Chapter 5

States of Matter

Solutions (Set-1)

Very Short Answer Type Questions :

1. Define equilibrium vapour pressure.

Sol. It is the vapour pressure exerted by the vapours in equilibrium with its liquid at a given temperature.

2. What is the S.I. unit of surface tension?

Sol. Newton per metre (Nm^{-1})

3. How is the volume and pressure of a gas related to each other at constant temperature?

Sol. At constant temperature, the pressure of a fixed amount of gas varies inversely with the volume of the gas.

4. Convert 23°C into Kelvin temperature.

Sol. 1°C temperature = 273.15 K

23°C temperature = 23 + 273.15 K

= 296.15 K

5. Define isotherms.

Sol. Isotherms are the curves obtained when we plot a graph between pressure and volume at a constant temperature.

6. What type of intermolecular forces are also known as London forces?

Sol. Dispersion forces that link the two non-polar molecules together are also known as London forces.

7. How is the density and molar mass of a gaseous substance related?

Sol. Molar mass = M

Density = d

$$M = \frac{dRT}{P}$$

8. What sort of deviation is shown by dihydrogen in the PV versus P plot?

Sol. Positive deviation.

9. What is the standard boiling point of water?

Sol. Standard boiling point of water is 99.6°C.

10. Name two factors on which the viscosity of a liquid depends.

Sol. (i) Intermolecular attractive forces

(ii) Temperature

Short Answer Type Questions :

11. What are real gases? Under what conditions they tend to follow the ideal gas equation?

Sol. Real gases are those gases which deviate from ideal gas behaviour and deviate from the gas laws at higher pressure and lower temperature.

So, they follow ideal gas equation only at

(i) High temperature

(ii) Low pressure

12. What does the Z value greater than unity for H_2 gas and Z value less than unity for CH_4 gas indicate?

Sol. Z value greater than unity ($Z > 1$) for H_2 gas indicates that there are forces of repulsion which operate between the hydrogen gas at high pressure.

Z value less than unity ($Z < 1$) for CH_4 gas indicate high attractive forces between its molecules.

13. Define critical temperature and critical pressure of a gas. What is the value of critical temperature of carbon dioxide gas?

Sol. **Critical Temperature (T_C) :** Critical temperature of a gas may be defined as the temperature above which the gas cannot be liquefied however high pressure may be applied on the gas.

T_C of carbon dioxide gas = 30.98°C.

Critical Pressure (P_C) : At critical temperature a certain pressure is needed to liquefy the gas. So, this pressure at critical temperature is called the critical pressure.

14. Discuss hydrogen bonding. Why is HCl a gas while HF is liquid at room temperature?

Sol. **Hydrogen Bonding :** Hydrogen bonding is a type of dipole-dipole interaction. Hydrogen bonding is a force of attraction between the hydrogen atom attached to the highly electronegative atom and the electronegative atom of the other polar molecules. *e.g.* H_2O.

HF is liquid and HCl is gas at room temperature because HF molecules are interacted by the hydrogen bonds whereas hydrogen bonding is absent in HCl molecules. Hydrogen bonding being very strong intermolecular interaction HF exists as liquid at room temperature.

15. Hydrogen gas is enclosed in a cylinder of volume 500 cm^3 at a pressure of 760 mm Hg and temperature 30°C. Calculate the number of moles of hydrogen gas in the cylinder.

Sol. $V = 500\ cm^3 = 500 \times 10^{-3}$ litre

$P = 760$ mm Hg = 1 atm (1 atm = 760 mm)

T = 30°C

= 303 K

R = 0.0820 atm L K^{-1} mol^{-1}

Ideal gas equation

PV = nRT

$1 \times 500 \times 10^{-3} = n \times 0.0820 \times 303$

$\boxed{n = 0.021\,mol}$

16. Which state of the substance has highest

(a) Intermolecular forces of attraction?

(b) Thermal energy?

(c) Density?

Sol. (a) Solid state

(b) Gaseous state

(c) Solid state

17. Why pressure cookers are employed at high altitudes to cook food?

Sol. At high altitude, the atmospheric pressure is very low. We know that the boiling point of a liquid is the temperature at which the vapour pressure of the liquid becomes equal to the atmospheric pressure. So, due to lower pressure at higher altitude the liquid starts boiling much before the food actually gets prepared. So, pressure cookers work to increase the pressure, so that the food gets cooked properly.

18. What is combined gas law?

Sol. The Boyle's and Charles' law can be combined to give a relationship between the three variables P, V and T. The initial temperature, pressure and volume of a gas are T_1, P_1 and V_1. With the change in either of the variables, all the three variables change to T_2, P_2 and V_2. Then we can write

$$\frac{P_1V_1}{T_1} = nR \text{ and } \frac{P_2V_2}{T_2} = nR$$

Combining the equations we get

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

The above relation is called the combined gas law.

19. Define surface energy. What are its dimensions?

Sol. Surface energy of the liquid is the energy required to increase the surface area of the liquid by one unit.

Dimensions = Jm^{-2}

20. Define (a) Vaporisation, (b) Condensation.

Sol. (a) **Vaporisation :** Vaporisation is the process by which liquid molecules go into the vapour phase.

$\boxed{\text{Liquid State} \longrightarrow \text{Vapours}}$

(b) **Condensation :** It is the process of conversion of vapours into the liquid state.

$\boxed{\text{Vapours} \longrightarrow \text{Liquid State}}$

21. F_2 and Cl_2 are gases, Br_2 is a liquid and I_2 is a solid at room temperature. Why?

Sol. All of these molecules are completely non-polar and according to theory, not attracted to each other, so it is predicted that they all should be gases at room temperature. But is not so, F_2 and Cl_2 are gases, Br_2 is a liquid and I_2 is a solid. The reason is that more are the number of electrons, more is the polarizability, diffuse electron cloud can be easily distorted. As I_2 has maximum electrons, so maximum extent of induced dipole intermolecular forces among the halogens. These interactions decrease as electrons decrease (Size decreases) moving from Br_2 to Cl_2 to F_2.

22. The density of CO_2 is 0.326 gL^{-1} at 27°C and 260 mm pressure. If the pressure remains constant, then what is the density of the gas at 40°C?

Sol. $d_1 = 0.326\ gL^{-1}$ $\quad d_2 = ?$

$T_1 = 27°C \quad T_2 = 40°C$

$= (27 + 273)\ K \quad = (40 + 273)\ K$

$= 300\ K \quad = 313\ K$

$d_1T_1 = d_2T_2$ (R, P and M constant)

$$d_2 = \frac{d_1T_1}{T_2}$$

$$= \frac{0.326 \times 300}{313}$$

$\boxed{d_2 = 0.312\ gL^{-1}}$

23. Calculate the total pressure in mixture of 8 g of oxygen and 4 g of hydrogen confined in a total volume of one litre at 27°C.

Sol. Moles of oxygen = $\frac{8}{32}$ = 0.25 mol

Moles of hydrogen = $\frac{4}{2}$ = 2 mol

Total number of moles = 0.25 + 2 = 2.25 mol

Using Ideal gas equation PV = nRT

$P \times 1 = 2.25 \times 0.0821 \times 273$

$\boxed{P = 50.42\ atm}$

24. (a) Will a real gas occupy the same volume at high pressure as that of ideal gas under similar conditions?

(b) Which van der Waal's constant signifies the intermolecular forces between the molecules?

Sol. (a) No, a real gas at high pressure will occupy more volume than an ideal gas under similar conditions. This is because the volume of the molecules themselves will have a significant value in case of a real gas at high pressure while the volume of the molecules of an ideal gas will be zero.

(b) van der Waal's constant 'a' signifies the intermolecular forces between the molecules.

25. Four litres of CO_2 are kept at 27°C. What will be the volume if the temperature is lowered to 150 K at the same pressure?

Sol. $V_1 = 4$ L $\quad\quad V_2 = ?$

$T_1 = 27°C \quad\quad T_2 = 150$ K

$= (27 + 273)$ K

$= 300$ K

Applying Charles law as pressure is constant $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$\Rightarrow \frac{4}{300} = \frac{V_2}{150}$$

$$\Rightarrow V_2 = \frac{150 \times 4}{300} = 2 \text{ L}$$

$$\Rightarrow \boxed{V_2 = 2 \text{ L}}$$

26. Working of syringe is an application of Boyle's law. Explain.

Sol. A syringe is a device used in a hospital to draw blood samples or give injections. When the plunger of the syringe is pulled back the volume of the syringe container increases, decreasing the pressure inside, since the same amount of gas is now spread over a greater volume, this is what is stated by Boyle's law. To balance this effect of low pressure, air or blood is sucked in through the needle, thus balancing the pressure inside and outside the container.

27. One litre of a gas weighs 3 g at 300 K at 1 atm pressure. If the pressure is made 0.85 atm, at which temperature will one litre of the same gas weigh one gram?

Sol. $P_1V_1 = n_1RT_1$

$P_2V_2 = n_2RT_2$

$$\Rightarrow \frac{P_1V_1}{P_2V_2} = \frac{n_1RT_1}{n_2RT_2}$$

$n_1 = \frac{w_1}{M_1} \quad\quad n_2 = \frac{w_2}{M_2}$

As the gas is same, so $M_1 = M_2$

$\therefore \quad \dfrac{P_1V_1}{P_2V_2} = \dfrac{w_1RT_1}{w_2RT_2}$

$\Rightarrow \quad \dfrac{1\times 1}{0.85\times 1} = \dfrac{3\times 300}{1\times T_2}$

$\Rightarrow \quad T_2 = 3 \times 300 \times 0.85$

$\Rightarrow \quad \boxed{T_2 = 765\ K}$

28. Pressure remaining constant, at what temperature the density of the gas becomes 0.625 d, when the density at 27°C is d?

Sol. $d = \dfrac{PM}{RT}$ or $\dfrac{d_1}{d_2} = \dfrac{T_2}{T_1}$

$d_1 = d \qquad T_1 = 27°C$

$d_2 = 0.625\ d \qquad = (27 + 273)\ K = 300\ K$

$T_2 = ?$

$\dfrac{d}{0.625\ d} = \dfrac{T_2}{300}$

$\boxed{T_2 = 480\ K}$

Long Answer Type Questions :

29. Derive the ideal gas equation. What is equation of state?

Sol. Ideal gas equation is an equation which is followed by the ideal gases. A gas that would obey Boyle's and Charles' Law under all the conditions of temperature and pressure is called an ideal gas.

As discussed the behaviour of gases is described by certain laws as Avogadro's law, Boyle's law, Charles' law.

According to Avogadro's law ; $V \propto n$ (P and T constant)

According to Boyle's law ; $V \propto \dfrac{1}{P}$ (T and n constant)

According to Charles law ; $V \propto T$ (P and n constant)

Combining the three laws ; we get

$V \propto \dfrac{nT}{P}$

$\Rightarrow \quad \boxed{V = R\dfrac{nT}{P}}$

where; 'R' is the proportionality constant

On rearranging the above equation we get,

$\boxed{PV = nRT}$

This is the ideal gas equation as it is obeyed by the hypothetical gases called ideal gases under all conditions of temperature and pressure.

However there is no gas that is perfectly ideal. But the gases may show nearly ideal behaviour under the conditions of **low pressure** and **high temperature** and are called **real gases**.

Equation of state : As the ideal gas equation expresses the quantitative relationship between the four variables that describe the state of a gas therefore it is called equation of state for gases.

When 1 mole of a gas is considered, then

PV = RT $(\because n = 1\,\text{mol})$

30. What is the effect of temperature on the compressibility of the gas above and below Boyle's temperature?

Sol. Pressure alone does not decide the behaviour of gases. **Temperature is also an important factor which plays role.**

Boyle Temperature or Boyle's Point : It is the temperature at which real gases obey ideal gas laws over an appreciable range of pressure.

Boyle temperature depends on the nature of the gas.

Effect of Temperature on the Compressibility Factor

(a) **Above the Boyle temperature :** Real gas show positive deviation (Z > 1) from ideality. This is because with increase in temperature, the molecules move far from each other So, volume increases thereby the forces of attraction between the molecules become feeble.

(b) **Below the Boyle's temperature :** Below the Boyle's temperature 'Z' value first decreases and reaches a minimum with increase in pressure because of forces of attraction which start operating between the molecules. Later, on further increase in pressure force of repulsion operates, So, now the value of Z increases continuously.

31. (a) Define surface tension.

(b) Explain why water has concave and mercury has convex surface in glass tubes, pipettes, burettes etc.

(c) Shaving blade floats on water surface. Why?

Sol. (a) **Surface Tension :** Surface tension may be defined as the force acting per unit length perpendicular to the line drawn on the surface of liquid.

(b) It is due to surface tension. Surface of water is concave because the adhesive forces between glass and water molecules are greater than intermolecular forces of attraction between molecules.

Whereas, the surface of mercury is convex because, glass-Hg adhesive forces are less than intramolecular forces of attraction between mercury molecules.

(c) A shaving blade, if placed gently floats on water surface due to surface tension of water.

32. (a) State Boyle's law.

(b) A sample of gas occupies 200 litres at 0.5 atm pressure at 2°C. If the volume of the gas is to be reduced to 20 litres at the same temperature, what additional pressure must be applied?

Sol. (a) **Boyle's Law :** Boyle's law states that "at constant temperature, the pressure of a fixed amount of gas varies inversely with the volume of the gas".

(b) P_1 = 0.5 atm P_2 = ?

V_1 = 200 litres V_2 = 20 litres

T_1 = 2°C T_2 = 275 K

= (2 + 273)

= 275 K

As temperature is constant, so applying Boyle's law

$P_1V_1 = P_2V_2$

$\Rightarrow$ $0.5 \times 200 = P_2 \times 20$

$\Rightarrow$ $P_2 = \dfrac{0.5 \times 200}{20} = 5$ atm

Additional pressure that should be applied $P_2 - P_1 = 5 - 0.5$ atm

$\boxed{P_2 - T_1 = 4.5 \text{ atm}}$

33. Explain in detail the concept of viscosity. Explain the factors on which it depends.

Sol. Viscosity is one of the characteristic properties of liquids. All liquids tend of flow. But some liquids flow faster than the other. This is because of the difference of intermolecular forces of attraction. Example, ink flows faster than honey.

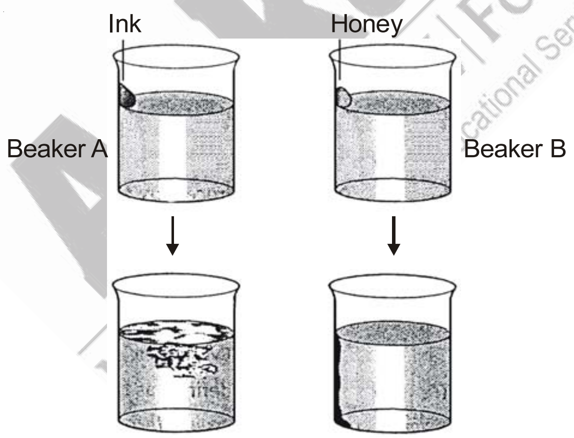


Fig. : An ink drop diffuses faster in water than does a drop of honey because honey is more viscous than ink

Let us understand the concept of viscosity. Viscosity is actually the measure of resistance to the flow of the liquid. The flow of liquid molecules can be analysed in terms of molecular laminar layers.

Laminar Flow : The liquid is considered to be consisting of molecular layers arranged one over the other. When the liquid flows over a glass surface then the layer of molecules immediately in contact with the glass surface are stationary with zero velocity. But layer immediately above it is not stationary but flows with some velocity. Further the next layer above it flows still more faster and this continues and the top most layer of molecules flow with maximum velocity. So, this type of flow in which there is gradual gradation in the velocities on passing from one layer to the another is called **laminar flow**.

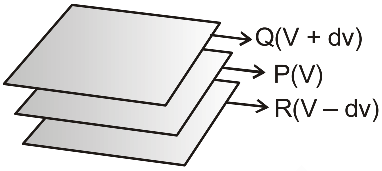


Fig. : Gradation of Velocity in the laminar flow

If any molecular layer (say P) we take, then the layer above it (say Q) accelerates its flow because the molecules from the above layer (Q) with higher velocity speeds the lower layer (P) molecules also. But the layer (R) below retards its flow because the molecules in the lower layer (R) are with lower velocity. This whole results in the friction between the two layers which give rise to viscosity.

So, viscosity is defined as the internal resistance of flow in liquids which arises due to the internal friction between the layers of liquid as they slip past one another while liquid flows.

Viscosity Depends upon the following two factors :

(a) **Intermolecular attractive forces :** Greater the intermolecular forces of attraction greater is the viscosity. Hydrogen bonding and van der Waals forces are strong enough to cause high viscosity. More viscous liquids flow slowly.

(b) **Temperature :** With the rise in temperature, the kinetic energy of the molecules increases. Molecules with greater kinetic energy can overcome the intermolecular forces to slip past one another between the layers. So, we can say that the viscosity of the liquids decreases with rise in temperature.

34. (a) Explain Dalton's law of partial pressure.

(b) How is the pressure of a dry gas calculated over water?

Sol. (a) According to ideal gas equation, if n_1 is the number of moles of one constituent gas of the gaseous mixture then P_1 is the pressure exerted by the gas at temperature (T) enclosed in the volume (V)

$$\boxed{P_1 = \frac{n_1RT}{V}} \qquad ...(i)$$

Similarly for the other two constituting gases of the gaseous mixture

$$P_2 = \frac{n_2RT}{V}$$

$$P_3 = \frac{n_3RT}{V}$$

According to Dalton's law of partial pressures,

$$P_{Total} = P_1 + P_2 + P_3 + ...$$

$$= \frac{n_1RT}{V} + \frac{n_2RT}{V} + \frac{n_3RT}{V} + ...$$

$$\boxed{P_{total} = (n_1 + n_2 + n_3)\frac{RT}{V}} \qquad ...(ii)$$

That means the total partial pressure of the mixture is determined by the total number of moles present.

Dividing equation (i) by (ii) we get total number of moles present.

$$\frac{P_1}{P_{total}} = \left(\frac{n_1}{n_1 + n_2 + n_3}\right)\frac{RTV}{RTV}$$

$$= \frac{n_1}{n_1 + n_2 + n_3} = \frac{n_1}{n}$$

where $n = n_1 + n_2 + n_3$

Now, $\dfrac{n_1 \left(\text{moles of } 1^{st} \text{ gas}\right)}{n\left(\text{Total number of moles}\right)}$ = Mole fraction of first gas (x_1)

Mole Fraction : It is the ratio of the number of moles of an individual gas to the total number of moles of all gases in a molecule.

$$\boxed{\frac{P_1}{P_{total}} = x_1}$$

Thus

$$\boxed{P_1 = x_1 P_{total}}$$

Similarly $\boxed{P_2 = x_2 P_{total}}$

Therefore the generalised equation becomes

$$\boxed{P_i = x_i P_{total}}$$

Where P_i = partial pressure of i^{th} gas

x_i = mole fraction of i^{th} gas

Thus, **the partial pressure of a gas in the mixture of gases is the product of its mole fraction and the total pressure of the mixture.**

Therefore the above equation is used to find out pressure exerted by an individual gas in the mixture of gases.

(b) **Calculation of the pressure of dry gas collected over water :** When the gas is collected over water it is moist because of the water vapours. Saturated water vapour exert its own partial pressure called aqueous tension. So, in order to calculate the partial pressure of dry gas, aqueous tension is subtracted from the pressure of moist gas (P_{moist} gas or P_{Total})

$$\boxed{P_{dry\ gas} = P_{total} - \text{Aqueous tension}}$$

35. Explain the four parameters which are used to describe the characteristics of gases along with various interconversions of units.

Sol. There are certain parameters or measurable properties which are used to describe the characteristics of gases :

(a) **Volume (V) :** The volume of the container is the volume of the gas sample as gases occupy the entire space available to them

S.I. unit = m^3

C.G.S. unit = cm^3

Commonly used unit = L

1 L = 1000 mL

1 mL = 10^{-3} L

1 $m^3 = 10^3\ dm^3 = 10^3\ L = 10^6\ cm^3 = 10^6$ mL

(b) **Pressure (P) :** Pressure of the gas is the force exerted by the gas per unit area on the walls of the container in all directions.

S.I. unit = Pascal (Pa)

1 Pa = 1 Nm^{-2}

= 1.013×10^5 Pa

Conversions

1 bar = 10^5 Pa = 0.987 atm

1 atm = 760 mm Hg = 760 torr = 1.013×10^5 Pa.

(c) **Temperature :** It is the measure of hotness of the system and energy of the energy.

S.I. unit = kelvin (K)

K = °C + 273

°C $\rightarrow$ centigrade degree (°C) or celsius degree

(d) **Mass :** The mass of a gas can be determined by weighing the container in which the gas is enclosed and again weighing the container after removing the gas.

The mass of the gas is related to the number of moles of the gas *i.e.*

$$\text{Moles of gas (n)} = \frac{\text{Mass in grams}}{\text{Molar mass}} = \frac{m}{M}$$

36. (a) What is boiling?

(b) Whether boiling occurs in an open or closed vessel?

(c) Explain the difference between normal boiling point and standard boiling point.

Sol. (a) **Boiling :** Boiling is a **bulk phenomenon**. At the boiling point, the vaporisation occurs throughout the bulk of the liquid and the vapours expand freely in the surroundings.

(b) Boiling **occurs in an open vessel it cannot occur in a closed vessel**.

(c) **Normal Boiling Point :** As the atmospheric pressure varies with altitude and other conditions, the boiling points are reported at 1 atm. So, the normal boiling point of a liquid is the temperature at which the vapour pressure of the liquid is 1 atm.

e.g. Normal boiling point of water = 100°C

Standard Boiling Point : It is the temperature at which the vapour pressure of the liquid is 1 bar.

e.g. Standard boiling point of water = 99.6°C

Standard boiling point of the liquid is slightly lower than the normal boiling point of the liquid.

37. (a) What is the effect of hydrogen bonding on the viscosity of a liquid?

(b) Liquids have a definite volume, but no definite shape. Explain

Sol. (a) Hydrogen bonding is a type of intermolecular force of attraction. So, it links the various units of liquid molecules, so the effective size of the moving unit in the liquid increases. Due to an increase in the size and mass of the molecule, their is greater internal resistance to the flow of the liquid. Therefore, viscosity of liquid increases.

(b) The intermolecular forces in liquids are strong enough to hold the molecules together, but not strong enough to fix them into definite positions as in solids. Therefore, liquids have a definite volume, but no definite shape.

38. (a) What is the volume of the 6 g of chlorine at 27°C and 101 kPa pressure?

(b) What is the volume of the chlorine in dm^3 and cm^3?

Sol. (a) T = 27°C = (27 + 273) K = 300 K

P = 101 kPa = 101 × 1000 = 101000 Pa

Molar mass of chlorine = 71 g

Given mass of chlorine = 6 g

Moles of chlorine (n) = $\frac{6}{71}$ = 0.084 mol

R = 8.314 Pa m^3 K^{-1} mol^{-1}

Applying ideal gas equation,

PV = nRT

$\Rightarrow$ 101000 × V = 0.084 × 8.314 × 300

$$\Rightarrow \quad V = \frac{0.084 \times 8.314 \times 300}{101000}$$

$\Rightarrow$ V = 2.074×10^{-3} m^3

$\Rightarrow$ V = 0.002074 m^3

(b) 1 m^3 = 1000 dm^3 = 10^6 cm^3

So, the volume in dm^3 = 2.074 dm^3

Volume in cm^3 = 2074 cm^3

39. 0.64 g of an oxide of sulphur occupies 0.224 L at 2 atm and 273°C. Identify the compound. Also find out the mass of one molecule of the gas.

Sol. P = 2 atm

V = 0.224 L

Given, mass (m) = 0.64 g

T = 273°C = (273 + 273) K = 546 K

R = 0.082 L atm mol^{-1} K^{-1}

PV = nRT

$$PV = \frac{m}{M}RT$$

$$M = \frac{mRT}{PV}$$

$$M = \frac{0.64 \times 0.082 \times 546}{2 \times 0.224} = 63.96 \approx 64$$

The oxide is SO_2 as its molar mass = 32 + 2 × 16 = 64 g/mol

Mass of 6.022×10^{23} molecules of oxide = 64 g

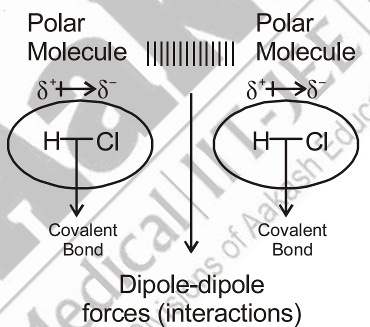
Mass of 1 molecule of oxide = $\frac{64}{6.022 \times 10^{23}}$ g = 1.063×10^{-22} g

40. (a) Explain dipole-dipole forces along with example.

(b) How the interaction energy varies with the distances for stationary as well as rotating polar molecules?

Sol. (a) **Dipole-Dipole Forces :** (Associated with Polar structures) : Polar molecules have a partially positive side and a partially negative side or a **dipole**. Dipole-dipole forces operate between the molecules which though neutral but possess permanent dipole. The separation of partial charges depends upon the electronegativity of the bonded atoms in a molecule. The partial charges are indicated by the Greek letter 'delta(δ)'. In these type of forces the partial positive end of the one molecule is attracted towards the negative end of the other molecule.

Example : Dipole-dipole forces are present between the two HCl molecules. Chlorine being more electronegative pulls the shared pair of electrons towards itself. So, it has a partial negative charge (δ^-) on it and hydrogen atom has a partial positive charge(δ^+)



(b) The interaction energy is dependent upon the distance between the polar molecules.

Stationary polar molecules : Dipole-dipole interaction energy is inversely proportional to the third power of the distance between stationary polar molecules (in solids)

$$\boxed{\text{Interaction Energy} \propto \frac{1}{r^3}}$$

Rotating polar molecules : Dipole-dipole interaction energy is inversely proportional to the sixth power of the distance between the rotating polar molecules (like water)

$$\boxed{\text{Interaction Energy} \propto \frac{1}{r^6}}$$

41. (a) State Gay–Lussac's Law.

(b) Give its graphical representation.

(c) What are isochores?

Sol. (a) Gay Lussac's Law or Pressure–Temperature Law can be stated as **'at constant volume, the pressure of a fixed amount of a gas is directly proportional to the temperature'.**

The law may be expressed mathematically as

$P \propto T$ (V, n are constant)

or $P = k_3\ T$

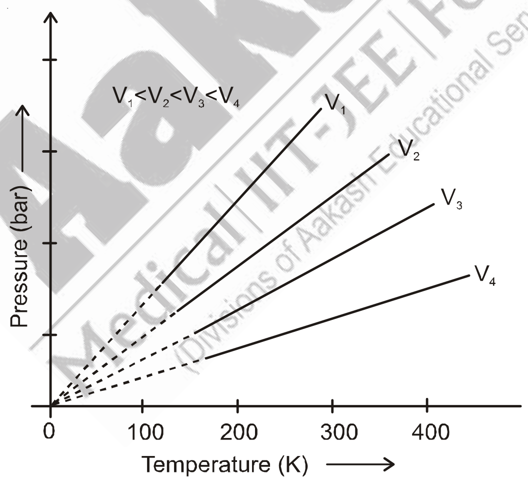
$$\frac{P}{T} = k_3\left(\text{constant}\right)$$

$$\frac{P_1}{T_1} = k = \frac{P_2}{T_2}$$

$$\Rightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

When we know P_1, T_1 and T_2 then we can easily calculate the value of P_2.

(b) **Graphical Representation**



Above is the temperature (kelvin) vs pressure graph at different fixed volume of the gas.

(c) **Isochores :** The lines showing the pressure temperature behaviour plotted at fixed volumes are called isochores.

42. (a) Explain the pressure correction applied to ideal gas equation to make it fit for real gases.

(b) Explain the isotherm of CO_2 at 30.98°C temperature.

Sol. (a) **Pressure Correction (Correction due to intermolecular forces of attraction)**

In the derivation of ideal gas equation, it is assumed that there are no intermolecular forces of attraction. But as now we have identified this faulty assumption, so there is need to incorporate results obtained from the intermolecular force of attraction between the gas molecules.

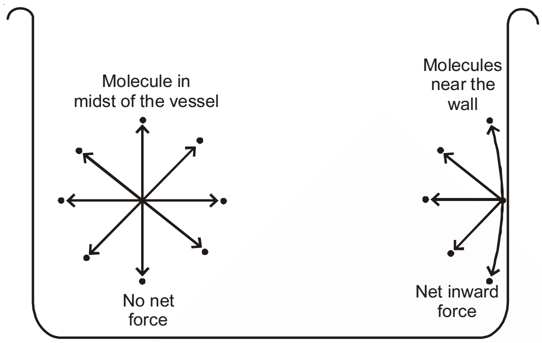


Fig. Correction due to Molecule attraction

For that let us take an example, molecule A when present in the midst of the vessel is attracted uniformly by the other molecules from all the directions. So, there is no net attractive force of the molecules but when this molecule approaches the wall of the vessel, then it only experiences attractive force from the bulk molecules behind it. So, now the molecule strikes the wall of the vessel with a lower velocity as it is dragged back by the other molecules. Therefore, the pressure exerted by the molecule now is lower than it would have exerted if there was no force of attraction. In other words, we can say that the pressure exerted by a real gas is less than that exerted by an ideal gas. Therefore, we need to add the pressure correction term to make the ideal gas equation fit for real gases also.

$$\boxed{P_{ideal} = \underbrace{P_{real}}_{\text{(observed pressure)}} + \underbrace{\frac{an^2}{V^2}}_{\text{(pressure correction term)}}} \quad ...(i)$$

Here 'a' is van der Waal’s constant.

Its value is

(i) Dependent upon the intermolecular forces of attraction within the gas.

(ii) Independent of temperature and pressure.

(b) **Isotherm at temperature 30.98°C :** At 30.98°C temperature gas changes into liquid while passing through a phase in the form of a point when liquid state and gaseous state of carbon dioxide co-exist. Above this temperature, the isotherm is continuous. That means carbon dioxide just exists in the gaseous state and does not liquefy even at very high pressure. So, this point or temperature (*i.e.* 30.98°C) is the critical temperature of carbon dioxide. In other words, we can say that at temperature 35°C or 50°C, carbon dioxide does not liquefy.

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Chapter 5

States of Matter

Solutions (Set-2)

[The Gas Laws]

1. 0.2 g of a gas X occupies a volume of 0.44 litre at given pressure and temperature. Under identical conditions of P and T, 0.1 g of CO_2 gas occupies 0.32 L volume. The gas X can be

(1) O_2 (2) SO_2 (3) NO (4) C_4H_{10}

Sol. Answer (2)

$M_x = 0.2$ g $\qquad V_x = 0.44$ L

$m_{CO_2} = 0.1$ g $\qquad V_{CO_2} = 0.32$ L

P and T are constant

$\therefore \dfrac{V_1}{n_1} = \dfrac{V_2}{n_2} \qquad \begin{bmatrix} V_1 \Rightarrow V_x \\ V_2 \Rightarrow V_{CO_2} \end{bmatrix}$

$\dfrac{0.44 \times M_x}{0.2} = \dfrac{0.32 \times 44}{0.1}$

$M_x = 64$

Molecular mass of SO_2 is also equal to 64.

2. A sample of gas at constant temperature occupies 95 cm^3 under a pressure of 9.962×10^4 N/m^2. At the same temperature, its volume at a pressure of 10.13×10^4 N/m^2 is

(1) 190 cm^3 (2) 93 cm^3 (3) 46.5 cm^3 (4) 47.5 cm^3

Sol. Answer (2)

$V_1 = 95$ ml $= 0.095$ L

$P_1 = 9.962 \times 10^4$ N/m^2 $\qquad [T_1 = T_2]$

$V_2 = ?$

$P_2 = 10.13 \times 10^4$ N/m^2

$P_1V_1 = P_2V_2$

$9.962 \times 10^4 \times 95 = 10.13 \times 10^4 \times V_2$

$V_2 = 93.42$ cm^3

$\therefore V_2 \cong 93$ cm^3

3. 200 ml of He at 0.66 atm pressure and 400 ml of O_2 at 0.52 atm pressure are mixed in a 400 ml vessel at 25°C. The partial pressure of He and O_2 will be

(1) 0.33, 0.52 (2) 0.52, 0.33 (3) 0.22, 0.45 (4) None of these

Sol. Answer (1)

V_1 = 200 ml, P_1 = 0.66 atm

V_2 = 400 ml, P_2 = 0.52 atm

$$P \propto \frac{1}{V}$$

Final volume of gas = volume at container

$\therefore$ volume of He increases from 200 ml to 400 ml.

$\therefore$ Pressure will decrease in the same ratio.

$$\therefore P_{\text{Final(He)}} = \frac{P_{\text{initial}}}{2} = \frac{0.66}{2} = 0.33 \text{ atm}$$

and for O_2 remains constant.

4. Two identical bulbs containing ideal gases A and B are taken. Density of A is twice that of B. Mol wt. of A is half that of B. If the two gases are at the same temperature, the ratio of pressure of A & B is

(1) 1 : 2 (2) 1 : 4 (3) 4 : 1 (4) 2 : 1

Sol. Answer (3)

$d_A = 2d_B$

$M_A = \frac{M_B}{2}$ $[T_1 = T_2]$

$P_A : P_B = ?$

PV = nRT

$\therefore P_AM_A = d_ART$ … (i)

and $P_BM_B = d_BRT$ … (ii)

(i) ÷ (ii)

$$\therefore \frac{P_AM_A}{P_BM_B} = \frac{d_A}{d_B}$$

$$\therefore \frac{P_A}{P_B} = 2 \times 2$$

$P_A : P_B = 4 : 1$

5. Which of the following statements is incorrect ?

(1) At 273°C and 1 atm pressure the volume of a given mass of gas will be twice the volume at 0°C and 1 atm pressure

(2) At –136.5°C and 1 atm pressure, the volume of a given mass of gas will be half its volume at 0°C and 1 atm

(3) The mass ratio of equal volumes of NH_3 and H_2S under similar conditions of temperature and pressure is 1 : 2

(4) The molar ratio of equal masses of CH_4 and SO_2 is 1 : 4

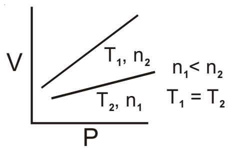
Sol. Answer (4)

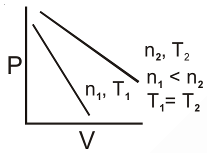
$$\frac{n_1}{n_2} = \frac{M_2}{M_1}$$

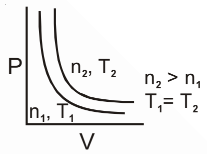
$$\therefore \frac{n_1}{n_2} = \frac{64}{16} = \frac{4}{1}$$

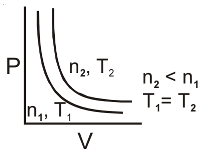
$n_1 : n_2 = 4 : 1$

6. Which of the following graphs represent Boyle's law correctly? (n_1 and n_2 are number of moles)

(1) 

(2) 

(3) 

(4) 

Sol. Answer (3)

$$P \propto \frac{n}{V}$$

Greater the number of moles, more will be pressure.

7. 2 g of a gas A is introduced into an evacuated flask kept at 25°C. The pressure is found to be 1 atm. If 3 g of another gas B is added to the same flask the total pressure becomes 1.5 atm, assuming ideal gas behaviour. The ratio of molecular weight of gas A to gas B ($M_A : M_B$) is

(1) 2 : 3 (2) 1 : 3 (3) 3 : 4 (4) 4 : 5

Sol. Answer (2)

PV = nRT

$$\therefore PM = \frac{mRT}{V}$$

$$\text{or } M = \frac{mRT}{PV} \qquad \ldots \text{(i)}$$

m_1 (A) = 2g, m_2 (B)= 3 g

P_1 = 1 atm P_2 = 1.5 atm

$$\therefore \frac{M_A}{M_B} = \frac{m_A \times P_B}{P_A \times m_B} \qquad [T = \text{constant}]$$

$$= \frac{2 \times 0.5}{1 \times 3} = \frac{1}{3} \qquad [\text{increase in pressure} = 0.5 \text{ atm}]$$

8. 50 ml of mixture of NH_3 and H_2 are decomposed to yield N_2 and H_2 and to the resulting mixture 40 ml O_2 is added and the mixture is sparked to yield H_2O. When the resulting mixture of gases were passed through alkaline pyrogallol 6 ml contraction was observed. Calculate the percentage composition of NH_3 in the original mixture

(1) 85% (2) 72% (3) 68% (4) 48%

Sol. Answer (2)

$$\underset{x\ ml}{2NH_3} \rightleftharpoons \underset{\frac{x}{2}}{N_2} + \underset{\frac{3}{2}x}{3H_2}$$

Volume of $H_2 = \frac{3}{2}x + 50 - x$

Volume of O_2 used = 40 –6 = 34 ml.

$$\underset{\frac{x+100}{2}}{2H_2} + \underset{\frac{1}{2}\times\frac{(x+100)}{2}}{O_2} \longrightarrow 2H_2O$$

$$\frac{x+100}{4} = 34$$

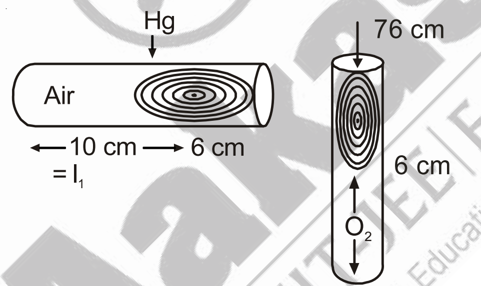
x = 136 – 100 = 36.

% of $NH_3 = \frac{36}{50} \times 100 = 72$

9. A 10 cm air column is trapped inside the tube (having uniform area of cross section) by 6 cm of Hg and is placed horizontally to the plane. Calculate the length of air column when the tube is placed vertically with opened end up.

(1) 9.26 cm (2) 10 cm (3) 10.25 cm (4) 11.5 cm

Sol. Answer (1)



$P_1V_1 = P_2V_2$

$P_1\ l_1\ a = P_2\ l_2\ a$

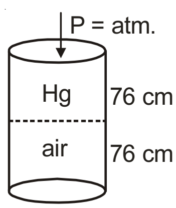
76×10 = (76+6) l_2

$$l_2 = \frac{760}{82} = \frac{190}{21} = 9.05$$

10. A vertical hollow cylinder of height 152 cm is fitted with a weightless piston. The lower half is filled with an ideal gas and the upper half with mercury. The cylinder is now heated at 300 K, so that $\frac{1}{4}$th of the mercury comes out. Find the temperature at which it will happen assuming thermal expansion of Hg to be negligible

(1) 340 K (2) 330.6 K (3) 328.12 K (4) 322.2 K

Sol. Answer (3)



P_1 = 76 + 76 P_2 = 76 + 57 = 133

$V_1 = \frac{V}{2}$ $V_2 = \frac{5}{8}$ V

T_1 = 300 K T_2 = ?

$$\Rightarrow \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$T_2 = \frac{133 \times 300 \times 5}{152 \times 4} = 328.12\text{ K}$$

11. The mass percent composition of dry air at sea level is given. The partial pressure of each component will be

(1) The ratio of their masses (2) The ratio of their volumes

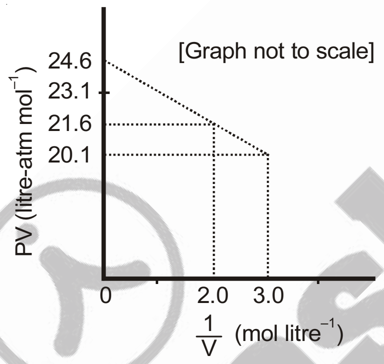
(3) The ratio of their moles (4) None of these

Sol. Answer (3)

$\because$ Partial pressure = mole fraction × Total pressure

$p_x = \frac{n}{N}P \Rightarrow p_x \propto n$

12. For one mole of a van der Waal's gas when b = 0 and T = 300 K, the PV vs. 1/V plot is shown below. The value of the van der Waal's constant 'a' (atm. litre^2 mol^{-2}) is



(1) 1.0 (2) 4.5 (3) 1.5 (4) 3.0

Sol. Answer (3)

$\left(P + \frac{a}{V^2}\right) V = RT$

$PV + \frac{a}{V} = RT$

$PV = RT - \frac{a}{V}$

So, Plot of (PV) vs $\left(\frac{1}{V}\right)$ has slope – a.

$\therefore$ slope $= \frac{20.1 - 24.6}{3} = -1.5$

$\therefore$ a = 1.5 atm L^2 mol^{-2}

[Kinetic Theory of Gas]

13. The average kinetic energy associated with one mole of a gas is

(1) $\frac{3}{2}$ RT (2) $\frac{3}{2}$ KT (3) $\frac{1}{2}$ RT (4) $\frac{1}{2}$ KT

Sol. Answer (1)

$PV = \frac{1}{3}mnu^2$

or, $RT = \frac{2}{3}K.E$ (For 1 mole)

$\therefore$ $K.E. = \frac{3}{2}RT$

14. At what temperature, the average speed of gas molecules will be double that at 27°C ?

(1) 27°C (2) 327°C (3) 527°C (4) 927°C

Sol. Answer (4)

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

$$\frac{u_{av_1}}{u_{av_2}} = \sqrt{\frac{T_1}{T_2}} \qquad [u_{av_2} = 2u_{av_1}]$$

$$\frac{1}{2} = \sqrt{\frac{T_1}{T_2}} \qquad \therefore \frac{T_1}{T_2} = \frac{1}{4}$$

$T_2 = 300 \times 4$

$T_2 = 1200$ K

$\therefore T_2 = 927°C$

15. Five molecules of a gas moving with speeds 1, 2, 3, 4, 5 km/s. What is their root mean square speed?

(1) $\sqrt{55}$ km/s (2) $\sqrt{44}$ km/s (3) $\sqrt{11}$ km/s (4) $\sqrt{6}$ km/s

Sol. Answer (3)

$$v_{rms} = \sqrt{\frac{1^2 + 2^2 + 3^2 + 4^2 + 5^2}{5}}$$

$$= \sqrt{\frac{5(5+1)(2\times5+1)}{6\times5}} = \sqrt{\frac{5\times6\times11}{6\times5}}$$

$= \sqrt{11}$ km/s.

16. Two samples of gases A and B are at the same temperature. The molecules of A are travelling four times faster than the molecules of B. The ratio of $\frac{m_A}{m_B}$ of their masses will be

(1) 16 (2) 4 (3) 1/4 (4) 1/16

Sol. Answer (4)

$$\frac{M_A}{M_B} = \frac{C_B^2}{C_A^2} = \frac{1^2}{4^2} = \frac{1}{16}$$

17. Pressure of the ideal gas depends on

(1) Force of each collision on the wall
(2) Frequency of collision with wall
(3) Nature of the gas
(4) Both (1) & (2)

Sol. Answer (4)

Pressure of the gas depends on both the frequency of collision with wall and force of each collision.

[Behaviour of Real Gases]

18. Critical temperature and critical pressure value of four gases are given

Gas	Critical Temp. (K)	Critical Pressure (atm)
P	5.1	2.2
Q	33	13
R	126	34
S	135	40

Which of the following gas(es) cannot be liquefied at a temperature 100 K and pressure 50 atm ?

(1) S only
(2) P only
(3) R and S
(4) P and Q

Sol. Answer (4)

$R \rightarrow T = 126$ K

$S \rightarrow T = 135$

The temperature above which gas cannot be liquefied both R and S have temperature greater than 100 K.

19. For H_2 and He, compressibility factor (Z) and molar volume (V_m) at STP are

(1) $Z > 1$, $V_m < 22.4$ litre
(2) $Z < 1$, $V_m > 22.4$ litre
(3) $Z > 1$, $V_m > 22.4$ litre
(4) $Z < 1$, $V_m < 22.4$ litre

Sol. Answer (3)

20. Select the order of following temperatures for a gas

(A) Boyle's temperature
(B) Critical temperature
(C) Inversion temperature

(1) A > C > B
(2) B > A > C
(3) A > B > C
(4) C > A > B

Sol. Answer (4)

$$T_B = \frac{a}{Rb},\ T_C = \frac{8a}{27Rb},\ T_i = \frac{2a}{Rb}$$

21. At relatively high pressure, van der Waal's equation reduces to

(1) $PV_m = RT$
(2) $PV_m = RT - a/V_m^2$
(3) $PV_m = RT + Pb$
(4) $PV_m = RT - a/V_m$

Sol. Answer (3)

At high pressure,

$$\left(P+\frac{a}{V_m^2}\right)\cong P \qquad \therefore \quad \left(P+\frac{a}{V_m^2}\right)(V_m-b)=RT$$

$\therefore$ $(V_m - b)P = RT$

$\Rightarrow PV_m - Pb = RT$

or $PV_m = RT + Pb$ or $\frac{PV_m}{RT}-\frac{Pb}{RT}=1$

$$\Rightarrow \; z-\frac{Pb}{RT}=1$$

$$\Rightarrow \; z=1+\frac{Pb}{RT}$$

22. Consider the following statements :

I. The pressure of moist gas is more than that of dry gas under identical condition.

II. Critical temperature is the highest temperature at which liquid and vapour coexist .

III. At constant temperature, PV vs P (P = pressure and V = volume) plot for real gases will be a straight line at very high pressure.

The correct statement(s) is/are

(1) Only II & III (2) Only I & II (3) Only I & III (4) I, II & III

Sol. Answer (4)

All the given statements are correct.

23. Which has highest value of critical temperature?

(1) He (2) H_2 (3) CO_2 (4) O_2

Sol. Answer (3)

$$T_c = \frac{8a}{27Rb}$$

Due to dipole – dipole interaction.

[Miscellaneous]

24. Both rate of diffusion and effusion is inversely proportional to the $\sqrt{M}$ because of the common fact that

(1) Diffusion & effusion are same (2) Molecular speed $\propto \frac{1}{\sqrt{M}}$

(3) Both take place due to pressure difference (4) Both take place due to concentration difference

Sol. Answer (2)

Fact

25. Considering air as a 4 : 1 mixture of N_2 and O_2, what is the density of air at 28°C and 1 atm?

(1) 1.18 g L^{-1} (2) 11.62 mg L^{-1} (3) 28.8 g L^{-1} (4) 1.29 g L^{-1}

Sol. Answer (1)

$$PM = dRT \Rightarrow d = \frac{PM}{RT}$$

26. A 50 ml sample of gas is collected over water what will be the effect on the calculated molar mass of the gas if the effect of the water vapour is ignored? It will be

(1) High because of the mass of the water in the collection flask

(2) High because of omitting the vapour pressure of the water in the calculation

(3) Low because of the mass of water in the collection flask

(4) Low because of omitting the vapour pressure of the water in the calculation

Sol. Answer (4)

Molecular weight of dry air is higher than humid air.

27. What is the major reason for using mercury in barometers rather than H_2O?

(1) Mercury is much denser than water so rises up to lower height

(2) Mercury has high boiling point than water

(3) Mercury is chemically unreactive

(4) Mercury expands with a decrease in air pressure whereas water does not

Sol. Answer (1)

Fact

28. 10 L of a sample of gas at 37° C and 1 atm pressure is compressed to a volume of 2.5 L at constant temperature. The percentage change in pressure is

(1) 75% (2) 300% (3) 400% (4) 80%

Sol. Answer (2)

$P_1V_1 = P_2V_2$

$$\Rightarrow P_2 = \frac{1 \times 10}{2.5} = 4 \text{ atm}$$

$$\Rightarrow \text{ \% change in pressure } = \frac{4-1}{1} \times 100 = 300\%$$

29. The compression factor (Z) for CO_2 at 7°C and 100 atm is 0.21. Calculate the volume of a 4 mole sample of CO_2 at same temperature and pressure (use R = 0.08 L. atm/K.mol

(1) 0.19 L (2) 0.05 L (3) 0.38 L (4) 0.44 L

Sol. Answer (1)

$$Z = \frac{V_{real}}{V_{ideal}} = 0.21$$

$\Rightarrow \quad \frac{PV_{real}}{nRT} = 0.21$

$\Rightarrow \quad V_{real} = \frac{0.21 \times 4 \times 0.08 \times 280}{100} = 0.19 \text{ L}$

30. Vapour pressure in a closed container can be changed by

(1) Adding water vapours from outside at same temperature

(2) Adding ice at same temperature

(3) Adding water at same temperature

(4) Increasing temperature

Sol. Answer (4)

Vapour pressure of liquid is function of temperature.

31. A 2 L vessel contains 4 g of Helium and 4 g of H_2 gas at 27°C. After sometime, 50% of the gas having higher average speed is removed. What is the percentage reduction in total pressure if temperature remains constant?

(1) 66.67% (2) 33.33% (3) 50% (4) 25%

Sol. Answer (2)

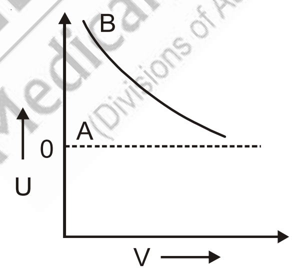
$P_1 = \frac{\left(\frac{4}{4}+\frac{4}{2}\right) R \times 300}{2} = 450 \text{ R}$

H_2 has higher average speed.

$P_2 = \frac{(1+1)\, R \times 300}{2} = 300 \text{ R}$

Percentage decrease in pressure = $\frac{150 \text{ R}}{450 \text{ R}} \times 100 = 33.33\%$

32. A graph between U (potential energy) and V (volume) is plotted at constant temperature for gases A and B.



Correct statement regarding B and A will be respectively

(1) Real gas in which attractions are dominant, ideal gas

(2) Real gas in which repulsions are dominant, ideal gas

(3) Ideal gas, ideal gas

(4) Real gas in which repulsions are dominant, real gas in which attractions are dominant

Sol. Answer (2)

Real gas in which repulsion dominates, U decreases with expansion.

33. The ratio of rate of diffusion of CH_4 and O_3 under similar conditions of temperature and pressure is

(1) 1 : 3 (2) 3 : 2 (3) $\sqrt{2}$: 1 (4) $\sqrt{3}$: 1

Sol. Answer (4)

34. Pressure of an ideal gas decreases to 5% at 5°C of its original value of 5 atm at 283°C. What is the percentage change in its density?

(1) 10% (2) 75% (3) 90% (4) 25%

Sol. Answer (3)

$$\frac{P_1}{d_1T_1} = \frac{P_2}{d_2T_2}$$

$$P_2 = \frac{5}{100} \times 5 = 0.25 \text{ atm}$$

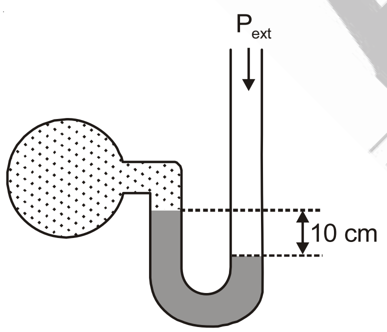
$$\frac{d_2}{d_1} = \frac{P_2}{P_1} \times \frac{T_1}{T_2} = \frac{0.25}{5} \times \frac{556}{278} = 0.1$$

$$\frac{\Delta d}{d_1} \times 100 = 90\%$$

35. A manometer consists of a U-shaped tube containing water. One side is connected to the apparatus and the other side is open to the atmosphere. If external pressure is 1 atm and the level of water on the open side of tube is 10 cm lower than the side connected to the apparatus. The pressure of gas is (Assume density of water is 1 g/ml and g is 10 m/s^2, 1 atm = 1.013 × 10^5 Pa)

(1) 1.1 atm (2) 0.99 atm (3) 1.2 atm (4) 0.90 atm

Sol. Answer (2)



$$P_{gas} + \rho\, gh = 1 \text{ atm} = 101300 \text{ Pa}$$

$$P_{gas} = 101300 - \rho\, gh$$

$$= \left[\frac{101300 - (1000 \times 10 \times 0.1)}{1.013 \times 10^5}\right] \text{atm}$$

36. 30 mL of a sample containing $H_2(g)$, $CH_4(g)$ and C(g) required 35 mL of O_2 for complete combustion. There was a contraction of 20 mL when the mixture was treated with KOH. What is the composition of $CH_4(g)$ and $H_2(g)$ respectively in original mixture?

(1) 50%, 25% (2) 33.33%, 33.33% (3) 20%, 35% (4) 66.67%, 15%

Sol. Answer (2)

$$\underset{x}{C(g)} + O_2 \longrightarrow \underset{x}{CO_2(g)}$$

$$\underset{y}{H_2} + \frac{1}{2}O_2 \longrightarrow H_2O$$

$$\underset{z}{CH_4} + 2O_2 \longrightarrow \underset{z}{CO_2} + 2H_2O$$

$x + y + z = 30$ ...(i)

Volume of O_2 required = $x + \frac{y}{2} + 2z = 35$ ...(ii)

From (i) and (ii),

$x + 3z = 40$

Volume of CO_2,

$x + z = 20$

by solving,

$z = 10,\ x = 10,\ y = 10$

37. At 37°C and 0.1 atm, the mass density of phosphorous vapour is 0.5 g/L. The molecular formula of phosphorus is $\left(\text{take } R = 0.08 \frac{\text{atm L}}{\text{mol K}}\right)$

(1) P (2) P_2 (3) P_3 (4) P_4

Sol. Answer (4)

PM = dRT

$$M = \frac{dRT}{P} = \frac{0.5 \times 0.08 \times 310}{0.1} = 124 \text{ g}$$

So formula is P_4.

38. What is the value of compressibility factor of O_2 if 1 mole of O_2 is present in 750 ml vessel at 17°C and pressure of O_2 is 14.5 atm?

(1) 1.2 (2) 1 (3) 0.46 (4) 0.20

Sol. Answer (3)

$$Z = \frac{PV}{RT} = \frac{14.5 \times 0.75}{0.082 \times 290} = 0.46$$

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