CBSE Test Paper 04
Chapter 13 Kinetic Theory

1. The average distance a molecule can travel without colliding is called the **1**
   a. mean free distance
   b. mean free motion
   c. mean free path
   d. mean free length
2. The order of inter atomic distance in liquids is about **1**
   a. $100A^{\circ}$
   b. $1000A^{\circ}$
   c. $20A^{\circ}$
   d. $2A^{\circ}$
3. Air in a thundercloud expands as it rises. If its initial temperature was 300 K, and if no energy is lost by thermal conduction on expansion, what is its temperature when the initial volume has doubled? $\gamma_{air} = 1.41$ **1**
   a. 257 K
   b. 237 K
   c. 247 K
   d. 227 K
4. Estimate the average thermal energy of a helium atom at the temperature on the surface of the Sun (6000 K) **1**
   a. 1.24×10^{-19} J
   b. 1.35×10^{-19} J
   c. 1.20×10^{-19} J
   d. 1.28×10^{-19} J
5. In a 30.0-s interval, 500 hailstones strike a glass window with an area of 0.600 m^2 at an angle of 45.0° to the window surface. Each hailstone has a mass of 5.00 g and a speed of 8.00 m/s. If the collisions are elastic, what are the average force and pressure on the window? **1**
   a. 0.913 N
   b. 0.943 N

c. 0.978 N
d. 1.043 N

6. If there are f degrees of freedom with n moles of a gas, then find the internal energy possessed at a temperature T. **1**

7. What is an ideal perfect gas? **1**

8. Air pressure in a car tyre increases during driving. Why? **1**

9. At what temperature, pressure remaining constant, will the rms speed of a gas be double of its value at 27 ^oC? **2**

10. i. Write ideal gas equation in terms of density,
    ii. If molar volume is the volume occupied by 1 mole of any (ideal) gas at STP, show that it is 22.4 L (take R = 8.313 $Jmol^{-1}K^{-1}$). **2**

11. What will be the internal energy of 8 g of oxygen at STP? **2**

12. A metre long narrow bore held horizontally (and closed at one end) contains a 76 cm long mercury thread, which traps a 15 cm column of air. What happens if the tube is held vertically with the open end at the bottom? **3**

13. What will be the mean free path of nitrogen gas at STP of given diameter of nitrogen molecule = 2 $\overset{o}{A}$? **3**

14. From a certain apparatus, the diffusion rate of hydrogen has an average value of 28.7 $cm^3\ s^{-1}$. The diffusion of another gas under the same conditions is measured to have an average rate of 7.2 cm^3s^{-1}. Identify the gas. [**Hint:** Use Graham's law of diffusion: $R_1/R_2 = (M_2/M_1)^{1/2}$, where R_1, R_2 are diffusion rates of gases 1 and 2, and M_1 and M_2 their respective molecular masses. The law is a simple consequence of kinetic theory.] **3**

15. i. Define mean free path.
    ii. Derive an expression for mean free path of a gas molecule. **5**

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Answer

1. c. mean free path

   Explanation: the mean free path is the average distance traveled by a moving particle (such as an atom, a molecule, a photon) between successive impacts (collisions), which modify its direction or energy or other particle properties

2. d. $2A^{\circ}$

   Explanation: Using the assumption of little spheres (for interatomic space) the spacing between the molecules at about 2X10^{-10} m i.e.$2A^{\circ}$

   The size of an atom is about an angstrom (10 $^{-10}$ m) . In solids, which are tightly packed, atoms are spaced about a few angstroms (2 Å) apart.

3. d. 227 K

   Explanation:
   $$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$
   $$\frac{300}{T_2} = (2)^{1.41-1}$$
   $$T_2 = 227K$$

4. a. 1.24×10^{-19} J

   Explanation: $E = \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 600 = 1.24 \times 10^{-19}J$

   k = boltzman constant

5. b. 0.943 N

   Explanation:

   $$F = 500 \times \frac{\Delta p}{\Delta t} = 500 \times \frac{2mv\cos 45^{\circ}}{\Delta t} = \frac{500 \times 2 \times 5 \times 10^{-3} \times 8 \times 1}{30 \times 1.41}$$

   $$F = 0.943N$$

6. For 1 mole with f number of degrees of freedom,

Internal energy, U = $1 \times C_V \times T = \frac{f}{2}RT$

For n moles of the gas internal energy becomes, U' = nC_VT = $\frac{nf}{2}RT$

7. A gas which obeys the following laws or characteristics is called as ideal gas.
   i. The size of the molecule of gas is zero.
   ii. There is no force of attraction or repulsion amongst the molecules of gas.
8. During driving, the temperature of the air inside the tyre increases due to motion. According to Charles's law, pressure $\propto$ Temperature, $\therefore$ As temperature increases, Pressure inside the tyres also increases.
9. Here T_1 = 27 ^oC = 300 K and let rms speed $\overline{v}_1$ = v_0. Let at a temperature T_2, the rms speed is doubled i.e., $\overline{v}_1$ = $2\overline{v}_1$= $2v_0$.

   $\therefore \frac{\overline{v}_1}{\overline{v}_2} = \sqrt{\frac{T_1}{T_2}} \Rightarrow \frac{v_0}{2v_0} = \sqrt{\frac{300}{T_2}}$

   $\Rightarrow$ T_2 = 300 $\times$ 4 = 1200 k = 927^oC.
10. i. The perfect gas equation can be written as, pV= nRT
    where, p is pressure and n number of moles,
    R = N_Ak_B is universal constant and T is absolute temperature in Kelvin. We know that,
    $n = \frac{M}{M_0} = \frac{N}{N_A}$
    where, M = mass of the gases
    In terms of density, perfect gas equation is
    $p = \frac{\rho RT}{M_0}$, ρ = M/V = density of the gas.

    ii. p = 1 atm = 0.76 m of Hg
    $= 0.76 \times \left(13.6 \times 10^3\right) \times 9.8\ Pa$
    T = 273 K, R =8.31 J $mol^{-1}K^{-1}$, n = 1 mole
    We know from ideal gas equation, pV = nRT
    or, $V = \frac{\mu RT}{p} = \frac{1 \times 8.31 \times 273}{0.76 \times \left(13.6 \times 10^3\right) \times 9.8}$
    = 22.4 $\times$ 10^{-3} m^3 = 22.4 L, this is the aquired volume by one mole of an ideal gas at NTP.

11. Oxygen is a diatomic gas having mass number 32.

So, number of moles of O_2 gas

$= \frac{\text{Atomic wt.}}{\text{Molecular wt.}} = \frac{8}{32}$

$= \frac{1}{4}$ = 0.25

Total energy associated with 1 mole of oxygen at STP, U = $\frac{5}{2}RT$

Hence, internal energy of 8 g of oxygen = $0.25 \times \frac{5}{2}RT$

$= 0.25 \times \frac{5}{2} \times 8.31 \times 273$

= 1417.9 J

12. Length of the narrow bore, L = 1 m = 100 cm

Length of the mercury thread, l = 76 cm

Length of the air column between mercury and the closed end, la = 15 cm

Since the bore is held vertically in air with the open end at the bottom, the mercury length that occupies the air space is: 100 – (76 + 15) = 9 cm

Hence, the total length of the air column = 15 + 9 = 24 cm

Let h cm of mercury flow out as a result of atmospheric pressure.

∴Length of the air column in the bore = 24 + h cm

And, length of the mercury column = 76 – h cm

Initial pressure, P_1 = 76 cm of mercury

Initial volume, V_1 = 15 cm3

Final pressure, P_2 = 76 – (76 – h) = h cm of mercury

Final volume,V_2 = (24 + h) cm3

Temperature remains constant throughout the process.

$\therefore P_1V_1 = P_2V_2$

76 × 15 = h (24 + h)

$h^2 + 24h – 1140 = 0$

$\therefore h = 23.8cm \ or \ -47.8cm$

Height cannot be negative. Hence, 23.8 cm of mercury will flow out from the bore and 52.2 cm of mercury will remain in it. The length of the air column will be 24 + 23.8 = 47.8 cm.

13. Given, Diameter of nitrogen molecule, d = 2$\overset{o}{\text{A}}$

= 2 $\times$ 10^{-10} m (1 $\overset{0}{A}$ = 10^{-10} m)

At STP, one mole of gas (or 22.4 L) of the gas have

N_A = 6.023 $\times$ 10^{23} molecules(N_A being Avogadro's number)

Number density of nitrogen molecules

$$n = \frac{N_A}{22.4\mathrm{L}} = \frac{6.023 \times 10^{23}}{22.4 \times 10^{-3}\mathrm{m}^3} = 2.69 \times 10^{25}\mathrm{m}^{-3}$$

Now at STP mean free path of nitrogen,

$$\lambda = \frac{1}{\sqrt{2}\pi n d^2}$$

$$\Rightarrow \lambda = \frac{1}{1.414 \times 3.142 \times \left(2.69 \times 10^{25}\right) \times \left(2 \times 10^{-10}\right)^2}$$

$$= 2.1 \times 10^{-7}\mathrm{m}$$

14. Rate of diffusion of hydrogen with respect to time, R_1 = 28.7 cm^3 s^{-1}

    Rate of diffusion of another gas with respect to time, R_2 = 7.2 cm^3 s^{-1}

    According to Graham's Law of diffusion, we have:

    $$\frac{R_1}{R_2} = \sqrt{\frac{\mathrm{M}_2}{\mathrm{M}_1}}$$

    Where,

    M_1 is the molecular mass of hydrogen = 2.020 g

    M_2 is the molecular mass of the unknown gas given in the question above. Hence from the above formula we get,

    $$\mathbf{M}_2 = \mathbf{M}_1 \times \left(\frac{R_1}{R_2}\right)^2$$

    $= 2.02 \times \left(\frac{28.7}{7.2}\right)^2$ = 32.09 g

    32 g is the molecular mass of oxygen. Hence, the unknown gas given in the question is oxygen.

15. i. The mean free path of a gas molecule is defined as the average distance travelled by a molecule between two successive collisions.
    ii. Let d be the diameter of each molecule of the gas, then a particular molecule will suffer a collision with any molecule that comes within a distance d between centres of two molecules.

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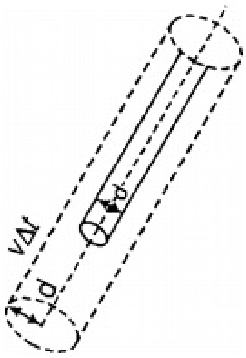

Volume swept by a molecule in time Δt

If $\vec{v}$ is the average speed of a molecule, then from the figure, the volume swept by the molecule in small time Δt in which any molecule will collide with it

$= \pi d^2 \langle v \rangle \Delta t$ [$\langle v \rangle$ is the magnitude of the velocity of the molecule]

If n is number of molecules per unit volume of the gas, then a number of collisions suffered by the molecule in time Δt.

$= \pi d^2 \langle v \rangle \Delta t \times n$

So, number of collisions per second

$= \frac{\pi d^2 \langle v \rangle \Delta t \times n}{\Delta t} = n\pi d^2 \langle v \rangle$

The average time between two successive collisions,$\tau = \frac{1}{n\pi d^2 \langle v \rangle}$

Mean free path(λ)= average distance between two successive collision

$\Rightarrow \lambda = \tau \times \text{ mean velocity}$

$= \frac{1}{n\pi d^2 \langle \nu \rangle} \times \bar{v} = \frac{1}{n\pi d^2}$ [since $\langle v \rangle = \bar{v}$]

Hence the required expression for the mean free path is $\lambda = \frac{1}{n\pi d^2}$