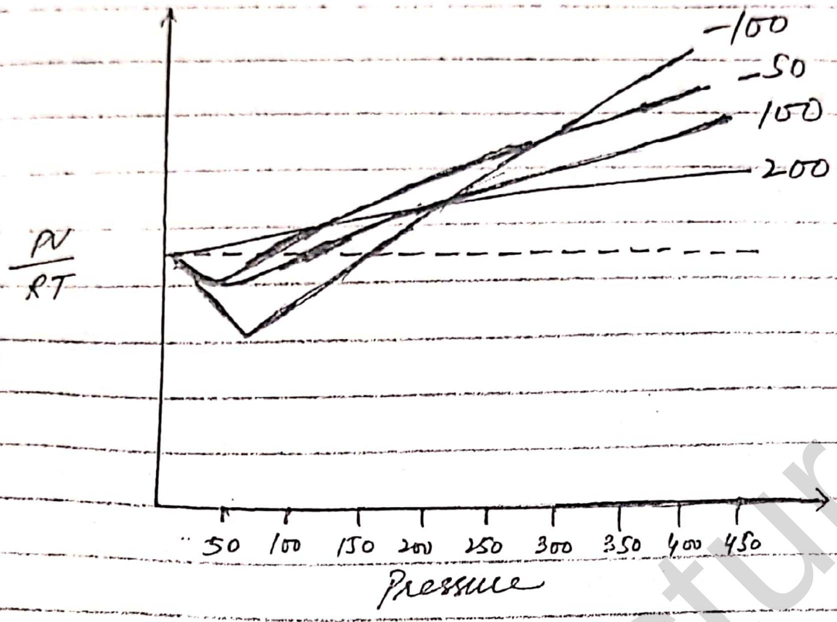
In order to understand the behaviour of ideal gas we will have to plot a graph by taking pressure at x-axis and $\frac{PV}{RT}$ or $\frac{PV}{nRT}$ on y-axis.

The value of $\frac{PV}{RT}$ or $\frac{PV}{nRT} = 1$

If at constant temperature, we increase the pressure of a glas, the volume of gas will decrease in such a way that the product of $\frac{PV}{RT}$ will remain one and a straight line will be obtained.



Non ideal or real gases :- Those gases which do not obey all postulates of kinetic particle theory under all conditions of temperature and pressure are called nonideal or real gases. All real gases are not ideal gases.



Graph shows that deviation of real gases from ideal behaviour increases with the increase in pressure and decrease in temperature.

Postulates of Kinetic particle theory which are not obeyed by real gases

(i) There are no forces of attraction or repulsion among gaseous molecules.

(ii) Volume of the gaseous molecules is negligible of the volume that they occupy.

Conditions at which real gases deviate from ideal behaviour

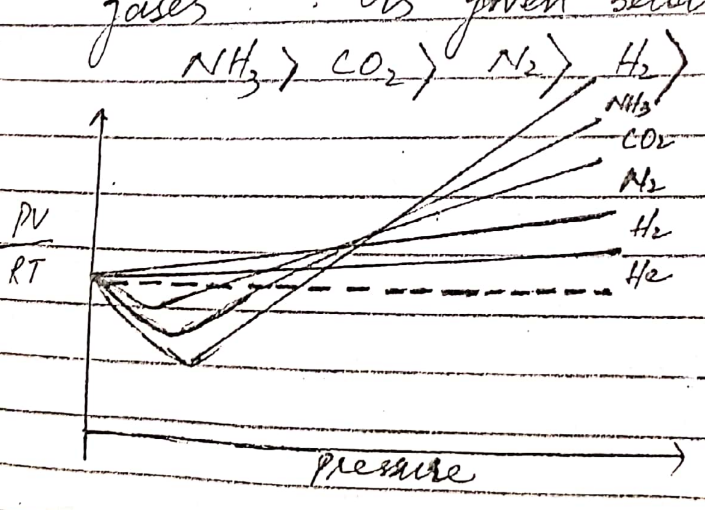
Low temperature: At low temperature

molecules of gases come closer together that there are enough attractive forces which cannot be ignored. Secondly, at low temp occupied volume of the gas is decreased and actual volume of the gas molecules does not remain negligible of the volume occupied by the gas.

High pressure :- At high pressure gas molecules come closer together and start attracting each other as well as occupied volume of the gas is also decreased, so the volume of gas molecules does not remain negligible of the volume occupied by the gas.

Nature of gas molecules :- Polar molecules and large size non polar molecules have greater intermolecular forces and show more deviation from ideal behaviour.
The order of deviation of some gases is given below

$NH_3 > CO_2 > N_2 > H_2 > He$.



In the beginning there is a greater decrease in volume as the ~~the~~ increase in pressure so $\frac{PV}{RT}$ decreases

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Conditions at which real gases behave ideally

High temperature:- At high temperature kinetic energy of the particles is increased, particles get far from each other, so there are no attractive forces as well as occupied volume is also increased.

Low pressure:- At low pressure volume occupied by the is increased, therefore actual volume of the gas molecules becomes negligible, moreover get far from each other so no attractive forces between molecules.

Liquid

Common properties of liquids
Vapour pressure

Solids

Properties of Solid
Types of solids or crystals e.g;
Ionic crystal of NaCl, MgO
molecular crystals include Iodine, sulphur, phosphorus
Giant molecular covalent solids
e.g; Diamond, Graphite silica

Numerical problems based on Dalton's law of partial pressure

There is a mixture of hydrogen, helium and methane occupying a vessel at a pressure of 100 kpa. the masses of H_2, He and methane are 0.8, 0.12 and 1.28 respectively. calculate the partial pressure of each gas.

Solution

number of moles of $H_2 = \frac{0.8}{2} = 0.4$ mol

number of moles of $He = \frac{0.12}{4} = 0.03$ mol

number of moles of $CH_4 = \frac{1.28}{16} = 0.08$ mol

Total number of moles $0.4 + 0.03 + 0.08 = 0.51$ mole

According to Dalton's law

$$\frac{p_g}{p_t} = \frac{n_g}{n_t}$$

$$p_{H_2} = \frac{0.4}{0.51} \times 100 = 78.43 \text{ Kpa}$$

$$p_{He} = \frac{0.03}{0.51} \times 100 = 5.88 \text{ Kpa}$$

$$p_{CH_4} = \frac{0.08}{0.51} \times 100 = 15.68 \text{ Kpa}$$

the sum of the partial pressures is almost equal to 100 kpa.

The solid state

There are two major types of solids.

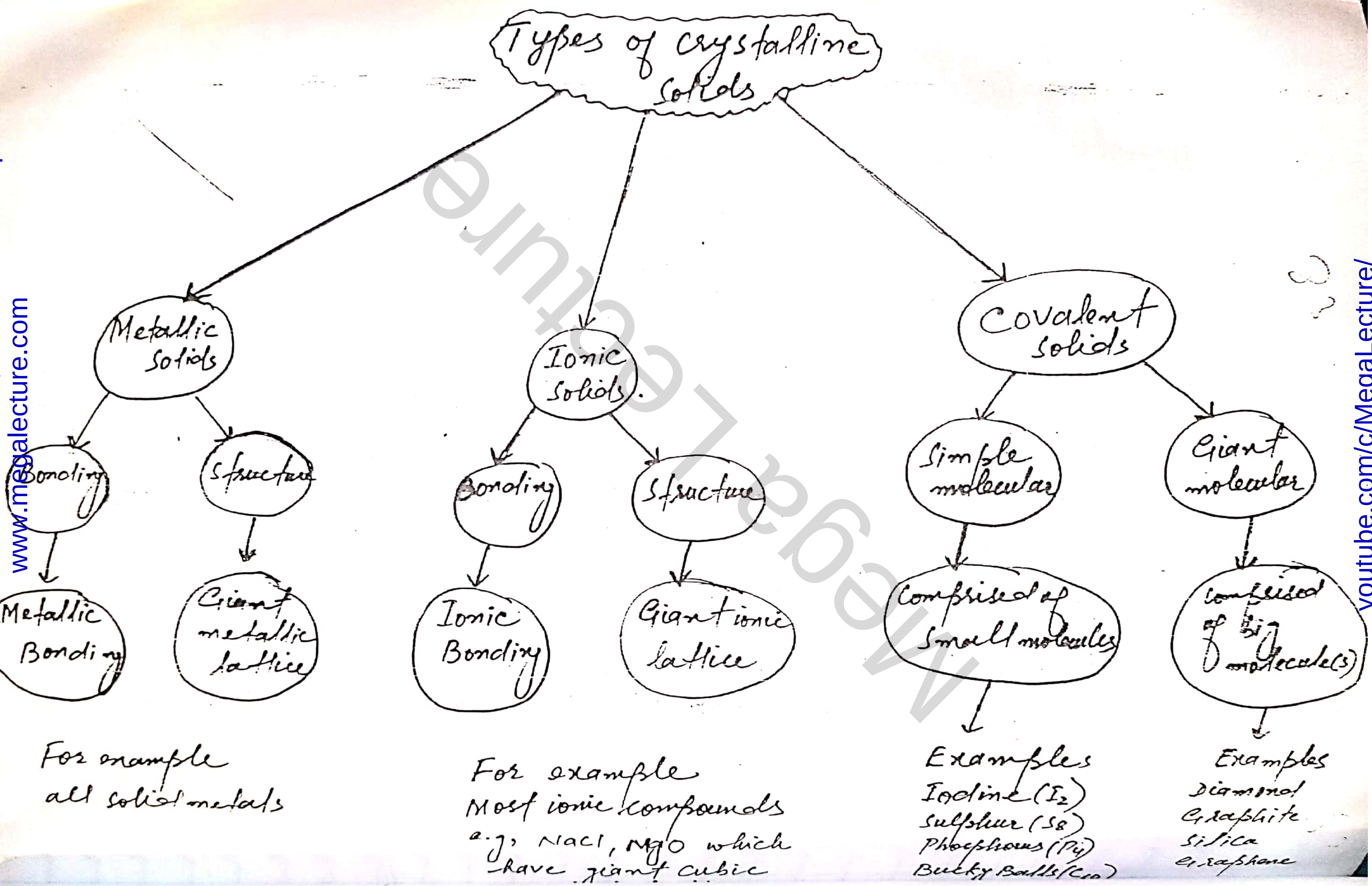
Non crystalline or Amorphous solids

In non crystalline solids, the particles are non arranged in a regular, repeating order. They are fixed in random positions, for example Glass.

Crystalline solids

In crystalline solids, the particles are arranged in a regular three dimensional pattern, which is called lattice. Common examples of crystalline solids

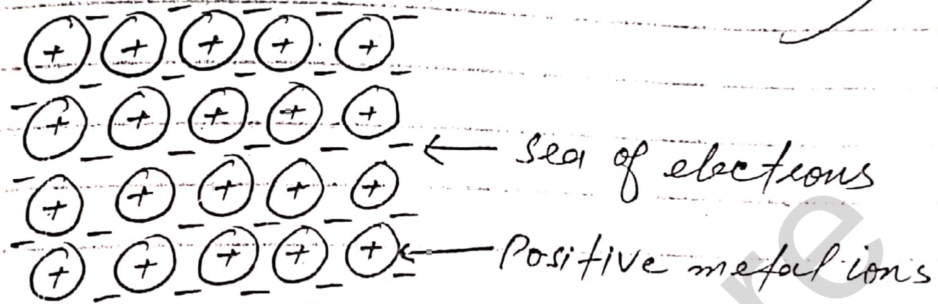
(i) All solid metals
(ii) Most ionic compounds
(iii) Most covalent solids


Types of crystalline solids
Metallic solids
Ionic solids.
Covalent solids
Bonding
Structure
Bonding
Structure
Simple molecular
Giant molecular
Metallic Bonding
Giant metallic lattice
Ionic Bonding
Giant ionic lattice
Comprised of small molecules
comprised of big molecule(s)
For example all solid metals
For example Most ionic compounds e.g. NaCl, MgO which have giant cubic
Examples Iodine (I2) Sulphur (S8) Phosphorus (P4) Bucky Balls (C60)
Examples Diamond Graphite Silica Graphene

Metallic lattices

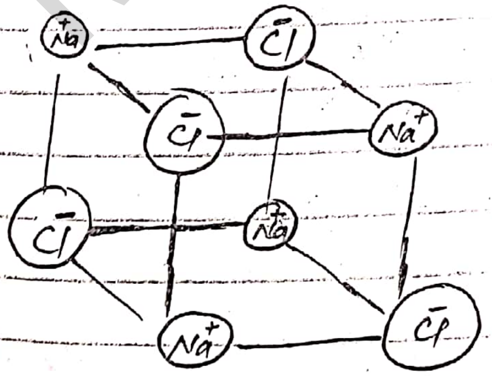
34

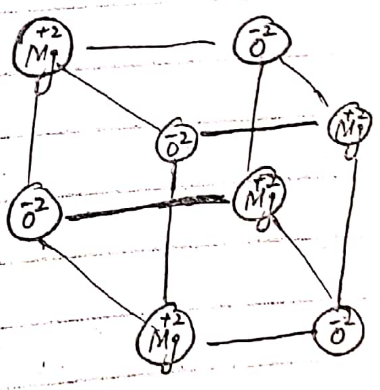
Metallic solids exist as metallic lattice which consists of positive ions surrounded by a sea of electrons.



Ionic lattices

Most ionic solids exist as ionic lattice which consists of three dimensional arrangement of alternating positive and negative ions to give giant ionic structure. For example NaCl and MgO which have giant cubic crystal lattice.

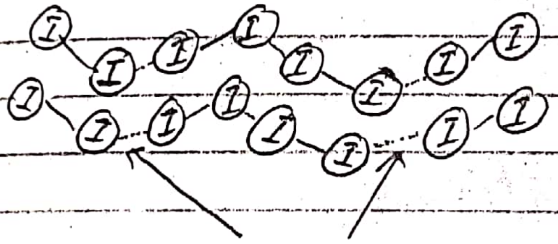




Simple covalent molecular lattices

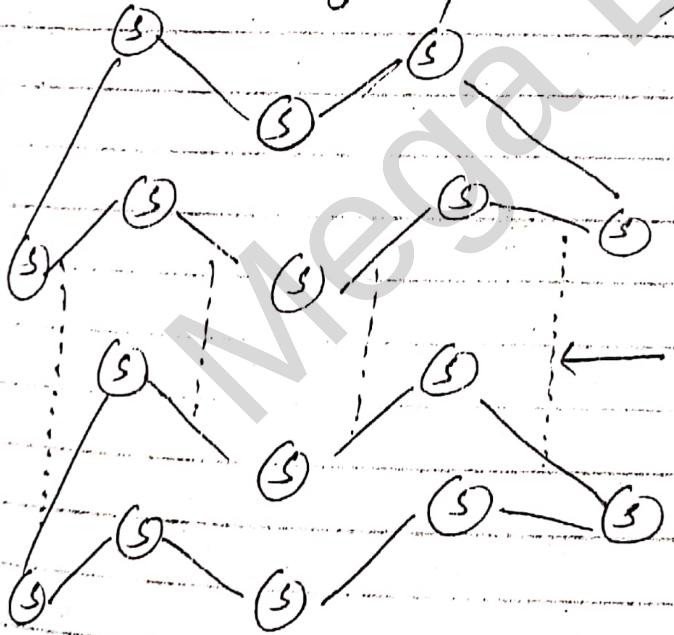
covalent solids made up of small independent molecules which are arranged in a regular repeating three dimensional arrangement are called simple molecular lattices.

For example Iodine I_2



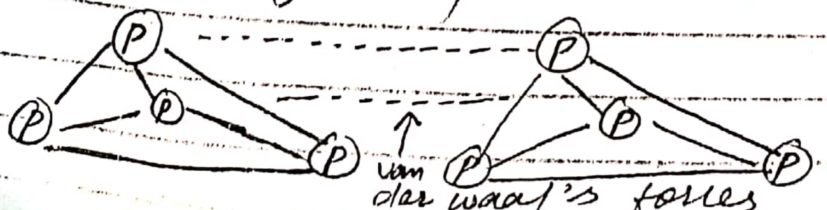
van der waal's forces

structure of sulphur (S_8)



← weak vander waal's forces

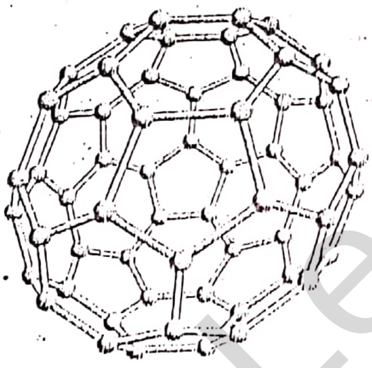
structure of Phosphorus (P_4)



van der waal's forces

Structure of Bucky Balls & Carbon nano tubes

Bucky Ball is a third allotrope of carbon comprised of 60 carbon atoms in one molecule forming a sphere which contains pentagons and hexagons. Bucky Balls are also called Buckminister-fullerene. Bucky Balls have simple molecular lattice.

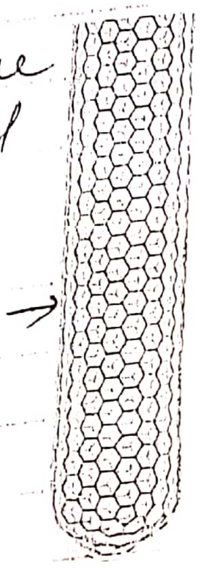


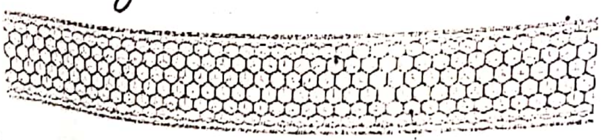
A 'buckyball'

Carbon nanotubes (simple molecular lattice)

Carbon nanotube is a single rolled up sheet of graphite which is cylindrical in structure.

If a nano tube is sealed at one end by a exactly half a bucky ball molecule, it becomes a bucky test tube.

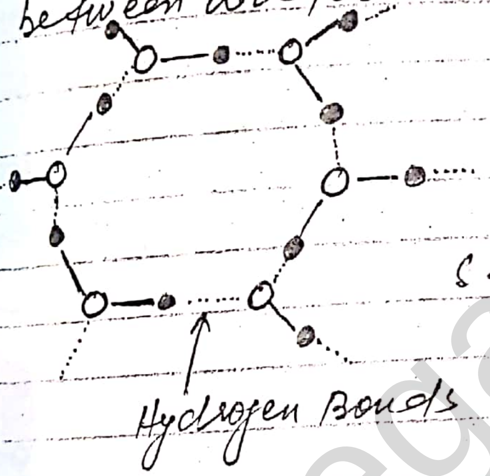




– a carbon nanotube open at both ends

Structure of Ice (H_2O)

Liquid water has a high surface tension due to hydrogen bonding between molecules to form a lattice across the surface of water, allowing objects to float over water. Ice is less dense than water. The hydrogen bonds between the water molecules in ice are positioned tetrahedrally around each oxygen atom, this produces empty spaces between water molecules.



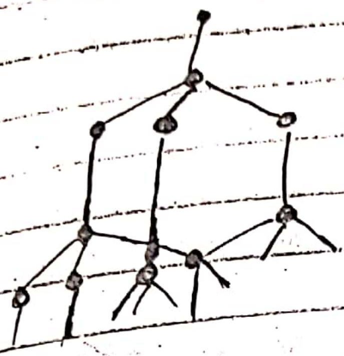
Structure of Ice

Giant covalent molecular structure

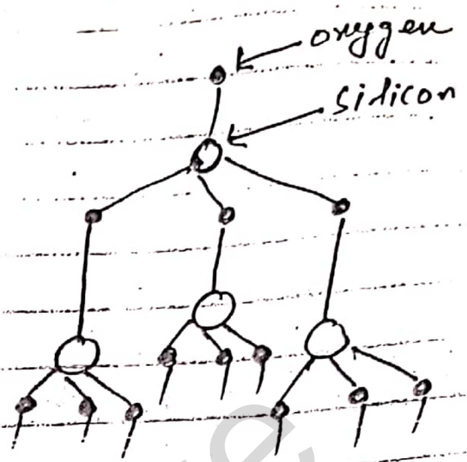
Crystal lattice made up of big molecules in which large number of atoms are bonded together through a network of covalent bonds. They have high M.P & B.P due to large number of covalent bonds.

Common examples are Diamond, Silica, graphite and graphene.

Structure of Diamond

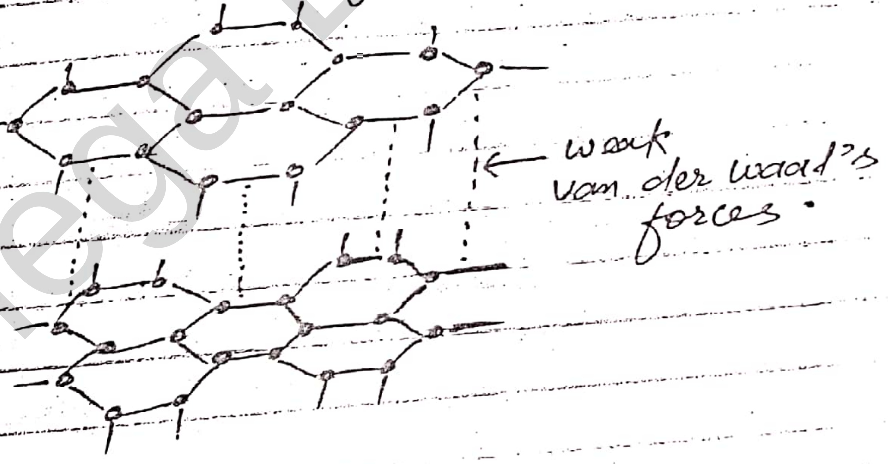


Structure of silica (SiO2) sand

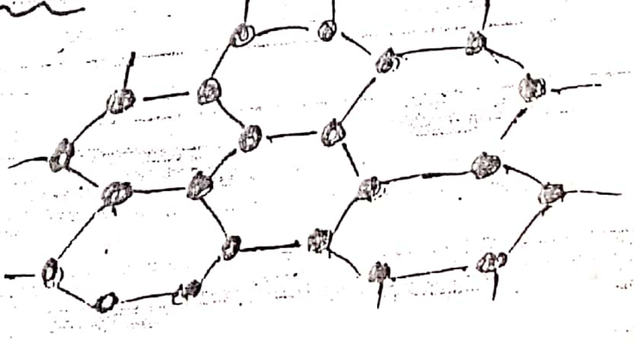


Structure of Graphite

In Graphite, carbon atoms are present in layers. Within the layers carbon atoms are arranged in hexagon. Each carbon atom is joined with 3 carbon atoms.



Structure of Graphene



Graphene is a single sheet of carbon atoms isolated from graphite, it consists of atom-thick layer of carbon atoms arranged in hexagons. Graphene is used for making carbon nano tubes.