Various Speeds of Gas Molecules.

The motion of molecules in a gas is characterized by any of the following three speeds.

(1) Root mean square speed: It is defined as the square root of mean of squares of the speed of different molecules i.e. $v_{rms} = \sqrt{\frac{v_1^2 + v_2^2 + v_3^2 + v_4^2 + ...}{N}}$

(i) From the expression for pressure of ideal gas $P = \frac{1}{3}\frac{m\,N}{V}v_{rms}^2$

$$v_{rms} = \sqrt{\frac{3PV}{m\,N}} = \sqrt{\frac{3PV}{\text{Mass of gas}}} = \sqrt{\frac{3P}{\rho}}$$ $\left[\text{As } \rho = \frac{\text{Mass of gas}}{V}\right]$

(ii) $v_{rms} = \sqrt{\frac{3PV}{\text{Mass of gas}}} = \sqrt{\frac{3\mu RT}{\mu M}} = \sqrt{\frac{3RT}{M}}$ [As if *M* is the molecular weight of gas $PV = \mu RT$ and Mass of gas $= \mu M$]

(iii) $v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3N_A kT}{N_A M}} = \sqrt{\frac{3kT}{m}}$ [As M = NAm and R = NAk]

$\therefore$ Root mean square velocity $v_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$

Important points

(i) With rise in temperature rms speed of gas molecules increases as $v_{rms} \propto \sqrt{T}$.

(ii) With increase in molecular weight rms speed of gas molecule decreases as $v_{rms} \propto \frac{1}{\sqrt{M}}$.

e.g., rms speed of hydrogen molecules is four times that of oxygen molecules at the same temperature.

(iii) rms speed of gas molecules is of the order of km/s

e.g., At NTP for hydrogen gas $(v_{rms}) = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8.31 \times 273}{2 \times 10^3}} = 1840\ m/s$.

(iv) rms speed of gas molecules is $\sqrt{\frac{3}{\gamma}}$ times that of speed of sound in gas

As $v_{rms} = \sqrt{\frac{3RT}{M}}$ and $v_s = \sqrt{\frac{\gamma RT}{M}}$ $\therefore$ $v_{rms} = \sqrt{\frac{3}{\gamma}} v_s$

(v) rms speed of gas molecules does not depends on the pressure of gas (if temperature remains constant) because P ∝ρ (Boyle's law) if pressure is increased n times then density will also increases by n times but vrms remains constant.

(vi) Moon has no atmosphere because vrms of gas molecules is more than escape velocity (ve).

A planet or satellite will have atmosphere only and only if $v_{rms} < v_e$

(vii) At T = 0; vrms = 0 i.e. the rms speed of molecules of a gas is zero at 0 K. This temperature is called absolute zero.

(2) Most probable speed: The particles of a gas have a range of speeds. This is defined as the speed which is possessed by maximum fraction of total number of molecules of the gas. e.g., if speeds of 10 molecules of a gas are 1, 2, 2, 3, 3, 3, 4, 5, 6, 6 km/s, then the most probable speed is 3 km/s, as maximum fraction of total molecules possess this speed.

Most probable speed $v_{mp} = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2kT}{m}}$

(3) Average speed: It is the arithmetic mean of the speeds of molecules in a gas at given temperature.

$$v_{av} = \frac{v_1 + v_2 + v_3 + v_4 + ...}{N}$$

and according to kinetic theory of gases

Average speed $v_{av} = \sqrt{\frac{8P}{\pi\rho}} = \sqrt{\frac{8}{\pi}\frac{RT}{M}} = \sqrt{\frac{8}{\pi}\frac{kT}{m}}$

Note: vrms > vav > vmp (order remembering trick) (RAM)

vrms:vav:vmp = $\sqrt{3} : \sqrt{\frac{8}{\pi}} : \sqrt{2} = \sqrt{3} : \sqrt{2.5} : \sqrt{2}$

For oxygen gas molecules vrms = 461 m/s, vav = 424.7 m/s and vrms = 376.4 m/s