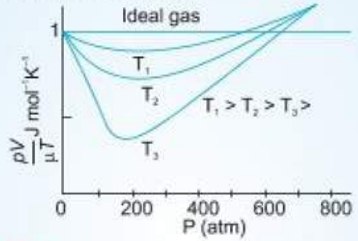
Kinetic Theory

13 Chapter

(1) LAWS ASSOCIATED WITH KTG

- An ideal gas is only theoretical model of a gas. No real gas is truly ideal. Without interactions gas behaves like an ideal gas. At low pressure or high temperature, molecules are far apart and molecular interaction is negligible.



- **Boyle's Law :** Pressure of a given ideal gas is inversely proportional to its volume if temperature is kept constant.
- **Charle's Law :** Volume of given ideal gas is directly proportional to its temperature in kelvin if pressure is kept constant.
- **Gay Lussac's Law :** Pressure of an ideal gas is directly proportional to its absolute temperature if volume is kept constant.
- **Avogadro's Law :** Equal volume of all the gases under similar conditions of temperature and pressure contain equal number of molecules.

$$\frac{P_1V_1}{N_1T_1} = \frac{P_2V_2}{N_2T_2} = K_B$$

Ideal gas equation connecting the variables is

$$PV = \mu RT = K_BNT \qquad P = \frac{\rho RT}{M_0}$$

- **Dalton's Law of Partial Pressure :** Total pressure of a mixture of non-reactive gases is the sum of their partial pressures.

(2) AVERAGE PRESSURE OF GAS

$$P = \frac{1}{3}n\,m\bar{v}^2 \text{ and } PV = \frac{1}{3}nV\,m\bar{v}^2$$

n → Number density m → Mass of molecule

$\bar{v}^2$ → Mean of squared speed

(3) KINETIC INTERPRETATION OF TEMPERATURE

- **Average kinetic energy of molecule**

$$= \frac{1}{2}m\bar{v}^2 = \frac{3}{2}K_BT$$

$$\bar{V}_{RMS} = (\bar{V}^2)^{\frac{1}{2}} = \sqrt{\frac{3K_BT}{m}}$$

- In a mixture of gases at a given temperature, heavier molecule has lower average speed.
- Translational kinetic energy of gas

$$E = \frac{3}{2}K_BNT \text{ and } PV = \frac{2}{3}E, \frac{E}{N} = \frac{1}{2}m\bar{v}^2 = \frac{3}{2}K_BT$$

- Average KE is proportional to temperature.
- R.M.S. speed of gas molecule,

$$V_{RMS} = \sqrt{\frac{3RT}{M}}$$

- Most probable speed of molecule

$$= \sqrt{\frac{2RT}{M}}$$

- Average speed of gas molecule

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

- This concept of maxwell energy distribution predict specific heat of gases theoretically.

LAW OF EQUIPARTITION OF ENERGY

- KTG is consistent with ideal gas equation.
- For a system in equilibrium at absolute temperature T, total energy is distributed equally in different modes of absorptions. Energy of each mode is equal to 1/2 K_BT.
- Each translational and rotational degree of freedom corresponds to one energy mode of absorption.

(4) SPECIFIC HEAT CAPACITIES

- Specific heat capacity for solids = $3R$
- Specific heat capacity of water = $9R$
- C_v(monoatomic gas) = $\frac{3}{2}R$ $\gamma = 1 + \frac{2}{f}$
- $\gamma = \frac{5}{3}$ (monoatomic) $\gamma = \frac{7}{5}$ (rigid diatomic)
- Polyatomic gases in general a polyatomic molecules has 3 translational, 3 rotational degree of freedom and a certain number (f) of vibrational modes. Then for one mole of gas

$$U = \left[\frac{3}{2}K_BT + \frac{3}{2}K_BT + fK_BT\right]N_A$$

$$C_V = (3 + f)R \qquad C_P = (4 + f)R \qquad \gamma = \frac{(4 + f)}{(3 + f)}$$

- Each vibrational frequency has two modes of energy with corresponding energy equal to K_BT.
- Molecules of a monatomic gas have only translational degree of freedom.
- Molecules like CO even at moderate temperature has mode of vibration.
- Diatomic molecule, like a dumbell, has five degree of freedom.
- Polyatomic molecule has 3 transitional, 3 rotational and a degree of a certain number of vibrational modes.

(5) MEAN FREE PATH

- Molecules of gas have rather large speeds of the order of speed of sound.
- Molecules of gas undergo collisions and their paths keep getting deflected.
- Average distance a molecule can travel without collision is called mean free path.
- Mean free path of gas molecule is related to number of molecules per unit volume and size of gas molecule.

$$\lambda = \frac{1}{\sqrt{2}\pi nd^2} = \lambda = \frac{K_BT}{\sqrt{2}\pi Pd^2}$$

n : number density; d : diameter of molecules

- Mean free path in gases is of order of thousands of angstrom.

P : Pressure of gas; T : Absolute temperature

K_B : Boltzmann's Constant

Sharpen Your Understanding

1. A vessel contains two non-reactive gases; monoatomic neon and diatomic oxygen. The ratio of their partial pressure is 5 : 3. Estimate the ratio of number of moles of neon and oxygen in a vessel. (Molar mass oxygen O_2 = 32.0 u and atomic mass of neon = 20.2 u) [NCERT Pg. 322]
   (1) 5 : 3
   (2) 3 : 5
   (3) 4 : 3
   (4) 2 : 5
2. In case of two ideal gases under ideal conditions of same temperature, pressure and volume, the ratio of mean free paths of molecules having molecular diameter 1Å and 2Å is [NCERT Pg. 337]
   (1) 2 : 1
   (2) 4 : 1
   (3) 1 : 4
   (4) 8 : 1
3. An inflated rubber balloon contains one mole of an ideal gas has a pressure P, volume V and temperature T. If temperature rises to 1.1 T and volume increases to 1.05 V, final pressure will be [NCERT Pg. 322]
   (1) 1.1 P
   (2) P
   (3) Less than P
   (4) Between P and 1.1 P

NCERT Based MCQs

4. Which of the following statement is incorrect? [NCERT Pg. 327]
   (1) In case of collision of gas molecules in a given amount of gas in container, total kinetic energy is conserved
   (2) All collisions of gas molecules is elastic in nature
   (3) Average kinetic energy per degree of freedom depends on temperature only and is independent of nature of gas
   (4) By law of equipartition of energy, the energy for each degree of freedom in thermal equilibrium is K_BT
5. Which of the following is not an assumption of kinetic theory of gases? [NCERT Pg. 327]
   (1) The volume occupied by molecule of gas is negligible
   (2) The force of attraction between molecules is negligible
   (3) All molecules have same speed at a temperature
   (4) The collisions of molecules among themselves are elastic
6. The temperature of the gas is increased from 120 K to 480 K. If at 120 K, the rms speed of gas molecules is V_{RMS} then at 480 K, it becomes [NCERT Pg. 325]
   (1) 4 V_{RMS} (2) 2 V_{RMS}
   (3) V_{RMS} (4) $\frac{V_{RMS}}{2}$
7. Three moles of oxygen are mixed with two moles of helium, what will be approx. ratio of specific heat at constant pressure and constant volume for the mixture? [NCERT Pg. 329]
   (1) 1.2
   (2) 1.4
   (3) 1.5
   (4) 1.67
8. The kinetic theory of gases gives the formula $P = \frac{1}{3}\frac{Nm}{V}(\bar{v}^2)$ for the pressure P exerted by a gas enclosed in a vessel of volume V, the term Nm represents [NCERT Pg. 324]
   (1) Mass of one mole of the gas
   (2) Mass of gas present in volume V
   (3) Total number of molecules present in volume V
   (4) Average mass of one molecule of the gas
9. A balloon contains 1500 m^3 of helium at 300 K and 4 atmospheric pressure. The volume of helium at 270 K and 2 atmospheric pressure will be
   [Assuming no leakage of gas] [NCERT Pg. 321]
   (1) 1500 m^3 (2) 1900 m^3
   (3) 1700 m^3 (4) 2700 m^3

10. A vessel contains 6 g of oxygen at pressure P and temperature 400 K. A small hole is made in it so that oxygen leaks out. How much oxygen leaks out if final pressure is $\frac{P}{2}$ and temperature is 300 K? [NCERT Pg. 339]

(1) 5 g (2) 3 g

(3) 2 g (4) 4 g

11. If the pressure and volume of a certain quantity of an ideal gas is halved, then its temperature becomes [NCERT Pg. 325]

(1) Doubled (2) One fourth

(3) Four times (4) Remains same

12. Pressure of a gas at constant volume is proportional to [NCERT Pg. 325]

(1) Total internal energy of gas

(2) Square of average kinetic energy of gas molecule

(3) Average potential energy of molecules

(4) Speed of the gas molecule

13. If three molecules have speeds of 2000 ms^{-1}, 1000 ms^{-1} and 500 ms^{-1}, the ratio of rms speed to average speed is [NCERT Pg. 325]

(1) 1.14

(2) 0.92

(3) 1.78

(4) 1.71

14. A real gas behaves like an ideal gas if its [NCERT Pg. 321]

(1) Both pressure and temperature are high

(2) Both pressure and temperature are low

(3) Pressure is high and temperature is low

(4) Pressure is low and temperature is high

15. What will be mean free path of a nitrogen molecule in a container at 2 atmospheric pressure and at 17°C, radius of nitrogen molecule is about 1Å? [NCERT Pg. 337]

(Molar mass of nitrogen = 28.0 u)

(1) 1.11×10^{-7} m

(2) 2.3×10^{-6} m

(3) 2.4×10^{-7} m

(4) 1.8×10^{-9} m

16. Air has density of 1.3 kg m^{-3} and temperature of air is 37°C. If molar mass of air is 28.8, what will be air pressure? [NCERT Pg. 326]

(1) 1.16×10^{5} N m^{-2}

(2) 2.1×10^{4} N m^{-2}

(3) 1.92×10^{5} N m^{-2}

(4) 0.92×10^{5} N m^{-2}

17. The ratio of degrees of freedom of a monoatomic gas to diatomic gas is [NCERT Pg. 327]

(1) 3:5 (2) 3:1

(3) 4:5 (4) 1:1

18. A flask contains argon and chlorine in the ratio of 2 : 1 by mass. The mixture temperature is 300 K. What is ratio of root mean square speed of molecules of two gases? [NCERT Pg. 330]

[Atomic mass of argon = 39.9 u and molecular mass of chlorine = 70.9 u]

(1) 1.33

(2) 1. 55

(3) 1.77

(4) 1.66

19. A polyatomic gas has 3 translational, 3 rotational degrees of freedom and 2 vibrational modes. What is molar specific heat ratio for the gas? [NCERT Pg. 334]

(1) 1.50

(2) 1.30

(3) 1.40

(4) 1.20

20. A cylinder of capacity 44.8 litres contains helium gas at standard temperature and pressure. What amount of heat is needed to raise the temperature of gas in cylinder by 10°C? [NCERT Pg. 335]

(1) 173.5 J

(2) 249.3 J

(3) 205.2 J

(4) 374.2 J

Thinking in Context

1. In a closed vessel if pressure is increased by adding some gas, the mean free path of a molecule of gas _____. [NCERT Pg. 332]
2. When an ideal gas undergoes an isothermal expansion, the pressure of the gas in enclosure _____. [NCERT Pg. 321]
3. If a gas container in motion is suddenly stopped, the temperature of the gas may _____. [NCERT Pg. 325]
4. The absolute temperature of a gas is increased three times; the root mean square speed of gas molecule will increase _____. [NCERT Pg. 325]
5. If the pressure of a closed vessel is reduced by drawing out some gas with help of a pump, the mean free path of molecules of the gas is _____. [NCERT Pg. 331]
6. Equal volume of all gases under similar conditions of temperature and pressure contains equal number of molecules. This statement was given by _____. [NCERT Pg. 320]
7. At low pressure or high temperature, the gas molecules are far apart and molecular interaction is minimum. Without interactions the gas behaves like _____. [NCERT Pg. 321]
8. Total pressure of a mixture of ideal gases is the sum of partial pressures. This is called _____ law of partial pressure. [NCERT Pg. 321]
9. Average kinetic energy of a gas molecule is proportional to _____ of the gas. [NCERT Pg. 325]
10. Internal energy of an ideal gas depends only on parameter _____ not on _____ and _____. [NCERT Pg. 325]
11. When gases diffuse, their rate of diffusion is inversely proportional to _____. [NCERT Pg. 327]
12. Molecules of monoatomic gas like argon have only _____ degrees of freedom. [NCERT Pg. 328]
13. In equilibrium, in a gas total energy is equally distributed in all possible energy modes, with each mode having an average energy equal to _____. This is known as the law _____. [NCERT Pg. 328]
14. For one mole of solid, total energy at absolute temperature T is equal to _____. [NCERT Pg. 330]
15. Mean free path depends inversely on _____ and inversely as square of _____ the gas molecules. [NCERT Pg. 331]
16. The ratio of specific heat of a gas at constant pressure and specific heat at constant volume for a diatomic gas is _____ than that of a monatomic gas. [NCERT Pg. 329]
17. Heat capacity of a system, in general depends on _____ it goes through when heat is supplied. [NCERT Pg. 329]
18. Number of molecules per unit volume is the same for all gases at fixed _____ and _____. [NCERT Pg. 320]
19. All collisions between molecules among themselves or between molecules and wall of container are _____. This is in accordance with kinetic theory of an ideal gas. [NCERT Pg. 320]
20. In equilibrium, total energy is equally distributed in all possible energy modes, with each mode has an average energy equal to $\frac{1}{2} K_B T$. But each vibrational mode has energy contribution of _____. [NCERT Pg. 333]

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