- Gases consist of large number of identical particles (atoms or molecules) that are so small and so far apart on the average that the actual volume of the molecules is negligible in comparison to the empty space between them. They are considered as point masses. This assumption explains the great compressibility of gases.
- There is no force of attraction between the particles of a gas at ordinary temperature and pressure. The support for this assumption comes from the fact that gases expand and occupy all the space available to them.
- Particles of a gas are always in constant and random motion. If the particles were at rest and occupied fixed positions, then a gas would have had a fixed shape which is not observed.
- Particles of a gas move in all possible directions in straight lines. During their random motion, they collide with each other and with the walls of the container. Pressure is exerted by the gas as a result of collision of the particles with the walls of the container.
- Collisions of gas molecules are perfectly elastic. This means that total energy of molecules before and after the collision remains same. There may be exchange of energy between colliding molecules, their individual energies may change, but the sum of their energies remains constant. If there were loss of kinetic energy, the motion of molecules will stop and gases will settle down. This is contrary to what is actually observed.
- At any particular time, different particles in the gas have different speeds and hence different kinetic energies. This assumption is reasonable because as the particles collide, we expect their speed to change. Even if initial speed of all the particles was same, the molecular collisions will disrupt this uniformity. Consequently the particles must have different speeds, which go on changing constantly. It is possible to show that though the individual speeds are changing, the distribution of speeds remains constant at a particular temperature.
- If a molecule has variable speed, then it must have a variable kinetic energy. Under these circumstances, we can talk only about average kinetic energy. In kinetic theory it is assumed that average kinetic energy of the gas molecules is directly proportional to the absolute temperature. It is seen that on heating a gas at constant volume, the pressure increases. On heating the gas, kinetic energy of the particles increases and these strike the walls of the container more frequently thus exerting more pressure.

Kinetic theory of gases allows us to derive

KTG

① $$\boxed{PV = \frac{1}{3} n M v_{rms}^2} = \frac{1}{3} N m v_{rms}^2$$

② Avg KE/molecule $= \frac{3}{2} kT$

Avg KE/mole $= \frac{3}{2} RT$

③ Root mean square speed

$$\Rightarrow \boxed{v_{rms} = \sqrt{\frac{3PV}{nM}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3P}{d}}}$$

where $P = Pa$ $\quad$ $R = 8.314$ J/mole-k

$V = m^3$ $\quad$ $d = kg/m^3$

$M = kg/mole$ $\quad$ $v_{rms} = m/s$

Particle	N_1	N_2	N_3	---	N_n
Speed	v_1	v_2	v_3	---	v_n

$$v_{ms} = \frac{N_1 v_1^2 + N_2 v_2^2 + \cdots + N_n v_n^2}{N_1 + N_2 + N_3 + \cdots + N_n}$$

= mean square speed

$$v_{rms} = \sqrt{v_{ms}} = \sqrt{\frac{N_1 v_1^2 + N_2 v_2^2 + \cdots + N_n v_n^2}{N_1 + N_2 + \cdots + N_n}}$$

Avg Speed (V_{avg})

Particle	N_1	N_2	N_3	---	N_n
Speed	V_1	V_2	V_3	---	V_n

$$V_{avg} = \frac{N_1V_1 + N_2V_2 + \cdots + N_nV_n}{N_1 + N_2 + \cdots + N_n}$$

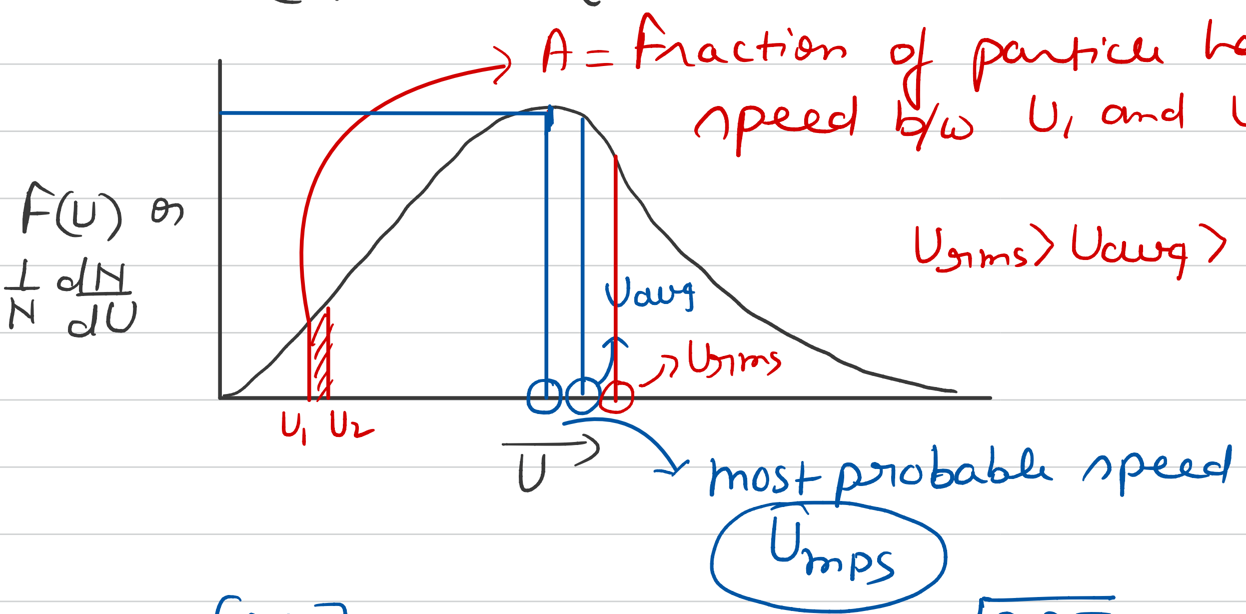
For large No of particle

$$V_{avg} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8PV}{\pi n M}} = \sqrt{\frac{8P}{\pi d}}$$

Maxwell speed distribution

$$\left(\frac{dN}{N}\right) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} \cdot e^{-MU^2/2RT} \cdot U^2 \cdot dU$$

$$\frac{1}{N}\left(\frac{dN}{dU}\right) = 4\pi\left(\frac{M}{2\pi RT}\right)^{3/2} \cdot e^{-MU^2/2RT} \cdot U^2 = F(U)$$



$U_{rms} > U_{avg} > U_{mps}$

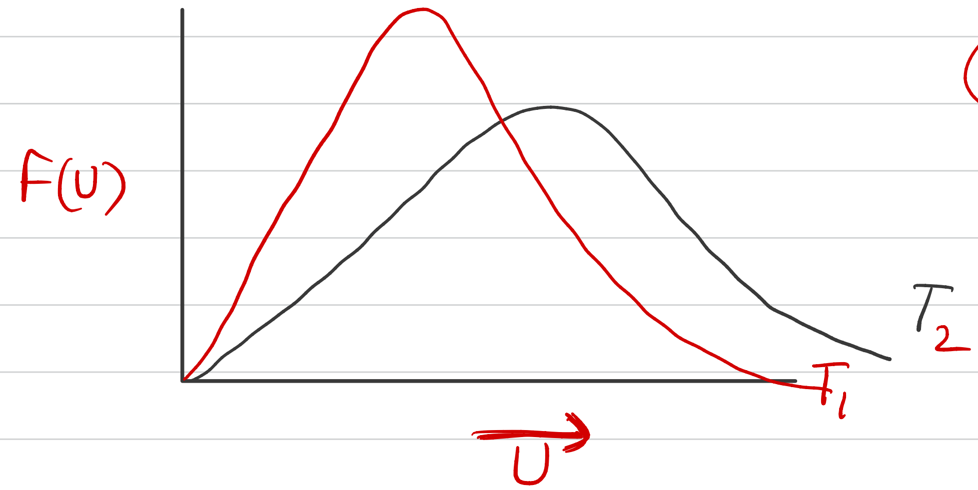
$$\frac{d[F(U)]}{dU} = 0 \Rightarrow U_{mps} = \sqrt{\frac{2RT}{M}}$$

eg:

Particle	5	10	25	15	12
Speed m/s	200	250	300	350	400

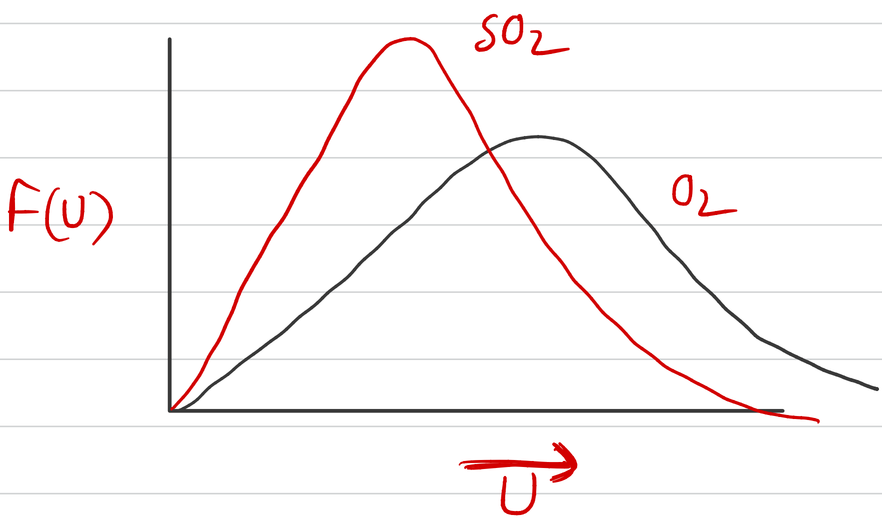
$\downarrow$

U_{mps}



$T_1 < T_2$

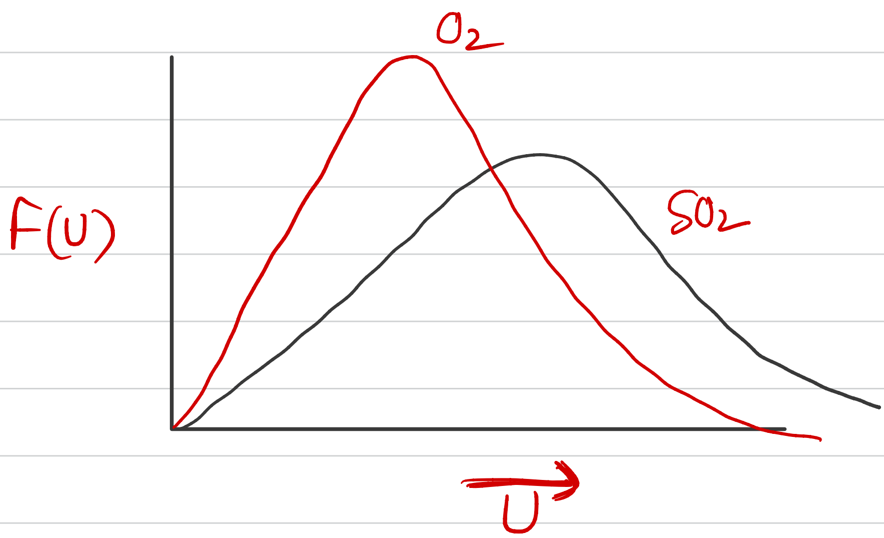
$T\uparrow \Rightarrow \longrightarrow$



SO_2

O_2

$M\uparrow \Rightarrow \longleftarrow$



SO_2 at 300 k $\Rightarrow \frac{300}{64}$

$O_{2(g)}$ at 100k $\Rightarrow \frac{100}{32} = \frac{200}{64}$

$\left(\frac{T}{M}\right)\uparrow \Rightarrow \longrightarrow$

The rms speed of the molecules of a gas of density 4 kg m^{-3} and pressure 1.2 x 10^5 N m^{-2} is:

(a) 120 m s^{-1} (b) 300 m s^{-1} (c) 600 m s^{-1} (d) 900 in s^{-1}

b

$$v_{rms} = \sqrt{\frac{3P}{d}} = \sqrt{\frac{3 \times \cancel{1.2}^{0.3} \times 10^5}{\cancel{4}}} = 300 \text{ m/s}$$

The mass of molecule A is twice that of molecule B. The root mean square velocity of molecule A is twice that of molecule B. If two containers of equal volume have same number of molecules the ratio of pressure $\frac{P_A}{P_B}$ will be:

(a) 8 : 1 (b) 1 : 8 (c) 4 : 1 (d) 1 : 4

a

$$v_{rms} = \sqrt{\frac{3PV}{nM}} \Rightarrow \frac{v_A}{v_B} = \sqrt{\frac{P_A}{P_B} \times \frac{M_B}{M_A}} \Rightarrow 2 = \sqrt{\frac{P_A}{P_B} \times \frac{1}{2}}$$

$$\Rightarrow \frac{P_A}{P_B} = \left(\frac{8}{1}\right)$$

The kinetic energy of N molecules of O_2 is x Joule at –123° C. Another sample of O_2 at 27°C has a kinetic energy of 2x. The latter sample contains …….. molecules of O_2.

(a) N (b) $\frac{N}{2}$ (c) 2N (d) 3N

a

KE/molecule $= \frac{3}{2}kT \Rightarrow KE = \frac{3}{2}NkT$

$x = \cancel{\frac{3}{2}} \times N \times \cancel{k} \times \cancel{150}$ —(i)

$2x = \cancel{\frac{3}{2}} N' \times \cancel{k} \times \cancel{300}^{2}$ —(ii)

$\Leftarrow$ $N' = N$

Which of the following statements is incorrect according to kinetic theory of gases?

(a) At constant temperature, velocity of an individual gas molecule changes many times in one second.

(b) All gas molecules are assumed to be spherical in shape.

(c) Between two collisions a gas molecule may travel in curved paths.

(d) There is no attraction or repulsion force between gas molecules.

c

The root mean square velocity of a gas molecule at 100 K and 0.5 atm pressure is $10614\ ms^{-1}$. If the temperature is raised to 400 K and the pressure is raised to 2 atm, the root mean square velocity becomes:

(a) $106.4\ m\ s^{-1}$ (b) $425.6\ m\ s^{-1}$ (c) $212.8\ m\ s^{-1}$ (d) $851.2\ m\ s^{-1}$

21228 m/s

c

$$v_{rms} = \sqrt{\frac{3RT}{M}} \qquad v_{rms} = \sqrt{\frac{3PV}{nm}}$$

$$\frac{10614}{v} = \sqrt{\frac{100}{400}} \Rightarrow v = 10614 \times 2 = \underline{21228}\ m/s$$

A 10 g sample of oxygen gas is taken in a container of volume 1 litre and is found to exert a pressure of 3 bar. Which of the following options is correct regarding speed of the molecules?

X (a) All the molecules are moving at a same speed which is equal to 310 m/sec.

X (b) $U_{avg} = 300$ m /sec. (c) $U_{mps} = 300 \times \sqrt{\frac{2}{5}}$ m/sec. (d) $U_{rms} = \cancel{310}$ m/sec.

300

d

c

$$\sqrt{\frac{PV}{nm}} = \sqrt{\frac{3\times10^5 \times \cancel{10^{-3}}}{10\times\cancel{10^{-3}}}} = \sqrt{3\times10^4}$$

$$U_{rms} = \sqrt{\frac{3PV}{nm}} = \sqrt{3\times3\times10^4} = 300\ m/s$$

Kinetic theory of gases proves:

(a) only Boyle's law (b) only Charle's law

(c) only Avogardo's law (d) all of these

d

The rms velocity of hydrogen is $\sqrt{7}$ times the rms velocity of nitrogen. If T is the temperature of the gas, then:

(a) $T_{(H_2)} = T_{(N_2)}$ (b) $T_{(H_2)} > T_{(N_2)}$ ✓(c) $T_{(H_2)} < T_{(N_2)}$ (d) $T_{(H_2)} = \sqrt{7}\,T_{(N_2)}$

c

$$\frac{v_{H_2}}{v_{N_2}} = \cancel{\sqrt{7}} = \sqrt{\frac{T_{H_2}}{T_{N_2}} \times \frac{\cancel{28}\,14}{\cancel{2}}} = \sqrt{\cancel{7}\times 2\times \frac{T_{H_2}}{T_{N_2}}} \Rightarrow \frac{T_{H_2}}{T_{N_2}} = \frac{1}{2}$$

Express the average kinetic energy per mole of a monoatomic gas of molar mass M, at temperature T K in terms of the average speed of the molecules U_{avg}:

(a) $\frac{8M}{3\pi}U^2_{avg}$ (b) $\frac{3M}{16}U^2_{avg}$ (c) $\left(\frac{2M}{\pi}\right)U^2_{avg}$ (d) $\left(\frac{3\pi M}{16}\right)U^2_{avg}$

d

$E = \frac{3}{2}RT = \frac{3}{2}\frac{\pi M}{8}V_{avg}^2$

$E = \frac{3\pi M}{16}V_{avg}^2$

$V_{avg} = \sqrt{\frac{8RT}{\pi M}}$

$RT = \frac{\pi M}{8}V_{avg}^2$

Comment about the fraction of molecules moving between 400 to 500 m/sec for a gas (molecular mass = 20 g/mol) if its temperature increases from 300 K to 400 K [R = 25/3 J/mol/K].

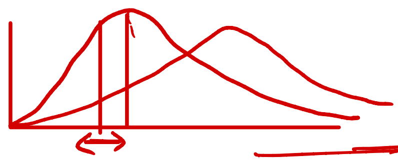
(a) Fraction of molecules increases

✓ (b) Fraction of molecules decreases

(c) Fraction of molecules remains constant

(d) Fraction of molecules may increase of decrease

b



$V_{mps} = \sqrt{\frac{2\times\frac{25}{3}\times 300}{20\times10^{-3}}}$ (with 300 → 100, 20 → 10)

$= \sqrt{25\times10^4}$

$= 500\ m/s$

If the absolute temperature of a sample of gas is increased by a factor of 1.5, by what ratio does the average molecular speed of its molecules increase?

(a) 1.2 (b) 1.5 (c) 2.2 (d) 3.0

a

$V_{avg} \propto \sqrt{T}$

Fraction of molecules (η) are related with velocity according to relation

$$f(v) = \eta' = -\frac{3}{4}v^2 + 3v - \frac{9}{4}\{1 \le v \le 3\}$$

Then find most probable speed?

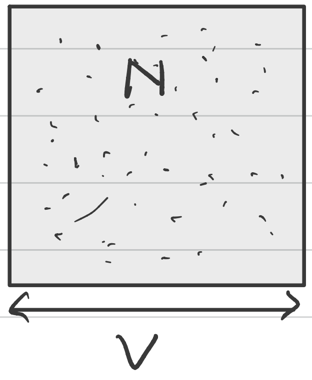
(a) 0 (b) 1 (c) 2 (d) 3

c

$\frac{d[f(v)]}{dv} = 0 \Rightarrow -\frac{3}{4}\times 2v + 3 = 0$

$V = 2$

Collision Frequency and mean free path



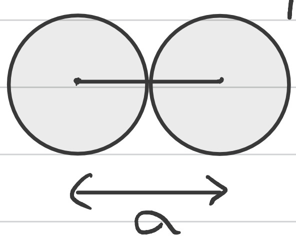
① $\boxed{\text{No. density} = \left(\frac{N}{V}\right) = \frac{PN_A}{RT} = N^*}$

$$PV = nRT = \frac{N}{N_A}RT \Rightarrow \frac{N}{V} = \left(\frac{PN_A}{RT}\right)$$

$$\boxed{N^* \propto \left(\frac{P}{T}\right)}$$

② Collision diameter (a):-

Min Distance b/w particle at the time of collision.



\# Only bimolecular collision are taking place b/w particle
Particle are hard rigid sphere.
All particle are moving with a common speed of v_{avg}

③ Z_1 = Total No of collision per unit time by a single particle.

$$\boxed{Z_1 = \pi a^2 (\sqrt{2}\, v_{avg}) N^*}$$

$$v_{rel} = \sqrt{2}\, v_{avg}$$