Kinetic Theory of Gases

Quick Revision

JEE Main | NEET | NCERT

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Postulates of KTG:

1. Molecule size negligible
2. Molecule is assumed to be hard sphere and all collision elastic
3. No interaction among molecules => Total Energy = K.E + P.E = K.E
4. Collision time is negligible
5. Effect of Gravity on molecule is neglected
6. Real gases obeys Ideal gas law PV=nRT at very high T and very low P

At STP, [P=1atm, T=273K]

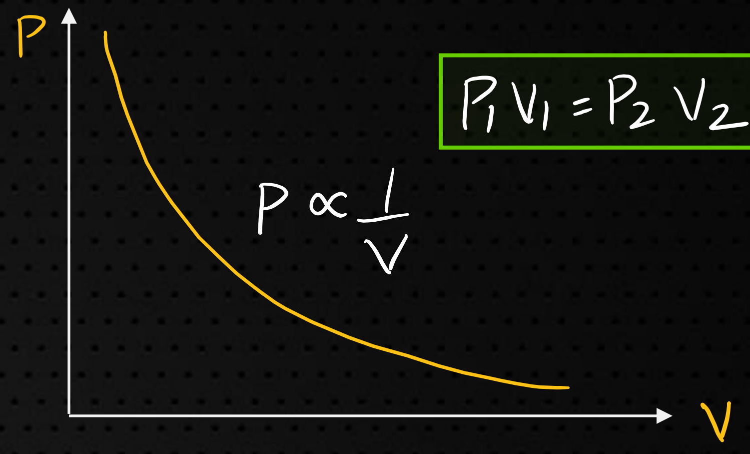
$PV = nRT$

$\Rightarrow V = \frac{1 \times 8.314 \times 273}{1.013 \times 10^5}$

$= 2.24 \times 10^{-2} m^3$

$= \boxed{22.4 L}$

BOYLE'S LAW, $T = \text{const.}$



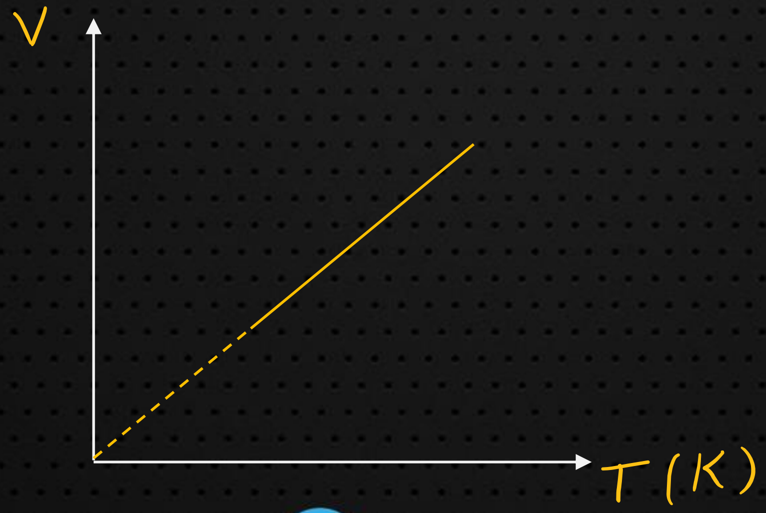
$$P_1 V_1 = P_2 V_2$$

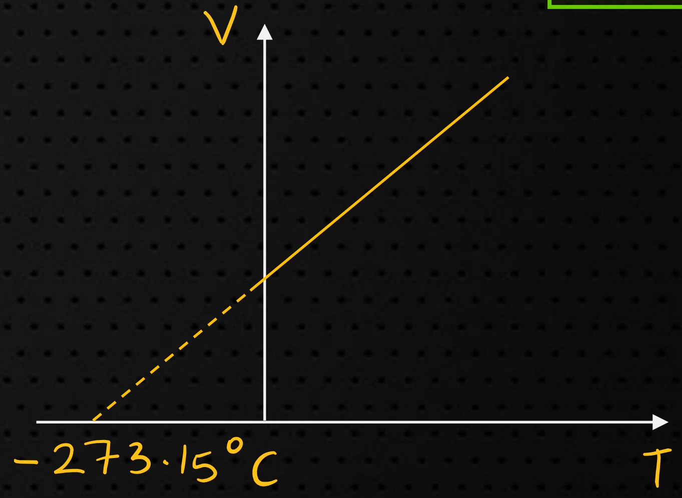
Boyle's law states that the pressure of a fixed amount of a gas varies inversely with the volume if the temperature is maintained constant.

CHARLES LAW, $P = \text{const.}$

Charles law states that the pressure remaining constant, the volume of a fixed amount of a gas varies directly with its absolute temperature.

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

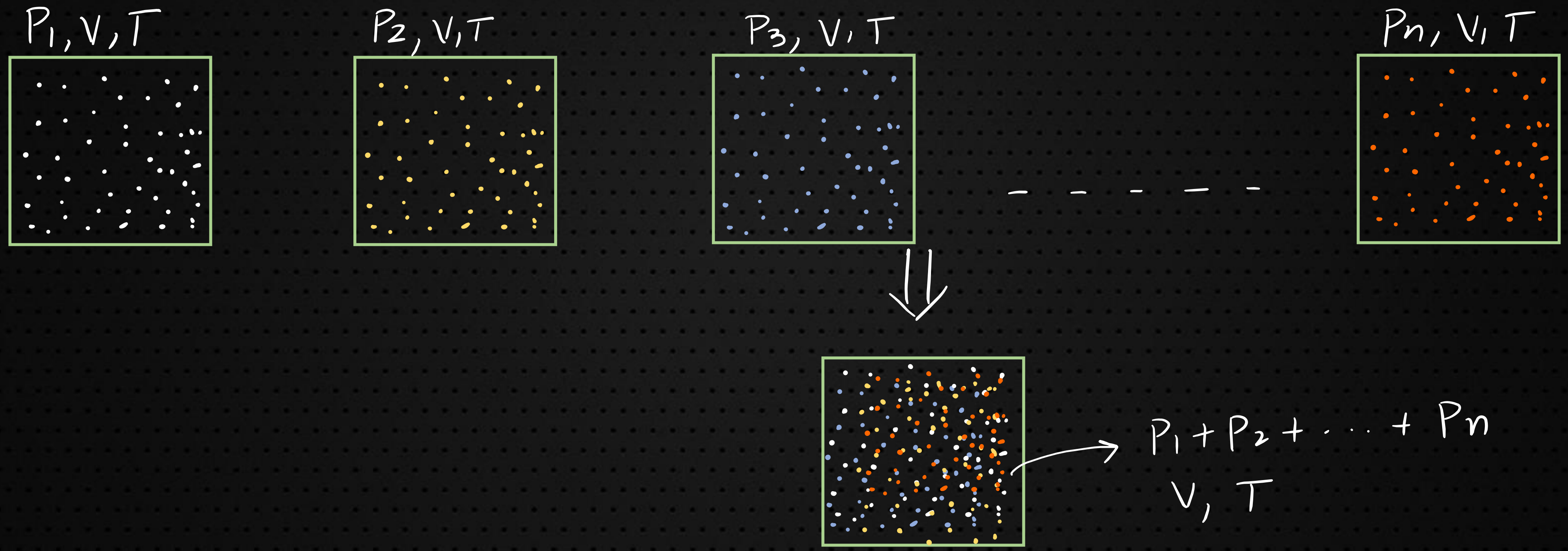




DALTON'S LAW OF PARTIAL PRESSURES

Pressure exerted by a mixture of non interacting gases is equal to the sum of their partial pressures. Hence, for a mixture of n gases, the total pressure of the gas is given by

$$\boxed{P = P_1 + P_2 + P_3 + \cdots + P_n}$$



DIFFERENT FORMS OF IDEAL GAS LAW

N : Total number of molecules of gas.

N_A : Avogadro No. , 6.023×10^{23}

m : mass of gas

M : molecular mass

$$PV = nRT$$

$$PV = \frac{N}{N_A} RT$$

$$\Rightarrow \boxed{PV = NkT}$$

where, $\boxed{k = \frac{R}{N_A}}$ is Boltzmann's Constant.

$$k = 1.38 \times 10^{-23}\ J/K.$$

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

$$\Rightarrow P = \frac{m}{V} \frac{RT}{M}$$

$$\Rightarrow \boxed{P = \frac{\rho RT}{M}}$$

PYQ (Uploaded on EDUNITI Channel)

Two non-reactive monoatomic ideal gases have their atomic masses in the ratio 2 : 3. The ratio of their partial pressures, when enclosed in a vessel kept at a constant temperature, is 4 : 3. The ratio of their densities is

(a) 1 : 4 (b) 1 : 2
(c) 6 : 9 (d) 8 : 9

2013 JEE Advanced

The volume V of an enclosure contains a mixture of three gases, 16 g of oxygen, 28 g of nitrogen and 44 g of carbon dioxide at absolute temperature T. Consider R as universal gas constant. The pressure of the mixture of gases is :

(1) $\frac{88RT}{V}$ (2) $\frac{3RT}{V}$

(3) $\frac{5}{2}\frac{RT}{V}$ (4) $\frac{4RT}{V}$

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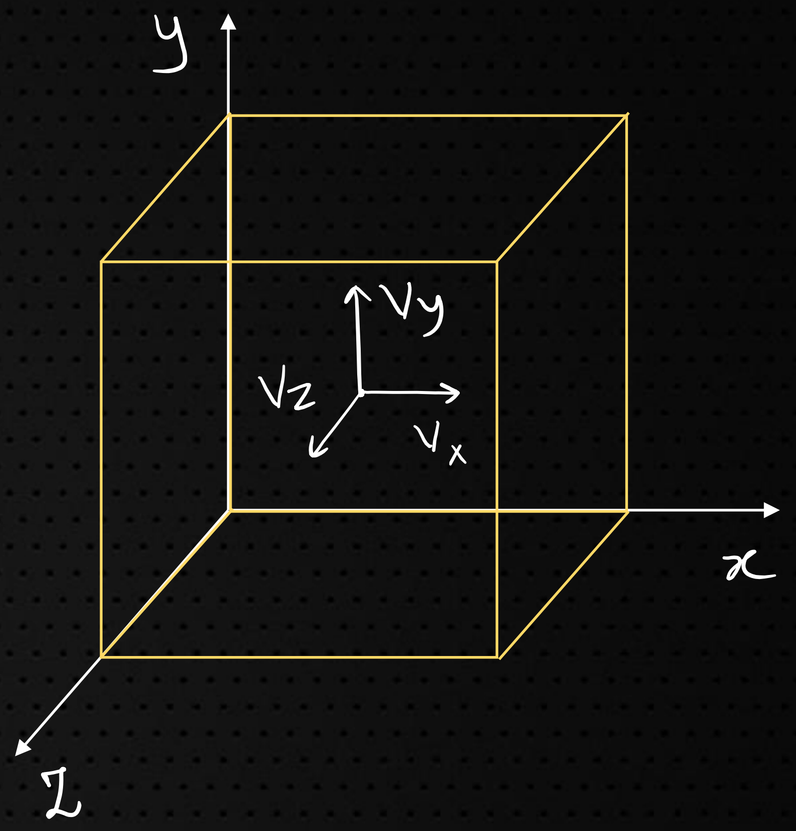
PRESSURE EXERTED BY GAS :

Momentum transferred to a container wall per second per unit of its surface area is

avg pressure , $\boxed{P = \frac{1}{3} \rho v_{rms}^2}$



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On the basis of kinetic theory of gases, the gas exerts pressure because its molecules :

(1) continuously lose their energy till it reaches wall.

(2) are attracted by the walls of container.

(3) continuously stick to the walls of container.

(4) suffer change in momentum when impinge on the walls of container.

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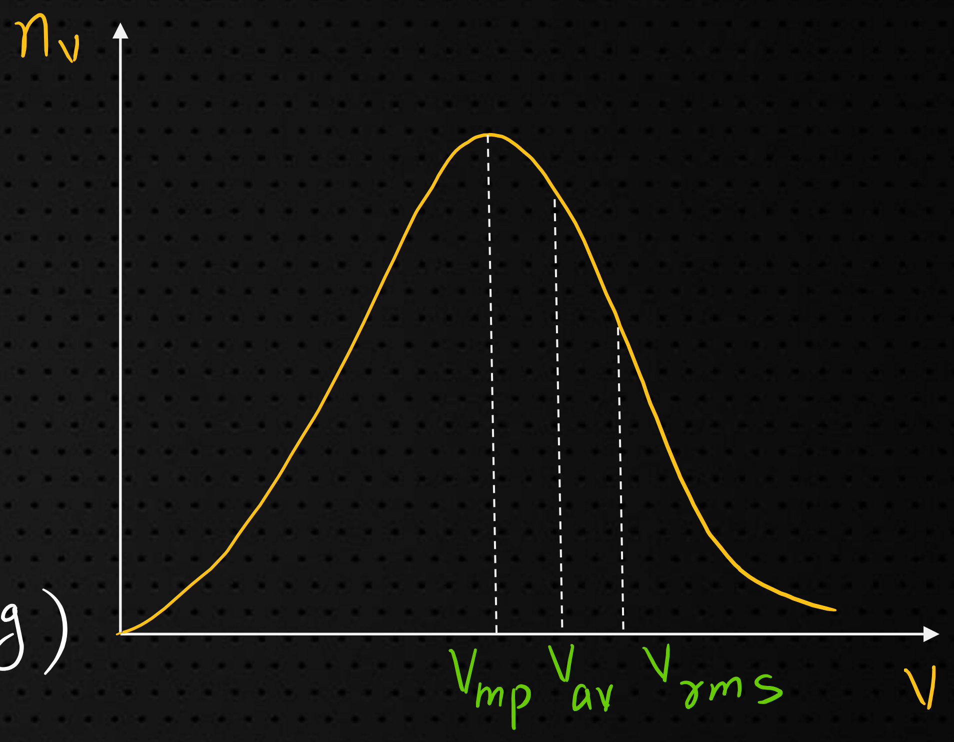
MAXWELL'S DISTRIBUTION OF VELOCITIES

A particle speed probability distribution shows how the speeds of molecules are distributed for an ideal gas.

n_v : no. of molecules per unit range of speeds.

$$\boxed{V_{mp} = \sqrt{\frac{2RT}{M}}} \qquad \boxed{V_{av} = \sqrt{\frac{8RT}{\pi M}}} \qquad \boxed{V_{rms} = \sqrt{\frac{3RT}{M}}}$$



NOTE :

(1.) T : Temp° in K

M : Molecular mass (Kg)

V : speed in m/s

(2) $V_{mp} < V_{av} < V_{rms}$ for a given gas at T temp°.

(3) Area under curve gives total no. of molecules

PYQ (Uploaded on EDUNITI Channel)

The root mean square speed of molecules of a given mass of a gas at 27°C and 1 atmosphere pressure is 200 ms^{-1}. The root mean square speed of molecules of the gas at 127°C and 2 atmosphere pressure is $\frac{x}{\sqrt{3}} ms^{-1}$. The value of x will be _____.

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Consider a sample of oxygen behaving like an ideal gas. At 300 K, the ratio of root mean square (rms) velocity to the average velocity of gas molecule would be :
(Molecular weight of oxygen is 32 g/mol; $R = 8.3\ J\ K^{-1}\ mol^{-1}$)

(1) $\sqrt{\frac{3}{3}}$ (2) $\sqrt{\frac{8}{3}}$

(3) $\sqrt{\frac{3\pi}{8}}$ (4) $\sqrt{\frac{8\pi}{3}}$

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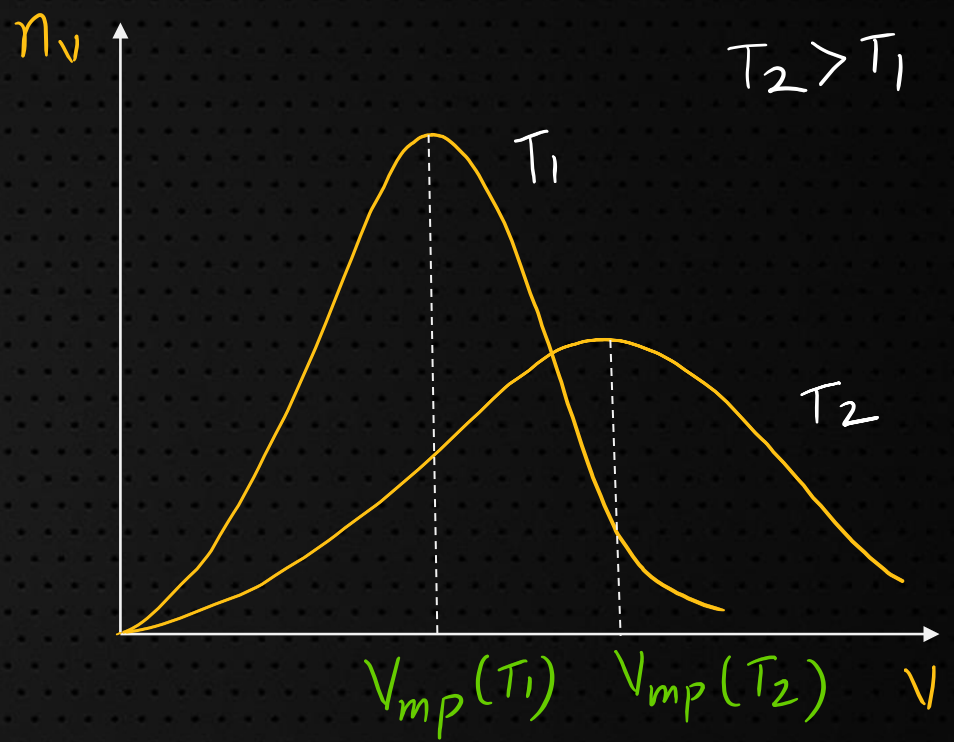
MAXWELL'S DISTRIBUTION OF VELOCITIES

A particle speed probability distribution shows how the speeds of molecules are distributed for an ideal gas.

ON Increasing T:

(1.) V_{mp} increases.

(2.) More molecules have high speed.



DEGREE OF FREEDOM, f

Number of ways a molecule can Participate in contributing to the total mechanical energy of that molecule

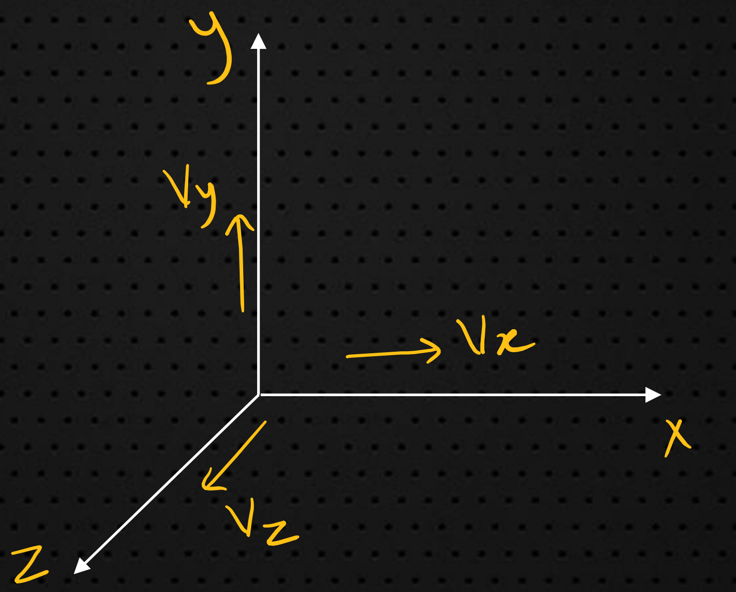
MODES

VIBRATIONAL

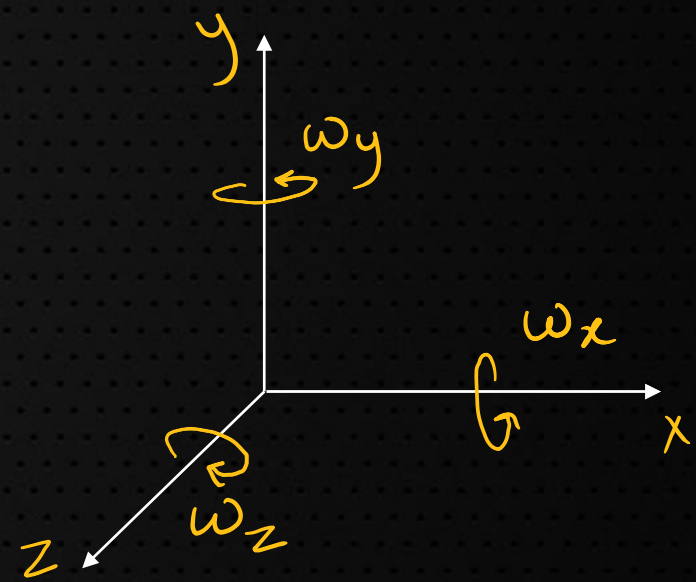
(1.) 2 DOF for each mode

(2.) Occurs at very temp°

TRANSLATIONAL



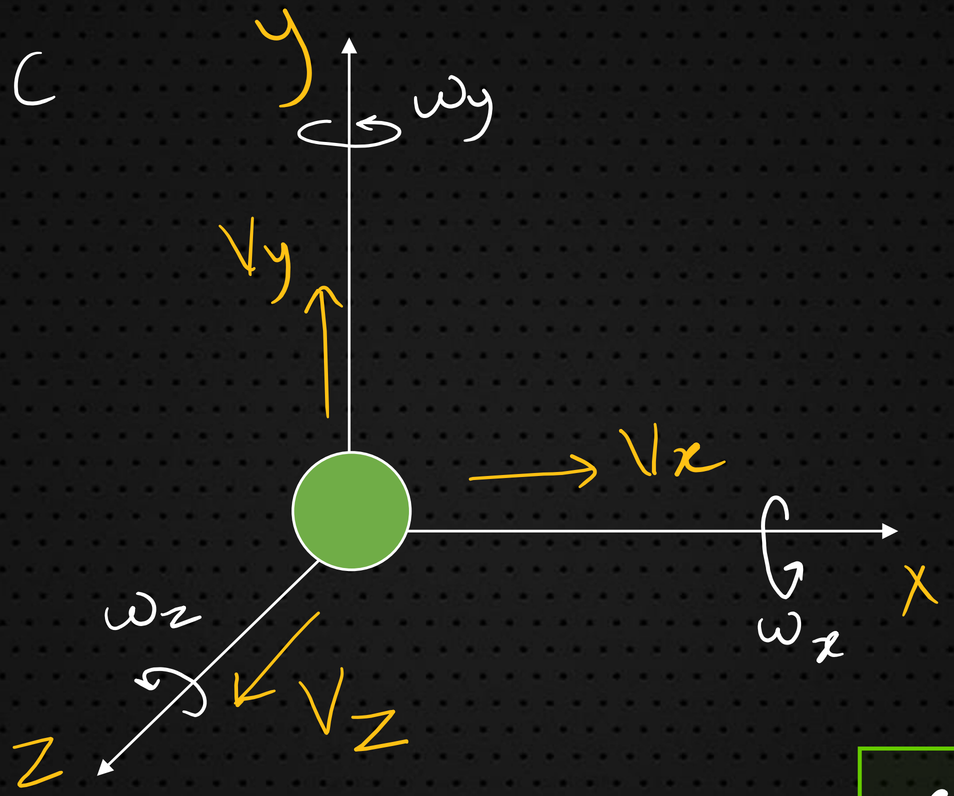
ROTATIONAL



DEGREE OF FREEDOM, f

(A) MONOATOMIC

(Eg: He, Ne, Ar)



NOTE:

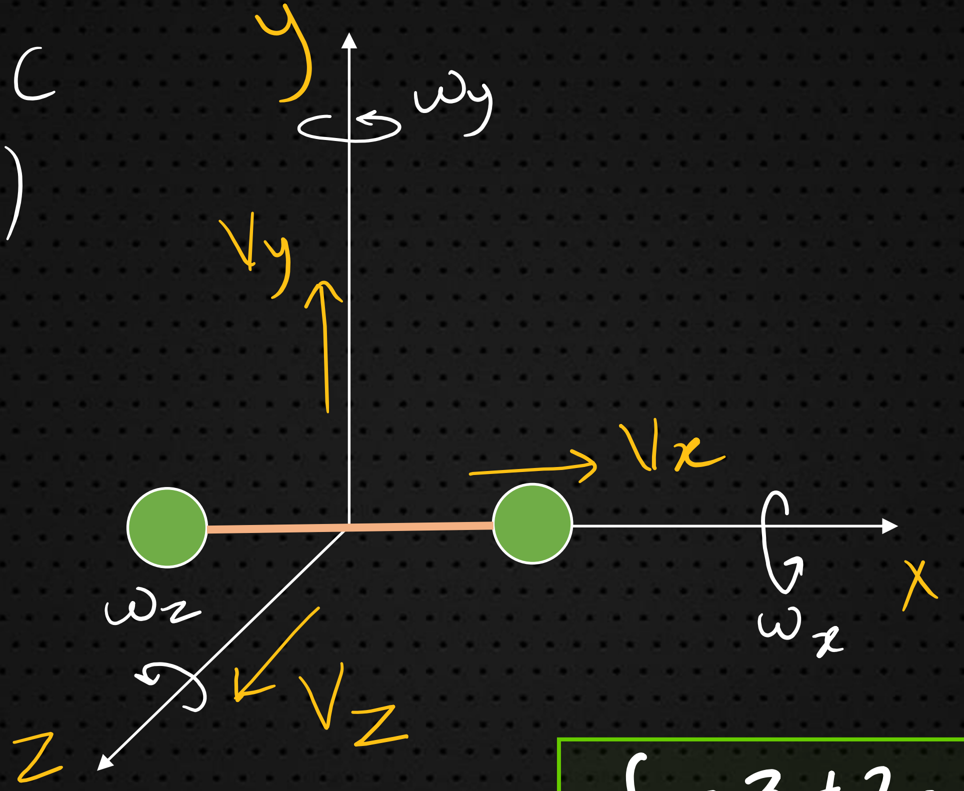
(1.) Since molecules size is assumed to be zero implies $\frac{1}{2}I\omega_y^2, \frac{1}{2}I\omega_x^2, \frac{1}{2}I\omega_z^2$ is zero as $I = 0$.

$$\boxed{f = 3}$$

Due to translational.

DEGREE OF FREEDOM, f

(B) DIATOMIC
(Eg: H_2, O_2, N_2)



NOTE:

(1.) SINCE molecules are along x-axis, implies $\frac{1}{2} I\omega_x^2 = 0$

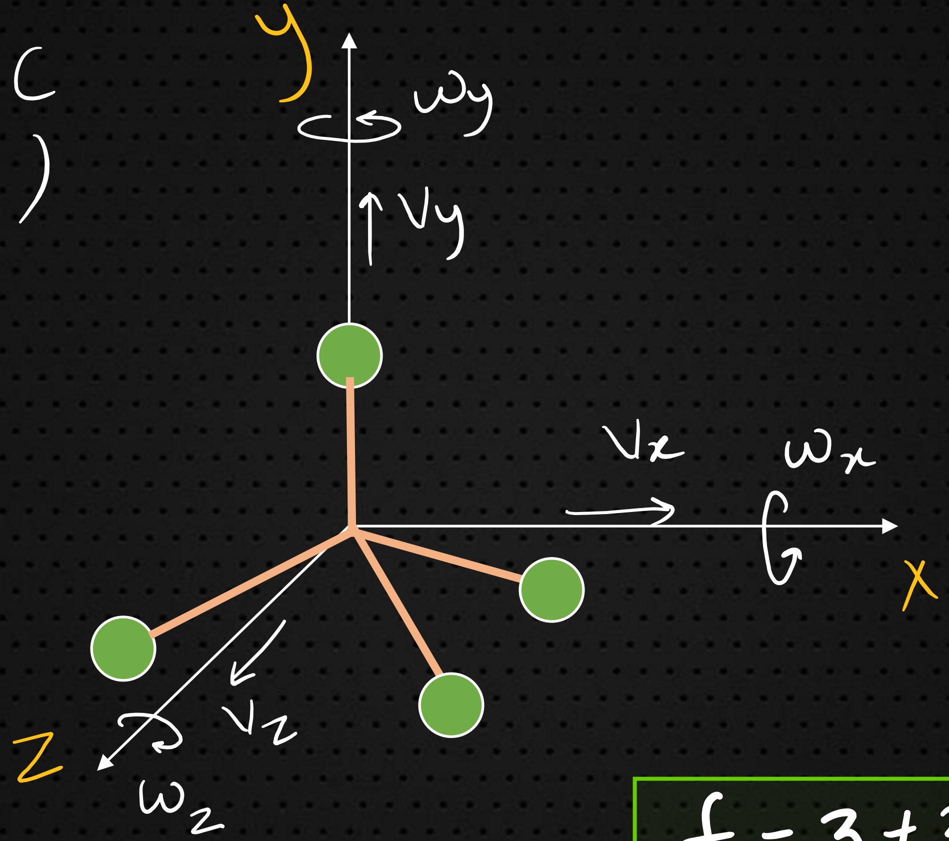
$\boxed{f = 3 + 2 = 5}$ At low temp°

$\boxed{f = 3 + 2 + 2 = 7}$ At high temp°

DEGREE OF FREEDOM, f

(C) POLYATOMIC (NON-LINEAR)

Eg: H_2O, CH_4



$$\boxed{f = 3+3 = 6}$$

NOTE:

(1.) LINEAR polyatomic

Eg: CO_2, $f = 3+2 = 5$

(2.) Vibrational DOF will be mentioned in problems.

EQUIPARTION OF ENERGY AND INTERNAL ENERGY, U

According to this law, for any system in thermal equilibrium, the total energy is distributed equally amongst all the degrees of freedom with the average energy associated with each degree of freedom equal to $\boxed{kT/2}$ per molecule $\boxed{RT/2}$ or per mole.

Implies If 1 mole of gas has f DOF,

$$U = \frac{fRT}{2}$$

$\therefore$ For n mole of gas

$$\boxed{U = \frac{fnRT}{2}}$$ Total Kinetic energy.

PYQs (Uploaded on EDUNITI Channel)

What will be the average value of energy along one degree of freedom for an ideal gas in thermal equilibrium at a temperature T ? (k_B is Boltzmann constant)

(1) $\frac{1}{2}k_BT$ (2) $\frac{2}{3}k_BT$

(3) $\frac{3}{2}k_BT$ (4) k_BT

JEE Main 2021, Mar 18 Morning

Statement I : In a diatomic molecule, the rotational energy at a given temperature obeys Maxwell's distribution.

Statement II : In a diatomic molecule, the rotational energy at a given temperature equals the translational kinetic energy for each molecule.

In the light of the above statements, choose the correct answer from the options given below :

(1) Statement I is false but Statement II is true.
(2) Both Statement I and Statement II are false.
(3) Both Statement I and Statement II are true.
(4) Statement I is true but Statement II is false.

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MIXING GASES

(1.) Equivalent f for a gaseous mixture (Gases mixed at same temp°)

$$\boxed{f_{mix} = \frac{n_1 f_1 + n_2 f_2 + \cdots + n_N f_N}{n_1 + n_2 + \cdots + n_N}}$$

(2.) FINAL temp° of gaseous mixture (Gases at different temp° mixed at const. volume in thermally insulated vessel, U remains const.)

$$\boxed{T_f = \frac{f_1 n_1 T_1 + f_2 n_2 T_2 + \cdots + f_N n_N T_N}{f_1 n_1 + f_2 n_2 + \cdots + f_N n_N}}$$

PYQs (Uploaded on EDUNITI Channel)

Two ideal polyatomic gases at temperatures T_1 and T_2 are mixed so that there is no loss of energy. If F_1 and F_2, m_1 and m_2, n_1 and n_2 be the degrees of freedom, masses, number of molecules of the first and second gas respectively, the temperature of mixture of these two gases is :

(1) $\dfrac{n_1T_1 + n_2T_2}{n_1 + n_2}$

(2) $\dfrac{n_1F_1T_1 + n_2F_2T_2}{n_1F_1 + n_2F_2}$

(3) $\dfrac{n_1F_1T_1 + n_2F_2T_2}{F_1 + F_2}$

(4) $\dfrac{n_1F_1T_1 + n_2F_2T_2}{n_1 + n_2}$

JEE Main 2021, March 17 Morning

MEAN FREE PATH, λ

The free path travelled by a molecule between two successive collisions

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

d : diameter of molecule

n : no. of molecules per unit volume, $\frac{N}{V}$

NOTE : using $PV = NkT$ or $\frac{P}{kT} = \frac{N}{V} = n$

$$\boxed{\lambda = \frac{kT}{\sqrt{2}\pi d^2 P}}$$

Replacing n by P/kT

PYQs (Uploaded on EDUNITI Channel)

Calculate the value of mean free path (λ) for oxygen molecules at temperature 27°C and pressure 1.01×10^5 Pa. Assume the molecular diameter 0.3 nm and the gas is ideal. ($k = 1.38 \times 10^{-23}$ JK^{-1})

(1) 58 nm
(2) 32 nm
(3) 86 nm
(4) 102 nm

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MEAN FREE TIME, τ

Time between two successive collisions

$$\boxed{\tau = \frac{\lambda}{V_{av}}}$$

NOTE: For τ calculation
Depending on problem we need to find dependence of τ with variables.

Eg: If T and P are changing

where, $\lambda = \dfrac{kT}{\sqrt{2}\pi d^2 P}$ and $V_{av} = \sqrt{\dfrac{8RT}{M}}$

$\lambda \propto \dfrac{T}{P}$ and $v_{av} \propto \sqrt{T}$

$$\Rightarrow \tau \propto \frac{T}{P} \times \frac{1}{\sqrt{T}} \Rightarrow \boxed{\tau \propto \frac{\sqrt{T}}{P}}$$

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An ideal gas is enclosed in a cylinder at pressure of 2 atm and temperature, 300 K. The mean time between two successive collisions is 6×10^{-8} s. If the pressure is doubled and temperature is increased to 500 K, the mean time between two successive collisions will be close to

(a) 4×10^{-8} s (b) 3×10^{-6} s
(c) 2×10^{-7} s (d) 0.5×10^{-8} s

JEE Main 2019, 12 Jan Evening

Two gases-argon (atomic radius 0.07 nm, atomic weight 40) and xenon (atomic radius 0.1 nm, atomic weight 140) have the same number density and are at the same temperature. The ratio of their respective mean free times is closest to

(a) 1.09 (b) 2.3
(c) 1.83 (d) 3.67

JEE Main 2020

Consider an ideal gas confined in an isolated closed chamber. As the gas undergoes an adiabatic expansion, the average time of collision between molecules increases as V^q, where V is the volume of the gas. The value of q is $\left(\gamma = \frac{C_p}{C_V}\right)$

(a) $\frac{3\gamma+5}{6}$ (b) $\frac{\gamma+1}{2}$
(c) $\frac{3\gamma-5}{6}$ (d) $\frac{\gamma-1}{2}$

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