CBSE Test Paper 03

Chapter 13 Kinetic Theory

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1. Two moles of an ideal gas ($\gamma = 1.4$) expands slowly and adiabatically from a pressure of 5.00 atm and a volume of 12.0 L to a final volume of 30.0 L. What are the initial and final temperatures? **1**

   a. 366 K, 253 K
   b. 346 K, 243 K
   c. 406 K, 273 K
   d. 386 K, 263 K

2. Three vessels of equal capacity have gases at the same temperature and pressure. The first vessel contains neon (monatomic), the second contains chlorine (diatomic), and the third contains uranium hexafluoride (polyatomic). The number of molecules **1**

   a. is the greatest in the vessel with uranium hexafluoride
   b. is the greatest in the vessel with neon
   c. is the same in all three vessels
   d. is the greatest in the vessel with chlorine

3. Approximate the air around you as a collection of nitrogen molecules, each of which has a diameter of 2.00 $\times 10^{-10}$ m. How far does a typical molecule move before it collides with another molecule? **1**

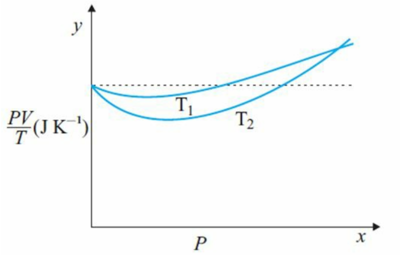
   a. 3.16 $\times 10^{-70}$ m
   b. 2.25 $\times 10^{-7}$ m
   c. 2.52 $\times 10^{-70}$ m
   d. 2.25 $\times 10^{-60}$ m

4. Consider 2.00 mol of an ideal diatomic gas. Find the total heat capacity at constant volume and at constant pressure, if the molecules rotate but do not vibrate **1**

   a. 9.45 cal/K, 13.2 cal/K
   b. 9.65 cal/K, 13.5 cal/K

c. 9.95 cal/K, 13.9 cal/K
d. 9.85 cal/K, 13.7 cal/K

5. Figure shows plot of $\frac{PV}{T}$ versus P for 1.00×10^{-3} kg of oxygen gas at two different temperatures. Comparing T_1 and T_2 **1**



a. $T_1 < T_2$
b. $T_1 = T_2$
c. $T_1 > T_2$
d. $T_1 \geq T_2$

6. Is molar specific heat of a solid, a constant quantity? **1**

7. Under which condition real gases behave as ideal gases? **1**

8. Write two conditions when real gases obey the ideal gas equation (PW = nRT). N → number of moles. **1**

9. A gas at 27° C in a cylinder has a volume of 4 L and pressure 100 N/m^2. If the gas is first compressed at constant temperature so that the pressure is 150 N/m^2. Estimate the change in volume. **2**

10. Molecules of which gas will possess higher rms speed, hydrogen or helium? Give reason too. **2**

11. Calculate the number of degrees of freedom in 15 cm^3 of nitrogen at NTP. **2**

12. At what temperature is the root mean square speed of an atom in an argon gas cylinder equal to the rms speed of a helium gas atom at - 20 °C? (Atomic mass of Ar = 39.9 u, of He = 4.0 u). **3**

13. A gas mixture consists of molecules of types A, B and C with masses

$m_A > m_B > m_C$ at constant temperature and pressure. Rank the three types of molecules in decreasing order of (a) average K.E.(b) rms speeds. **3**

14. Molar volume is the volume occupied by 1 mol of any (ideal) gas at standard temperature and pressure (STP: 1 atmospheric pressure, 0 °C). Show that it is 22.4 litres. **3**

15. i. What do you understand by specific heat capacity of water?
    ii. If one mole of ideal monoatomic gas (γ = 5/3) is mixed with one mole of diatomic gas (γ = 7/ 5). What is the value of y for the mixtures?
    (here, γ represents the ratio of specific heat at constant pressure to that at constant volume) **5**

Answer

1. a. 366 K, 253 K

   Explanation: $T_i = \frac{P_i V_i}{nR} = \frac{(5\times1.01\times10^5)\times(12\times10^{-3})}{2\times8.31} = 366K$

   $P_1 V_1{}^{\gamma} = P_2 V_2{}^{\gamma}$

   $P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 5\times\left(\frac{12}{30}\right)^{1.4} = 5\times(0.4)^{1.4} = 1.39atm$

   $T_f = \frac{P_f V_f}{nR} = \frac{(1.39\times1.01\times10^5)\times(30\times10^{-3})}{2\times8.31} = 253K$

2. c. is the same in all three vessels

   Explanation: Avogadro's law states that, "equal volumes of all gases, at the same temperature and pressure, have the same number of molecules".

3. b. 2.25 $\times\ 10^{-7}$ m

   Explanation: no. of molecule per unit volume

   $n_V = \frac{N}{V} = \frac{P}{kT} = \frac{1.01\times10^5}{1.38\times10^{-23}\times293} = 2.5\times10^{25}$

   mean free path

   $\lambda = \frac{1}{\sqrt{2}\pi d^2 n_V} = \frac{1}{1.41\times3.14\times(2\times10^{-2})^2\times2.5\times10^{25}} = 2.25\times10^{-7}m$

4. c. 9.95 cal/K, 13.9 cal/K

   Explanation: for diatomic gas C_V = 2.5 R, C_P = 3.5 R

   Heat capacity = mc = nC

   at const. volume Heat capacity = $nC_V = 2\times2.5\times1.986 = 9.95cal/K$

   at const. pressure Heat capacity = $nC_P = 2\times3.5\times1.986 = 13.9cal/K$

5. c. $T_1 > T_2$

   Explanation: For 1 mole of ideal gas, according to ideal gas equation

   PV = RT

   $\frac{PV}{T}$ = R = constant

   Hence graph must be with zero slope. So that dotted line show ‘ideal’ gas behaviour and curved line shows deviation from ‘ideal’ gas behavior.

A real gas behave as ideal gas at high temperature. Temperature T_1 is close to dotted line.

so that $T_1 > T_2$

6. Yes, the molar specific heat of a solid is a constant quantity as its value is 3R J $mol^{-1}K^{-1}$.(R being universal gas constant)

7. Mostly real gases behave as almost ideal gases at low pressures and high temperatures.

8. i. Low pressure
   ii. High temperature

9. Given, initial volume, V_1 =4 L, final volume, V_2 = ?, initial pressure, p_1 =100 N/m^2

   final pressure, p_2 = 150 N/m^2, ΔV = ?

   Using Boyle's Law for constant temperature, we have

   $p_1V_1 = p_2V_2$

   $\Rightarrow V_2 = \frac{p_1V_1}{p_2} = \frac{100\times4}{150} = 2.667 \text{ L}$

   Change in Volume = $\Delta V = V_1 - V_2$ = 4 - 2.667 = 1.33 L

10. The rms speed of hydrogen molecules will be more because density (or molar mass) of hydrogen is less than that of helium gas molecules under similar conditions of pressure, temperature etc.

    From kinetic theory of gases, the rms speed is given by :

    $v_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M_0}}$, where M_0 is the total mass of given gas. Keeping temperature constant,

    $\Rightarrow v_{rms} \propto \frac{1}{\sqrt{M_o}}$

    $\frac{v_{H_2}}{v_{He}} = \sqrt{\frac{M_{He}}{M_{H_2}}} = \sqrt{\frac{4}{2}} = \sqrt{2} : 1$

    Thus, the rms speed of hydrogen molecules will be more than helium.

11. Number of nitrogen molecules in 22400 cm^3 of the gas at NTP

    $= 6.023 \times 10^{23}$

Hence, number of nitrogen molecules in 15 cm^3 of the gas at NTP

$= \frac{6.023\times10^{23}\times15}{22400} = 4.03 \times 10^{20}$ (using unitary method)

Now, number of degrees of freedom of nitrogen (diatomic) molecule at NTP i.e. at 273 K = 5

Hence, total degrees of freedom of 15 cm^3 of the given nitrogen gas at NTP =

$4.03 \times 10^{20} \times 5 = 2.015 \times 10^{21}$

12. Root mean square speed of Argan atom

$V_{rms1} = \sqrt{\frac{3RT_1}{M_1}}$ ---(1)

Root mean square speed of Helium atom $V_{rms2} = \sqrt{\frac{3RT_2}{M_2}}$ ----(2)

Divide equations (1) by (2)

$\frac{V_{rms1}}{V_{rms2}} = \frac{\sqrt{\frac{3RT_1}{M_1}}}{\sqrt{\frac{3RT_2}{M_2}}}$

$= \sqrt{\frac{T_1 M_2}{T_2 M_2}}$

But, $V_{rms1} = V_{rms2}$ [Accroding to question ,]

$1 = \sqrt{\frac{T_1 M_2}{T_2 M_2}}$

$\frac{M_1}{M_2} = \frac{T_1}{T_2}$

So, $T_1 = T_2 \times \frac{M_1}{M_2}$

Here, T_2 = -20°C = -20+273 = 253 K

M_1 = 40g/mol

= 4 g/mol

$T_1 = 253 \times \frac{40}{4}$

= 2530 K

13. a. Average velocity of an ideal gas molecule,

$v_{av} = \overline{v} = \sqrt{\frac{8N_AK_BT}{\pi m}} = \sqrt{\frac{8RT}{\pi m}} = \sqrt{\frac{8PV}{\pi m}}$

(As the temperature and pressure are same in this question.)

Now $v_{av} = \overline{v} \propto \frac{1}{\sqrt{m}}$

Since $m_A > m_B > m_C, \therefore v_C > v_B > v_A$. Again velocity of the gas molecules will affect the KE more than mass of the molecules. So, average KE of molecules in decreasing order is $KE_C > KE_B > KE_A$

b. Again we know that rms velocity of an ideal gas molecule, $v_{rms=} = \sqrt{\frac{3K_BT}{m}}$

Pressure, Temperature are constant

$\therefore v_{rms} \propto \frac{1}{\sqrt{m}}$

Here also since $m_A > m_B > m_c$ (given)

$\therefore (V_{rms})_C > (V_{rms})_B > (V_{rms})_A$

14. One mole of an ideal gas equation relating pressure (P), volume (V), and absolute temperature (T) is given as:

PV = nRT...(i)

Where,

R is the universal gas constant = 8.314 J mol^{-1} K^{-1}

n = Number of moles = 1

T = absolute standard temperature = 0^0C = 273 K

P = Standard pressure of atmosphere = 1 atm = 76 $\times$ 13.6 $\times$ 9.8 = 1.013 $\times$ 10^5 Nm^{-2}

Now from equation (i), we get

$\therefore V = \frac{nRT}{P}$

$= \frac{1 \times 8.314 \times 273}{1.013 \times 10^5}$

= 0.0224 m^3

= 22.4 litres (As, 1 litre = 10^{-3} m^3)

Hence, the molar volume of an ideal gas at STP is 22.4 litres. This value is same for all ideal gases at standard temperature and pressure.

15. i. We know that water molecule is made up of 3 atoms (2 hydrogen and 1 oxygen). By using law of equipartition of energy, average energy associated with one atom of water molecule

$= 2 \times \left(\frac{1}{2} k_B T\right) = k_B T$

In three dimension, the average energy per atom of water molecule = $3k_BT$

Total energy of one molecule of water is

$= 3 \times (3k_BT) = 9k_BT$

Now, total energy of 1 mole of water is

$U = 3 \times 3k_BT \times N_A = 9RT$

Molar specific heat of water,

$C = \frac{\Delta Q}{\Delta T} = \frac{\Delta U}{\Delta T} = 9R$

Specific heat capacity of water, C = 9 R

$\Rightarrow$ C = 74.79 J $mol^{-1}K^{-1}$(putting the value of R = 8.314 J mol^{-1} K^{-1})

ii. For monoatomic gas, $C_V = \frac{3}{2}R$

For diatomic gas, $C'_V = \frac{5}{2}R$

Let μ and μ' be the number of moles of mono-atomic and diatomic gases, then

C_V(mixture) = $\frac{\mu C_V + \mu' C'_V}{\mu + \mu'}$

$\Rightarrow C_V = \frac{1 \times \frac{3}{2}R + 1 \times \frac{5}{2}R}{1+1} = 2R$

$\therefore \gamma(\text{ mixture }) = 1 + \frac{R}{C_{V(\text{ mixture })}}$, using the relation $C_P - C_V = R$

$= 1 + \frac{R}{2R}$ = 1.5