Subject ⇒ Chemistry
Paper ⇒ 1A (Physical chemistry)
Chapter ⇒ Gaseous state (Group - A)
Topic ⇒ Kinetic theory of gases.

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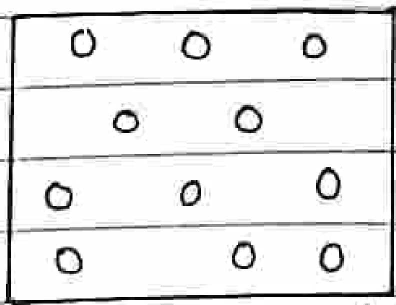
Kinetic theory of gases

Assumptions

1. A gas consists of extremely small discrete particles called molecules dispersed throughout the container.

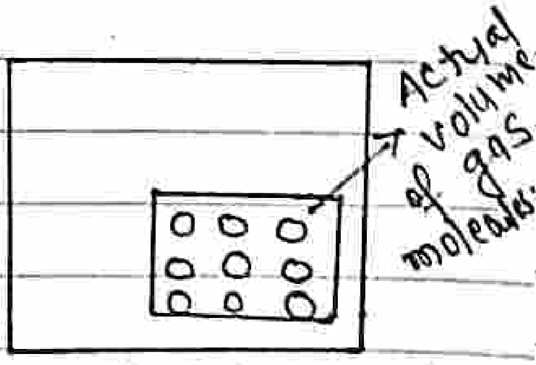
Fig.

(A)



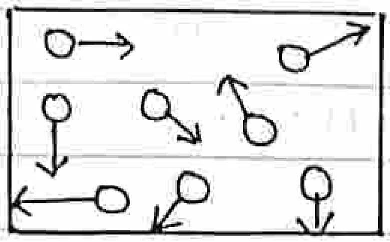
A gas is made of molecules dispersed in space in the container.

(B)



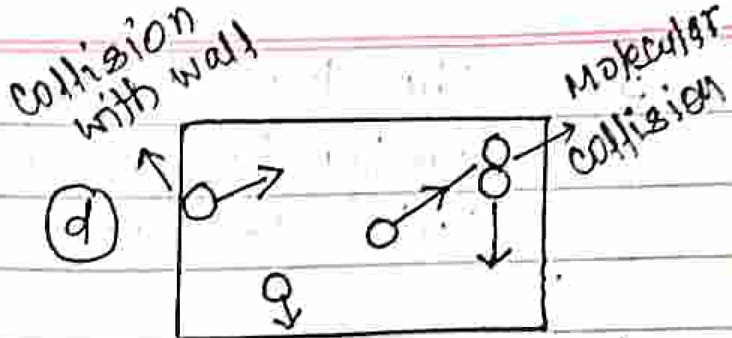
Actual volume of gas molecules is negligible.

(c)



Gas molecules are in constant motion in all possible directions.

(d)



Molecules move in straight line and change direction on collision with another molecule or wall of container.

2. Gas molecules are in constant random motion with high velocities.
They move in straight lines with uniform velocity and change direction on collision with other molecules or the walls of the container.

3. The distance between the molecules are very large and it is assumed that vanderwaals attractive forces between them do not exist.
Thus the gas molecules can move freely independent of each other.

4. All collisions are perfectly elastic. Hence there is no loss of the kinetic energy of a molecule during a collision.

5. The pressure of the gas is due to the bombardment or hit of the molecules on the walls of the container.

6. The average kinetic energy ($\frac{1}{2}mu^2$) of the gas molecules is directly proportional to absolute temperature (Kelvin temperature).

This implies that the average kinetic energy of molecules is same at a given temperature.

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Subject ⇒ Chemistry
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Chapter ⇒ Gaseous state (Group-A)
Topic ⇒ Derivation of Kinetic gas equation.

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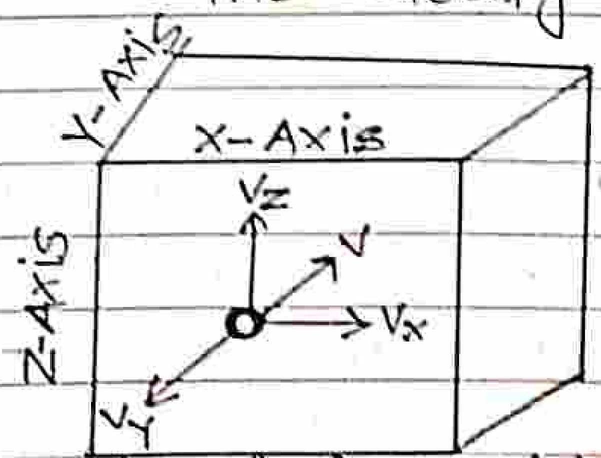
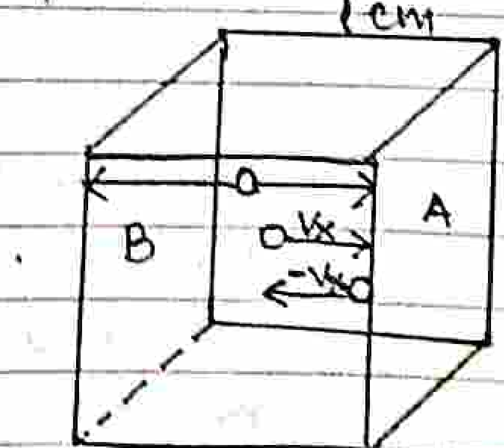
Derivation of Kinetic gas equation

Let us consider a certain mass of gas enclosed in a cubic box at a fixed temperature.

The length of each side of the box = 1 cm
The total no. of gas molecules = n
The mass of one molecule = m
The velocity of a molecule = v



Resolution of velocity v into components Vx, Vy and Vz.



Molecular collisions along X-axis.

The kinetic gas equation is derived by the following steps.

1. Resolution of velocity v of a single molecule along X, Y and Z Axes ⇒

According to the kinetic theory, a molecule of a gas move with velocity v in any direction and resolved into the components V_x, V_Y and V_z along X, Y and Z axes.

$$V^2 = V_x^2 + V_Y^2 + V_Z^2$$

Now, we consider the motion of a single molecule moving with the component velocities independently in each direction.

2. The no. of collisions per second on face A due to one molecule. ⇒

Let us consider a molecule moving in X direction between opposite faces A and B. It will strike the face A with velocity V_x and Rebound with velocity $-V_x$. To hit the same face again, the molecule ~~[illegible]~~ must travel l cm to collide with the opposite face B and then again l cm to return to face A. Therefore,

The time between two collisions of face A_v = $\frac{2l}{V_x}$ seconds

The no. of collisions per second on face A = $\frac{V_x}{2l}$

3. The total change of momentum on all faces of the box due to one molecule only:-

Each impact of the molecule on the face A causes a change of momentum (Mass × velocity).

The momentum before the impact $= mV_x$

The momentum after the impact $= m(-V_x)$

∴ The change of momentum $= mV_x - (-mV_x)$
$= 2mV_x$

But the no. of collisions per second on face A due to one molecule $= \frac{V_x}{2l}$

∴ The total change of momentum per second on face A caused by one molecule =

$$2mV_x \times \left(\frac{V_x}{2l}\right) = \frac{mV^2x}{l}$$

The change of momentum on both the opposite faces A and B along x-axis would be double i.e.

$$\frac{2mv_x^2}{l}$$

Similarly,

The change of momentum along Y axis $= \frac{2mv_y^2}{l}$

The change of momentum along z axis $= \frac{2mv_z^2}{l}$

$\therefore$ The overall change of momentum per second on all faces of the box will be

$$= \frac{2mv_x^2}{l} + \frac{2mv_y^2}{l} + \frac{2mv_z^2}{l}$$

$$= \frac{2m}{l}(v_x^2 + v_y^2 + v_z^2)$$

$$= \frac{2mv^2}{l} \qquad (\because v^2 = v_x^2 + v_y^2 + v_z^2)$$

4. Total change of Momentum due to impact of all the Molecules on all faces of the Box $\Rightarrow$

Let N molecules in the box each of which is moving with a different velocity v_1, v_2 and v_3 respectively.

∴ The total change of momentum due to impact of all the molecules on all faces of the Box $= \frac{2m}{l}(v_1^2 + v_2^2 + v_3^2 + \cdots)$

Multiplying and dividing by n we get

$$= \frac{2mN}{l}\left(\frac{v_1^2 + v_2^2 + v_3^2 + \cdots}{n}\right)$$

$$= \frac{2mNu^2}{l}$$

where u^2 is the mean square velocity.

5. Calculation of Pressure from change of momentum ; Derivation of Kinetic gas equation ⟹

The change in momentum per second is called force.

$$\therefore \text{Force} = \frac{2mNu^2}{l}$$

But, $\text{Pressure} = \frac{\text{Total force}}{\text{Total Area}}$

$$P = \frac{2mNu^2}{l} \times \frac{1}{6l^2}$$

$$= \frac{1}{3}\frac{mNu^2}{l^3}$$

Since l^3 = volume of the cube V

$$\therefore P = \frac{1}{3}\frac{mNu^2}{V}$$

or $\boxed{PV = \frac{1}{3} mNu^2}$

This is the fundamental equation of the kinetic molecular theory of gases. It is called the kinetic gas equation.