



States of Matter

Boyle's law

It states that, “*For a fixed amount of a gas at constant temperature, the gas volume is inversely proportional to the gas pressure.*”

Thus, $P \propto 1/V$ at constant temperature and mass

or $P = K/V$ (where K is constant)

or $PV = K$ or $P_1V_1 = P_2V_2 = K$ (For two or more gases)

(4) At constant mass and temperature density of a gas is directly proportional to its pressure and inversely proportional to its volume.

Thus, $d \propto P \propto \frac{1}{V}$ $\left[\because V = \frac{\text{mass}}{d} \right]$

or $\frac{d_1}{d_2} = \frac{P_1}{P_2} = \frac{V_2}{V_1} = \dots\dots = K$

(5) At altitudes, as P is low d of air is less. That is why mountaineers carry oxygen cylinders.



Charle's law

It states that, “*The volume of a given mass of a gas is directly proportional to the absolute temperature ($=^{\circ}\text{C} + 273$) at constant pressure*”.

Thus, $V \propto T$ at constant pressure and mass

or $V = kT = K(t^{\circ}\text{C}) + 273.15$, (where k is constant),

$K = \frac{V}{T}$ or $\frac{V_1}{T_1} = \frac{V_2}{T_2} = K$ (For two or more gases)

Gay-Lussac's law

It states that, “*The pressure of a given mass of a gas is directly proportional to the absolute temperature ($=^{\circ}\text{C} + 273$) at constant volume.*”

Thus, $P \propto T$ at constant volume and mass

or $P = kT = K(t^{\circ}\text{C}) + 273.15$ (where K is constant)

$K = \frac{P}{T}$ or $\frac{P_1}{T_1} = \frac{P_2}{T_2} = K$ (For two or more gases)

Avogadro's law

According to this law, “*Equal volumes of any two gases at the same temperature and pressure contain the same number of molecules.*”

Thus, $V \propto n$ (at constant T and P)

or $V = Kn$ (where K is constant)



$$\text{or } \frac{V_1}{n_1} = \frac{V_2}{n_2} = \dots = K$$

Ideal gas equation

The simple gas laws relating gas volume to pressure, temperature and amount of gas, respectively, are stated below:

$$\text{Boyle's law: } P \propto \frac{1}{V} \text{ or } V \propto \frac{1}{P} \quad (n \text{ and } T \text{ constant})$$

$$\text{Charle's law: } V \propto T \quad (n \text{ and } P \text{ constant})$$

$$\text{Avogadro's law: } V \propto n \quad (T \text{ and } P \text{ constant})$$

If all the above law's combines, then

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

$$\text{or } V = \frac{nRT}{P} \quad (R = \text{Ideal gas constant})$$

$$\text{or } PV = nRT$$

This is called ***ideal gas equation***. R is called ***ideal gas constant***. This equation is obeyed by isothermal and adiabatic processes.

Dalton's law of partial pressures

According to the Dalton's law, “ *when we keep two or more gases, that do not react chemically with each other in a closed vessel then the total pressure exerted by the mixture of all the gases is equal to the sum of the partial pressures of individual gases.* ”

$$\text{Thus, } P_{\text{total}} = P_1 + P_2 + P_3 + P_4 \dots$$



Where $P_1, P_2, P_3, P_4, \dots$ are partial pressures of individual gases 1, 2, 3, 4

Graham's law of diffusion and Effusion

According to Graham's law, “*The rate of diffusion or effusion of a gas at constant temperature and pressure is inversely proportional to the square root of its vapour density.*”

Thus, rate of diffusion $(r) \propto \frac{1}{\sqrt{d}}$ (P and T constant)

Rate of diffusion for two gases “A” and “B” at constant pressure and temperature,

$$\frac{r_A}{r_B} = \sqrt{\frac{d_B}{d_A}}$$

Here, d_A and d_B are densities of gases A and B respectively.

Kinetic theory of gases

Kinetic gas equation: On the basis of above postulates, the following gas equation was derived,

$$PV = \frac{1}{3} mnu_{rms}^2$$

Where, P = pressure exerted by the gas

V = volume of the gas

m = average mass of each molecule

n = number of molecules

u = root mean square (*RMS*) velocity of the gas.



Molecular speeds or velocities

(i) **Root mean square velocity (u_{rms})** : It is the square root of the mean of the squares of the velocity of a large number of molecules of the same gas.

$$u_{rms} = \sqrt{\frac{u_1^2 + u_2^2 + u_3^2 + \dots + u_n^2}{n}}$$

(ii) **Average velocity (v_{av})** : It is the average of the various velocities possessed by the molecules.

$$v_{av} = \frac{v_1 + v_2 + v_3 + \dots + v_n}{n} ; \quad v_{av} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8kT}{\pi m}}$$

(iii) **Most probable velocity (α_{mp})** : It is the velocity possessed by maximum number of molecules of a gas at a given temperature.

$$\alpha_{mp} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2PV}{M}} = \sqrt{\frac{2P}{d}}$$

Relation between molecular speeds or velocities,

Relation between α_{mp} , v_{av} and u_{rms}

$$\alpha_{mp} \quad : \quad v_{av} \quad : \quad u_{rms}$$

$$\sqrt{\frac{2RT}{M}} \quad : \quad \sqrt{\frac{8RT}{\pi M}} \quad : \quad \sqrt{\frac{3RT}{M}}$$

Vander Waal's equation



- (i) Volume correction (ii) Pressure correction
 (2) Vander Waal's equation is obeyed by the real gases over wide range of temperatures and pressures, hence it is called *equation of state for the real gases*.
 (3) The Vander Waal's equation for n moles of the gas is,

$$\left(P + \frac{n^2 a}{V^2} \right) [V - nb] = nRT$$

Pressure correction for molecular attraction Volume correction for finite size of molecules

a and b are Vander Waal's constants whose values depend on the nature of the gas. Normally for a gas $a \gg b$.

The two Vander Waal's constants and Boyle's temperature (T_B) are related as,

$$T_B = \frac{a}{bR}$$

(4) Vander Waal's equation at different temperature and pressures

- (i) **When pressure is extremely low:** For one mole of gas,

$$\left(P + \frac{a}{V^2} \right) (V - b) = RT \quad \text{OR} \quad PV = RT - \frac{a}{V} + Pb + \frac{ab}{V^2}$$

- (ii) **When pressure is extremely high:** For one mole of gas,

$$PV = RT + Pb ; \quad \frac{PV}{RT} = 1 + \frac{Pb}{RT} \quad \text{OR} \quad Z = 1 + \frac{Pb}{RT}$$

Where, Z is compressibility factor.

- (iii) **When temperature is extremely high:** For one mole of gas,

$$PV = RT \bullet$$



(iv) **When pressure is low:** For one mole of gas,

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT \quad \text{OR} \quad PV = RT + Pb - \frac{a}{V} + \frac{ab}{V^2}$$

$$\text{Or } \frac{PV}{RT} = 1 - \frac{a}{VRT} \quad \text{or} \quad Z = 1 - \frac{a}{VRT}$$

Solid State

The solids are the substances which have definite volume and definite shape

(1) Types of solids

Solids can be broadly classified into following two types,

(i) Crystalline solids/True solids,

They have definite melting point

They are given cleavage *i.e.* they break into two pieces with plane surfaces

There is a sudden change in volume when it melts.

These possess interfacial angles.

(ii) Amorphous solids/Pseudo solids

Not have definite melting point

Not be compressed to any appreciable extent

They are isotropic because of these substances show same property in all directions

Not possess any symmetry.



Table: 5.1 Some characteristics of different types of crystalline solids

Types of Solid	Bonding	Examples	Physical Nature	Electrical Conductivity
Ionic	Coulombic	<i>NaCl, KCl, CaO, MgO, LiF, ZnS, BaSO₄ and K₂SO₄ etc.</i>	Hard but brittle	Conductor (in molten state and in aqueous solution)
Covalent	Electron sharing	<i>SiO₂ (Quartz), SiC, C (diamond), C(graphite) etc.</i>	Hard Hard Hard	Insulator except graphite
Molecular	(i) Molecular interactions (intermolecular forces) (ii) Hydrogen bonding	<i>I₂, S₈, P₄, CO₂, CH₄, CCl₄ etc.</i> Starch, sucrose, water, dry ice or drycold (solid CO ₂) etc.	Soft Soft	Insulator Insulator
Metallic	Metallic	Sodium, <i>Au</i> , <i>Cu</i> , magnesium,	Ductile malleable	Conductor

		metals and alloys		
Atomic	London dispersion force	Noble gases	Soft	Poor thermal and electrical conductors

Space lattice and Unit cell

Crystal system	Emples
Cubic $a = b = c,$ $\alpha = \beta = \gamma = 90^\circ.$	Pb, Hg, Ag, Au, Cu, ZnS, diamond, KCl, CsCl, NaCl, Cu_2O , CaF_2 and alums. etc.
Tetragonal $a = b \neq c,$ $\alpha = \beta = \gamma = 90^\circ$	SnO_2 , TiO_2 , ZnO_2 , NiSO_4 , ZrSiO_4 , PbWO_4 , white Sn etc.
Orthorhombic (Rhombic) $a \neq b \neq c,$ $\alpha = \beta = \gamma = 90^\circ$	KNO_3 , K_2SO_4 , PbCO_3 , BaSO_4 , rhombic sulphur, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ etc.
Rhombohedral or Trigonal $a = b = c,$ $\alpha = \beta = \gamma \neq 90^\circ$	NaNO_3 , CaSO_4 , calcite, quartz, As, Sb, Bi etc.



Hexagonal $a = b \neq c, \alpha = \beta = 90^\circ$ $\gamma = 120^\circ$	ZnO, PbS, CdS, HgS, graphite, ice, Mg, Zn, Cd etc.
Monoclinic $a \neq b \neq c,$ $\alpha = \gamma = 90^\circ, \beta \neq 90^\circ$	Na ₂ SO ₄ .10H ₂ O, Na ₂ B ₄ O ₇ .10H ₂ O, CaSO ₄ .2H ₂ O, monoclinic sulphur etc.
Triclinic $a \neq b \neq c,$ $\alpha \neq \beta \neq \gamma \neq 90^\circ$	CaSO ₄ .5H ₂ O, K ₂ Cr ₂ O ₇ , H ₃ BO ₃ etc.

Analysis of cubic system

Co-ordination number (C.N.):

For simple cubic system C.N. = 6.

For body centred cubic system C.N. = 8

For face centred cubic system C.N. = 12.

Density of the unit cell (ρ) : It is defined as the ratio of mass per unit cell to the total volume of unit cell.

$$\rho = \frac{Z \times M}{a^3 \times N_0}$$

Where Z = Number of particles per unit cell

M = Atomic mass or molecular mass

N_0 = Avogadro number ($6.023 \times 10^{23} \text{ mol}^{-1}$)

a = Edge length of the unit cell = $a \text{ pm} = a \times 10^{-10} \text{ cm}$

a^3 = volume of the unit cell

i.e.
$$\rho = \frac{Z \times M}{a^3 \times N_0 \times 10^{-30}} \text{ g/cm}^3$$



The density of the substance is same as the density of the unit cell.

Packing fraction (P.F.):

Let the radius of the atom is “ r ”, edge length of the cube is “ a ” and the volume of the cube is V which is equal to “ a^3 ”.

We know that,

Volume of the atom (spherical) $v = \frac{4}{3}\pi r^3$

Thus, the packing density $= \frac{vZ}{V} = \frac{\frac{4}{3}\pi r^3 Z}{a^3}$

Structure	Simple cubic	Face-centred cubic	Body-centred cubic
r related to a	$r = \frac{a}{2}$	$r = \frac{a}{2\sqrt{2}}$	$r = \frac{\sqrt{3}a}{4}$
Packing density	$\frac{\pi}{6} = 0.52$	$\frac{\sqrt{2}\pi}{6} = 0.74$	$\frac{\sqrt{3}\pi}{8} = 0.68$