Thermal Physics
Lecture 2

KINETIC THEORY OF GASES

Assumptions of Kinetic Theory of Gases

- Matter is composed of very large number of atoms and molecules.

- Kinetic theory of gases attempts to relate the macroscopic or bulk properties such as pressure, volume and temperature of an ideal gas with its microscopic properties such as speed and mass of its individual molecules.

- The kinetic theory is based on certain assumptions. (A gas whose molecules can be treated as point masses and there is no intermolecular force between them is said to be ideal.) A gas at room temperature and atmospheric pressure (low pressure) behaves like an ideal gas

Assumptions of Kinetic Theory of Gases

Clark Maxwell in 1860 showed that the observed properties of a gas can be explained on the basis of certain assumptions about the nature of molecules, their motion and interaction between them. These resulted in considerable simplification

Assumptions1 of Kinetic Theory of Gases

A gas consists of a very large number of identical rigid molecules, which move with all possible velocities randomly. The intermolecular forces between them are negligible. The number of molecules in a kilo-mole is $6.023 x 10^{26.}$And this is known as Avagadro’s number.

Assumption 2 of Kinetic Theory of Gases

Gas molecules collide with each other and with the walls of the container. These collisions are perfectly elastic or the molecules of a gas behave as rigid ,perfectly elastic hard spheres. It means that molecules neither lose energy nor deform in shape when they collide amongst themselves or with the walls of the container.

Assumption 3 of Kinetic Theory of Gases

The gas can be regarded as point masses. Experiments show that the diameter of a gas molecule is about 2-3x10^{-10}m which is negligible compared to the separation between them. The distance between any two neighboring gas molecules at STP, on an average is about 3x10^{-9}m , which is an order of magnitude bigger than their diameter.

Assumption 4 of Kinetic Theory of Gases

The gas molecules are in the state of constant random motion. Infact, the motion of gas molecules resembles the motion of honeybees distributed from their hive. It means that molecules of an ideal gas can move in all possible directions and all positions are equally probable. The support for this assumption came in the form of Brownian motion.

Assumption 5 of Kinetic Theory of Gases

In absence of any external force field, the molecules are distributed uniformly in the container .It means an ideal gas behaves as an isotropic medium. In practice, however some randomness in the direction of the velocities may arise because of irregularity on the walls of the container.

Assumption 6 of Kinetic Theory of Gases

The molecules of a gas experience force only during collisions. This assumption implies that there are no intermolecular forces (of mutual attraction or repulsion) between the molecules and the walls of the container. That is, molecule of a gas can be thought of as moving freely unaware of the presence of other molecules. In other words, the molecules of an ideal gas possess only kinetic energy.

Since the particles are always in motion, they have average kinetic energy proportional to the temperature of the gas.

The average kinetic energy of the gas particles changes with temperature. i.e., The higher the temperature, the higher the average kinetic energy of the gas.

Assumption 7 of Kinetic Theory of Gases

Time taken in a collision is negligible as compared to the time taken by a molecule between two successive collisions

Assumption 8 of Kinetic Theory of Gases

These molecules are in constant random motion which results in colliding with each other and with the walls of the container. As the gas molecules collide with the walls of a container, the molecules impart some momentum to the walls. Basically, this results in the production of a force that can be measured. So, if we divide this force by the area it is defined to be the pressure.

Assumption 9 of Kinetic Theory of Gases

All molecules do not move with the same speed. That is, there is spread of molecular speeds ranging from zero to infinity .

Assumption 10 of Kinetic Theory of Gases

The gravitational potential energy does not in any way affect the motion of gas molecules. This assumption is quite justified since the magnitude of gravitational force is 10^{-43}N,which is much less than the molecular force whose magnitude is about 10^{-13}N for normal separation between two molecules.

Pressure Exerted by an Ideal gas

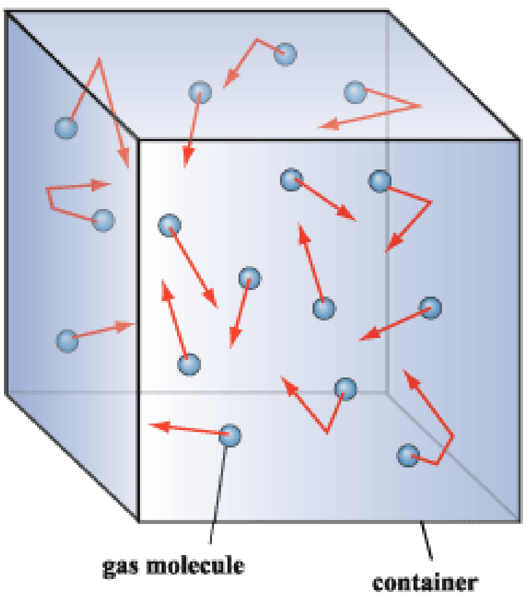
Pressure Exerted by a Gas

- Every body is made up of molecules. Depending on its nature and temperature, the molecules may possess translatory motion, vibratory motion and rotatory motion about its axis.

- Each type of motion provides some kinetic energy to the molecules. Heat possessed by a body is the total thermal energy of the body, which is the sum of kinetic energies of all the individual molecules of the body.

- Temperature of a body is the degree of hotness or coldness of the body. Heat flows from a body at high temperature to a body at low temperature when they are in contact with each other. Temperature is the thermal state of the body, that decides the direction of flow of heat.

Pressure Exerted by a Gas



The molecules of a gas are in a state of random motion. They continuously collide against the walls of the container.

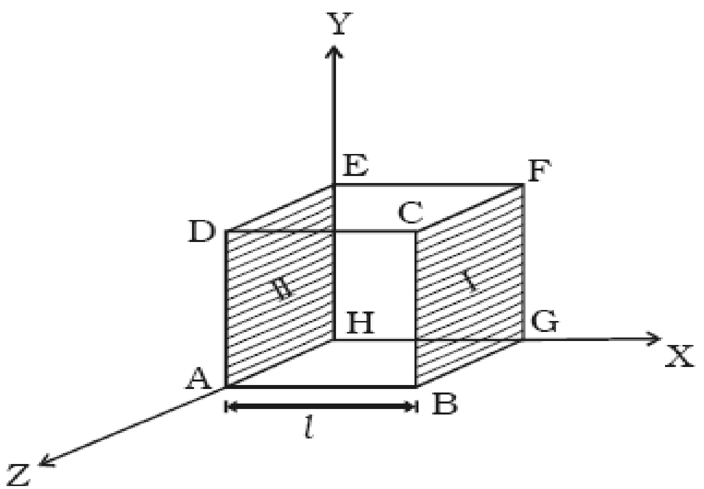
During each collision, momentum is transferred to the walls of the container. The pressure exerted by the gas is due to the continuous collision of the molecules agai nst the walls of the container.

Dueto this continuous collision, the walls exp erience a continuous force which is equal to the total momentum imparted to the walls per second. The force experienced per unit area of the walls of the container determines the pressure exerted by the gas.

Pressure Exerted by a Gas

Consider a cubic container of side containing n molecules of perfect gas moving with velocities C_1, C_2, C_3 ... C_n as shown in figure.

A molecule moving with a velocity C_1, will have velocities u_1, v_1 and w_1 as components along the x, y and z axes respectively. Similarly u_2, v_2 and w_2 are the velocity components of the second molecule and so on.



Pressure exerted by a gas

Let a molecule P as shown in figure having velocity C collide against the wall marked I (BCFG) perpendicular to the x-axis.

Only the x-component of the velocity of the molecule is relevant for the wall I. Hence momentum of the molecule before collision is mu_1 where m is the mass of the molecule. Since the collision is elastic, the molecule will rebound with the velocity u_1 in the opposite direction. Hence momentum of the molecule after collision is $-mu_1$.

Change in the momentum of the molecule

= Final momentum - Initial momentum

$= -mu_1 - mu_1 = -2mu_1$

During each successive collision on face **I** the molecule must travel a distance **2l** from face I to face II and back to face I.

Time taken between two successive collisions is $= 2l / u_1$

∴ Rate of change of momentum = Change in the momentum/Time taken

$= -\,2mu_1/(2l/u_1) = -2mu_1^2/2l = -\,mu_1^2/l$

(i.e) Force exerted on the molecule = $-\,mu_1^2/l$

According to Newton's third law of motion, the force exerted by the molecule,

$= -(-mu_1^2)/l = mu_1^2/l$

Force exerted by all the *n* molecules is

$F_x = mu_1^2/l + mu_2^2/l + \ldots\ldots + mu_n^2/l$

Pressure exerted by the molecules,

$P_x = F_x/A$

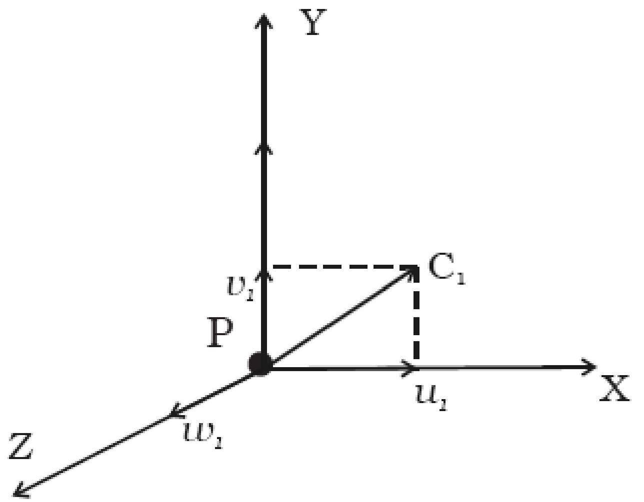
$= 1/l^2\,(mu_1^2/l + mu_2^2/l + \ldots\ldots + mu_n^2/l)$

$= m/l^3\,(u_1^2 + u_2^2 + \ldots\ldots + u_n^2)$

Similarly, pressure exerted by the molecules along Y and Z axes are,

$P_y = m/l^3\,(v_1^2 + v_2^2 + \ldots\ldots + v_n^2)$

$P_z = m/l^3\,(\omega_1^2 + \omega_2^2 + \ldots\ldots + \omega_n^2)$



Components of velocity

Similarly, pressure exerted by the molecules along Y and Z axes are,

$$P_y = m/l^3\,(v_1^2 + v_2^2 + \ldots\ldots + v_n^2)$$

$$P_z = m/l^3\,(\omega_1^2 + \omega_2^2 + \ldots\ldots + \omega_n^2)$$

Since the gas exerts the same pressure on all the walls of the container

$$P_x = P_y = P_z = P$$

$$P = [P_x + P_y + P_z]/3$$

$$P = [(1/3)\,(m/l^3)]\,[(u_1^2 + u_2^2 + \ldots\ldots + u_n^2) + (v_1^2 + v_2^2 + \ldots\ldots + v_n^2) + (\omega_1^2 + \omega_2^2 + \ldots\ldots + \omega_n^2)]$$

$P = [(1/3)\ (m/l^3)]\ [(u_1^2 + v_1^2 + \omega_1^2) + (u_2^2 + v_2^2 + \omega_2^2) + \ldots\ldots\ldots\ldots + (u_n^2 + v$

$P = [(1/3)\ (m/l^3)]\ [C_1^2 + C_2^3 + \ldots\ldots + C_n^2]$

Here, $C_1^2 = (u_1^2 + v_1^2 + \omega_1^2)$

$P = [(1/3)\ (mn/l^3)]\ [C_1^2 + C_2^3 + \ldots\ldots + C_n^2/n]$

$P = (1/3)\ (mn/V)\ C^2$

$$\boxed{P = \frac{1}{3}\frac{mn}{V}C^2}$$

where C is called the root mean square (RMS) velocity, which is defined as the square root of the mean value of the squares of velocities of individual molecules.

That is, $C = \sqrt{[C_1^2 + C_2^3 + \ldots\ldots + C_n^2/n]}$

The pressure exerted by an ideal gas is numerically equal to two-third of the mean kinetic energy of translation per unit volume of the gas.

The kinetic energy of the gas is expressed as

$$K.E = 1/2Mv^2$$

Divide Pressure equation by Kinetic energy, we get

$$\frac{P}{KE} = \frac{2}{3V}$$

Pressure P = 2/3 X Kinetic Energy per unit volume