



# SHORT NOTES

C H A P T E R

## Kinetic Theory of Gases

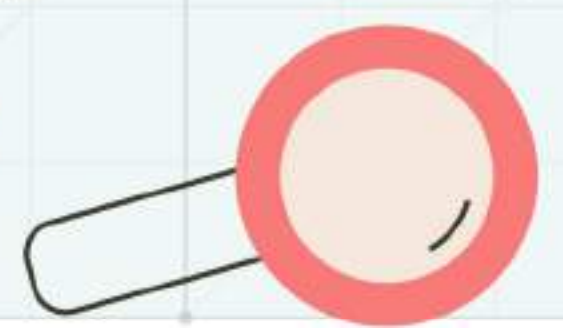
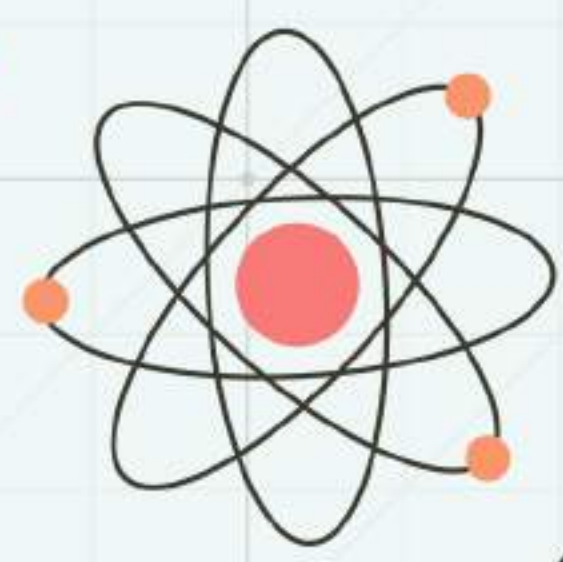
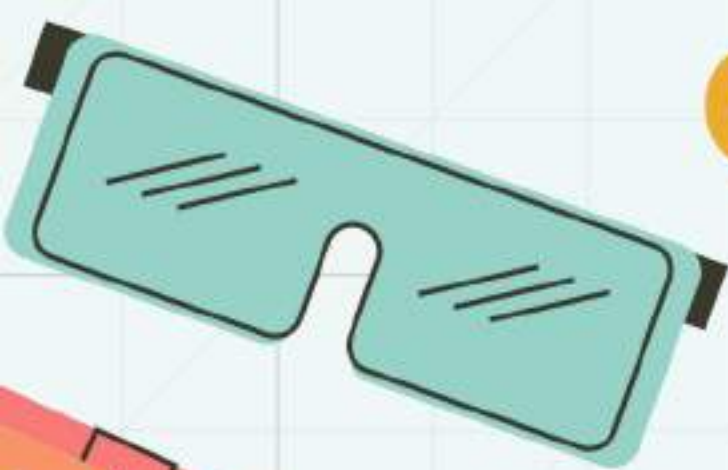
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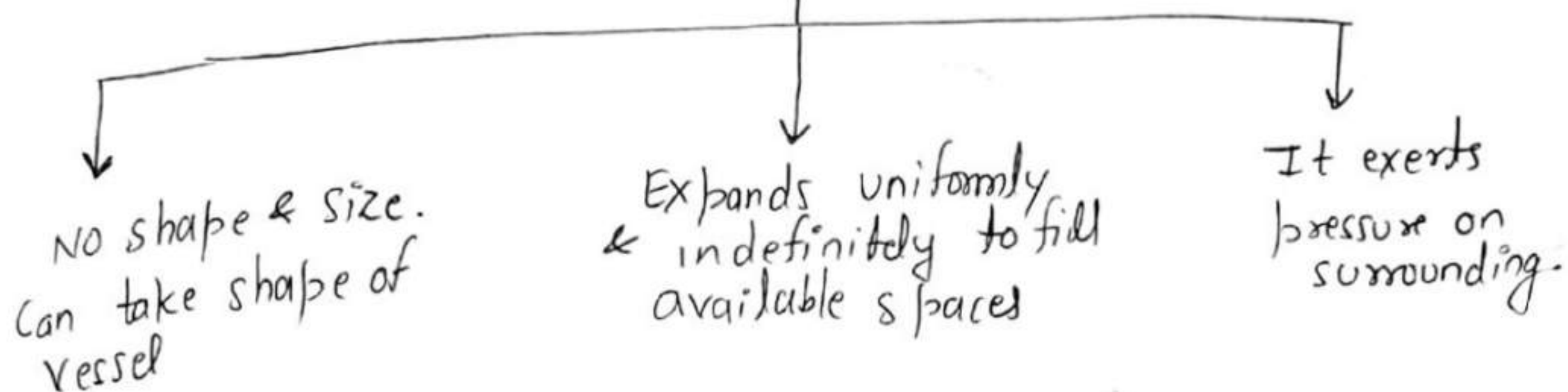
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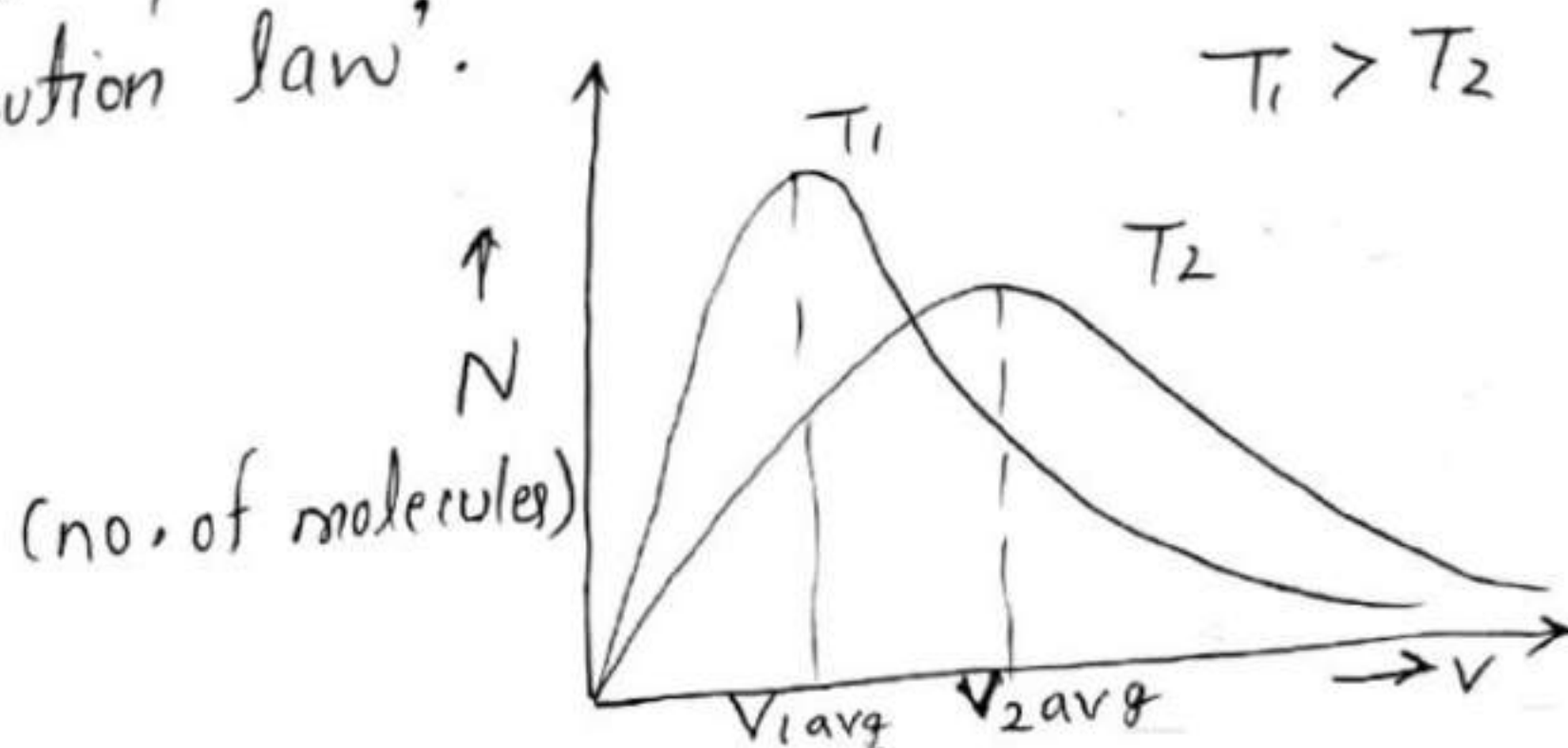
# KINETIC THEORY of GASES

## Characteristic of gases



## Assumptions of Kinetic Theory of Gases:

- Every gas made up of small particles called molecules. For a gas it is identical but different from another gas.
- molecules are elastic, spherical & rigid. (perfectly elastic point mass)
- Molecular size is negligible in comparison to the intermolecular distance.
- molecular volume is negligible compared to volume of gas
- In a gas, molecules moves in all possible directions with all possible speed, accordance with 'Maxwell's distribution law'.





- Maximum molecules moves with most probable speed
- Collision between molecules & molecule & wall are perfectly elastic
- Molecules moves in a straight line with constant speed between successive collisions.
- The number of collisions per unit volume in a gas remains constant.
- No attractive or repulsive force acts between gas molecules.
- Gravitational attraction among molecules is ineffective due to extremely small masses.
- Density of a gas is constant at all points of the container
- Molecules constantly collide with the wall of container, and this results in pressure by gas molecules on wall.

# GAS LAWS

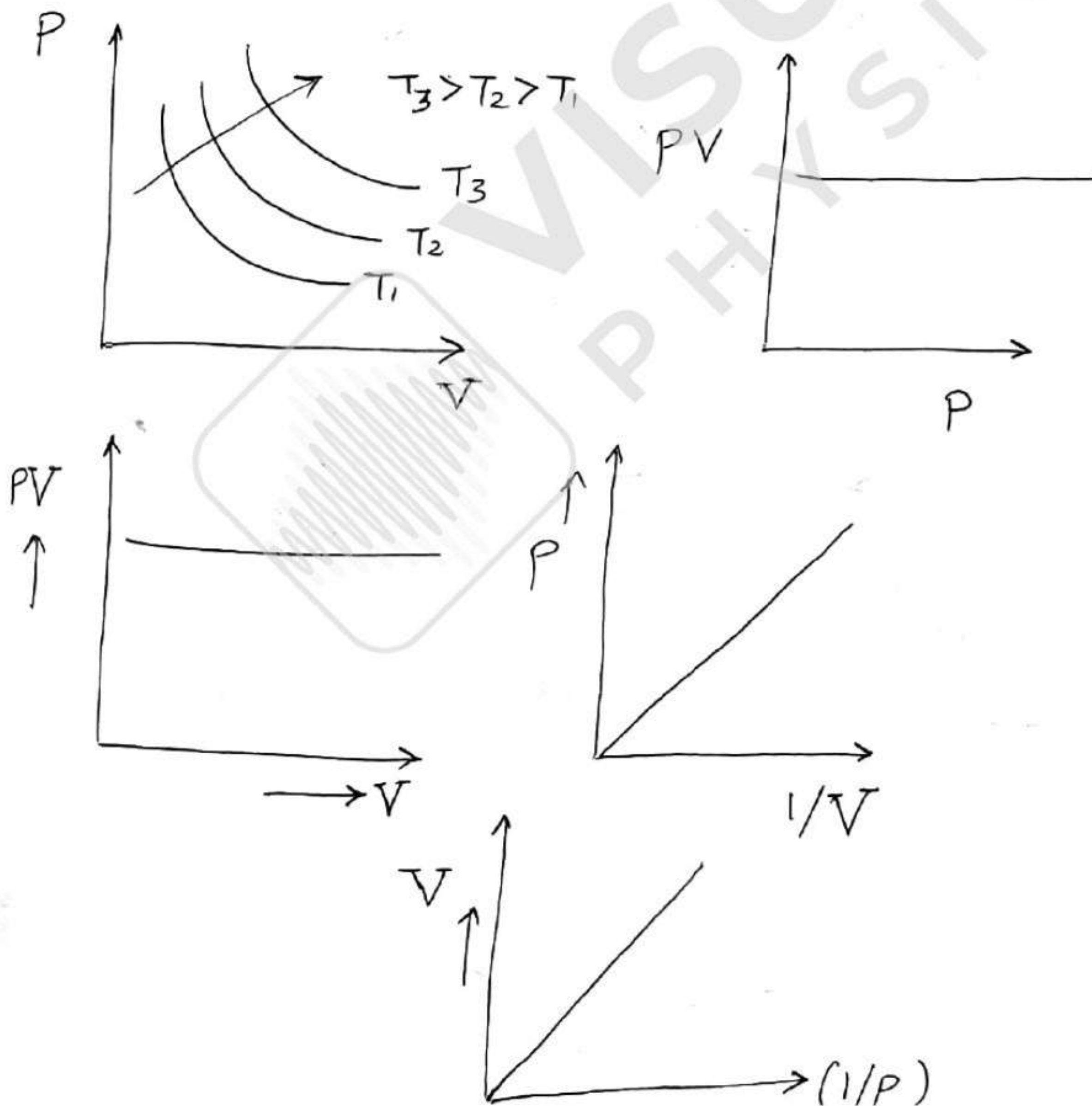
## Boyle's law:

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

→ for constant Temperature of gas in given situation (moles)

$$\Rightarrow PV = \text{constant}$$

for constant mass & Temperature we get graphs as:

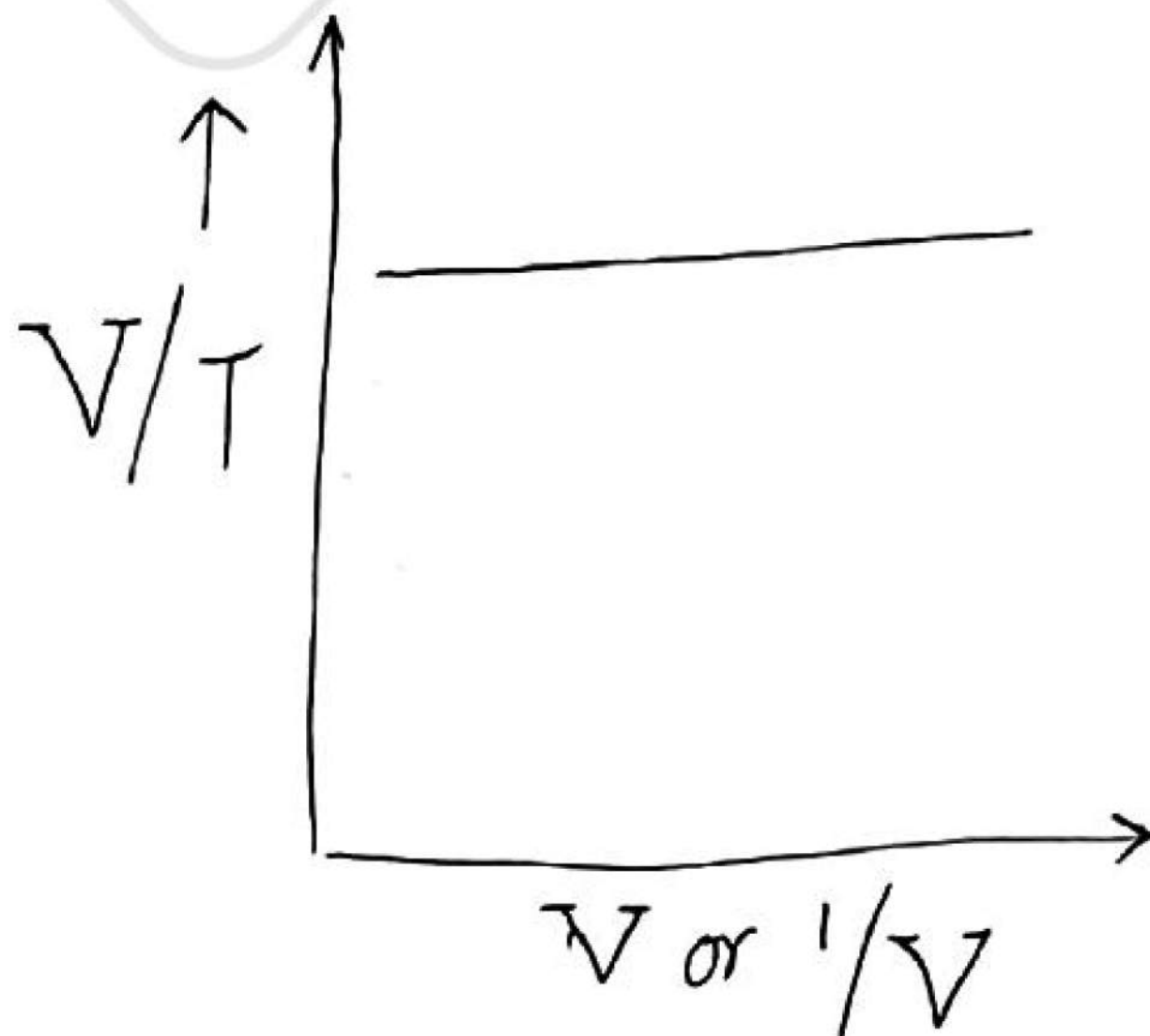
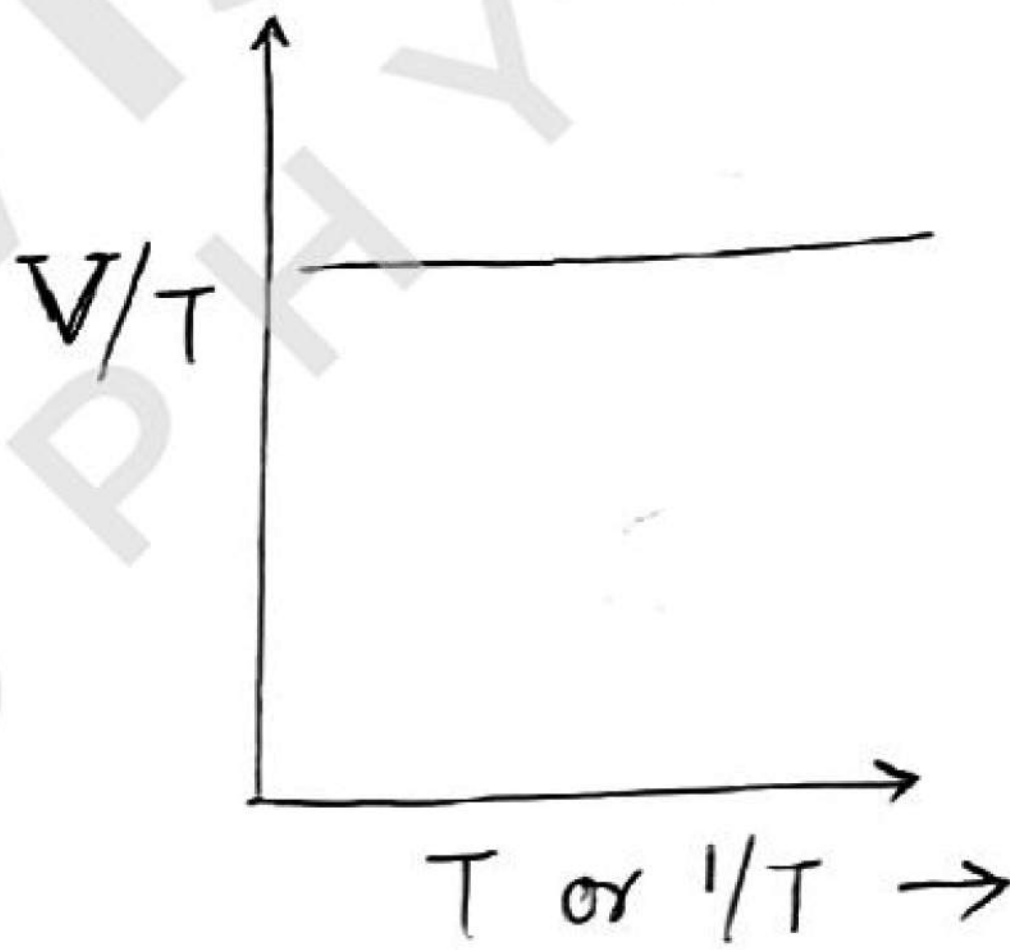
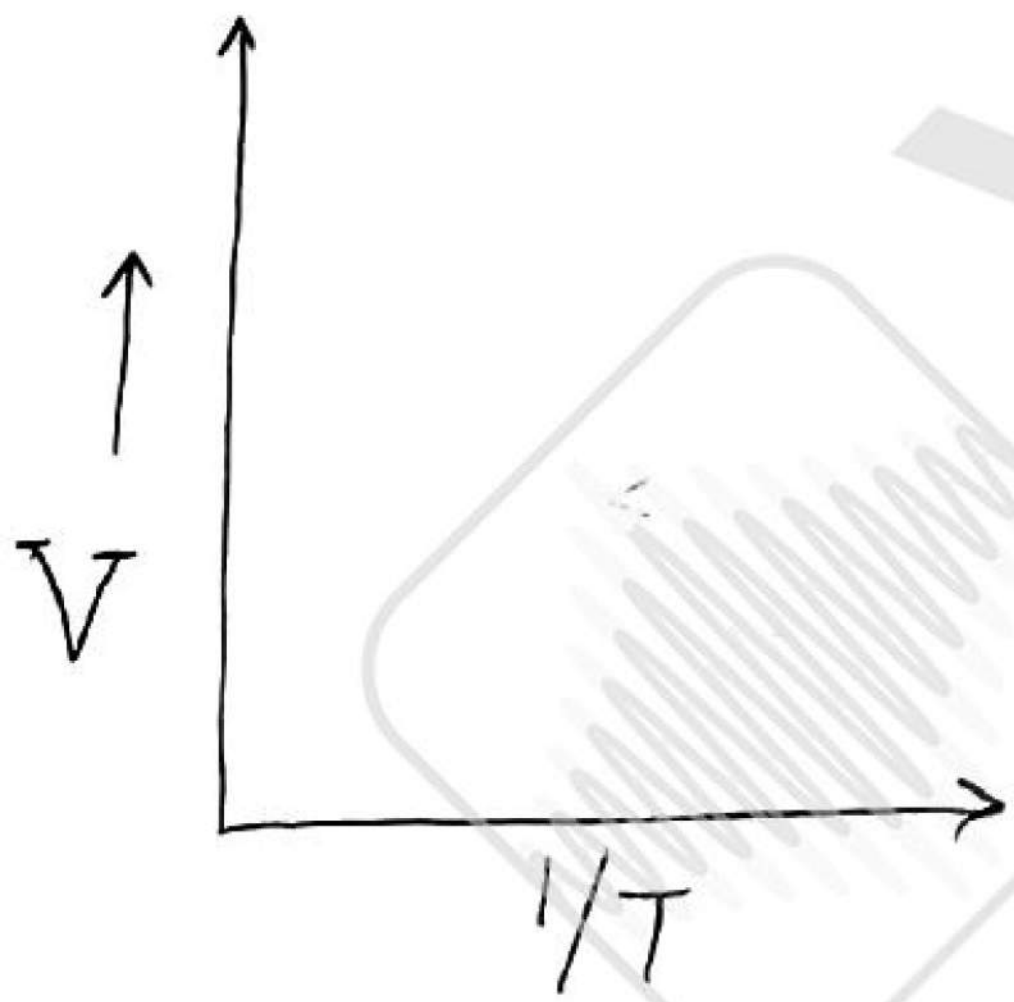
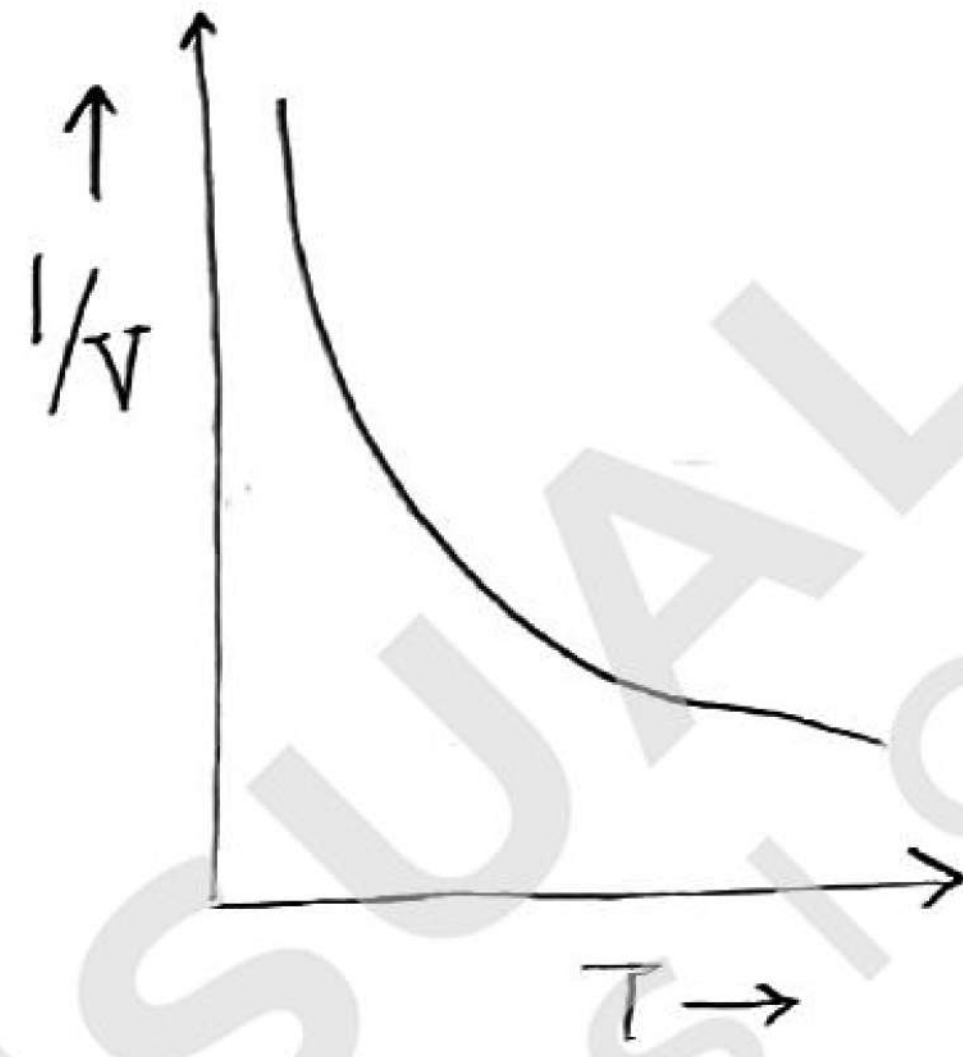
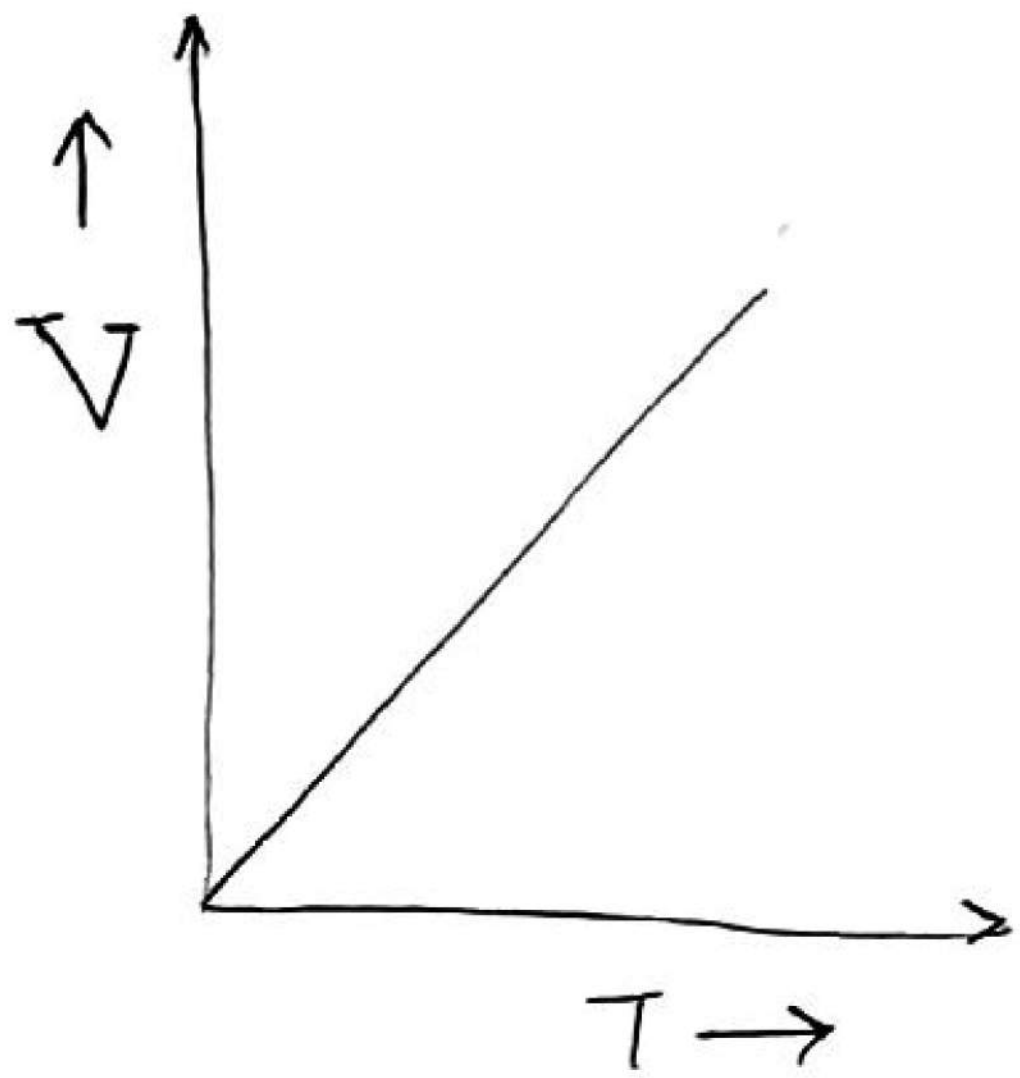




charle's law:

$$V \propto T$$

→ for constant pressure and moles

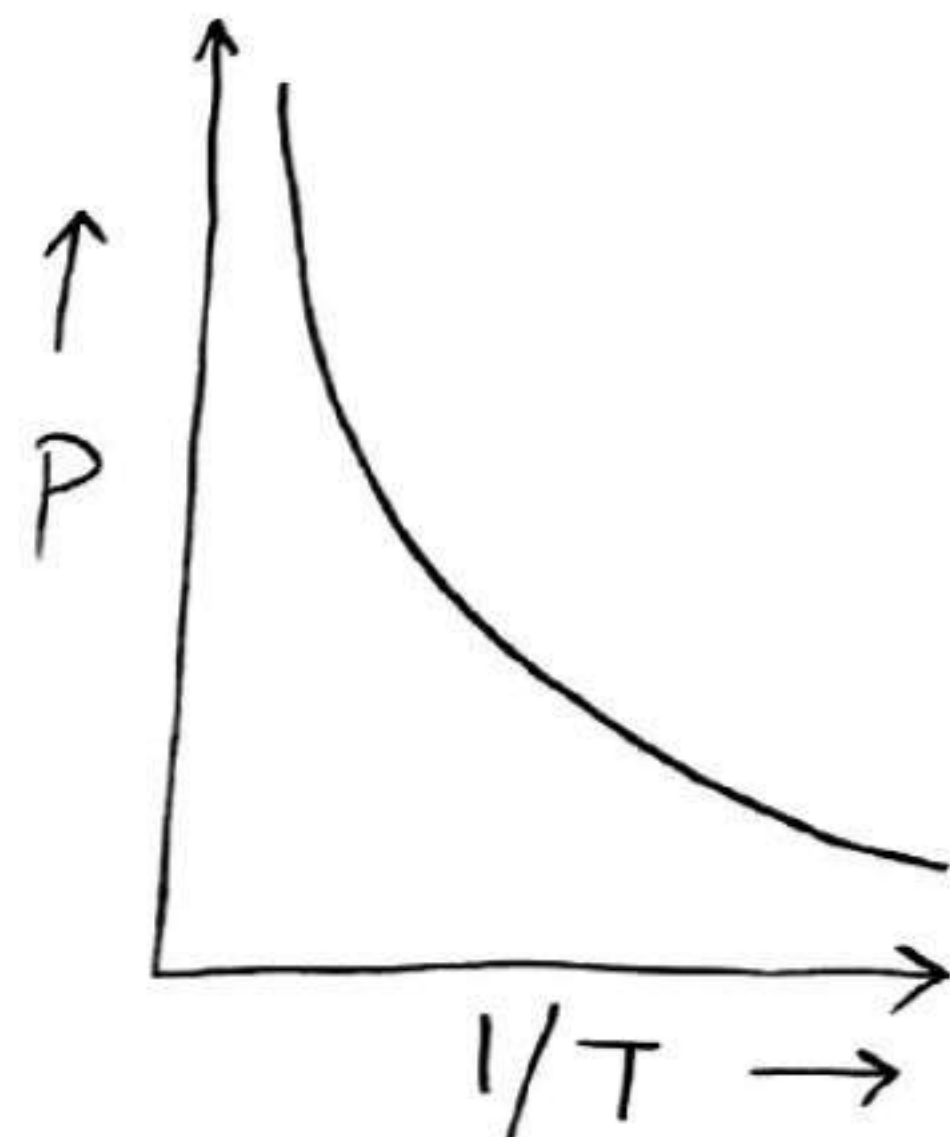
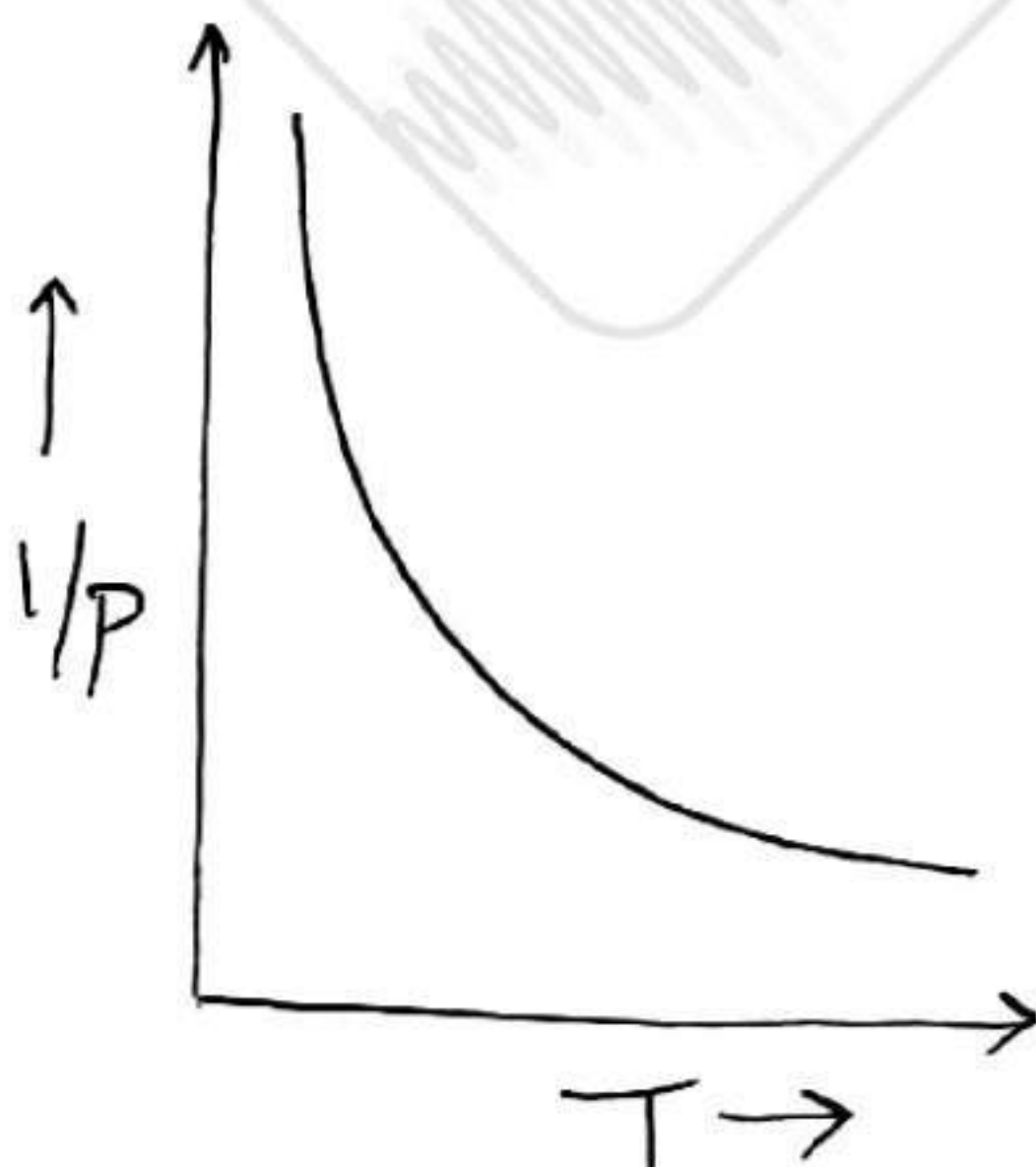
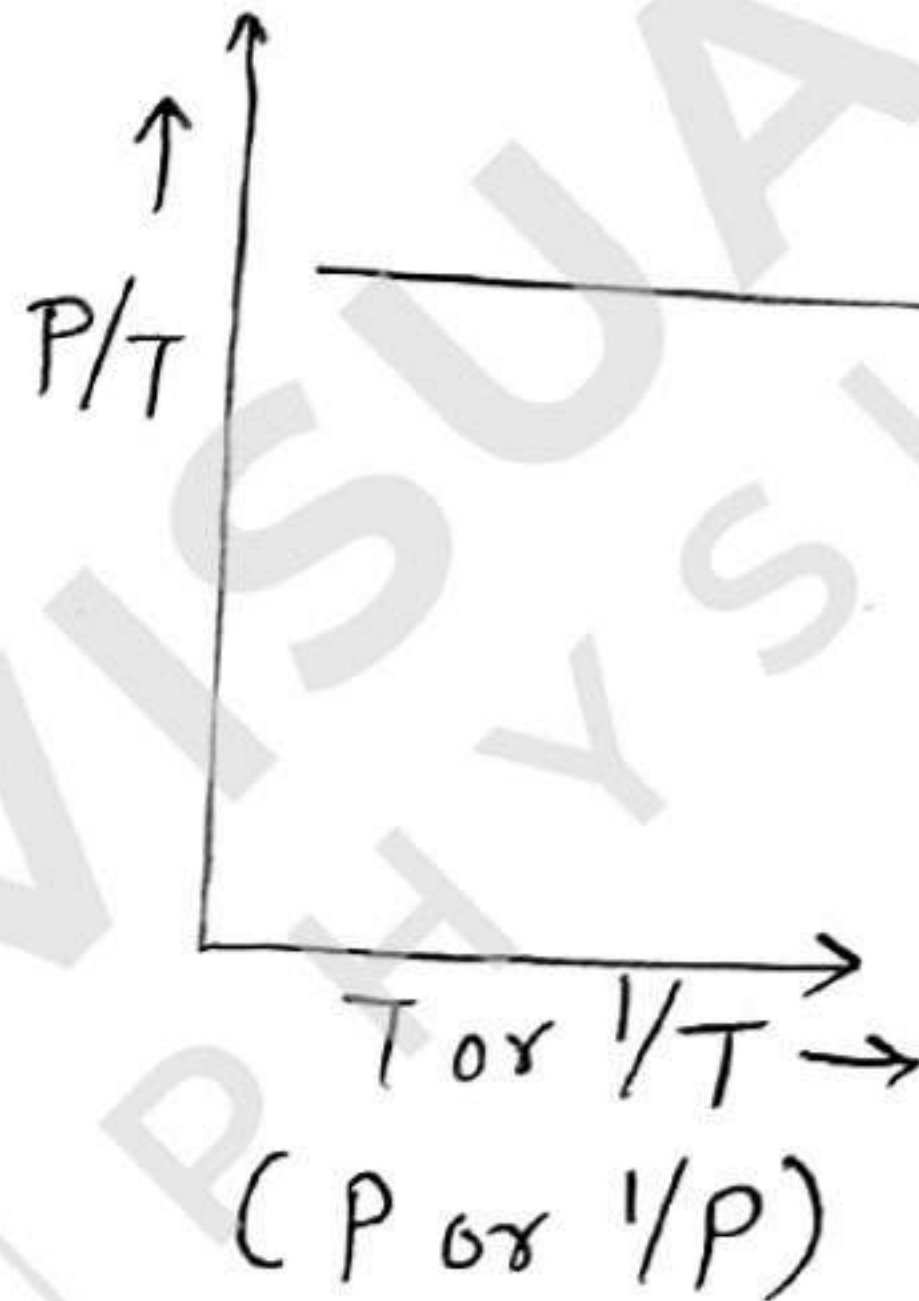
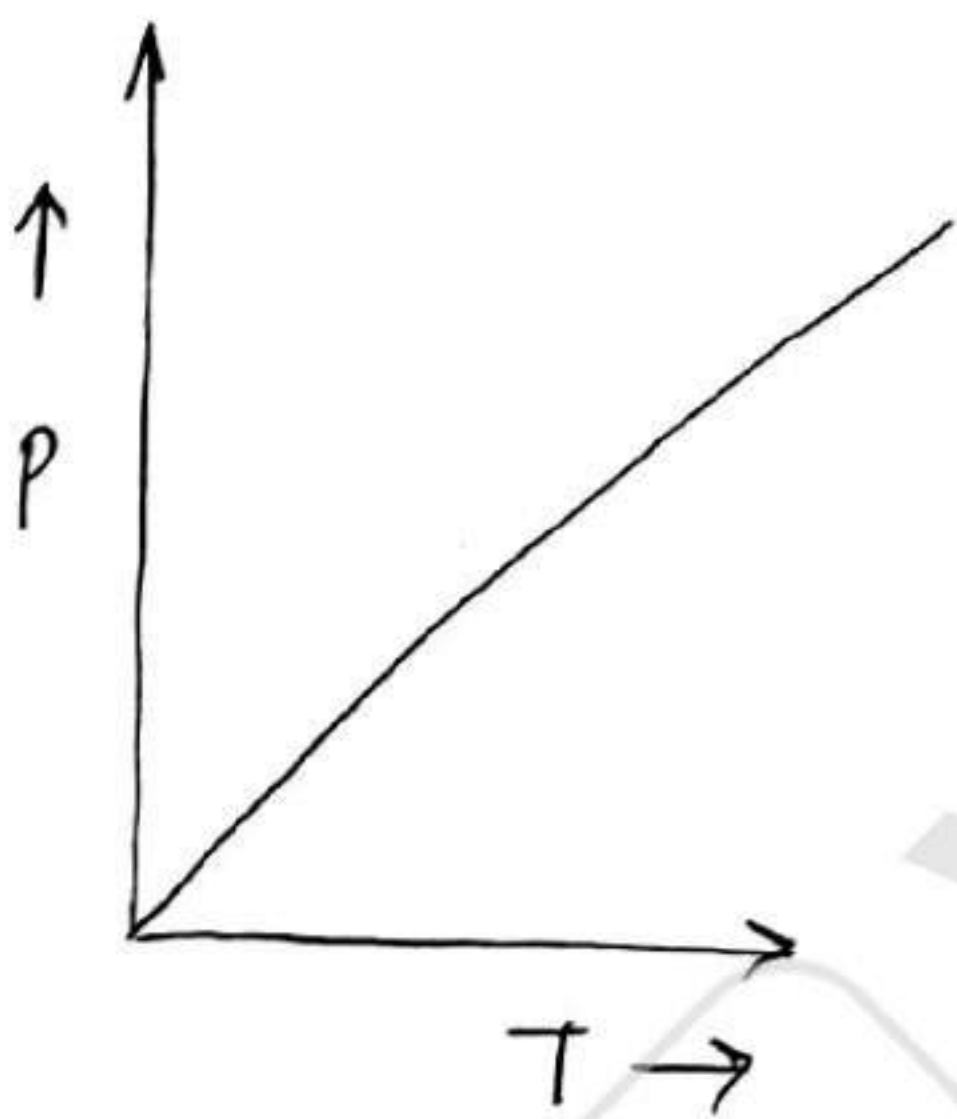


# Gay-Lussac's law:

$$P \propto T$$

→ for constant volume and moles

$$\frac{P}{T} = \text{constant}$$





## Avogadro's Law:

Equal volume of all the gases under similar conditions of temperature and pressure contain equal number of molecules.

$$N_A = 6.023 \times 10^{26} \text{ mole/kg}$$

$$N_A = 6.023 \times 10^{23} \text{ mole/gram}$$

Avogadro's number.

★  
→ At STP or NTP ( $T = 273\text{K}$  and  $P = 1\text{atm}$ )  
22.4 L of any gas has  $6.023 \times 10^{23}$  molecules

## IDEAL GAS EQUATION:

- Gas that strictly obeys gas law is called perfect or ideal gas
- All real gases are not perfect gases.
- At extremely low pressure and high Temperature gases like hydrogen, nitrogen & helium are nearly perfect gases.

$$PV = nRT$$

↗ ideal gas equation

P → Pressure

V → Volume

n → number of moles

R → Universal gas constant

T → Temperature

$$R = 8.31 \text{ J/molK}$$

$$k = \frac{R}{N_A}$$

↗ Avogadro's number  
↘  $6.023 \times 10^{23} \text{ mol}^{-1}$   
↘ Boltzmann's constant

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

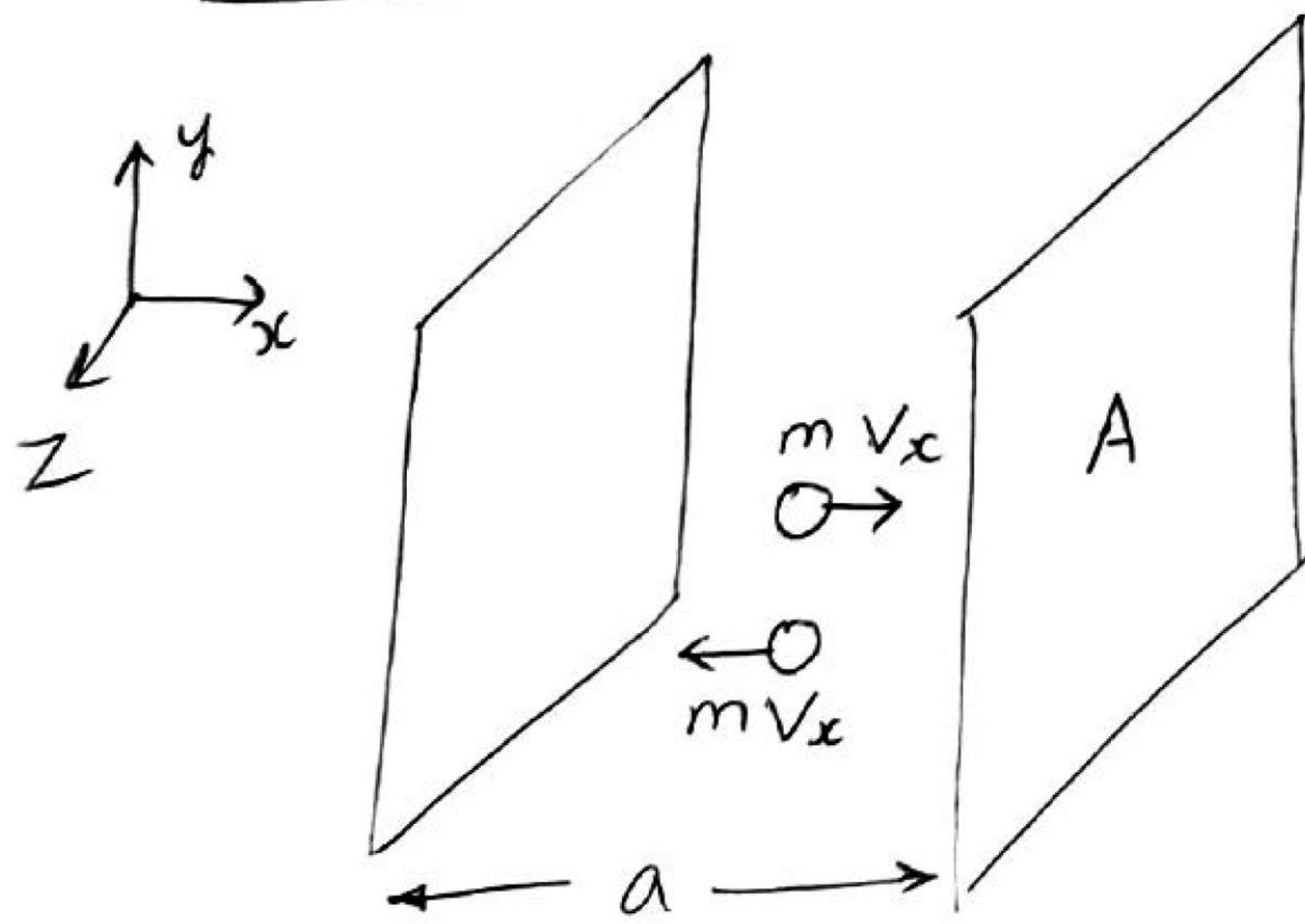
$$r = \frac{R}{M}$$

↘ Specific gas constant

↘ Molar mass of given gas



# Pressure of an Ideal gas:



$A \rightarrow$  Area of wall  
 $v_x \rightarrow$  Velocity component in  $x$  direction  
 $a \rightarrow$  separation between walls

$$t = \frac{2a}{v_x}$$

So number of collisions per second

time between successive collisions on same wall

$$\frac{1}{t} = \frac{v_x}{2a}$$

momentum change in successive collisions =  $2mv_x$

So,

$$\frac{\text{change in momentum per second}}{= (2m)v_x \times \left(\frac{v_x}{2a}\right)}$$

Force exerted in  $x$ -direction =  $f_x$

$\Rightarrow f_x = \frac{m v_x^2}{a}$ 
 force because of one molecule

$F_x = \text{Net force in } x\text{-direction} = \sum f_x = m \sum \frac{v_x^2}{a}$



$$P_x = \text{pressure} = \frac{F_x}{A} = \frac{m}{A a} \sum V_x^2 = \frac{m}{V} \sum V_x^2$$

So net pressure

$$P_x + P_y + P_z = \frac{m}{V} \left[ \sum V_x^2 + \sum V_y^2 + \sum V_z^2 \right]$$

As  $P_x = P_y = P_z = P$

$$3P = \frac{m}{V} \sum (V_x^2 + V_y^2 + V_z^2)$$

$$P = \frac{m}{3V} \sum (V_x^2 + V_y^2 + V_z^2)$$

As net speed,  $v = \sqrt{V_x^2 + V_y^2 + V_z^2}$

$$\Rightarrow v^2 = V_x^2 + V_y^2 + V_z^2$$

$$P = \frac{m}{3V} \sum v^2$$

as  $V_{\text{rms}}^2 = \frac{V_1^2 + V_2^2 + \dots + V_N^2}{N} = \frac{\sum V^2}{N}$

$$\Rightarrow \sum V^2 = N V_{\text{rms}}^2$$

$$P = \frac{m}{3V} N V_{\text{rms}}^2$$



as  $mN = M = \text{total mass of gas}$

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

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

$\rho \rightarrow \text{density of gas} = \frac{M}{V}$

$\rightarrow v_{rms}^2 \propto T \Rightarrow P \propto \frac{(mN)T}{V}$

for constant  $V$  &  $T$

$$P \propto (mN)$$

$\rightarrow$  increasing mass of gas  
increases pressure.

for constant  $m, N, T$

$$P \propto 1/V$$

and also for constant  $V, m$  &  $N$

$$P \propto T$$

# Various Speeds of Gas Molecules

1. Root mean square speed:

$$V_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$$

$\hookrightarrow$  molar mass                       $\hookrightarrow$  mass of one molecule

2. Most probable speed:

$$V_{mp} = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2kT}{m}}$$

3. Average speed:

$$V_{avg} = \sqrt{\frac{8P}{\pi\rho}} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8}{\pi} \frac{kT}{m}}$$

$$\Rightarrow V_{rms} > V_{avg} > V_{mp}$$

$$V_{rms} : V_{avg} : V_{mp} = \sqrt{3} : \sqrt{2.5} : \sqrt{2}$$



## Kinetic energy of ideal gas:

→ for one molecule:

$$\frac{1}{2} m v_{rms}^2 = \frac{1}{2} m \left( \frac{3kT}{m} \right) = \boxed{\frac{3}{2} kT}$$

$$\text{as } v_{rms} = \sqrt{\frac{3kT}{m}}$$

→ for 1 mole or M mass

$$= \frac{1}{2} M v_{rms}^2 = \frac{1}{2} M \left( \frac{3RT}{M} \right) = \boxed{\frac{3}{2} RT}$$

★

⇒ Kinetic energy per molecules do not depend on mass of the molecules but only on Temperature.



## Degree of freedom:

\* Minimum number of variables required to completely specify the state of system.

→ Translational degree of freedom (maximum) = 3 (x, y, z direction)

→ Rotational degrees of freedom = 3 (maximum)

→ Vibrational degree of freedom → depends on atoms arrangement.

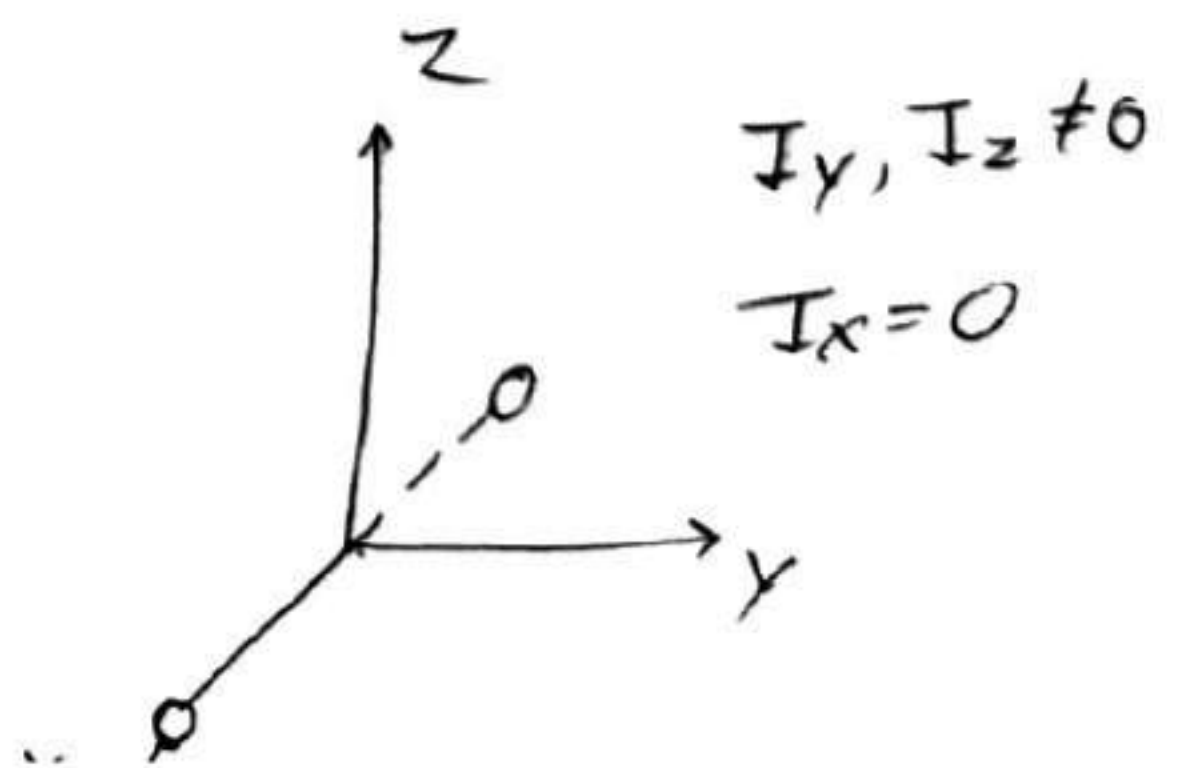
\* At room temperature only translational and rotational degree of freedom are taken into account.

### 1. monoatomic gas:

(3) → as three independent translation motion along x, y & z

### 2. Diatomic gas:

(5) → 3 translational  
2 rotational





### 3. Triatomic :

(6) → 3 translational  
→ 3 rotational.

At high temperature vibration degree of freedom is also considered

So for diatomic → (7)

↓  
3 translational      ↓  
2 rotational      ↓  
(2) (vibrational)

★ a vibration gives 2 degree of freedom

### Law of Equipartition of Energy :

★ In thermal equilibrium, total energy is equally distributed amongst its various degrees of freedom.

$$\text{per degree of freedom energy} = \frac{1}{2} kT$$

↓  
Boltzmann's  
constant



## Specific heat Capacity of Gases

→ Specific heat of gas at constant volume ( $c_v$ )

$$S_v = \frac{(\Delta Q_c)}{m \Delta T} \quad \rightarrow \text{heat at constant volume}$$

$$C_v = \frac{\Delta Q_c}{n \Delta T}$$

→ Specific heat of gas at constant pressure ( $c_p$ )

$$S_p = \frac{\Delta Q_p}{m \Delta T} \quad \rightarrow \text{heat at constant pressure}$$

$$C_p = \frac{\Delta Q_p}{n \Delta T}$$

$n$  → no. of moles

$C_p, C_v$  → molar specific heat capacity  
or molar heat capacity.

## Mayer's Formula

for constant volume

$w = 0$  = work done by gas

$$\rightarrow (\Delta Q)_v = \Delta U = n C_v \Delta T$$