

(English Medium)

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KINETIC THEORY OF GASES & THERMODYNAMICS**KEY CONCEPT****KINETIC THEORY OF GASES****1. Assumption of kinetic theory of gases**

- (1) A gas consists of particles called molecules which move randomly in all directions.
- (2) These molecules obey Newton's law of motion.
- (3) Size of molecule negligible in comparison to average separation between the molecules.
- (4) The forces on molecule are negligible except at the time of collision.
- (5) All collision between molecules or between molecules and wall are perfectly elastic.
Time of collision is very small.
- (6) For large number of molecules the density and distribution of molecules with different velocities are independent of position, direction and time.

2. Pressure of an ideal gas

$$P = \frac{1}{3} \rho \bar{v}^2 = \frac{1}{3} \rho v_{\text{rms}}^2$$

Here \bar{v} = mean square speed ρ = density of gas v_{rms} = root mean square speed

$$P = \frac{2}{3} \left(\frac{1}{2} \rho v_{\text{rms}}^2 \right)$$

$$P = \frac{2}{3} E$$

$$E = \frac{3}{2} P$$

So total K.E.

$$K = \frac{3}{2} PV$$

3. R.M.S. velocity – depends on temperature only for any gas.

$$v_{\text{rms}} = \sqrt{\frac{v_1^2 + v_2^2 + v_3^2 + \dots + v_n^2}{n}}$$

$$P = \frac{1}{3} \rho v_{\text{rms}}^2$$

$$v_{\text{rms}} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M}}$$

4. Most Probable velocity – velocity which maximum number of molecules may have $v_{\text{mp}} = \sqrt{\frac{2RT}{M}}$ **5. Average velocity**

$$v_{\text{avg}} = \frac{\vec{v}_1 + \vec{v}_2 + \dots + \vec{v}_n}{n} = 0$$

6. Average speed

$$v_{\text{avg}} = \frac{|\vec{v}_1| + |\vec{v}_2| + |\vec{v}_3| + \dots + |\vec{v}_n|}{n} = \sqrt{\frac{8RT}{\pi M}}$$

7. Ideal gas equation $PV = nRT$ (container form of gas law/ pressure volume form)

$$P = \left(\frac{\rho}{M} \right) RT \quad (\text{open atmosphere / pressure density form})$$

8. Graham's law of diffusion

When two gases at the same pressure and temperature are allowed to diffuse into each other the rate of diffusion of each gas is inversely proportional to the square root of the density of the gas

$$r \propto v_{\text{rms}} \text{ where } r = \text{rate of diffusion} \quad \text{so, } \frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}}$$

9. Doltans Law of Partial Pressure -

The total pressure exerted by a mixture of non-reacting gases occupying a vessel is equal to the sum of the individual pressures which each gas would exert if it alone occupied the whole vessel.

That $P = P_1 + P_2 + \dots$

P_1, P_2, \dots respectively the partial pressures of the gases.

10. The barometric formula : describes the law of reduction of the pressure of a gas with altitude in the gravity field

$$p_h = p_0 e^{-\frac{\mu gh}{RT}}$$

Here p_h = gas pressure at the altitude h

p_0 = pressure at the altitude $h = 0$

g = gravity acceleration.

The formula is approximate, since the temperature T cannot be assumed identical for great differences in altitude.

11. The mean free path of gas molecules :

$$\ell = \frac{\bar{v}}{\bar{z}} = \frac{1}{\sqrt{2}\pi\sigma^2 n}$$

where \bar{v} = arithmetic mean speed

\bar{z} = mean number of collisions of each molecule with the others in a unit time

σ = effective diameter of a molecule

n = number of molecules in a unit volume.

12. Degree of Freedom (f) – No. of ways in which a gas molecule can distribute its energy**13. Law of equipartition of energy :** – Energy in each degree of freedom per molecule = $\frac{1}{2} kT$

If degree of freedom is f . Energy = $\frac{f}{2} kT$.

$$U = \frac{f}{2} kTnN_A = \frac{f}{2} nRT$$

Where k is Boltzmann constant

14. Degree of freedom (f) in different gas molecules

Molecules	Translational	Rotational
Monoatomic	3	0
Diatomic	3	2
Polyatomic	3	2 (linear molecule) (eg CO_2) 3 (non-linear molecule)

$$\text{Translational energy for all type of molecules} = \frac{3}{2} (nRT)$$

LAW OF THERMODYNAMICS

1. **Zeroth law of thermodynamics :-** If two bodies A and B are in thermal equilibrium and A and C are also in thermal equilibrium. Then B and C are also in thermal equilibrium.

2. **First law of Thermodynamics:-** Energy conservation for gaseous system.

Heat supplied to the gas = Increment in internal energy + work done by the gas.

$$\Delta Q = \Delta U + \Delta W \quad \Delta Q \text{ is +ve for heat supplied}$$

$$\Delta Q \text{ is -ve for heat rejected}$$

in differential form $dQ = dU + dW$

and $dQ = nC_dT$ $C = \text{molar specific heat}$

$$C = C_p \text{ (constant pressure)} ; C = C_v \text{ (constant volume)}$$

$$dU = \frac{f}{2} nRdT$$

$$dW = \int_{v_1}^{v_2} P dv \quad (P = \text{pressure of the gas of which work is to be calculated})$$

$$\Delta W = +ve \text{ for work done by gas} \quad (\text{in expansion of gas})$$

$$\Delta W = -ve \text{ for work done on the gas} \quad (\text{in Compression of gas})$$

(a) Molar specific heat for a given process (i) $C = \frac{f}{2}R + \frac{PdV}{ndT} = C_v + \frac{PdV}{ndT}$

C	Monoatomic	Diatomic
$C_v = (f/2)R$	$(3/2)R$	$(5/2)R$
$C_p = \frac{f+2}{2}R$	$(5/2)R$	$(7/2)R$

(b) Meyer's Relation $C_p = C_v + R$

Note :- C of a gas depends on the process of that gas, which can be infinite in types.

(c) **Ratio of specific heat :**

$\gamma = \frac{C_p}{C_v} = \frac{f+2}{f}$ and $f = \frac{2}{\gamma-1}$

$\gamma = \frac{C_p}{C_v} = \frac{f+2}{f}$

monoatomic $\rightarrow 5/3 = 1.67$
 diatomic $\rightarrow 7/5 = 1.4$
 Polyatomic $\rightarrow 4/3 = 1.33$

$C_v = \frac{R}{\gamma-1}; \quad C_p = \frac{\gamma R}{\gamma-1}$

Analysis of Various Processes

(i) **Isochoric Process (V= constant)**

$$dV = 0$$

$$\Rightarrow dW = 0$$

$$Q = \int_{T_1}^{T_2} nC_v dT = nC_v (T_2 - T_1)$$

By FLT

$$dQ = dU = nC_v dT$$

Be careful if $\Delta V = 0$ then not necessarily an Isochoric Process.

(ii) Isobaric Process (P = constant)

$$dP = 0$$

$$\text{By FLT} \quad dQ = dU + dW$$

$$nC_p (T_2 - T_1) = \left(\frac{f}{2}\right) nR(T_2 - T_1) + nR(T_2 - T_1)$$

$$W = nR(T_2 - T_1)$$

If $\Delta P = 0$ then not necessarily an Isobaric Process.

(iii) Isothermal Process (T = constant)

$$dT = 0, dU = 0$$

$$Q = W = (nRT) \int_{V_1}^{V_2} dV/V$$

$$W = nRT \ln \frac{V_2}{V_1} = nRT \ln \frac{P_1}{P_2}$$

$$\left(\frac{V_2}{V_1} = \frac{P_1}{P_2} = \text{compression ratio}\right)$$

(iv) Adiabatic Process

$dQ = 0$ but if $\Delta Q = 0$, it is not necessarily adiabatic.

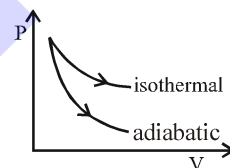
$$dW = -dU \quad \text{By FLT}$$

$$(a) \quad W = \int_{T_1}^{T_2} \frac{nRdT}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$(b) \quad \text{For Adiabatic Process } PV^\gamma = \text{constant}$$

$$(c) \quad \left| \frac{dP}{dV} \right|_{\text{adiabatic}} = -\frac{\gamma P}{V}$$

$$\left| \frac{dP}{dV} \right|_{\text{isothermal}} = -\frac{P}{V}$$

**(v) Polytropic process**

$$PV^n = \text{constant} : P = \frac{K}{V^n} \Rightarrow \frac{dP}{dV} = n \left| \frac{K}{V^{n+1}} \right| ; C = \frac{R}{\gamma - 1} + \frac{R}{1 - n}$$

So C is constant for polytropic process

Efficiency of a cyclic process

$$\Delta U = 0 \quad \text{so } \Delta Q = \Delta W$$

$$\text{Efficiency } \eta = \frac{\text{work done by gas}}{\text{heat input}}$$

$$\eta = \frac{W}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

