KINETIC THEORY OF GASES

- Pressure, Temperature and volume depends on velocity (c)

$$\text{Mean velocity} = \frac{c_1 + c_2 + c_3 + \dots + c_n}{n}$$

$$\text{Root Mean Square Velocity} = \sqrt{\frac{c_1^2 + c_2^2 + c_3^2 + \dots + c_n^2}{n}}$$

- Postulates :-

(1) Shape of gas molecules is spherical and size of molecules is negligible

(2) There is some volume of gas in its original state. But actual volume of gas is zero. (Molecules ko paas laaye to vo bahut chhota ho jata hai ... almost zero)

(3) Collision is perfectly elastic.

(4) Particles move randomly and in straight path

(5) Their density is uniform

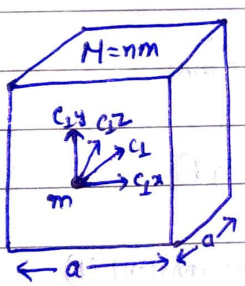
(6) No force between molecules.

- Derivation of pressure by KTG

m = mass of one molecules

M = Total mass

n = no. of molecules

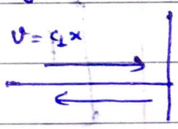


$$\boxed{c_1 = c_{1x} + c_{1y} + c_{1z}}$$

For magnitude,

$$\boxed{c_1^2 = c_{1x}^2 + c_{1y}^2 + c_{1z}^2}$$

m mass ka molecule x-axis mein chalta hua yz-plane se takraya aur vapis aagaya



Change in momentum = Final momentum - Initial

$$= mc_{1x} - (-mc_{1x})$$

$$\boxed{\Delta p = 2mc_{1x}}$$

$$\text{Time of collision } t = \frac{2a}{c_{1x}}$$

$$\text{Force } F_{1x} = \frac{\Delta P}{t} = \frac{2mc_{1x} \times c_{1x}}{2a} = \frac{m}{a}(c_{1x})^2$$

$$\text{Force by all the molecules} = \frac{m}{a}(c_{1x}^2 + c_{2x}^2 + \dots + c_{nx}^2)$$

$$\boxed{P_x = \frac{F}{A} = \frac{m}{a^3}(c_{1x}^2 + c_{2x}^2 + \dots c_{nx}^2)}$$

$$P_y = \frac{m}{a^3}\left(c_1y^2 + c_2y^2 + \dots + c_ny^2\right)$$

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$$P_z = \frac{m}{a^3}\left(c_1z^2 + c_2z^2 + \dots + c_nz^2\right)$$

$P_x = P_y = P_z = P$ (Pressure in all directions is same) $\left(P = \frac{P_x + P_y + P_z}{3}\right)$

$$P = \frac{1}{3}\frac{m}{a^3}\left(c_1x^2 + c_1y^2 + c_1z^2 + c_2x^2 + c_2y^2 + c_2z^2 + \dots + c_nx^2 + c_ny^2 + c_nz^2\right)$$

$$P = \frac{1}{3}\frac{mn\,c_{rms}^2}{a^3} \quad \left[\because c_{rms} = \sqrt{\frac{c_1x^2 + c_1y^2 + c_1z^2}{n}} \Rightarrow nc_{rms}^2 = c_1x^2 + c_1y^2 + c_1z^2\right]$$

$$\boxed{P = \frac{M}{3a^3}\cdot c_{rms}^2 \qquad P = \frac{M}{3V}\cdot c_{rms}^2 \qquad PV = \frac{1}{3}Mc_{rms}^2}$$

$$\boxed{P = \frac{1}{3}\rho c_{rms}^2} \rightarrow \text{Pressure depends on velocity}$$

(Boyle's law) $PV = \text{constant}$ Value of constant $= \frac{1}{3}Mc_{rms}^2$

$PV = \frac{1}{3}Mc_{rms}^2 \rightarrow$ constant [because temperature is constant and temperature is releated with kinetic energy (ΔU)]

constant

- <u>Derivation of temperature by KTG</u>

$$PV = \frac{1}{3}Mc_{rms}^2 \qquad PV = \frac{1}{3}mn\,c_{rms}^2$$

$$PV = \frac{2}{3}\times\frac{1}{2}mn\,c_{rms}^2 \qquad PV = \frac{2}{3}nE$$

$$E = \frac{3PV}{2n} \qquad E = \frac{3}{2}\frac{RT}{n}$$

$\frac{R}{n}$ → Boltzman's constant (K)

$$\boxed{E = \frac{3}{2}KT} \qquad \frac{1}{2}mc_{rms}^2 = \frac{3}{2}KT$$ (Temperature depends on velocity)

- <u>Equipartition of Energy</u>

Degree of freedom

Monoatomic → Linear Degree of Freedom (3)

Diatomic → Linear Degree of Freedom (3)
Rotational Degree of Freedom (2)

$\boxed{DOF \rightarrow 3\times n - R}$ $n =$ atomicity
$R =$ Relation

Triatomic

Linear: O=C=O ($DOF = 3\times3-2 = 7$)

Non-linear: H_2O (H–O–H) ($DOF = 3\times3-3 = 6$)

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$$\boxed{E = \frac{3}{2}KT} \rightarrow \text{monoatomic}$$

Energy associated with each degree of freedom $= \frac{3}{2\times3}KT = \frac{1}{2}KT$

Diatomic $= \underset{DOF}{5} \times \frac{1}{2}KT$

Triatomic = Linear $\rightarrow \underset{DOF}{7} \times \frac{1}{2}KT = \frac{7}{2}KT$

Non Linear $\rightarrow \underset{DOF}{6} \times \frac{1}{2}KT = 3KT$

First law of thermodynamics, $\Delta Q = \Delta U + \Delta W$

At constant volume, $ms\Delta T = \Delta U + 0$ $\quad (\because W = P.dV)$

$1.C_v.1 = \Delta U$ $\qquad \boxed{C_v = \Delta U}$

Energy for n atoms, $\Delta U = \frac{3}{2}\times K \times T \times n = \frac{3}{2}\times \frac{R}{\cancel{K}} \times K \times \cancel{T}$ (and $\Delta T = 1$)

$$\boxed{\Delta U = \frac{3}{2}R} \qquad \boxed{C_v = \frac{3}{2}R}$$

From Mayer's formula, $C_p - C_v = R$

$C_p - \frac{3}{2}R = R$ $\qquad \boxed{C_p = \frac{5}{2}R}$

FLOT, $\Delta Q = \Delta U + \Delta W$ (for Adiabatic)

$0 = C_v + R(\Delta T)$ $\qquad C_v = \frac{-R(\Delta T)}{1-\gamma}$ $\qquad C_v = \frac{C_p - C_v}{\gamma - 1}$ $\quad (\Delta T = 1)$

$\Rightarrow C_v\gamma - \cancel{C_v} = C_p - \cancel{C_v}$ $\quad \Rightarrow C_v\gamma = C_p$ $\quad \Rightarrow \boxed{\gamma = \frac{C_p}{C_v}}$

$$\boxed{\gamma = \frac{5\cancel{R}}{\cancel{2}} \times \frac{\cancel{2}}{3\cancel{R}} = \frac{5}{3} = 1.6}$$

Atomicity	Energy per molecule	Energy per mole	C_v	C_p	γ
Monoatomic	$3/2\ KT$	$3/2\ RT$	$3/2\ R$	$5/2\ R$	1.6
Diatomic	$5/2\ KT$	$5/2\ RT$	$5/2\ R$	$7/2\ R$	1.4
Triatomic					
Linear	$7/2\ KT$	$7/2\ RT$	$7/2\ R$	$9/2\ R$	1.3
Non-Linear	$3KT$	$3RT$	$3R$	$4R$	1.3

C_v for solids $= 3R$

C_v for liquids $= 9R$

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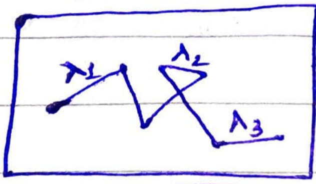
- **Mean free path**

Mean free path of a gas molecule may be defined as the average distance travelled by the molecule between two successive collisions.



$$\boxed{\bar{\lambda} = \frac{\lambda_1 + \lambda_2 + \lambda_3 + \cdots + \lambda_n}{\text{no. of collisions}}}$$

$$\boxed{\lambda = \frac{KT}{\sqrt{2}\pi d^2 p}}$$ → For one mole of gas

$$\boxed{\bar{\lambda} = \frac{1}{\sqrt{2} n \pi d^2}}$$

$d =$ diameter of molecule

$n =$ no. of molecules

- **Relation Time (τ)**

$$\boxed{\tau = \frac{1}{\sqrt{2} n \pi d^2 v}}$$

Relaxation time depends on velocity of the molecules.

Q. Molar Volume is the volume occupied by 1 mole of any gas at Standard Temperature and Pressure (1 atm and $0^\circ C$). Show that it is 22.4 litres.

→ $T = 273.15K$ $\quad P = 1 \text{ atm} = 10^5 \text{ Pa}$

$PV = nRT$ $\quad V = \frac{8.31 \times 273}{1.013 \times 10^5} = 22.4$ litres.