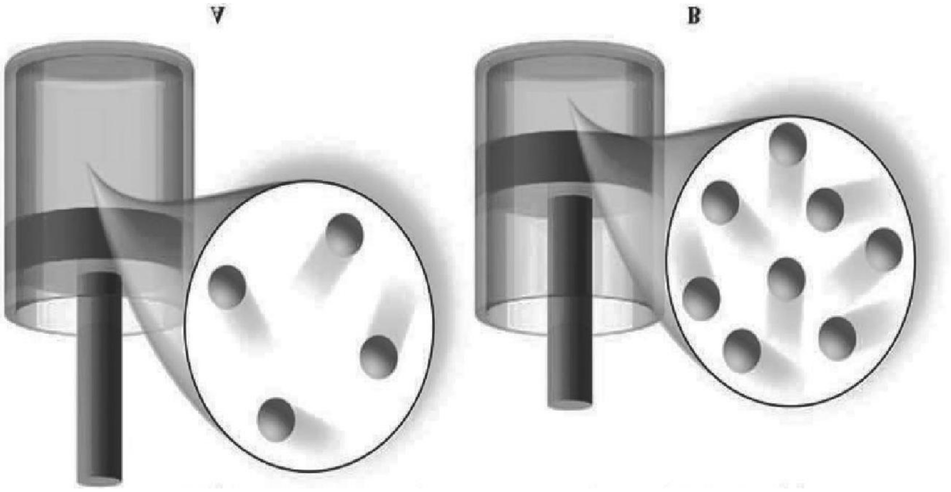
STATES OF MATTER

Table of Contents



THEORY

INTRODUCTION

Any substance that has mass and occupies space is called Matter. Matter is composed of atoms or molecules. The arrangement of these building blocks gives matter various states, physical and chemical properties. The force of interaction between these particles give matter its physical properties based on which matter can be classified into solid, liquid or gases. The force of interaction between atoms/ molecules is **highest in solids** and **least in liquids.**

In this unit, we will learn more about these three physical states of matter particularly liquid and gaseous states.

1. INTERMOLECULAR FORCES

The forces of attraction existing among the molecules of a substance (gaseous, liquid or solid) are called intermolecular forces.

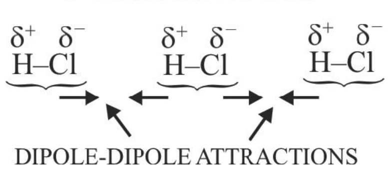
Dipole-dipole, dipole-induced dipole and dispersion forces are collectively called as van der Waals forces. Ion-dipole and ion-induced dipole forces are not van der Waals forces. Further, hydrogen bonding is only a special type of dipole-dipole attraction shown only by limited number of elements.

The different types of intermolecular forces are :

1.1 Dipole-Dipole Interactions

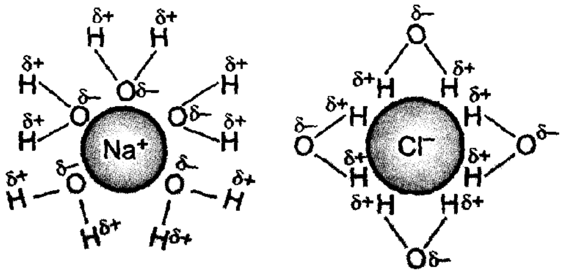
These forces of attraction occur among the polar molecules. Polar molecules have parmanent dipoles. The positive ple of one molecule is thus attracted by the negative pole of the other molecule.

HCl in which chlorine being more electronegative acquires a slight negative charge whereas the hydrogen end becomes slightly positively charged. The dipole-dipole interactions then take place among the HCl molecules :



1.2 Ion-Dipole Interactions

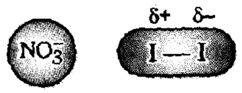
This is the attraction between an ion (cation or anion) and a polar molecule. For example, when NaCl is dissolved in water, the polar water molecules are attracted towards Na^+ ion as well as towards Cl^- ion.



Ion-dipole attractions between Na^+ and H_2O molecules and Cl– ion and H_2O molecules

1.3 Ion-Induced dipole Interactions

A non-polar molecule may be polarized by the presence of an ion near it, i.e., it becomes an induced dipole. The interactions between them are called ion-induced dipole interactions.

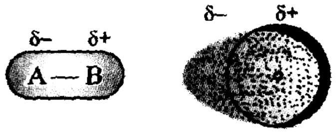


Ion-induced dipole attractions between NO_3^- ion and I_2 molecule

For example, in the presence of nitrate ion (NO_3^-), iodine molecule (I_2), which is non-polar, gets polarized as $(\overset{\delta+}{\text{I}} - \overset{\delta-}{\text{I}})$ as shown in fig.

1.4 Dipole-Induced dipole Interactions

A non-polar molecule may be polarized by the presence of a polar molecule (dipole) near it, thereby making it an induced dipole. The interactions between them are then called dipole-induced dipole interactions.

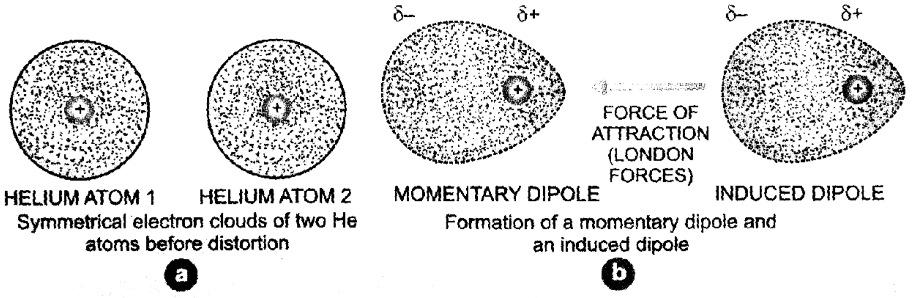


Dipole-induced dipole attractions

For example, noble gases get polarized in the presence of polar molecules.

1.5 London forces or Dispersion forces

At any instant of time, the electron cloud of the molecule may be distorted so that an instantaneous dipole or momentary dipole (i.e., a dipole for a short while) is produced in which one part of the molecule is slightly more negative than the rest. The momentary dipoles induce dipoles in the neighbouring molecules. These are then attracted to each other. The forces of attraction between the induced momentary dipoles are called London dispersion forces.



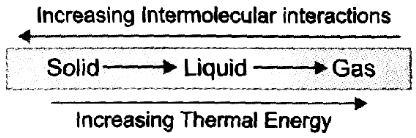
Forces of attraction between momentary dipoles and induced dipoles (London forces) in helium atoms

2. INTERMOLECULAR FORCES VERSUS THERMAL ENERGY

Whether a substance will exist as a solid or a liquid or a gas is the result of competition between :

(i) intermolecular forces, i.e., the forces of interaction between the molecules of that substance which try to bring the molecules closer, and

(ii) thermal energy possessed by the molecules due to temperature which results into the movement of the molecules and hence tries to keep them apart.



3. IDEAL GAS

An ideal gas is a **hypothetical concept** of matter and is treated as a standard of comparison while studying the various states of matter. There are various assumptions associated with an ideal gas. The most notable of these assumptions are:

- Volume of the molecules are infinitely small and the force of interaction between the molecules is zero
- The molecules of the gas undergo random motion colliding with each other and the walls of the container
- Laws of classical mechanics are applicable on the molecules.

4. STATE OF A GAS AND STATE VARIABLES

"State" of a gas means the physical condition of the system. Certain variables are used to represent physical condition of the gas which are termed as **state variables.**

There are majorly three variables for a given sample of a gas, i.e. **Pressure, Volume and Temperature (P, V and T).** When the values of these three parameters are fixed for a gas, we say it to be in a fixed state.

4.1 Pressure

A force is exerted on the walls of the container due to the collisions of the atoms/molecules. This force averaged per unit area is called the pressure.

4.1.1 Measurement of pressure of a gas

The most common instrument used to measure the pressure of a gas is called a **barometer.** Another instrument used to measure pressure is **manometer.**

4.2 Volume

In case of rigid containers, the volume of the gas is same as the volume of the container it is kept in. However, for containers which can expand (e.g. balloon), the volume of the gas is determined by the other two state functions and **moles of the gas taken.**

4.3 Temperature

Temperature is a measure of the amount of heat contained in the gas. When the temperature of the gas equals the surrounding temperature, no heat flows in or out of the gas and the gas is said to be in a state of **Thermal Equilibrium.**

4.3.1 Measurement of Temperature

The instrument used to measure the temperature of a gas is called a thermometer. There are three units used in measuring temperature viz. ^{o}C, ^{o}F and K.

Pressure relations	Temperature relations	Volume relations
1 atm = 1.0132×10^5 Pa 1 bar = 10^5 Pa 76 cm Hg = 1 atm =760 mm Hg 1 torr = 1 mm Hg 1 kPa = 1000 Pa	1.8 T (^{0}C) = T (^{0}F) – 32 T (K) = T (^{0}C) + 273.15	1 L = 1000 mL 1 m^3 = 1000 L 1 mL = 1 cc 1 dm^3 = 1 L

5. IDEAL GAS LAW

There are four laws which relate the state variables of a gas in two states. These four laws are :

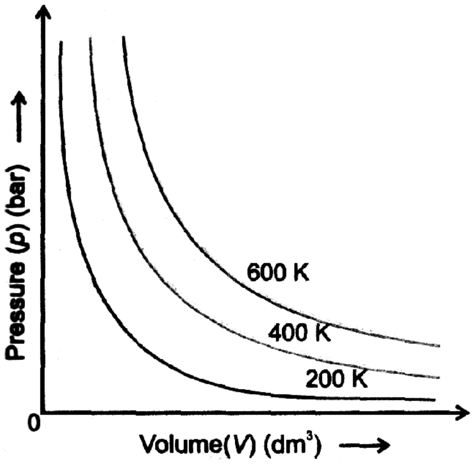
5.1 Boyle's Law (Pressure – Volume Relationship)

It states that at constant temperature, the pressure of a fixed amount (i.e. number of moles n) of gas varies inversely with its volume. This is known as Boyle's law Mathematically

$$p \propto \frac{1}{V} \text{ (at constant T and n)}$$

PV = constant

$$\Rightarrow p_1V_1 = p_2V_2$$

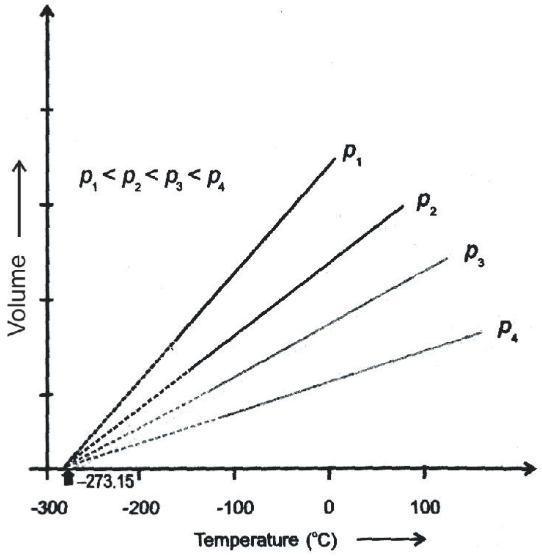


Graph of pressure, p vs. Volume, V of a gas at different temperature

Each curve corresponds to a different constant temperature and is known as an isotherm.

5.2 Charles's Law (Temperature - Volume Relationship)

It states the pressure remaining constant, the volume of a fixed mass of a gas is directly proportional to its absolute temperature.



Each line of the volume vs temperature graph is called isobar.

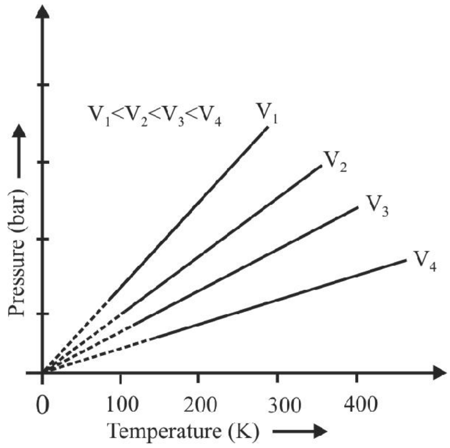
5.3 Gay Lussac's Law (Pressure-Temperature Relationship)

It states that at constant volume, pressure of a fixed amount of a gas varies directly with the temperature. Mathematically,

$$p \propto T$$

$$\Rightarrow \frac{P}{T} = \text{constant}$$

Each line of pressure is temperature graph is called isochore.



Pressure vs temperature (K) graph (Isochores) of gas.

5.4 Avogadro Law (Volume - Amount Relationship)

It states that equal volumes of all gases under the same conditions of temperature and pressure contain equal number of molecules.

Mathematically

$V \propto n$ where n is the number of moles of the gas.

6. IDEAL GAS EQUATION

The above laws can be combined together in a single equation which is known as ideal gas equation.

At constant T and n; $V \propto \frac{1}{p}$ Boyle's Law

At constant p and n; $V \propto T$ Charles's Law

At constant p and T; $V \propto n$ Avogadro Law

Thus,

$$V \propto \frac{nT}{p}$$

$$\Rightarrow \quad V = R\frac{nT}{p}$$

where R is proportionality constant. On rearranging the equation we obtain

$pV = nRT$

This equation is called ideal gas equation.

$$\Rightarrow \quad R = \frac{pV}{nT}$$

R is called gas constant. It is same for all gases. Therefore it is also called universal gas constant.

Values of R :

(i) $R = 8.314\ J\ K^{-1}\ mol^{-1}$, (ii) $R = 0.0821\ L\ atm\ K^{-1}\ mol^{-1}$.

(iii) $R = 2\ cal\ K^{-1}\ mol^{-1}$.

If temperature, volume and pressure of a fixed amount of gas vary from T_1, V_1 and p_1 to T_2, V_2 and p_2 then we can write

$$\frac{p_1V_1}{T_1} = nR \text{ and } \frac{p_2V_2}{T_2} = nR$$

$$\Rightarrow \quad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

This equation is alos known as combined gas law.

7. VARIATION OF THE IDEAL GAS EQUATION

Ideal gas equation can be rearranged as follows :

$$\frac{n}{V} = \frac{p}{RT}$$

Replacing n by $\frac{m}{M}$, we get

$$\frac{m}{MV} = \frac{p}{RT}$$

$$\frac{d}{M} = \frac{p}{RT} \text{ (where d is the density)}$$

$$\Rightarrow \quad pM = dRT$$

8. DALTON'S LAW OF PARTIAL PRESSURES

It states that the total pressure exerted by the mixture of non-reactive gases is equal to the sum of the partial pressures of individual gases i.e., the pressures which these gases would exert if they were enclosed separately in the same volume and under the same conditions of temperature. In a mixture of gases, the pressure exerted by the individual gas is called partial pressure. Mathematically,

$p_{Total} = p_1 + p_2 + p_3 + ...$ (at constant T, V)

where p_{Total} is the total pressure exerted by the mixture of gases and p_1, p_2, p_3 etc. are partial pressures of gases.

Partial pressure in terms of mole fraction

Suppose at the temperature T, three gases, enclosed in the volume V, exert partial pressure p_1, p_2 and p_3 respectively. then,

$$p_1 = \frac{n_1RT}{V}$$

$$p_2 = \frac{n_2RT}{V}$$

$$p_3 = \frac{n_3RT}{V}$$

where n_1 n_2 and n_3 are number of moles of these gases. Thus expression for total pressure will be

$$p_{Total} = p_1 + p_2 + p_3$$

$$= n_1\frac{RT}{V} + n_2\frac{RT}{V} + n_3\frac{RT}{V}$$

$$= (n_1 + n_2 + n_3)\frac{RT}{V}$$

On dividing p_1 by p_{total} we get

$$\frac{p_1}{p_{total}} = \left(\frac{n_1}{n_1 + n_2 + n_3}\right)\frac{RTV}{RTV}$$

$$= \frac{n_1}{n_1 + n_2 + n_3} = \frac{n_1}{n} = x_1$$

where $n = n_1 + n_2 + n_3$

x_1 is called mole fraction of first gas.

Thus, $p_1 = x_1\, p_{total}$

Similarly for other two gases we can write

$p_2 = x_2\, p_{total}$ and $p_3 = x_3\, p_{total}$

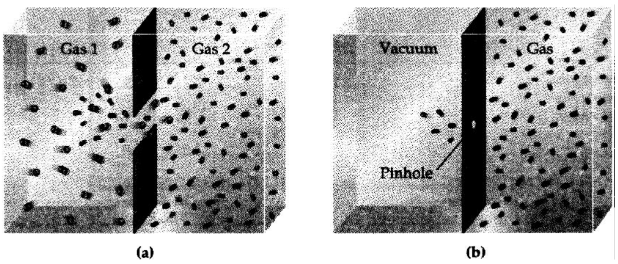
Thus a general equation can be written as

$p_i = x_i\, p_{total}$

9. GRAHAM'S LAW OF DIFFUSION

Diffusion is a process of intermixing of gases. This is a natural tendency of any gas to occupy the whole volume available to it. So even without pressure difference gases mix with each other. If the pressure difference is increased the diffusion process becomes faster.

Effusion is flow of a gas through small openings due to pressure difference that is it is a case of fast diffusion.



(a) Diffusion is mixing of gas molecules by random motion under conditions where molecular collisions occur.

(b) Effusion is the escape of a gas through a pinhole without molecular collisions.

According to Graham's Law the rate of diffusion depends on pressure and molecular weight of a gas. Rate of Diffusion is directly proportional to Partial Pressure of the gas and inversely proportional to the square root of molar mass of the gas. That is, greater the pressure faster is the movement of molecules and heavier the molecules, slower are their movement.

Rate of diffusion $\propto$ P (partial pressure)

Also, $\propto 1/\sqrt{M}$

Therefore we can write:

Rate, r $\propto$ P/ $\sqrt{M}$

Rate of diffusion may be defined in various ways. It may be number of moles transferred per unit time, Volume transferred per unit time, distance travelled per unit time and even pressure drop per unit time. While comparing the rates of two gases, we should take similar definitions of rate, it may be n/t, V/t or d/t.

$$\frac{r_2}{r_1} = \frac{P_2}{P_1}\sqrt{\frac{M_1}{M_2}}$$

Graham's Law can be applied to diffusion and effusion both.

10. KINETIC THEORY OF GASES

Assumptions or postulates of the kinetic-molecular theory of gases are given below. These postulates are related to atoms and molecules which cannot be seen, hence it is said to provide a microscopic model of gases.

(i) Gases consist of large number of identical particles (atoms or molecules) that are so small and so far apart on the average that the actual volume of the molecules is negligible in comparison to the empty space between them.

(ii) There is no force of attraction between the particles of a gas at ordinary temperature and pressure.

(iii) Particles of a gas are always in constant and random motion.

(iv) Particles of a gas move in all possible directions in straight lines. During their random motion, they collide with each other and with the walls of the container. Pressure is exerted by the gas as a result of collision of the particles with the walls of the container.

(v) Collisons of gas molecules are perfectly elastic. This means that total energy of molecules before and after the collision remains same.

(vi) At any particular time, different particles in the gas have different speeds and hence different kinetic energies.

It is possible to show that though the individual speeds are changing, the distribution of speeds remains constant at a particular temperature.

If a molecule has variable speed, then it must have a variable kinetic energy. Under these circumstances, we can talk only about average kinetic energy. In kinetic theory it is assumed that average kinetic energy of the gas molecules is directly proportional to the absolute temperature.

The important mathematical results from this Theory are ;

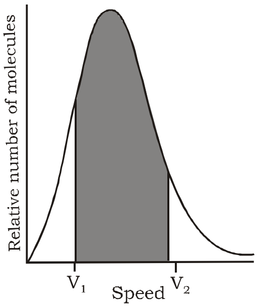
K.E. per mole = 3/2 nRT

K.E. per molecule = 3/2 kT

where R = 8.314 and $k = R/N_A = 1.38 \times 10^{-23}$ J/K

11. Molecular Distribution of speeds (Max well Boltzmann Distribution)

The Maxwell Boltzmann Distribution is a plot of **fraction of molecules in the gas sample** vs. the **speed of the gas molecules.** The distribution is shown below followed by the salient features of the graph.



The graph shows that :

- The fraction of molecules having very low or very high speeds is very less.
- Most of the molecules have a speed somewhere in the middle, this is called the most probable speed. (μ_{MP})
- The area covered between any two velocities is the number of molecules in that velocity range.
- The total area covered by the graph gives the total number of molecules in the sample and is constant.
- There are two more molecular speeds defined for a sample called average speed (u_{AVG}) and root mean square speed (u_{RMS})

$$u_{RMS} = \sqrt{\frac{3RT}{M}} \qquad u_{MP} = \sqrt{\frac{2RT}{M}} \qquad u_{AVG} = \sqrt{\frac{8RT}{\pi M}}$$

NB : ***Always remember to take molecular mass in kg in the above relations.***

It's useful to remember the ratio of $u_{MP} : u_{AVG} : u_{RMS}$ = 1:1.128:1.224 for a given gas at the same temperature.

12. REAL GASES

In case of real gases two of assumption taken for ideal gases become invalid or restricted only to some particular conditions.

(i) We assumed that there are no interactions between molecules of an ideal gas.

(ii) We assumed that volume of the molecules of a gas is negligible as compare to entire volume of gases.

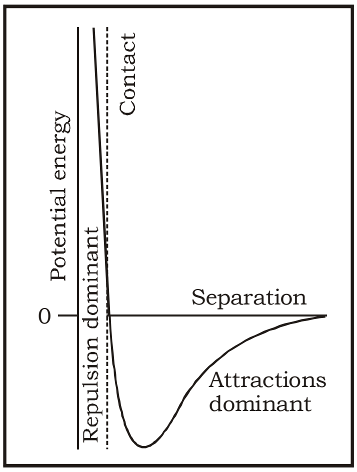
In case of real gases, we cannot ignore the molecular interactions any more.

There are two types of forces of interaction :

Long Ranged attractive forces. &

Short Ranged repulsive forces.

When the molecules of a real gas are far apart, the interactive forces are negligible. When the molecules are brought closer to each other attractive forces start to develop and when the molecules are too close they start repelling each other. The following curve represents the variation of potential energy of a system of two molecules of a real gas with distance between them.



13. COMPRESSIBILITY FACTOR

The deviation from ideal behaviour can be measured in terms of compressibility factor (Z).

$Z = V_m(\text{real})/V_m(\text{ideal})$

- At very low pressures, there are no interactions between the molecules of the real gas and Z = 1.
- At low or moderate pressure, there are attractive forces dominant due to which a real gas is compressed to a greater volume than expected, therefore Z < 1.

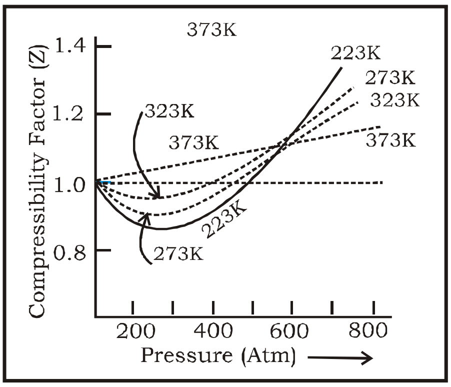
- At high pressures, repulsions dominate and it is tough to compress the real gas so it is compressed to smaller volume than expected thus $Z > 1$.

  Z is always 1 for ideal gases.

  For real gases $Z = PV/nRT$.

13.1 Variation of Z with P and T

The graph of compressibility factor, Z, with pressure for an ideal gas is a straight line. However, for real gases the value of Z is <1 for low pressures and then Z becomes >1 as pressure increases and keeps on increasing. On increasing the temperature the graph tends more towards Z=1 i.e. ideal gas.



It can be concluded from the above graphs that real gas follows ideal behavior at low pressure and high temperature. This does not mean that if you keep on increasing the temperature a real gas will convert to ideal gas. There is a characteristic temperature at which a gas follows ideal behavior most closely; this is called **Boyle's temperature.**

14. VANDERWALL'S EQUATION

This equation was formulated taking into account correction factors for pressure and volume into the ideal gas equation.

$$\left(P + {an^2}/{V^2}\right)(V - nb) = nRT$$

Constants a and b are called vander waals constants and their value depends on the characteristic of a gas.

Note :

(i) Unit of a $\equiv \frac{L^2\ \text{atm}}{\text{mol}^2}$; $b \equiv \frac{L}{\text{mol}}$

(ii) a ≡ Relates to the forces interacting between the gas molecules and modifies the pressure term.

('a' is high if the gas molecules have more attractive forces)

(iii) b ≡ Relates to the volume occupied by the gas molecules and takes into account the fact that the space actually occupied by the molecules themselves is unavailable for the molecules to move in and is given by :

$b = 4 \times$ volume of 1 mol of gas molecules.

(iv) For a given gas Van der Waal's constant 'a' is always greater than 'b'.

(v) The gas having higher values of 'a' can be liquefied easily.

14.1 Applicability of Vanderwaal's Equation

Under the conditions of high temperature and low/moderate pressure and also under very low pressure Z = 1 and the above equation becomes $PV_m = RT$.

14.2 At low/moderate Pressure

The volume correction factor can be ignored and Z<1 where the attractive forces dominate. The equation becomes:

$$Z = \left(1 - \frac{a}{V_m RT}\right)$$

14.3 At high Pressure

The volume correction factor cannot be ignored but the pressure correction factor can be ignored. Z > 1 and the equation is:

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

$$\Rightarrow Z = \left(1 + \frac{Pb}{RT}\right)$$

15. LIQUEFICATION OF GASES

When the molecules of a gas are brought closer to each other, due to increase in the attractive forces, a stage may be reached when the gas changes its phase to liquid. This phenomenon is called Liquefaction of gases.

15.1 Critical Temperature, T_C

The characteristic temperature of a real gas above which it cannot be liquefied.

$\mathbf{T_C = 8a/27Rb}$

15.2 Critical Pressure, P_C

It is the minimum pressure required for liquefaction to take place at critical temperature

$\mathbf{P_C = a/27b^2}$

15.3 Critical Volume, V_C

It is the volume occupied by one mole of a gas under critical temperature and pressure.

$V_C = 3b$

NB: *The compressibility factor at critical point is constant for all gases and has a value of 0.375.*

For liquefication of real gases, we can do either of the following :

(1) Increase the pressure on the gas

(2) Decrease the temperature of gas but temperature is the dominant factor and pressure assumes a secondary role.

16. LIQUID STATE

Intermolecular forces are stronger in liquid state than in gaseous state.

1. Properties of liquids : Molecules in liquids are so close that there is very little empty space between them and under normal conditions liquids are denser than gases.

2. Molecules of liquids are held together by attractive intermolecular forces. Liquids have definite volume because molecules do not separate from each other.

3. Molecules of liquids can move past one another freely, therefore, liquids can flow, can be poured and can assume the shape of the container in which these are stored.

4. **Vapour pressure** of a liquid at any temperature may be defined as the pressure exerted by the vapour present above the liquid in equilibrium with the liquid at that temperature.

Factors affecting vapour pressure

Two important factors on which the vapour pressure of a liquids depends are :

(a) **Nature of the liquid :** If the intermolecular forces of attraction in the liquid are weak, the molecules can easily leave the liquid and come into the vapour phase and hence the vapour pressure is higher.

(b) **Effect of temperature :** As the temperature of a liquid is increased, the vapour pressure of the liquid increases.

Boiling point of a liquid is defined as the temperature at which the vapour pressure of the liquid becomes equal to the external pressure (i.e., the atmospheric pressure).

When the external pressure is normal atmospheric pressure (i.e., 760 mm), the boiling point is called the normal boiling point.

When the external pressure is equal to 1 bar, the boiling point is called standard boiling point of the liquid.

Some Applications of Effect of External Pressure on Boiling point.

(i) Obviously, if the external pressure is higher, more heat will be required to make the vapour pressure equal to the external pressure and hence higher will be the boiling point. That is why in hospitals, surgical instrumnts are sterilized in autoclaves in which boiling point of water is raised by using a weight to cover the vent.

(ii) Similarly, if the external pressure is decreased, the boiling point is lowered. This is the reason that a liquid boils at a lower temperature on the top of a mountain (where pressure is low) than on the sea shore. That is why at hills, use of pressure cooker is essential for cooking food.

5. **Surface tension** is a characteristic property of liquids which arises due to the fact that the molecules of the liquid at the surface are in different situation than those in the interior of the liquid.

Surface tension of a liquid is defined as the force acting at right angles to the surface along one centimetre length of the surface. Thus, the units of surface tension are dynes per cm (or Newtons per metre, i.e., N m^{-1} in the S.I. system.

Some important Results

(i) **Spherical shape of drops** the lowest energy state of a liquid will be when the surface area is minimum. Surface tension tries to decrease the surface area of the liquid to the minimum. The drops of a liquid (or the bubbles of a gas) are spherical because for a given volume, a sphere has minimum surface area.

(ii) **Fire polishing of glass.** Sharp glass edges are heated to make them smooth. This is because on heating, the glass melts and takes up rounded shape at the edges which has minimum surface area.

(iii) **Rise of a liquid in a capillary tube.** This rise is obviously due to the inward pull of surface tension acting on the surface which pushes the liquid into the capillary tube.

(iv) **Effect of nature of the liquid on surface tension.** Surface tension is a property that arises due to the intermolecular forces of attraction among the molecules of the liquid. Greater are the intermolecular forces of attraction, higher is the surface tension of that liquid.

(v) **Effect of temperature on surface tension.** The surface tension of liquids generally decreases with increase of temperature and becomes zero at the critical temperature (where the meniscus between the liquid and the vapour disappears). The decrease in surface tension with increase of temperature is obviously due to the fact that with increase of temperature, the kinetic energy of the molecules (and hence the speeds of molecules) increases and, therefore, the intermolecular attraction decreases.

6. **Viscosity** is one of the characteristic properties of liquids. Viscosity is a measure of resistance to flow which arises due to the internal friction between layers of fluid as they slip past one another while liquid flows.

The type of flow in which there is a regular gradation of velocity in passing from one layer to the next is called laminar flow.

If the velocity of the layer at a distance dz is changed by a value du then velocity gradient is given by the amount $\frac{du}{dz}$.

A force is required to maintain the flow of layers. This force is proportional to the area of contact of layers and velocity gradient i.e.

$F \propto A$ (A is the area of contact)

$F \propto \frac{du}{dz}$ (where, $\frac{du}{dz}$ is velocity gradient; the change in velocity with distance)

$$F \propto A.\frac{du}{dz}$$

$$\Rightarrow \; F \propto \eta A\frac{du}{dz}$$

'η' is proportional constant and is called coefficient of viscosity. Viscosity coefficient is the force when velocity gradient is unity and the area of contact is unit area. Thus 'η' is measure of viscosity. SI unit of viscosity coefficient is 1 newton second per square metre ($N\ s\ m^{-2}$) = pascal second ($Pa\ s = 1 kg\ m^{-1}s^{-1}$). In cgs system the unit of coefficient of viscosity is poise.

1 poise = $1\ g\ cm^{-1}s^{-1} = 10^{-1} kg\ m^{-1}s^{-1}$

- Greater the viscosity, the more slowly the liquid flows. Hydrogen bonding and van der Waals forces are strong enough to cause high viscosity. Glass is an extremely viscous liquid.
- Viscosity of liquids decreases as the temperature rises because at high temperature molecules have high kinetic energy and can overcome the intermolecular forces to slip past one another between the layers.

MEASUREMENT OF PRESSURE OF A GAS

The pressure of a gas can be measured by various methods. Mostly it is measured in terms of heights of liquid column. We know that a liquid exerts pressure on the bottom of a container or a tube due to gravity.

Suppose there is a liquid of density ρ filled in a tube (cross sectional area A) up to a height h and there is vacuum above it.

Then :

Volume of the liquid = $\mathbf{A \times h}$

Mass of the liquid = $\mathbf{\rho \times A \times h}$

Force applied at the bottom = weight of the liquid = $\mathbf{\rho \times g \times A \times h}$

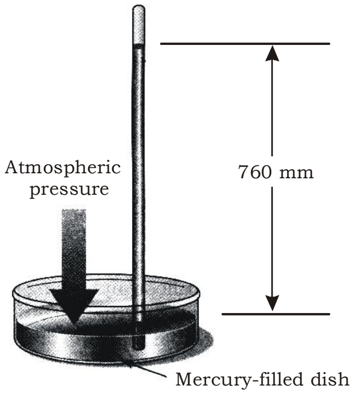
Pressure = F/A = ρgh

If a tube filled with a liquid is kept at an angle θ then only the vertical component of weight is taken.

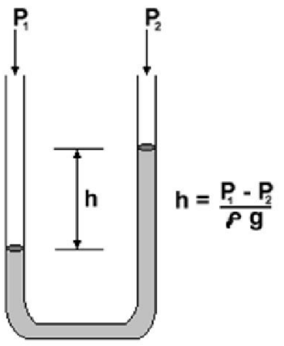
Pressure = $\rho gh \times \sin\theta$

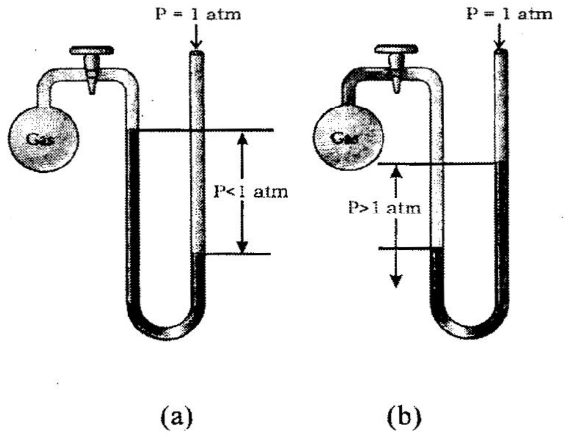
A common arrangement to measure pressure of a gas is called ***"Barometer"*** as shown in the figure.

A mercury barometer is used to measure atmospheric pressure by determining the height of a mercurry column supported in a sealed glass tube.



Another arrangement to measure gas pressure is called "U-tube manometer".





Open-end manometers for measuring ressure in a gas-filled bulb. In (a), the pressure in the bulb is lower than atmospheric, so the mercury level is higher in the arm open to the bulb, in (b), the pressure in the bulb is higher than atmospheric, so the mercury level is higher in the arm open to the atmosphere.

TABLE FOR FORMULAE USED IN THE CHAPTER

- For a U tube manometer; $\Delta h = \frac{P_1 - P_2}{\rho g}$
- **Boyle's Law :** $PV = \text{constant} \Rightarrow P_1V_1 = P_2V_2$
- **Charles' Law :** $V/T = \text{constant} \Rightarrow V_1/T_1 = V_2/T_2$
- **Gay Lussac's Law :** $P/T = \text{constant} \Rightarrow P_1/T_1 = P_2/T_2$
- **Avogadro's Law :** $V \propto n$
- **Ideal Gas Equation :** $PV = nRT$
- Variation of ideal gas equation: $PM = \rho RT$
- **Dalton's Law of Partial Pressure :** Pressure due a gas in a gas mixture $P_A = X_A P_{TOTAL}$
- **Graham's Law of diffusion :**

  rate of diffusion $\propto$ Pressure/$\sqrt{M}$
- $u_{RMS} = \sqrt{\frac{3RT}{M}}$ $\quad u_{MP} = \sqrt{\frac{2RT}{M}}$

  $u_{AVG} = \sqrt{\frac{8RT}{\pi M}}$
- $u_{MP} : u_{AVG} : u_{RMS} = 1:1.128:1.224$
- **Compressibility Factor,** $Z = V_{real}/V_{ideal}$
- **Vander waal's Equation :**

  $(P+an^2/V^2)(V-nb) = nRT$
- Vanderwaal's constant or co-volume:

  $b = 4\times(4/3\pi r^3)\,N_A$
- *At low/moderate pressure* $(P + an^2/V^2)\,V = nRT$

  and $Z = PV/nRT = 1 - \frac{an}{VRT}$
- *At high pressure:* $P(V-nb) = nRT$ and

  $Z = (1+Pb/RT)$
- *At very low pressure or at high temperature and moderate/low pressure:* $Z = 1$ and $PV = nRT$
- ***Critical Temperature* :** $T_c = 8a/27Rb$
- ***Critical Pressure :*** $P_C = a/27b^2$
- ***Critical Volume :*** $V_C = 3b$

SOLVED EXAMPLES

Example - 1

A gas occupies 200 mL at a pressure of 0.820 bar at 20°C. How much volume will it occupy when it is subjected to external pressure of 1.025 bar at the same temperature ?

Sol. $p_1 = 0.820$ bar $\quad p_2 = 1.025$ bar

$V_1 = 200$ ml $\quad V_2 = ?$

Since temperature is constant, therefore, by applying Boyle's law,

$$p_1V_1 = p_2V_2 \quad \text{or} \quad V_2 = \frac{p_1V_1}{p_2}$$

$$V_2 = \frac{(0.820\text{bar}) \times (200\text{ mL})}{1.025\text{ bar}} = 160\text{ ml}$$

Example - 2

A ballon is filled with hydrogen at room temperature. It will burst if pressure exceeds 0.2 bar. If at 1 bar pressure the gas occupies 2.27 L volume, upto what volume can the balloon be expanded ?

Sol. According to Boyle's law, at constant temperature,

$$p_1 V_1 = p_2 V_2$$

If $\quad p_1 = 1$ bar then $V_1 = 2.27$ L

if $\quad p_2 = 0.2$ bar, then

$$V_2 = \frac{p_1V_1}{p_2}$$

$$= \frac{1\text{ bar} \times 2.27\text{ L}}{0.2\text{ bar}}$$

$$= 11.35\text{ L}$$

Since ballon bursts at 0.2 bar pressure, the volume of the ballon should be less than 11.35 L.

Example - 3

On a ship sailing in a pacific ocean where temperature is 23.4°C, a ballon is filled with 2L air. What will be the volume of the ballon when the ship reaches Indian ocean, where temperature is 26.1°C ?

Sol. According to Charles' law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$V_1 = 2\text{L} \quad V_2 = ?$

$T_1 = 273 + 23.4 = 296.4\text{ K} \quad T_2 = 273 + 26.1 = 299.1$

$$\therefore \quad V_2 = \frac{V_1T_2}{T_1}$$

$$= \frac{2\text{L} \times 299.1\text{K}}{296.4\text{ K}} = 2.018\text{ L}$$

Example - 4

A chamber of constant volume contains hydrogen gas. When the chamber is immersed in a bath of melting ice (0°C), the pressure of the gas is 1.07 × 10² kPa. What pressure will be indicated when the chamber is brought to 100°C ?

Sol. $T_1 = 273 + 0 = 273$ K $\quad p_1 = 1.07 \times 10^2$ kPa

$= 107$ kPa

$T_2 = 273 + 100 = 373$ K $p_2 = ?$

Since volume remains constant, therefore, according to Gay Lussac's law.

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \quad \text{or} \quad \frac{p_1T_2}{p_2}$$

$$= \frac{(107\text{ kPa}) \times (373\text{ K})}{(273\text{ K})}$$

$$= 1.462 \times 10^2\text{ kPa.}$$

Example - 5

A sample of nitrogen occupies a volume of 1.0 L at a pressure of 0.5 bar at 40ºC. Calculate the pressure if the gas is compressed to 0.225 ml at –6ºC.

Sol. $p_1 = 0.5$ bar $\qquad p_2 = ?$

$V_1 = 1.0$ L $\qquad V_2 = 0.225$ mL

$= 0.225 \times 10^{-3}$ L

$T_1 = 273 + 40 = 313$ K

$T_2 = 273 - 6 = 267$ K

According to gas equation,

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$p_2 = \frac{p_1V_1T_2}{V_2T_1}$$

$$= \frac{0.5\ \text{bar} \times 1.0\text{L} \times 267\text{K}}{0.225 \times 10^{-3}\text{L} \times 313\ \text{K}} \mathbf{= 1895.6\ bar.}$$

Example - 6

Calculate the volume occupied by 4.045 × 10²³ molecules of oxygen at 27ºC and having a pressure of 0.935 bar.

Sol. Here, number of molecules = 4.045×10^{23}

$p = 0.933$ bar

$T = 27 + 273 = 300$ K

$R = 0.083$ bar dm^3 mol^{-1} K^{-1}

Let us first calculate the number of moles, n. We know that number of moles,

$$n = \frac{\text{No. of molecules}}{6.022 \times 10^{23}} = \frac{4.045 \times 10^{23}}{6.022 \times 10^{23}} = 0.672\ \text{mol}$$

Now, according to general gas equation,

$$pV = nRT \qquad \text{or} \qquad V = \frac{nRT}{p}$$

$$\therefore V = \frac{0.672\ \text{mol} \times 0.083\ \text{bar dm}^3\ \text{K}^{-1}\text{mol}^{-1} \times 300\ \text{K}}{0.993\ \text{bar.}}$$

= 17.93 dm³ (or L)

Example - 7

2.9 g of a gas at 95ºC occupied the same volume as 0.184 g of hydrogen at 17ºC at the same pressure. What is the molar mass of the gas ?

Sol. Let molar mass of gas is M.

Moles of gas $= \frac{2.9}{M}$, $T = 273 + 95 = 368$ K

Volume of gas, $\qquad V = \frac{nRT}{p}$

$$= \frac{2.9 \times R \times 368}{M \times p}$$

Moles of dihydrogen $= \frac{0.184}{2} = 0.092$,

$T = 273 + 17 = 290$ K

Volume of dihydrogen $= \frac{0.092 \times R \times 290}{p}$

Volume of gas = Volume of dihydrogen at same pressure, p

$$\frac{2.9 \times R \times 368}{M} = 0.092 \times R \times 290$$

$$\therefore \qquad M = \frac{2.9 \times 368}{0.092 \times 290} \mathbf{= 40}$$

Example - 8

The density of a gas at 27ºC and 1 bar presssure is 2.56 g L⁻¹. Calculate the molar mass.

Sol. We are given

$p = 1.0$ bar, $T = 27 + 273 = 300$ K,

$d = 2.56$ g L^{-1} or 2.56 g dm^{-3}

We know that

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

where R = 0.083 bar dm^3 mol^{-1} K^{-1}

$$M = \frac{2.56\text{g dm}^{-3} \times 0.083\ \text{bar dm}^3\ \text{mol}^{-1}\text{K}^{-1} \times 300\ \text{K}}{1\ \text{bar}}$$

$= 63.74$ g mol^{-1}

Molar mass of gas = 63.74

Example - 9

At 273 K, the density of a gaseous oxide at 2 bar is same as that of nitrogen at 5 bar. Calculate the molecular mass of oxide.

Sol. $d = \frac{pM}{RT}$

For nitrogen gas at 5 bar pressure and 273 K temperature

$$d(N_2) = \frac{5\text{bar} \times 28\text{g mol}^{-1}}{R \times 273\text{ K}}$$

For gaseous oxide at 2 bar pressure and 273 K temperature

$$d(\text{oxide}) = \frac{2\text{ bar} \times M\text{ g mol}^{-1}}{R \times 273\text{K}}$$

Now $\quad d\,(N_2) = d\,(\text{oxide})$

$$\frac{5\text{ bar} \times 28\text{ g mol}^{-1}}{R \times 273\text{ K}} = \frac{2\text{ bar} \times M\text{ g mol}^{-1}}{R \times 273}$$

$$\therefore \quad M = \frac{5 \times 28}{2} = \mathbf{70\ g\ mol^{-1}}$$

Example - 10

Calculate the total pressure in a mixture of 8g of oxygen and 4g of hydrogen confined in a vessel of 1 dm^3 at 27°C (R = 0.083 bar dm^3 K^{-1} mol^{-1}).

Sol. Partial pressure of oxygen gas,

$$p = \frac{nRT}{V}$$

$n = \frac{8}{32}$ mol, $\quad V = 1\text{ dm}^3, T = 300\text{ K}$

$$p_{(O_2)} = \frac{8 \times 0.083 \times 300}{32 \times 1}$$

$= 6.225$ bar

Partial pressure of hydrogen gas

$$p = \frac{nRT}{V}$$

$$n = \frac{4}{2} = 2\text{ mol}$$

$$p(H_2) = \frac{2 \times 0.083 \times 300}{1}$$

$= 49.8$ bar

Total pressure = $p_{(O_2)} + p_{(H_2)}$

$= 6.225 + 49.8 =$ **56.025 bar.**

Example - 11

A 10 dm^3 flask at 298 K contains a gaseous mixture of CO and CO$_2$ at a total pressure of 2.0 bar. If 0.20 mole of CO is present, find its partial pressure and also that of CO$_2$.

Sol. According to Dalton's law of partial pressure

$$p_{\text{total}} = p_{(CO)} + p_{(CO_2)} = 2.0\text{ bar}$$

Partial pressure of CO, $p_{(CO)} = \frac{n(CO)\,RT}{V}$

$$= \frac{(0.2\text{ mol}) \times (0.083\text{ bar dm}^3\text{K}^{-1}\text{mol}^{-1}) \times (298\text{ K})}{10\text{ dm}^3}$$

$= 0.495$ bar.

Partial pressure of CO$_2$, $p_{(CO_2)}$

$= p_{\text{total}} - p_{(CO)}$

$= 2.0 - 0.495 =$ **1.505 bar.**

Example - 12

Calculate the kinetic energy of 2g of oxygen at –23°C.

Sol. Kinetic energy is given as

$$E_k = \frac{3}{2}nRT$$

$$n = \frac{2}{32} = \frac{1}{16}\text{ mol},$$

$R = 8.314\text{ JK}^{-1}\text{ mol}^{-1}$, $T = 273 - 23 = 250\text{ K}$

$$E_k = \frac{3}{2} \times \frac{1}{16} \times 8.314 \times 250 \quad = \mathbf{194.86\ J}$$

Example - 13

Calculate the root mean square speed of methane molecules at 27ºC.

Sol. Root mean square speed,

$$u_{r.m.s.} = \sqrt{\frac{3RT}{M}}$$

$T = 27 + 273 = 300\ K, M = 16, R = 8.314 \times 10^7$

$$u_{r.m.s.} = \sqrt{\frac{3 \times 8.314 \times 10^7 \times 300}{16}}$$

$$= 683.9 \times 10^2\ cm\ s^{-1}$$

$$\mathbf{= 683.9\ m\ s^{-1}}$$

Example - 14

One mole of CO_2 occupies 1.5 L at 25ºC. Calculate the pressure exerted by the gas using

(i) ideal gas equation

(ii) Van der Waals' gas equation with $a = 3.6\ L^2$ bar mol^{-2} and $b = 0.04\ L\ mol^{-1}$.

Sol. (i) According to ideal gas equation,

$$pV = nRT \quad \text{or} \quad p = \frac{nRT}{V}$$

$n = 1\ mol, T = 273 + 25 = 298\ K, V = 1.5\ L, R = 0.083\ atm\ L\ bar\ K^{-1}\ mol^{-1}$

$$\therefore p = \frac{1\ mol \times 0.083\ L\ bar\ mol^{-1}K^{-1} \times 298\ K}{1.5\ L}$$

= 16.49 bar

(ii) According to van der Waals' gas equation,

$$\left(p + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

or $$p = \frac{nRT}{(V - nb)} - \left(\frac{an^2}{V^2}\right)$$

$$p = \frac{1\ mol \times 0.083\ L\ bar\ mol^{-1}\ K^{-1} \times 298\ K}{(1.5 - 1 \times 0.04)\ L}$$

$$- \frac{3.6\ L^2\ bar\ mol^{-2} \times (1\ mol^2)}{(1.5\ L)^2}$$

$= 16.94 - 1.60$ **= 15.34 bar**

Example - 15

For oxygen gas, the Van der Waals, constant is 0.0318 L mol^{-1}. Calculate the diameter of oxygen molecule.

Sol. Van der Waals' constant,

b = 4 × Volume occupied by molecules in 1 mole of gas

$$= 4 \times \frac{4}{3}\pi r^3 \times 6.023 \times 10^{23}$$

$b = 0.0318\ L\ mol^{-1} = 0.0318 \times 10^3\ cm^3\ mol^{-1}$

$$0.0318 \times 10^3 = = 4 \times \frac{4}{3} \times 3.14 \times r^3 \times 6.023 \times 10^{23}$$

or $$r^3 = \frac{0.0318 \times 10^3 \times 3}{16 \times 3.14 \times 6.023 \times 10^{23}}$$

$$r = \left(\frac{0.0318 \times 10^3 \times 3}{16 \times 3.14 \times 6.023 \times 10^{23}}\right)^{1/3}$$

$$= 1.47 \times 10^{-8}\ cm$$

Diameter of oxygen molecule = 2 × 1.47 × 10–8

$$\mathbf{= 2.94 \times 10^{-8}\ cm.}$$

Example - 16

A vessel of 25 L capacity contains 10 mol of steam under 50 bar pressure. Calculate the temperature of steam using Van der Waals' equation if for water :

$a = 5.46$ bar $L^2\ mol^{-2}$ and $b = 0.031\ L\ mol^{-1}$.

Sol. Van der Waals' equation is

$$\left(p + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

or $$T = \frac{\left(p + \frac{an^2}{V^2}\right)(V - nb)}{nR}$$

$n = 10\ mol, V = 25\ L, p = 50\ bar$

$a = 5.46\ bar\ L^2\ mol^{-2}, b = 0.031\ L\ mol^{-1}$

$$\therefore \quad T = \frac{\left(50 + \frac{5.46 \times 100}{(25)^2}\right)(25 - 0.031)}{10 \times 0.082}$$

= 1531.7 K.

Example - 17

1 mole of sulphur dioxide occupies a volume of 350 ml at 27°C and 5 × 10^6 Pa pressure. Calculate the compressibility factor of the gas. Is it less or more compressible than an ideal gas ?

Sol. Compressibility factor,

$$Z = \frac{pV}{nRT}$$

n = 1 mol, p = 5 × 10^6 Pa, V = 350 mL = 0.350 × 10^{-3} m^3

R = 8.314 Nm K^{-1} mol^{-1}, T = 27 + 273 = 300 K

$$\therefore Z = \frac{5 \times 10^6 \times 0.350 \times 10^{-3}}{1.0 \times 8.314 \times 300} = 0.702$$

SO_2 is more compressible than an ideal gas (which has Z=1).

Example - 18

Calculate the critical temperature of a Van der Waals gas for which p_c is 100 atm and b is 0.050 dm3 mol^{-1}.

Sol. $$Tc = \frac{8a}{27Rb}$$

But a = $3p_c V_c^2 = 3p_c \times (3b)^2 = 27\, p_c\, b^2$

$$\therefore \quad T_c = \frac{8\,(27p_c b^2)}{27Rb} = \frac{8p_c b}{R}$$

p_c = 100 atm, b = 0.050 dm^3 mol^{-1}

$$\therefore \quad T_c = \frac{8 \times (100\ \text{atm}) \times (0.050\ \text{dm}^3\text{mol}^{-1})}{0.082\ \text{dm}^3\text{atm mol}^{-1}\ \text{K}^{-1}}$$

= 487.2 K.

Example - 19

A mixture of dihydrogen and dioxygen at one bar pressure contains 20% by weight of dihydrogen. Calculate the partial pressure of dihydrogen.

Sol. Mass of H_2 = 20g, Mass of O_2 = 80 g

Moles of $H_2 = \frac{20}{2}$ = 10 mol, Moles of $O_2 = \frac{80}{32}$

= 2.5 mol

Mole fraction of $H_2 = \frac{10}{10 + 2.5} = 0.8$

Partial pressure = 0.8 × p = 0.8 × 1 bar = **0.8 bar**

Example - 20

Which type of intermolecular forces exist among the following molecules ?

(i) H_2S molecules **(ii) H_2O molecules**

(iii) Cl_2 and CCl_4 molecules

(iv) SiH_4 molecules **(v) Helium atoms**

(vi) He atoms and HCl molecules

Sol. (i) Dipole-dipole interactions (because H_2S is polar).

(ii) Hydrogen bonding.

(iii) London dispersion force (because both are non-polar).

(iv) London dispersion forces (because SiH_4 is non-polar).

(v) London dispersion forces (because He atoms have symmetrical electron clouds).

(vi) Dipole-induced dipole forces (because HCl is polar while He atom has symmetrical electron cloud).

Example - 21

How is the partial pressure of a gas in a mixture related to the total pressure of the gaseous mixture ?

Sol. Partial pressure of a gas = Mole fraction of that gas × Total pressure.

Example - 22

Out of N_2 and NH_3, which one will have greater value for van der Waals constant 'a' and which one will have greater value for van der Waals constant 'b' ?

Sol. (i) As NH_3 is more easily liquefiable (due to hydrogen bonding), intermolecular forces of attraction are stronger than in N_2. Hence, NH_3 will have greater value for 'a'.

(ii) As N_2 molecule is larger in size than NH_3, hence N_2 will have greater value for 'b'.

(For NH_3, a = 4.17 L^2 atm mol^{-2}, b = 0.0371 L mol^{-1}

For N_2, a = 1.39 L^2 atm mol^{-2}, b = 0.0391 L mol^{-1})

Example - 23

Why liquids have a difinite volume but no definite shape ?

Sol. This is because the intermolecular forces are strong enough to hold the molecules together but not so strong as to fix them into definite positions (as in solids). Instead, they possess fluidity and hence no definite shape.

Example - 24

Why vegetables are cooked with difficulty at a hill station ?

Sol. The atmospheric pressure is less and so the boiling point is lowered.

Example - 25

Why falling liquid drops are spherical ?

Sol. This is due to property of surface tension possessed by the liquids. This makes the surface area minimum. For a given volume, sphere has the minimum surface area.

Example - 26

What is the difference between vapour and gas ?

Sol. A substance which is in gaseous state at room temprature is called a gas. However, if a substance is not in gaseous state at room temperature but changes into gaseous state on heating, then the gaseous state obtained is called vapour or when a gas is below its critical temperature, it is called vapour.

Example - 27

What is the difference between normal boiling pint and standard boiling point ?

Sol. When the external pressure is equal to one atmosphere pressure, the boiling point is called normal boiling point. When the external pressure is 1 bar, it is called standard boiling point.

Example - 28

Pressure of 1g of an ideal gas A at 27°C is found to be 2 bar. When 2g of another ideal gas B is introduced in the same flask at same temperature, the pressure becomes 3 bar. Find the relationship between their molecular masses.

Sol. Suppose molecular masses of A and B are M_A and M_B respectively. Then their number of moles will be

$$n_A = \frac{1}{M_A}, \quad n_B = \frac{2}{M_B}$$

$P_A = 2$ bar, $P_A + P_B = 3$ bar, i.e., $P_B = 1$ bar

Applying the relation, $PV = nRT$

$$P_AV = n_ART, \ P_BV = n_BRT$$

$$\therefore \quad \frac{P_A}{P_B} = \frac{n_A}{n_B} = \frac{1/M_A}{2/M_B} = \frac{M_B}{2\,M_A}$$

or $$\frac{M_B}{M_A} = 2 \times \frac{P_A}{P_B} = 2 \times \frac{2}{1} = 4$$

or $\mathbf{M_B = 4\,M_A}$.

Example - 29

What will be the pressure of the gas mixture when 0.5 L of H_2 at 0.8 bar and 2.0 L of oxygen at 0.7 bar are introduced in a 1 L vessel at 27°C ?

Sol. Calculation of partial pressure of H_2 in 1L vessel

$P_1 = 0.8$ bar, $\quad V_1 = 0.5$ L

$P_2 = ?$ $\quad V_2 = 1.0$ L

As temperature remains constant, $P_1V_1 = P_2V_2$

$(0.8 \text{ bar})(0.5 \text{ L}) = P_2\,(1.0 \text{ L})$

or $P_2 = 0.40$ bar, i.e., $p_{H_2} = 0.40$ bar

Calculation of partial pressure of O_2 in 1L vessel

$$P_1' V_1' = P_2' V_2'$$

$(0.7 \text{ bar})(2.0 \text{ L}) = P_2'$ (1 L) or $P_2' = 1.4$ bar, i.e., $p_{O_2} = 1.4$ bar

$\therefore$ Total pressure = $p_{H_2} + p_{O_2} = 1.4$ bar + 1.4 bar = **1.8 bar**

Example - 30

34.05 mL of phosphorus vapour weigh 0.0625 g at 546°C and 1.0 bar pressure. What is the molar mass of phosphorus ?

Sol. **Step1.** Calculation of volume at 0°C and 1 bar pressure

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}, \text{ i.e., } \frac{1 \times 34.05}{546 + 273} = \frac{1 \times V_2}{273} \text{ or } V_2 = 11.35 \text{ mL}$$

11.35 mL of vapour at 0°C and 1 bar pressure weigh = 0.0625g

$\therefore$ 22700 mL of vapour at 0°C and 1 bar pressure will weight

$$= \frac{0.0625}{11.35} \times 22700 = 125 \text{ g}$$

$\therefore$ Molar mass = **125 g mol^{-1}**

Alternatively, using

$$R = 0.083 \text{ bar dm3 } K^{-1} \text{ mol}^{-1}$$

$$PV = nRT, \text{ i.e., } n = \frac{PV}{RT} = \frac{1.0 \text{ bar} \times (34.05 \times 10^{-3} \text{dm}^3)}{0.083 \text{ bar dm}^3 \text{ K}^{-1} \times 819\text{K}}$$

$$= 5 \times 10^{-4} \text{ mol}$$

$\therefore$ Mass of 1 mole $= \frac{0.0625}{5\times10^{-4}} g = 125$ g

$\therefore$ Molar mass = **125 g mol^{-1}**

Example - 31

Critical temperature for CO_2 and CH_4 are 31.1°C and –81.9°C respectively. Which of these has stronger intermolecular forces and why ?

Sol. Higher the critical temperature, more easily the gas can be liquefied, i.e., greater are the intermolecular forces of attraction. Hence, CO_2 has stronger intermolecular forces than CH_4.

Example - 32

Explain the significance of van der Waals parameters ?

Sol. 'a' is a measure of the magnitude of the intermolecular forces of attraction while b is a measure of the effective size of the gas molecules.

Example - 33

What is SI unit of coefficient of viscosity ? How is it related to poise ?

Sol. SI unit = kg m^{-1} s^{-1}

Poise = 1 g cm^{-1} s^{-1}

$\therefore$ 1 poise = 10^{-1} kg m^{-1} s^{-1} = $\frac{1}{10}$ th of SI unit.

Example - 34

A neon-dioxane mixture contains 70.6g of dioxygen and 167.5 g of neon. If pressure of the mixture of gases in the cylinder is 25 bar, what is the partial pressure of dioxygen and neon in the mixture.

Sol. No. of moles of dioxygen $= \frac{70.6}{32} = 2.21$ mol

No. of moles of neon $= \frac{167.5}{20} = 8.375$ mol

Mole fraction of dioxygen, $x_{O_2} = \frac{2.21}{2.21+8.375}$

Mole fraction of neon, $x_{Ne} = \frac{8.375}{2.29+8.375} = 0.79$

Now partial pressure of a gas = mole fraction × total pressure

$\therefore$ Partial pressure of oxygen = 0.21 × (25 bar) = **5.25 bar**

Partial pressure of neon = 0.79 × (25 bar) = **19.75 bar.**

Example - 35

A gaseous mixture containing 50 g of nitrogen and 10g of oxygen were enclosed in a vessel of 10L capacity at 27°C. Calculate

(a) the number of moles of each gas.

(b) the partial pressure of each gas.

(c) the total pressure of gaseous mixture.

Sol. Volume of vessel = 10 L

Temperature = 27 + 273 = 300 K

Step I. To calculate the moles of each gas.

Weight of nitrogen = 50g

Molar mass of nitrogen = 28

Moles of nitrogen $= \frac{50}{28} = \mathbf{1.79}$

Weight of oxygen = 10 g

Molar mass of oxygen = 32

Moles of oxygen $= \frac{10}{32} = \mathbf{0.31}$

Step II. To calculate the partial pressure of each gas.

According to general gas equation

$$PV = nRT \quad \text{or} \quad p = \frac{nRT}{V}$$

$\therefore$ Partial pressure of nitrogen,

$$p_{N_2} = \frac{1.79\times0.082\times300}{10} = \mathbf{4.40\ atm.}$$

Partial pressure of oxygen,

$$p_{O_2} = \frac{0.31\times0.082\times300}{10} = \mathbf{0.76\ atm.}$$

Step III. To calculate the total pressure

According the Dalton's law of partial pressures, the total pressure of the gaseous mixture :

$$p = p_{N_2} + p_{O_2}$$

$$= 4.40 + 0.76 = \mathbf{5.16\ atm.}$$

Example - 36

Density of a gas is found to be 5.46 g dm^{-3} at 27°C and 2 bar pressure. What will be its density at STP ?

Sol. We know that

$$pV = nRT$$

or $$p = \frac{m}{V} \times \frac{RT}{M} = \frac{dRT}{M}$$

$\therefore$ $$d = \frac{pM}{RT}$$

or $$d \propto \frac{P}{T} \text{ (R and M constant for a given gas)}$$

or $$\frac{d_1}{d_2} = \frac{p_1}{p_2} \times \frac{T_2}{T_1}$$

or $$d_2 = \frac{d_1 \times p_2 \times T_1}{p_1 \times T_2}$$

$d_1 = 5.46$ g dm^{-3}, $p_1 = 2$ bar

$T_1 = 273 + 27 = 300$ K

$d_2 = ?$ $p_2 = 1$ bar $T_2 = 273$ K

$$\therefore \ d_2 = \frac{5.46 \text{g dm}^{-3} \times 1 \text{ bar} \times 300 \text{ K}}{2 \text{ bar} \times 273 \text{ K}}$$

= 3.0 g dm^{-3}

Example - 37

At what centigrade temperature will a given volume of a gas at 0°C become double its volume, pressure remaining constant ?

Sol. Let the volume of the gas at 0°C be V.

$V_1 = V$

$T_1 = 273 + 0 = 273$ K

$V_2 = 2V$

$T_2 = ?$

Since pressure remains constant, therefore, by applying Charles' law,

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{V}{273} = \frac{2V}{T_2}$$

$$T_2 = \frac{2V \times 273}{V} = 546 \text{ K}$$

Changing the temperature to centigrade scale,

Temperature = 546 – 273 = **273°C.**

Example - 38

What is the increase in volume when the temperature of 800 mL of air increases from 27°C to 47°C under constant pressure of 1 bar ?

Sol. Since the amount of gas and the pressure remains constant, Charles' law is applicable. i.e.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$V_1 = 800$ mL $V_2 = ?$

$T_1 = 273 + 27 = 300$ K $T_2 = 273 + 47 = 320$ K

$$\frac{800 \text{ mL}}{300 \text{ K}} = \frac{V_2}{320 \text{ K}}$$

or $$V_2 = \frac{(800 \text{ mL})}{(300 \text{ K})} \times (320 \text{ K})$$

$= 853.3$ mL

$\therefore$ Increase in volume of air = 853.3 – 800 = **53.3 mL**

Example - 39

A gas occupies volume of 250 mL at 745 mm Hg and 25°C. What additional pressure is required to reduce the gas volume to 200 mL at the same temperature ?

Sol. $p_1 = 745$ mm Hg $p_2 = ?$

$V_1 = 250$ mL $V_2 = 200$ mL

Since temperature remains constant, therefore, by applying Boyle's law,

$$p_1 V_1 = p_2 V_2$$

or $$p_2 = \frac{p_1 V_1}{V_2} = \frac{(745 \text{ mm Hg}) \times (250 \text{ mL})}{(200 \text{ mL})}$$

$= 931.25$ mm Hg

The additional pressure required = 931.25 – 745

= 186.25 mm.

Example - 40

The two ends of a U tube manometer are subject to pressure 1 atm and 1.5 atm. If the liquid in the manometer has a density of 1g/cc, calculate the difference in height of the two columns.

Sol. We know that the difference in height h = $\frac{P_1 - P_2}{\rho g}$.

Thus, h = $\frac{0.5 \times 101325}{1000 \times 10} = 5.066\text{m}$

Remember to use S.I. units

Example - 41

An open vessel containing air at atmospheric pressure at an initial temperature of 300 K is heated to a temperature of 500 K. What fraction of air will escape out?

Sol. Here, the amount of gas in the two states is not equal.

Initially, the no. of moles of gas in the vessel n_1

= PV/RT = V/300R

Finally, the no. of moles of gas in the vessel n_2

= V/500R

Thus moles of gas escaped out = $\frac{V}{300R} - \frac{V}{500R} = \frac{2V}{1500R}$

Thus, fraction escaped out $\frac{\frac{2V}{1500R}}{\frac{V}{300R}} = \frac{2}{5}$ **Ans.**

Example - 42

A container having 3 gases P, Q and R have partial pressures 4, 9, 7 atm. What are the mole fractions of each gas ?

Sol. Total pressure of the gas mixture = 4+9+7 atm = 20 atm

Mole fraction of P = 4/20 = 0.2;

Thus, $X_Q = 9/20 = 0.45$; $X_R = 0.35$

Example - 43

What is the ratio of the rate of diffusion of CO_2 at 2 atm pressure to that of He at 5 atm pressure?

Sol. $\frac{r_{CO_2}}{r_{He}} = \frac{2}{\sqrt{44}} \times \frac{\sqrt{4}}{5} = 0.1206$

Example - 44

At what temperature will the RMS of a gas be twice its MP speed at 100°C.

Sol. $u_{MP} = \sqrt{(2RT_1/M)}$ and $u_{RMS} = \sqrt{(3RT_2/M)}$;

where $T_1 = 373\text{K}$.

Given, $u_{RMS} = 2u_{MP}$

thus, $T_2 = (8 \times 373/3) = 994.67$ K **Ans.**

Example - 45

A commercial gas cylinder contains 75 L of He at 15 bar (Gauge pressure). Assuming ideal gas behaviour for the isothermal expansion (T = constant) . How many 3.0 L ballons at 1.1 bar pressure can be filled by the gas in the cylinder ?

Sol. Assuming atmospheric pressure to be one bar, initial pressure and final pressure of He gas present in cylinder will be :

$p_i = 15 + 1 = 16$ bar and $p_f = 1.1$ bar

Volume of He gas when expanded isothermally to 1.1 bar =

$\frac{16 \times 75}{1.1} = 1100\text{ L}$

Out of 1100L, 75 L of gas will remain in cylinder since at this point pressure equilibrium will be established.

⇒ No. of ballons = $\frac{1100 - 75}{3} = 340$

Example - 46

12.00 g of a gaseous mixture of He and methane was taken in a container and to the mixture 8.00g of oxygen gas was added at same temperature. The pressure inside the container increased to a factor of 7/6. What was the weight percentage of methane in the original mixture ?

Sol. Since, volume and temperature are constant before and after addition of oxygen gas,

$$n \propto p$$

Let if x moles of gases were present in the 12.00 g mixture of methane and helium at pressure p_1, then

$$x \propto p_1$$

and $$\left(x + \frac{8}{32}\right) \propto \left(\frac{7}{6} p_1\right)$$

⇒ $$\frac{x}{x + 0.25} = \frac{6}{7};$$

Hence, x = 1.5

Now, if the mixture contains m g of methane, then

$$\frac{m}{16}+\frac{12-m}{4}=1.5$$

$\Rightarrow$ m = 8 and weight percentage of

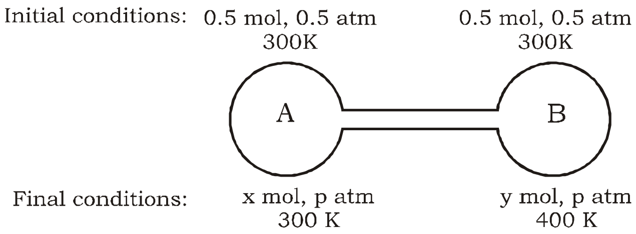
$$CH_4=\frac{8}{12}\times 100=66.67$$

Example - 47

Two flasks of equal volume, connected by a narrow tube of negligible volume contain 1.0 mol of H_2 gas at 300 K and 0.5 atmosphere. Now one of the flasks is immersed into a thermostat maintained at 400 K and other was maintained at constant 300 K temperature. Determine final pressure and amount of H_2 gas in each flask.

Sol. Initially, both the flasks contained equal moles of $H_2(g)$ i.e., 0.5 mol each, (Avogadro's law).

On heating one of the flasks, keeping other at constant temperature, kinetic energy of the gas molecule present in the hotter flask will increase and they will migrate towards colder flask. Equilibrium will be re-established when the two flasks acquire a constant uniform pressure and at equilibrium, amount of gas will be more in colder flask than in hotter flask.



On applying gas equations in final conditions :

$$300x = 400y$$

$\Rightarrow$ $3x=4y$

Also, $x+y=1$

$$\Rightarrow \quad x+\frac{3}{4}x=\frac{7}{4}x=1$$

$$x=\frac{4}{7}\text{ and } y=\frac{3}{7}$$

Now, apply gas laws on flask A in its initial and final conditions :

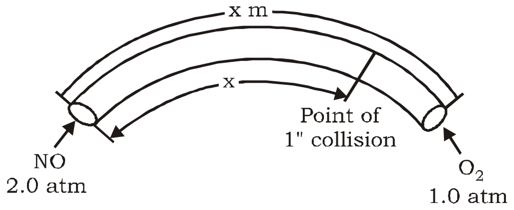
$$\frac{0.5}{p}=\frac{0.5}{x}\Rightarrow p=x=\frac{4}{7}\text{atm}$$

Example - 48

Nitric oxide (NO) gas at 2.0 atm and oxygen at 1 atm are injected simultaneously through pinholes of identical geometry, attached at the two ends of a semi-circular discharge tube made up of glass. The arc radius of discharge tube is 1.0 m and gases are at same temperature. Determine the distance from oxygen end at which first flash of brown fume would be osberved.

Sol. Here, the two gases being injected are at different pressures, their rates of effusion will depend on both molar mass and gas pressure as

$$\frac{r(NO)}{r(O_2)}=\frac{P_{NO}}{P_{O_2}}=\sqrt{\frac{32}{30}}=\frac{2}{1}\sqrt{\frac{32}{30}}=2.065$$



Arc length of tube = πr = 3.14 m

$$\Rightarrow \frac{r_{(NO)}}{r_{(O_2)}}=\frac{x}{3.14-x}\Rightarrow x=2.11\text{ m}$$

Distance from oxygen end = 3.14 – 2.11 = 1.03m.

Example - 49

The density of steam of 100°C and 1.0 atm pressure is 0.5974 kg m^{-3}. Determine compressibility factor for steam in the given condition.

Sol. $Z=\frac{pM}{\rho RT}=\frac{1\times 18}{0.5974\times 0.082\times 373}=0.985$

Example - 50

Density of van der Waals' gas at 500 K and 1.0 atm was found to be 0.8 kg/m^3. Also gas was found to effuse 1.37 times slower than oxygen under identical condition. Determine compressibility factor (Z) and predict the type of force dominating. Also determine molar volume of the gas in the given condition.

Sol. $\frac{r_{O_2}}{r_x}=\sqrt{\frac{M_x}{32}}=1.37\Rightarrow M_x=60$

Also, pM = ZρRT

$$\Rightarrow \quad Z=\frac{pM}{\rho RT}=\frac{1\times 60}{0.8\times 0.82\times 500}=1.83$$

$\Rightarrow$ Repulsive force is dominating

Also, $V_m=\frac{60}{0.8}=75\text{ L}$

EXERCISE - 1 : BASIC OBJECTIVE QUESTIONS

Types of Forces

1. The strength of van der Waals' forces increases with :

(a) increase in molecular size

(b) increase in the number of electrons in the molecule

(c) increase in molecular weight

(d) all of the above

Ideal Gas

2. Which is not true in case of an ideal gas ?

(a) It cannot be converted into a liquid

(b) There is no interaction between the molecules

(c) All molecules of the gas move with same speed

(d) At a given temperature, PV is proportional to the amount of the gas

Pressure

3. Dimensions of pressure are the same as that of :

(a) Energy (b) Force

(c) Energy per unit volume

(d) Force per unit volume

4. The pressure at the base of a column of liquid of length *l* and held at an angle θ to the vertical is

(a) $\rho g l$ (b) $\rho g l \sin\theta$

(c) $\rho g \cos\theta$ (d) $\rho g l \cos\theta$

5. Pressure of a gas is due to

(a) collisions of gas molecules

(b) the random movement of gas molecules

(c) the intermolecular forces of attraction between the gas molecules

(d) the collision of gas molecules against the walls of the container

6. One atmosphere is numerically equal to approximately :

(a) 10^6 dyne cm^{-2} (b) 10^2 dyne cm^{-2}

(c) 10^4 dyne cm^{-2} (d) 10^8 dyne cm^{-2}

Temperature

7. 1ºC rise in temperature is equal to a rise of

(a) 1ºF (b) 9/5ºF

(c) 5/9ºF (d) 33ºF

Ideal Gas Laws

8. At constant temperature, in a given mass of an ideal gas

(a) The ratio of pressure and volume always remains constant

(b) Volume always remains constant

(c) Pressure always remains constant

(d) The product of pressure and volume always remains constant

9. If 20 cm^3 gas at 1 atm. is expanded to 50 cm^3 at constant T, then what is the final pressure ?

(a) $20\times\frac{1}{50}$ (b) $50\times\frac{1}{20}$

(c) $1\times\frac{1}{20}\times 50$ (d) none of these.

10. A gas of volume 100 cc. is kept in a vassel at pressure 10^4 Pa maintained at temperature 24ºC if now the pressure is increased to 10^5 Pa, keeping the temperature constant, then the volume of the gas becomes

(a) 10 cc (b) 100 cc

(c) 1 cc (d) 1000 cc

11. At 25ºC temperature and 730 mm pressure, 380 mL of dry oxygen was collected. If the temperature is held constant, what volume will be oxygen occupy at 760 mm pressure ?

(a) 365 mL (b) 449 mL

(c) 569 mL (d) 621 mL

12. A gas at 298 K is shifted from a vessel of 250 cm^3 capacity to that of 1L capacity. The pressure of the gas will

(a) become double (b) becomes four times

(c) decrease to half of the original value

(d) decrease to one-fourth of the original value

13. A gas volume 100 cc. is kept in a vessel at pressure 10^4 atm maintained at temperature 24ºC. If now the pressure is increased to 10^5 atm, keeping the temperature constant, then the volume of the gas becomes

(a) 10 cc (b) 100 cc

(c) 1 cc (d) 1000 cc

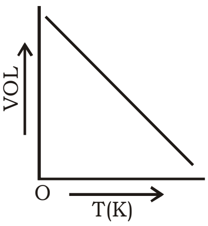
14. 300 ml of a gas at 27°C is cooled to –3°C at constant pressure, the final volume is

(a) 540 ml (b) 135 ml

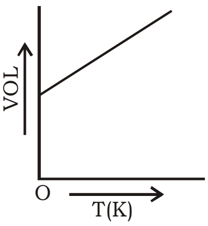
(c) 270 ml (d) 350 ml

15. The correct representation of Charles's law is given by

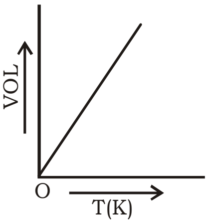
(a)



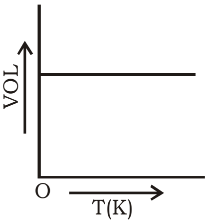
(b)



(c)



(d)



16. When gases are heated from 20 to 40°C at constant pressure, their volumes

(a) increase by the same magnitude

(b) become double

(c) increase in the ratio of their molecular masses

(d) increase but to different extent

17. A sample of gas occupies 100 ml at 27°C and 740 mm pressure. When its volume is changed to 80 ml at 740 mm pressure, the temperature of the gas will be

(a) 21.6°C (b) 240°C

(c) –33°C (d) 89.5°C

18. A sample of gas has a volume of 0.2 lit measured at 1 atm pressure and 0°C. At the same pressure, but at 273°C, its volume will become

(a) 0.1 litre (b) 0.4 litre

(c) 0.6 litre (d) 0.8 litre

19. A gas is initially at 1 atm pressure. To compress it to 1/4 th of its initial volume, assuming temperature to be constant pressure to be applied is

(a) 1 atm (b) 2 atm

(c) 4 atm (d) 1/4 atm

20. "One gram molecule of a gas at N.T.P. occupies 22.4 litres." This fact was derived from

(a) Dalton's theory (b) Avogadro's hypothesis

(c) Berzelius hypothesis (d) Law of gaseous volume

21. Gay-Lussac's law of combining volume is applicable for those gases which on mixing :

(a) do not react (b) react with each other

(c) diffuse (d) all of these

22. The volume of ammonia obtained by the combination of 10 mL of N_2 and 30 mL of H_2 is :

(a) 20 mL (b) 40 mL

(c) 30 mL (d) 10 mL

Ideal Gas Equation

23. In the gas equation PV = nRT, the value of R depends upon

(a) nature of gas (b) the pressure of gas

(c) unit of measurement (d) temperature of gas

24. Correct gas equation is :

(a) $\frac{V_1T_2}{P_1} = \frac{V_2T_1}{P_2}$ (b) $\frac{P_1V_1}{P_2V_2} = \frac{T_1}{T_2}$

(c) $\frac{P_1T_2}{V_1} = \frac{P_2V_2}{T_2}$ (d) $\frac{V_1V_2}{T_1T_2} = P_1P_2$

25. Pure hydrogen sulphide is stored in a tank of 100 litre capacity at 20°C and 2 atm pressure. The mass of the gas will be

(a) 34 g (b) 340 g

(c) 282.68 g (d) 28.24 g

26. The weight of CH_4 in a 9-L cylinder at 27°C temperature and 16 atm pressure is ($R = 0.08\ L\ atm\ K^{-1}\ mol^{-1}$)

(a) 9.6 g (b) 96.0 g

(c) 4.8 g (d) 48.0 g

27. When the temperature of 23 ml of dry CO_2 gas is changed from 10° to 30°C at constant pressure of 760 mm, the volume of gas becomes closest to which one of the following ?

(a) 7.7 ml (b) 21.5 ml

(c) 24.6 ml (d) 69 ml.

28. If two moles of an ideal gas at 546 K occupies a volume of 44.8 litres, the pressure must be

(a) 2 atm (b) 3 atm

(c) 4 atm (d) 1 atm

29. The volume of balloon filled with 4.0g of He at 22°C and 720 mm of Hg is :

(a) 25.565 litre (b) 20 litre

(c) 15 litre (d) 30 litre

30. The equation of state corresponding to 8g of O_2 is :

(a) $PV = 8RT$ (b) $PV = RT/4$

(c) $PV = RT$ (d) $PV = RT/2$

31. For an ideal gas ratio of $\frac{P}{d}$ is equal to :

(a) $\frac{RT}{M}$ (b) $\frac{M}{RT}$

(c) $\frac{MT}{R}$ (d) $\frac{R}{TM}$

32. If P, V, M, T and R are pressure, volume, molar mass, temperature and gas constant respectively, then for an ideal gas, the density is given by

(a) $\frac{RT}{PM}$ (b) $\frac{P}{RT}$

(c) $\frac{M}{V}$ (d) $\frac{PM}{RT}$

33. The density of a gas at 27°C and 1 atm is d. Pressure remaining constant at which of the following temperatures will its density become 0.75 d ?

(a) 20°C (b) 30°C

(c) 400 K (d) 300 K

34. Under what conditions will a pure sample of an ideal gas not only exhibit a pressure of 1 atm but also a concentration of 1 mole litre^{-1} ?

($R = 0.082$ litre atm mol^{-1} deg^{-1})

(a) At STP

(b) When $V = 22.4$ litres

(c) When $T = 12$ K

(d) Impossible under any conditions

35. The density of gas A is four times that of gas B. If the molecular weight of A is M, then at same pressure and temperature molecular weight of B is

(a) 2M (b) M/2

(c) 4M (d) M/4

36. The density of CCl_4 vapour at 0°C and 76 cm Hg in g/litre is :

(a) 11.2 (b) 77

(c) 6.88 (d) none of these

37. The correct gas equation is :

(a) $\frac{P_1V_1}{P_2V_2} = \frac{T_1}{T_2}$ (b) $\frac{V_2T_2}{P_1} = \frac{V_1T_1}{P_2}$

(c) $\frac{P_1T_1}{V_1} = \frac{P_2T_2}{V_2}$ (d) $\frac{V_1V_2}{T_1T_2} = P_1P_2$

38. The pressure of sodium vapour in a 1.0 L container is 10 torr at 1000°C. How many atoms are in the container ?

(a) 9.7×10^{17} (b) 7.6×10^{19}

(c) 4.2×10^{17} (d) 9.7×10^{19}

39. Dry ice is solid carbon dioxide. A0.050 g sample of dry ice is placed in an evacuated 4.6 L vessel at 30°C. Calculate the pressure inside the vessel after all the dry ice has been converted to CO_2 gas.

(a) 6.14 atm (b) 0.614 atm

(c) 0.0614 atm (d) 6.14×10^{-3} atm

40. The closed containers of the same capacity and at the same temperature are filled with 44g of H_2 in one and 44g of CO_2 in the other. If the pressure of carbon dioxide in the second container is 1 atm. That of hydrogen in the first container would be :

(a) 1 atm (b) 10 atm

(c) 22 atm (d) 44 atm

41. Equal volumes of oxygen and an unknown gas weigh 3.00g and 7.50g, respectively. Which of the following is the unknown gas ?

(a) CO_2 (b) NO

(c) NO_2 (d) SO_3

Dalton's Law

42. If three unreactive gases having partial pressures P_A, P_B and P_C and their moles are 1, 2, and 3 respectively then their total pressure will be :

(a) $P = P_A + P_B + P_C$ (b) $P = \frac{P_A + P_B + P_C}{6}$

(c) $P = \frac{\sqrt{P_A + P_B + P_C}}{3}$ (d) none.

43. Which of the following mixtures of gases does not obey Dalton's law of partial pressure ?

(a) O_2 and CO_2 (b) N_2 and O_2

(c) Cl_2 and O_2 (d) NH_3 and HCl

44. 3.2 g of oxygen (At. wt. = 16) and 0.2 g of hydrogen (At. wt. = 1) are placed in a 1.12 litre flask at 0°C. The total pressure of the gas mixture will be

(a) 1 atm (b) 4 atm

(c) 3 atm (d) 2 atm

45. The ratio of partial pressure of a gaseous component to the total vapour pressure of the mixture is equal to

(a) mass of the component

(b) mole fraction of the component

(c) mass % of the component

(d) molecular mass of the component

46. Equal weights of two gases of molecular weight 4 and 40 are mixed. The pressure of the mixture is 1.1 atm. The partial pressure of the light gas in this mixture is

(a) 0.55 atm (b) 0.11 atm

(c) 1 atm (d) 0.11 atm

47. 16 gm of oxygen and 3 gm of hydrogen are mixed and kept in 760 mm presusre at 0°C. The total volume occupied by the mixture will be nearly

(a) 22.4*l* (b) 33.6*l*

(d) 448 litres (d) 44800 ml

48. A cylinder is filled with a gaseous mixture containing equal masses of CO and N_2. The partial pressure ratio is :

(a) $P_{N_2} = P_{CO}$ (b) $P_{CO} = 0.875\, P_{N_2}$

(c) $P_{CO} = 2\, P_{N_2}$ (d) $P_{CO} = 1/2\, P_{N_2}$

49. The pressure of real gases is less than that of ideal gas because of

(a) increase in the number of collisions

(b) finite size of particles

(c) intermolecular attraction

(d) increase in kinetic energy of the molecules.

Graham's Law

50. If some moles of O_2 diffuse in 18 sec and same moles of other gas diffuse in 45 sec then what is the molecular weight of the unknown gas ?

(a) $\frac{45^2}{18^2}\times 32$ (b) $\frac{18^2}{45^2}\times 32$

(c) $\frac{18^2}{45^2\times 32}$ (d) $\frac{45^2}{18^2\times 32}$

51. Which of the following gas will have highest rate of diffusion ?

(a) NH_3 (b) N_2

(c) CO_2 (d) O_2

52. The relative rate of diffusion of helium w.r.t. methane under similar conditions of pressure and temperature is

(a) 2 (b) 0.5

(c) 4 (d) 0.25

53. The rate of diffusion of methane at a given temperature is twice that of a gas X. The molecular weight of X is

(a) 64.0 (b) 32.0

(c) 4.0 (d) 8.0

54. A certain gas effuses through a small opening of a vessel at a rate which is exactly one-fifth the rate at which helium does the same. Thus, the molecular weight of the gas is

(a) 100 (b) 75

(c) 50 (d) 25

54. In a closed room of 1000 m^3, a perfume bottle is opened up. The whole room develops smell. This is due to which property of gases ?

(a) Viscosity (b) Density

(c) Diffusion (d) None

56. A bottle of ammonia and a bottle of dry hydrogen chloride connected through a long tube are opened simultaneously at both ends, the white ammonium chloride ring first formed will be

(a) at the centre of the tube

(b) near the hydrogen chloride bottle

(c) near the ammonia bottle

(d) throughout the length of the tube

Kinetic Theory

57. The kinetic energy for 14 grams of nitrogen gas at 127°C is nearly (mol. mass of nitrogen = 28 and gas constant = 8.31 $JK^{-1}\ mol^{-1}$)

(a) 1.0 J (b) 4.15 J

(c) 2493J (d) 3.3 J

58 The kinetic theory of gases predicts that total kinetic energy of a gaseous assembly depends on

(a) Pressure of the gas (b) Temperature of the gas

(c) Volume of the gas

(d) Pressure, temperature and volume of the gas

59. Which one of the following is not a correct postulate of kinetic theory of gases ?

(a) The molecules of a gas are continuously moving in different directions with different velocities

(b) The average kinetic energy of the gas molecules is directly proportional to the absolute temperature of the gas

(c) The volume of the gas is due to the large number of molecules present in it

(d) The pressure of the gas is due to hitting of the molecules on the walls of the container.

60. The internal energy of one mole of an ideal gas is given by

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

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

61. At what temeprature will the molar KE of 0.3 mol of He be the same as that of 0.4 mol of argon at 400 K ?

(a) 700 K (b) 500 K

(c) 800 K (d) 400 K

62. Consider three one-litre flasks labeled A, B and C filled with the gases NO, NO_2, and N_2O, respectively, each at STP. In which flask do the molecules have the highest average kinetic energy ?

(a) Flask C (b) All are the same

(c) Flask A (d) None

63. Which system contains molecules with the same average kinetic energy as the molecules in 10.0g of carbon dioxide at 10ºC ?

(a) 10g of CO_2 at 40ºC (b) 20g of CO_2 at 20ºC

(c) 20g of CO_2 at 5ºC (d) 40g of CO_2 at 10ºC

Maxwell Curve & Speeds

64. Root mean square velocity of a gas molecule is proportional to

(a) $M^{1/2}$ (b) M^0

(c) $M^{-1/2}$ (d) M

65. The ratio among most probable velocity, mean velocity and root mean square velocity is given by

(a) $1:2:3$ (b) $1:\sqrt{2}:\sqrt{3}$

(c) $\sqrt{2}:\sqrt{3}:\sqrt{8/\pi}$ (d) $\sqrt{2}:\sqrt{8/\pi}:\sqrt{3}$

66. The root mean square speeds at STP for the gases H_2, N_2, O_2 and HBr are in the order :

(a) $H_2 < N_2 < O_2 < HBr$ (b) $HBr < O_2 < N_2 < H_2$

(c) $H_2 < N_2 = O_2 < HBr$ (d) $HBr < O_2 < H_2 < N_2$.

67. The temperature of the gas is raised from 27ºC to 927ºC, the root mean square velocity is

(a) $\sqrt{927/27}$ times the earlier value

(b) same as before

(c) halved

(d) doubled

68. According to kinetic theory of gases, the root mean square velocity is directly proportional to

(a) T (b) T^2

(c) $\sqrt{T}$ (d) 1/T

69. Which of the following gases would have the highest R.M.S. velocity at 25ºC ?

(a) Oxygen (b) Carbon dioxide

(c) Sulphur dioxide (d) Carbon monoxide

70. The ratio of the root mean square velocity to average velocity of a gas molecule at a particular temperature is

(a) 1.086 : 1 (b) 1: 1.086

(c) 2 : 1.086 (d) 1.086 : 2

71. The ratio between the root mean square velocity of H_2 at 50 K and that of O_2 at 800 K is

(a) 4 (b) 2

(c) 1 (d) 1/4

72. At STP the order of mean square velocity of molecules of H_2, N_2, O_2 and HBr is

(a) $H_2 > N_2 > O_2 > HBr$ (b) $HBr > O_2 > N_2 > H_2$

(c) $HBr > H_2 > O_2 > N_2$ (d) $N_2 > O_2 > H_2 > HBr$

73. At what temperature most probable speed of O_2 molecules have the same value of root mean square speed of O_2 molecules at 300 K ?

(a) 150 K
(b) 600 K
(c) 750 K
(d) 450 K

74. The average speed at temperature T°C of $CH_4(g)$ is $\sqrt{\frac{28}{88}} \times 10^3\ ms^{-1}$. What is the value of T ?

(a) 240.55°C
(b) – 32.45°C
(c) 3000°C
(d) –24.055°C

Real Gas

75. A gas is said to behave like an ideal gas when the relation PV/T = constant. When do you expect a real gas to behave like an ideal gas ?

(a) When the temperature is low
(b) When both the temperature and pressure are low
(c) When both the temperature and pressure are high
(d) When the temperature is high and pressure is low

76. The pressure of real gases is less than that of ideal gas because of

(a) increase in the number of collisions
(b) finite size of particles
(c) intermolecular attraction
(d) increase in kinetic energy of the molecules.

77. For a gas deviation from ideal behaviour is maximum at :

(a) 0°C and 1.0 atm
(b) 100°C and 2.0 atm
(c) – 13°C and 1.0 atm
(d) – 13°C and 2.0 atm

Van der wall Equation

78. Van der Waal's equation of state is obeyed by real gases. For n moles of a real gas, the expression will be

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

(b) $\left(p+\frac{a}{V^2}\right)(V-b)=nRT$

(c) $\left(p+\frac{na}{V^2}\right)(nV-b)=nRT$

(d) $\left(p+\frac{n^2a}{V^2}\right)(V-nb)=nRT$

79. Van der Waal's constants 'a' and 'b' are related with..... respectively.

(a) Attractive force and bond energy of molecules
(b) Volume and repulsive force of molecules
(c) Shape and repulsive forces of molecules
(d) Attractive force and volume of the molecules

80. The units of the van der Waal's constant 'a' are

(a) $atm\ L^2\ mol^{-2}$
(b) $atm\ L^{-2}\ mol^{-2}$
(c) $atm\ L\ mol^{-1}$
(d) $atm\ mol\ L^{-1}$

81. The units of the van der Waal's constant 'b' are

(a) atmosphere
(b) joules
(c) $L\ mol^{-1}$
(d) $mol\ L^{-1}$

82. Any gas shows maximum deviation from ideal gas at

(a) 0°C and 1 atmospheric pressure
(b) 100°C and 2 atmospheric pressure
(c) –100°C and 5 atmospheric pressure
(d) 500°C and 1 atmospheric pressure

83. Two separate bulbs contain ideal gases A and B. The density of gas A is twice that of gas B. The molecular mass of A is half that of gas B. The two gases are at the same temperature. The ratio of the pressure of A to that of gas B is

(a) 2
(b) 1/2
(c) 4
(d) 1/4

84. In case of hydrogen and helium, the van der Waal's forces are

(a) Strong
(b) Very strong
(c) Weak
(d) Very weak.

Z-factor

85. For H_2 gas, the compressibility factor,

Z = PV/n RT is :

(a) equal to 1
(b) equal to 0
(c) always greater than 1
(d) initially less than 1 and then becomes greater than 1 at high pressures

86. The compressibility factor of an ideal gas is

(a) 0
(b) 1
(c) 2
(d) 4

Critical Phenomenon

87. The critical temperature of a substance is defined as :

(a) the temperature above which the substance decomposes.

(b) the temperature above which a substance can exist only as a gas

(c) melting point of the substance

(d) boiling point of the substance.

Liquification

88. Which set of conditions represents easiest way to liquiefy a gas ?

(a) Low temperature and high pressure

(b) High temperature and low pressure

(c) Low temperature and low pressure

(d) High temperature and high pressure.

89. An ideal gas can't be liquefied because

(a) its critical temperature is always above 0°C

(b) its molecules are relatively smaller in size

(c) it solidifies before becoming a liquid

(d) forces operative between its molecules are negligible

EXERCISE - 2 : PREVIOUS YEAR JEE MAINS QUESTION

1. For an ideal gas, number of moles per litre in terms of its pressure p, temperature T and gas constant R is **(2002)**

(a) $\frac{pT}{R}$ (b) pRT

(c) $\frac{p}{RT}$ (d) $\frac{RT}{p}$

2. Based on kinetic theory of gases following laws can be proved **(2002)**

(a) Boyle's law (b) Charles' law

(c) Avogadro's law (d) All of these

3. According to the kinetic theory of gases, in an ideal gas, between two successive collisions a gas molecule travels **(2003)**

(a) in a circular path (b) in a wavy path

(c) in a straight line path

(d) with an accelerated velocity

4. In van der Waals' equation of state of the gas law, the constant 'b' is a measure of **(2004)**

(a) intermolecular repulsions

(b) intermolecular attraction

(c) volume occupied by the molecules

(d) intermolecular collisions per unit volume

5. As the temperature is raised from 20°C to 40°C, the average kinetic energy of neon atoms changes by a factor of which of the following ? **(2004)**

(a) 1/2 (b) $\sqrt{313/293}$

(c) 313/293 (d) 2

6. Which one of the following statements is not true about the effect of an increase in temperature on the distribution of molecular speeds in a gas ? **(2005)**

(a) the area under the distribution curve remains the same as under the lower temperature

(b) The distribution becomes broader

(c) The fraction of the molecules with the most probable speed increases

(d) The most probable speed increases.

7. When r, p and M represent rate of diffusion, pressure and molecular mass, respectively, then the ratio of the rates of diffusion (r_A/r_B) of two gases A and B, is given as **(2011)**

(a) $(p_A/p_B)^{1/2}\ (M_A/M_B)$ (b) $(p_A/p_B)\ (M_B/M_A)^{1/2}$

(c) $(p_A/p_B)^{1/2}\ (M_B/M_A)$ (d) $(p_A/p_B)\ (M_A/M_B)^{1/2}$

8. The molecular velocity of any gas is **(2011)**

(a) inversely proportional to the square root of temperature

(b) inversely proportional to absolute temperature

(c) directly proportional to square of temperature

(d) directly proportional to square root of temperature

9. a and b are van der Waals' constants for gases. Chlorine is more easily liquefied than ethane because **(2011)**

(a) a and b for Cl_2 > a and b for C_2H_6

(b) a and b for Cl_2 < a and b for C_2H_6

(c) a for Cl_2 > a for C_2H_6 but b for Cl_2 > b for C_2H_6

(d) a for Cl_2 > a for C_2H_6 but b for Cl_2 < b for C_2H_6

10. The compressibility factor for a real gas at high pressure is **(2012)**

(a) $1+\frac{RT}{pb}$ (b) 1

(c) $1+\frac{pb}{RT}$ (d) $1-\frac{pb}{RT}$

11. For gaseous state, if most probable speed is denoted by C*, average speed by $\overline{C}$ and root square speed by C, then for a large number of molecules, the ratios of these speeds are **(2013)**

(a) $C^*:\overline{C}:C = 1.225:1.128:1$

(b) $C^*:\overline{C}:C = 1.128:1.225:1$

(c) $C^*:\overline{C}:C = 1:1.128:1.225$

(d) $C^*:\overline{C}:C = 1:1.125:1.128$

12. If Z is a compressibility factor, van der Waals equation at low pressure can be written as : **(2014)**

(a) $Z = 1 - \frac{a}{VRT}$ (b) $Z = 1 - \frac{Pb}{RT}$

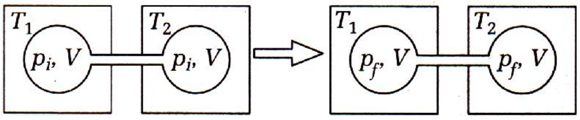
(c) $Z = 1 + \frac{Pb}{RT}$ (d) $Z = 1 + \frac{RT}{Pb}$

13. The intermolecular interaction that is dependent on the inverse cube of distance between the molecules is : **(2015)**

(a) London force (b) hydrogen bond

(c) ion - ion interaction (d) ion - dipole interaction

14. Two closed bulbs of equal volume (V) containing an ideal gas initially at pressure p_i and temperature T_1 are connected through a narrow tube of negligible volume as shown in the figure below. The temperature of one of the bulbs is then raised to T_2. The final pressure P_f is **(2016)**



(a) $2p_i\left(\frac{T_1}{T_1+T_2}\right)$ (b) $2p_i\left(\frac{T_2}{T_1+T_2}\right)$

(c) $2p_i\left(\frac{T_1T_2}{T_1+T_2}\right)$ (d) $p_i\left(\frac{T_1T_2}{T_1+T_2}\right)$

JEE MAINS ONLINE QUESTION

1. van der Waal's equation for a gas is stated as,

$$p = \frac{nRT}{V - nb} - a\left(\frac{n}{V}\right)^2$$

This equation reduces to the perfect gas equation, $p = \frac{nRT}{V}$ when, **Online 2014 SET (1)**

(a) temperature is sufficiently high and pressure is low.

(b) temperature is sufficiently low and pressure is high.

(c) both temperature and pressure are very high.

(d) both temperature and pressure are very low.

2. The temperature at which oxygen molecules have the same root mean square speed as helium atoms have at 300 K is: (Atomic masses : He = 4u, O = 16u)

Online 2014 SET (1)

(a) 300 K (b) 600 K

(c) 1200 K (d) 2400 K

3. The initial volume of a gas cylinder is 750.0 mL. If the pressure of gas inside the cylinder changes from 840.0 mm Hg to 360.0 mm Hg, the final volume the gas will be: **Online 2014 SET (2)**

(a) 3.60 L (b) 4.032 L

(c) 7.50 L (d) 1.750 L

4. Sulphur dioxide and oxygen were allowed to diffuse through a porous partition. 20 dm^3 of SO_2 diffuses through the porous partition in 60 seconds. The volume of O_2 in dm^3 which diffuses under the similar condition in 30 seconds will be (atomic mass of sulphur = 32 u) :

Online 2014 SET (4)

(a) 14.1 (b) 10.0

(c) 28.2 (d) 7.09

5. When does a gas deviate the most from its ideal behavior ? **Online 2015 SET (1)**

(a) At low pressure and low temperature

(b) At low pressure and high temperature

(c) At high pressure and low temperature

(d) At high pressure and high temperature

6. Initially, the root mean square (rms) velocity of N_2 molecules at certain temperature is u. If this temperature is doubled and all the nitrogen molecules dissociate into nitrogen atoms, then the new rms velocity will be :

Online 2016 SET (2)

(a) u/2 (b) 2u

(c) 4u (d) 14u

7. Among the following, the **incorrect** statement is :

Online 2017 SET (1)

(a) At low pressure, real gases show ideal behaviour.

(b) At very low temperature, real gases show ideal behaviour.

(c) At very large volume, real gases show ideal behaviour.

(d) At Boyle's temperature, real gases show ideal behaviour.

8. At 300 K, the density of a certain gaseous molecule at 2 bar is double to that of dinitrogen (N_2) at 4 bar. The molar mass of gaseous molecule is :**Online 2017 SET (2)**

(a) 28 g mol^{-1} (b) 56 g mol^{-1}

(c) 112 g mol^{-1} (d) 224 g mol^{-1}

9. Assuming ideal gas behaviour, the ratio of density of ammonia to that of hydrogen chloride at same temperature and pressure is : (Atomic wt. of Cl = 35.5 u)

(Online 2018 SET 3)

(a) 1.46 (b) 0.46

(c) 1.64 (d) 0.64

EXERCISE - 3 : ADVANCED OBJECTIVE QUESTIONS

1. All questions marked **“S”** are single choice questions
2. All questions marked **“M”** are multiple choice questions
3. All questions marked **“C”** are comprehension based questions
4. All questions marked **“A”** are assertion–reason type questions

   (A) If both assertion and reason are correct and reason is the correct explanation of assertion.

   (B) If both assertion and reason are true but reason is not the correct explanation of assertion.

   (C) If assertion is true but reason is false.

   (D) If reason is true but assertion is false.
5. All questions marked **“X”** are matrix–match type questions
6. All questions marked **“I”** are integer type questions

Ideal Gas

1. (X) Match Column-I with Column-II

Column-I **(Pair of molecules)**	**Column-II** **(Type of intermolcular force**
(A) Two molecules of HCl	(p) Hydrogen bonding
(B) Two propane molecules	(q) Dipole induced dipole interaction
(C) CH_4 and HCl molecules	(r) Dipole-dipole interaction
(D) Two molecules of NH3	(s) London dispersion force

2. (S) Which of the following exhibits the weakest intermolecular forces ?

(a) NH_3 (b) HCl

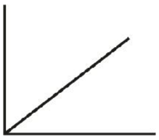
(c) He (d) H_2O

3. (X) Match Column-I with Column-II

Column-I **Column-II**

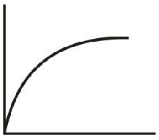
(A) Plot of $\frac{1}{V^2}$ against P for ideal gas at constant temperature and number of moles

(p)



(B) Plot of V against $\frac{1}{T}$ for ideal gas at constant pressure and number of moles

(q)

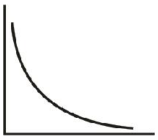


(C) Plot of P against T for ideal gas at constant volume and number of moles

(r)

(D) Plot of V against $\frac{1}{P^2}$ for ideal gas at constant temperature and number of moles

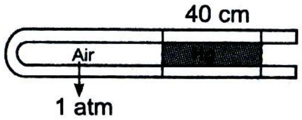
(s)



Pressure

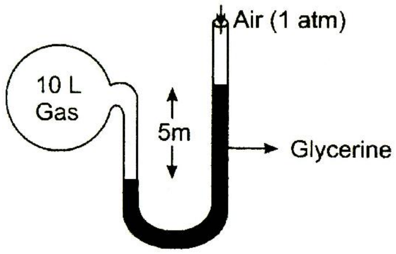
4. (I) A thin tube sealed at both ends, is 100 cm long. It lies horizontally, the middle 0.1 m containing mercury and the two ends containing air at standard atmospheric pressure. If the tube is turned to a vertical position, by what amount will the mercury be displaced ? (in cm)

5. (I) Air is trapped in a horizontal glass tube by 40 cm mercury column as shown below :



If the tube is held vertical keeping the open end up, length of air column shrink to 19 cm. Length in cm by which the mercury column shifts down is

6. (S)



Calculate the number of moles in the glass bulb shown in figure at 300 K.

Given : d glycerine = 2.72 g/mL;

d mercury = 13.6g/mL

(a) 0.36 mol (b) 0.94 mol

(c) 0.49 mol (d) 0.64 mol

Ideal Gas Laws

7. (S) Which one of the following plot will be a parabola at constant temperature ?

(a) P vs 1/V (b) PV vs P

(c) V vs P (d) None of these

8. (S) In a closed flask of 5 litres, 1.0 g of H_2 is heated from 300 to 600 K. Which statements is not correct ?

(a) pressure of the gas increases

(b) The rate of collision increases

(c) The number of moles of gas increases

(d) The energy of gaseous molecules increases

9. (M) To raise the volume of the gas by four times, which of the following methods are correct ?

(a) T is doubled and P is also doubled

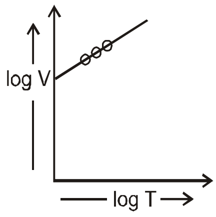
(b) Keeping P constant, T is raised by four times

(c) Temperature is doubled and pressure is halved

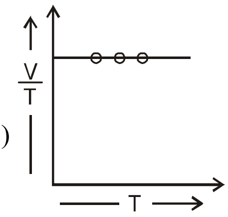
(d) Keeping temperature constant, pressure is reduced to 1/4th of its initial value.

10. (M) Among the plots, which of them represent Charle's law, at constant pressure ?

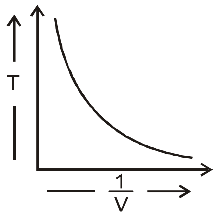
(a)



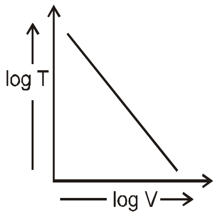
(b)



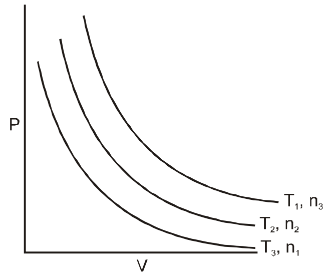
(c)



(d)



11. (M) The graph of P vs V is given at different temperatures and number of rule curves, n_1, n_2, n_3 are number of moles



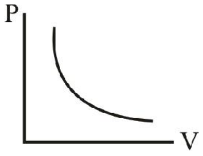
The correct relationship are

(a) $T_1 > T_2 > T_3$ (b) $T_1 < T_2 < T_3$

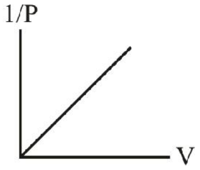
(c) $n_1 > n_2 > n_3$ (d) $n_3 > n_2 > n_1$

12. (M) Which of the following curves represent(s) Boyle's law ?

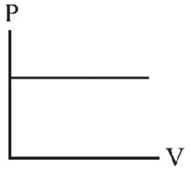
(a)



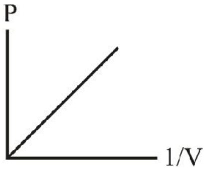
(b)



(c)



(d)



13. (A) **Assertion :** The pressure of a gas is inversely proportional to the volume at constant temperature and n.

Reason : The gas volume is directly proportional to n at constant temperature and pressure.

(a) A (b) B

(c) C (d) D

14. (A) **Assertion :** For a given amount of an ideal gas, a plot of pressure (p) versus (1/V) is a straight line at a constant temperature.

Reason : A given amount of an ideal gas at a constant temperature obeys Boyle's law.

(a) A (b) B

(c) C (d) D

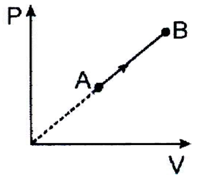
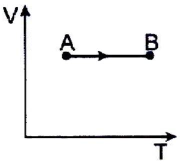
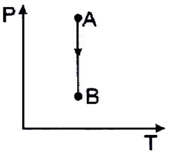
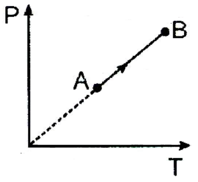
15. (A) **Assertion :** According to Charles' law, for a given amount of an ideal gas at a given pressure, plot of gas volume versus absolute temperature is a straight line passing through origin.

Reason : Gaseous volume never vanishes.

(a) A (b) B

(c) C (d) D

16. (X) **Match the following :**

Column–I	Column–II
(A) 	(p) Temperature is increasing
(B) 	(q) Temperature is constant
(C) 	(r) Volume is constant
(D) 	(s) Pressure is increasing

Ideal Gas Equation

17. (S) A flask containing air (open to atmosphere) is heated from 300 K to 500 K. The percentage of air escaped to the atmosphere is nearly

(a) 16.6 (b) 40

(c) 60 (d) 20.

18. (S) At N.T.P. the volume of a gas is found to be 273 mL. what will be the volume of this gas at 600 mm Hg and 273°C ?

(a) 391.8 mL (b) 380 mL

(c) 691.6 mL (d) 750 mL

19. (S) The vapour density of a gas is 11.2. The volume occupied by 11.2 g of this gas at N.T.P. is

(a) 1L (b) 11.2 L

(c) 22.4 L (d) 20 L

20. (S) If the weight of 5.6 litres of a gas at NTP is 11 gm. The gas may be

(a) PH_3 (b) $COCl_2$

(c) NO (d) N_2O

21. (S) An open flask contains air at 27°C temperature and one atm pressure. The flask is heated to 127°C at the same pressure. What fraction of the original air will remain in the flask ?

(a) 2/5th (b) 2/3rd

(c) 2/7th (d) 3/4th

22. (S) If the pressure is tripled and temperature (in kelvins) is halved, the volume of a given mass of an ideal gas becomes

(a) 3/2 times its original volume

(b) 2/3rd of its original volume

(c) 1/6th of its original volume

(d) 6 times its original volume

23. (S) How many O_2 molecules are present in 2.0 L of oxygen gas at 27°C temperature and 3.0 atm pressure ?

(a) 1.0×10^3 (b) 1.5×10^{23}

(c) 1.5×10^{24} (d) 2.5×10^{24}

24. (S) If the absolute temperature of a gas is doubled and the pressure is reduced to one-half, the volume of the gas will

(a) remain unchanged (b) be doubled

(c) increase four-fold (d) be reduced to 1/4th

25. (S) For an ideal gas, number of moles per litre in terms of its pressure P, gas constant R and and temperature T is

(a) PT/R (b) PRT

(c) P/RT (d) RT/P

26. (S) 1.0 litre of N_2 and 7/8 litre of O_2 at the same temperature and pressure were mixed together. What is relation between the masses of the two gases in the mixture ?

(a) $m_{N_2} = 3m_{O_2}$ (b) $m_{N_2} = 8m_{O_2}$

(c) $m_{N_2} = m_{O_2}$ (d) $m_{N_2} = 16m_{O_2}$

27. (S) Five grams each of the following gases at 87°C and 750 mm pressure are taken. Which of them will have the least volume ?

(a) HF (b) HCl

(c) HBr (d) HI

28. (S) The vapour density of a gas is 11.2. The volume occupied by 11.2 gm of the gas at N.T.P. is

(a) 1 litre (b) 11.2 litre

(c) 22.4 litre (d) 44.8 litre

29. (S) Densities of two gases having same molar mass are in the ratio 1 : 2 and their temperatures are in the ratio 2 : 1, then the ratio of their respective pressures is

(a) 1 : 1 (b) 1 : 2

(c) 2: 1 (d) 4 : 1

30. (S) The density of a gas is 1.4 g/ml at one atmosphere pressure and 27°C. At what pressure will the gas have density thrice this value, the temperature is kept constant ?

(a) same pressure (b) 2 atmosphere

(c) 3 atmosphere (d) 4.2 atmosphere

31. (S) The value (pV_m) depends only on

(a) temperature (b) pressure

(c) molar mass (d) volume

32. (M) A mixture of CO and CO_2 is found to have a density of 1.5 g/L at 30^0C and 740 torr. The composition of mixture is

(a) CO is 35.5% (b) CO_2 is 35.7 %

(c) CO_2 is 64.5% (d) CO is 64.3%

33. (I) A vessel containing 1 gm of oxygen at a pressure of 10 atm and a temperature of 47°C. It is found that because of a leak, the pressure drops to 5/8 th of its original value and the temperature falls to 27°C. Find the mass of oxygen that has leaked out in grams (10^{-1})

34. (I) If an ideal gas at 100 K is heated to 109 K, the pressure increases by x%. x is

35. (M) 0.28g of a gas occupies 224 mL at STP. The gas could be

(a) N_2 (b) CO

(c) C_2H_4 (d) N_2O_4

Comprehension

Density of gas is inversely proportional to temperature and directly proportional to pressure.

$$\Rightarrow\ d \propto \frac{P}{T} \qquad \Rightarrow\ \frac{dT}{P} = \text{constant}$$

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

Density at a particular temperature & pressure can be calculated by using ideal gas equation

$$PV = nRT \Rightarrow PV = \frac{\text{mass}}{\text{molar mass (M)}} \times RT$$

$$\Rightarrow\ P \times M = \frac{\text{mass}}{\text{volume}} \times RT$$

$$\Rightarrow\ P \times M = d \times RT \qquad \Rightarrow\ d = \frac{PM}{RT}$$

36. (C) Which of the following has maximum density?

(a) O_2 at 25^0C and 1 atm (b) O_2 at 0^0C and 2 atm

(c) O_2 at 273^0C and 1 atm (d) O_2 at 0^0C and 1 atm

37. (C) The density of CO_2 at 1 atm and 273 K is

(a) 1.96 g L^{-1} (b) 2.12 g L^{-1}

(c) 1.09 g L^{-1} (d) 2.02 g L^{-1}

38. (C) The density of gas is 3.8 g L^{-1} at STP. The density at 27^0C and 700 mm Hg pressure will be

(a) 3.185 g L^{-1} (b) 3.185 g ml^{-1}

(c) 3.185 kg L^{-1} (d) 3.185 kg ml^{-1}

Dalton's Law

39. (S) To which of the following gaseous mixtures is Dalton's law not applicable ?

(a) $Ne + He + SO_2$ (b) $NH_3 + HCl + HBr$

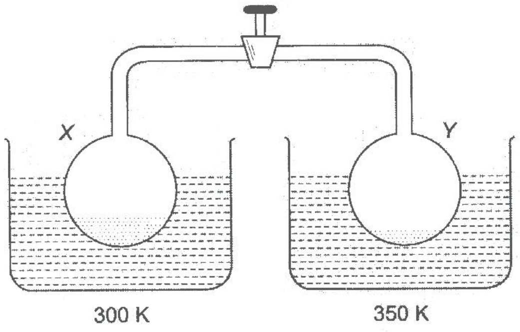
(c) $O_2 + N_2 + CO_2$ (d) $N_2 + H_2 + O_2$

40. (S) Equal weights of ethane and hydrogen are mixed in an empty container at 25°C.The fraction of the total pressure exerted by hydrogen is

(a) 1: 2 (b) 1 : 1

(c) 1 : 16 (d) 15 : 16

41. (M) Two container each containing liquid water are connected as shown in diagram



Given that vapour pressure of H_2O (*l*) at 300 K and 350 K are 22 torr and 40 torr. Select right statement(s) :

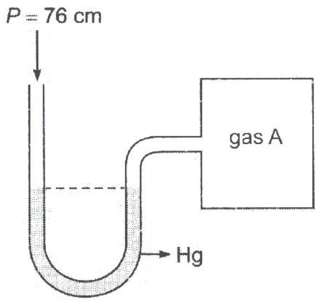
(a) The final pressure in each container if valve is opened while keeping the containers at the given temperature is 22 torr

(b) The final pressure in each container if valve is opened while keeping the containers at the given temperature is 40 torr

(c) Mass of $H_2O(l)$ is decreased in vessel X

(d) Mass of $H_2O(l)$ is decreased in vessel Y

42. (M) A open ended mercury manometer is used to measure the pressure exerted by a trapped gas as shown in the figure. Initially manometer shows no difference in mercury level in both columns as shown in diagram.



After sparking 'A' dissociated according to following reaction

$$A(g) \longrightarrow B(g) + 3C(g)$$

If pressure of Gas "A" decreases to 0.9 atm. Then (Assume temperature to be constant and is 300 K)

(a) total pressure increased to 1.3 atm

(b) total pressure increased by 0.3 atm

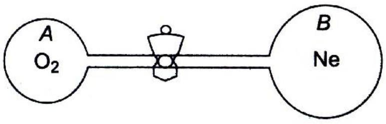
(c) total pressure increased by 22.3 cm of Hg

(d) difference in mercury level is 228 mm.

Comprehension

Consider the adjacent diagram to answer these questions :

Initially, flask A contained oxygen gas at 27ºC and 950 mm of Hg, and flask B contained neon gas at 27ºC and 900 mm. Finally, the two flasks were joined by means of a narrow tube of negligible volume equipped with a stopcork and gases were allowed to mixup freely. The final pressure in the combined system was found to be 910 mm of Hg.



43. (C) What is the correct relationship between volumes of the two flasks ?

(a) $V_B = 3V_A$	(b) $V_B = 4V_A$
(c) $V_B = 5V_A$	(d) $V_B = 4.5V_A$

44. (C) If volume of flask B was measured to be 10L, mass of oxygen gas present initially in flask A was

(a) 2.00 g	(b) 4.00 g
(c) 8.00 g	(d) 16.00 g

45. (C) How many moles of gas are present in flask A in the final condition ?

(a) 0.155	(b) 0.122
(c) 0.022	(d) 0.222

Graham's Law

46. (S) Helium diffuses twice as fast as another gas B. If the vapour density of helium is 2, the molecular weight of B is

(a) 4	(b) 8
(c) 16	(d) 24

47. (S) The atomic weight of helium is 4 times of hydrogen. Its rate of diffusion as compared to hydrogen is

(a) Twice	(b) $\frac{1}{\sqrt{2}}$ times
(c) $\sqrt{2}$ times	(d) 1/4th

48. (S) X ml of H_2 gas effuses through a hole in a container in 5 seconds. The time taken for the effusion of the same volume of the gas specified below under identical condition is

(a) 10 seconds : He	(b) 20 seconds : O_2
(c) 25 seconds : CO	(d) 55 seconds : CO_2

49. (S) 50 ml of gas A diffuses through a membrane in the same time as for the diffusion of 40 ml of a gas B under identical pressure- temperature conditions. If the molecular weight of A is 64 that of B would be

(a) 100	(b) 250
(c) 200	(d) 80

50. (A) **Assertion :** A lighter gas diffuses more rapidly than a heavier gas.

Reason : At a given temperature, the rate of diffusion of a gas is inversely proportional to the density.

(a) A	(b) B
(c) C	(d) D

51. (S) At STP, 0.50 mol H_2 gas and 1.0 mol He gas

(a) have equal average molar kinetic energies

(b) have equal molecular speeds

(c) occupy equal volumes

(d) have equal effusion rates

Kinetic Theory

52. If a gas expands at a constant temperature

(a) the pressure decreases

(b) the kinetic energy of the molecule remains the same

(c) the kinetic energy of the molecule decreases

(d) the number of molecules of the gas increases

53. (S) Indicate which of the following statements are correct.

(a) At constant temperature, the KE of all gas molecules

is the same.

(b) At constant temperature, the KE of different molecules is different.

(c) At constant temperature, the KE is greater for heavier gas molecules.

(d) At constant temperature, the KE is less for heavier gas molecules.

54. (S) At the same temperature and pressure, which of the following gases will have the highest kinetic energy per mole ?

(a) Hydrogen (b) Oxygen

(c) Methane (d) All the same

55. (M) The kinetic energy of one mole of a gas is given by the expression :

$$\text{K.E.} = \frac{3PV}{2} \text{ and } \text{K.E.} = \frac{3}{2}RT$$

Hence, it can be said that

(a) K.E. $\propto$ P at constant temperature

(b) K.E. $\propto$ T at constant pressure

(c) K.E. is not directly proportional to volume at constant temperature

(d) K.E. $\propto$ V at constant temperature

56. (S) **Assertion :** According to kinetic theory of gases, gas molecules occupy some space.

Reason : Gases can be liquefied and solidified.

(a) A (b) B

(c) C (d) D

57. (A) **Assertion :** For a real gas, the gas pressure is always less than the pressure calculated from kinetic theory of gases.

Reason : In kinetic theory, both molecular volumes and intermolecular attractions were ignored.

(a) A (b) B

(c) C (d) D

58. (S) The molecules of which of the following gases has the highest speed ?

(a) O_2 at 0ºC (b) N_2 at 1000ºC

(c) CH_4 at 298 K (d) H_2 at –50ºC

Maxwell Curve & Speeds

59. (S) The energy of given amount an ideal gas depends only on its

(a) pressure (b) volume

(c) number of moles (d) temperature

60. (S) According to kinetic theory of gases, for a diatomic molecule

(a) the pressure exerted by the gas is proportional to the mean velocity of the molecule.

(b) the pressure exerted by the gas is proportional to the root mean square velocity of the molecules

(c) the root mean square velocity of the molecule is inversely proportional to the temperature.

(d) the kinetic energy of the molecules is proportional to the absolute temperature.

61. (S) At what temperature will the average speed of CH_4 molecules have the same value as O_2 has at 300 K ?

(a) 1200 K (b) 150 K

(c) 600 K (d) 300 K

62. (A) **Assertion :** Most probable velocity is the velocity possessed by maximum fraction of molecules at the same temperature.

Reason : On collision, more and more molecules acquire higher speed at the same temperature.

(a) A (b) B

(c) C (d) D

63. (A) **Assertion :** Different gases at the same condition of temperature and pressure have same root mean square speed.

Reason : Average KE of gas is directly proportional to temperature in Kelvin.

(a) A (b) B

(c) C (d) D

64. (M) Which of the following is correct ?

(a) The kinetic energy of H_2 at 600 K is similar to kinetic energy of SO_2 at 327°C

(b) The density of N_2 is less than that of CO_2

(c) The rms velocity of CH_4 at 400 K is similar to rms velocity of He at 100 K

(d) The volume of an ideal gas can never be zero

65. (I) If root mean square speed of CH_4 (methane) at 48 K is same as the most probable speed of H_2 at TK, then T is

66. (M) The factor(s) which measure(s) the deviation from ideal behaviour of a gas are

(a) collision diameter

(b) compressibility factor

(c) van der Waals' constant 'a'

(d) collision frequency

Real Gas

67. (A) **Assertion :** The gases He and H_2 are very different in their behaviour at any temperature and pressure but their compressibility factors are nearly the same at the critical point.

Reason : They have nearly the same critical constant.

(a) A (b) B

(c) C (d) D

68. (S) Which of the following gases has the highest value of the van der Waals constant a ?

(a) $CCl_4 (l)$ (b) NH_3 (g)

(c) CO_2(g) (d) H_2O(g)

Van der Waal Equation

69. (S) The constant 'a' in van der Waal's equation is maximum in

(a) Helium (b) Hydrogen

(c) Oxygen (d) Ammonia

70. (M) $\left(P+\frac{n^2a}{V^2}\right)(V - nb) = nRT$

Which of the following statements is/are correct ?

(a) It is real gas equation

(b) Higher the value of 'a' more easily the gas can be liquified

(c) 'a' is expressed in atm $L^2 mol^{-2}$ and 'b' in L mol^{-1}

(d) At high temperature this equation reduced into PV = nRT

71. (S) The correct order of '*a*' of the gases shown as in the above graph is

(a) $CO > H_2 > He > CH_4$

(b) $NH_3 > CH_4 > CO > He > H_2$

(c) $H_2 > He > CO > CH_4 > NH_3$

(d) $NH_3 > CO > CH_4 > He > H_2$

72. (S) For NH_3 gas Z < 1. So the volume occupied by one mole of NH_3 (V_m) at STP is

(a) $V_m = 22.4$ L (b) $V_m > 22.4$ L

(c) $V_m < 22.4$ L (d) $V_m = 0$

73. (S) At lower temperatures, all gases show

(a) negative deviation

(b) positive deviation

(c) positive and negative deviation

(d) none.

74. (X) Match Column-I with Column-II

Column-I	**Column-II**
(A) Real gas at high pressure	(p) PV = RT + Pb
(B) Force of attraction among gas molecules is negligible	(q) PV = nRT
(C) At high temperature and low pressure	(r) Z = 1
(D) Real gas at N.T.P.	(s) $\left(P+\frac{an^2}{V^2}\right)(V-nb) = nRT$

Z-factor

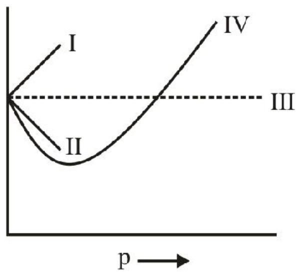
75. (A) **Assertion :** Compressibility factor (Z) for non-ideal gases is always greater than 1.

Reason : Non-ideal gases always exert higher pressure than expected.

(a) A (b) B

(c) C (d) D

76. (M) The diagram displays the plot of the compression factor Z versus p for a few gases.



Which of the following statement(s) is (are) correct for a van der Waals' gas ?

(a) The plot I is applicable provided the van der Waals' constant a is negligible.

(b) The plot II is applicable provided the van der Waals' constant b is negligible.

(c) The plot III is applicable provided the van der Waals' constant a and b are negligible.

(d) The plot IV is applicable provided the temperature in the gas is much higher than its critical temperature.

77. (X) Match the properties in the left column with corresponding functions in the right column.

Column I	**Column II**
(A) Compression factor (Z) of ideal gas	(p) $\frac{8a}{27\,Rb}$
(B) Z for real gas at low P	(q) $1+\frac{pb}{RT}$
(C) Z for real gas at high pressure	(r) 1.00
(D) Critical temperature (T_c)	(s) $1-\frac{a}{VRT}$

78. (A) **Assertion :** When hydrogen gas expands adiabatically from high pressure to low pressure at room temperature then heating effect is observed.

Reason : Hydrogen gas at room temperature is above its inversion temperature.

(a) A (b) B

(c) C (d) D

Critical Phenomenon

79. (S) NH_3 can be liquefied at ordinary temperature without the application of pressure. But O_2 cannot, because

(a) its critical temp. is very high

(b) its critical temp. is low

(c) its critical temp. is moderate

(d) its critical temperature is higher than that of ammonia.

80. (M) The van der Waals' constants of a gas are

$a = 0.751\ dm^6\ atm\ mol^{-2}$ $b = 0.0226\ dm^3\ mol^{-1}$

Hence,

(a) $V_C = 0.678\ dm^3\ mol^{-1}$ (b) $V_C = 0.0678\ dm^3\ mol^{-1}$

(c) $P_C = 54.5$ atm (d) $T_C = 120$ K

81. (X) Match the following :

	Column–I	**Column–II**
(A)	attractive tendency dominates	(p) $Z = 3/8$
(B)	at the Boyle's temperature in the high pressure region	(q) $Z < 1$
(C)	For a gas at very very low pressure and very very high temperature	(r) $Z > 1$
(D)	At the critical point	(s) $Z = 1$

82. **Assertion :** Above critical temperature gaseous state cannot be observed.

Reason : Above critical temperature, the average kinetic energy of a molecule is always greater than the maximum kinetic energy a molecule can possess in liquid state.

(a) A (b) B

(c) C (d) D

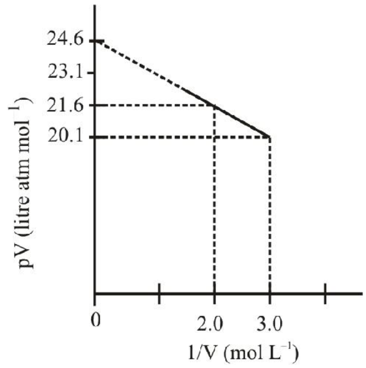
83. (X) Match Column-I with Column-II

Column-I	**Column-II**
(A) Boyle's temperature	(p) a/Rb
(B) 1/2 (Inversion temperature)	(q) 8a/27Rb
(C) Critical temperature	(r) The gas cannot be liquefied above this temperature, on applying pressure
(D) Critical pressure	(s) $a/27b^2$

EXERCISE - 4 : PREVIOUS YEAR JEE ADVANCED QUESTION

Objective Questions (Only one Correct Option)

1. For one mole of a van der Waals' gas when b = 0 and T = 300 K, the pV vs. 1/V plot is shown below. The value of the van der Waals' constant a (atm L mol^{-2}) **(2012)**



(a) 1.0 (b) 4.5

(c) 1.5 (d) 3.0

2. The term that corrects for the attractive forces present in a real gas in the van der Waals' equation is **(2009)**

(a) nb (b) $n^2 a/V^2$

(c) $-(n^2 a/V^2)$ (d) – nb

3. If helium and methane are allowed to diffuse out of the container under the similar conditions of temperature and pressure, then the ratio of rate of diffusion of helium to methane is **(2005)**

(a) 2.0 (b) 1.0

(c) 0.5 (d) 4.0

4. For a monatomic gas kinetic energy = E. The relation with rms velocity is **(2004)**

(a) $u = \left(\frac{2E}{m}\right)^{1/2}$ (b) $u = \left(\frac{3E}{2m}\right)^{1/2}$

(c) $u = \left(\frac{E}{2m}\right)^{1/2}$ (d) $u = \left(\frac{E}{3m}\right)^{1/2}$

5. Positive deviation from ideal behaviour takes place because of **(2003)**

(a) molecular interaction between atom and pV/nRT > 1

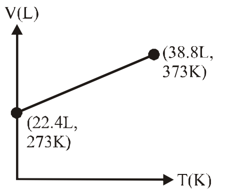
(b) molecular interaction between atom and pV/nRT < 1

(c) finite size of atoms and pV/nRT > 1

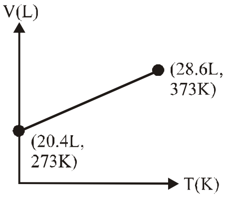
(d) finite size of atoms and pV/nRT < 1

6. Which of the following volume (V)-temperature (T) plots represents the behaviour of one mole of an ideal gas at the atmospheric pressure ? **(2002)**

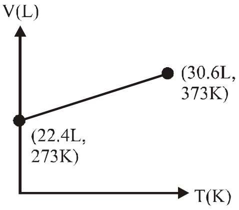
(a)



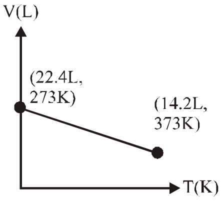
(b)



(c)



(d)



7. The root mean square velocity of an ideal gas at constant pressure varies with density (d) as **(2001)**

(a) d^2 (b) d

(c) $\sqrt{d}$ (d) $1/\sqrt{d}$

8. At 100°C and 1 atm if the density of the liquid water is 1.0 g cm^{-3} and that of water vapour is 0.0006 g cm^{-3}, then the volume occupied by water molecules in 1L of steam at this temperature is **(2000)**

(a) 6 cm^3 (b) 60 cm^3

(c) 0.6 cm^3 (d) 0.06 cm^3

9. The compressibility of a gas is less than unity at STP. Therefore,

(a) $V_m > 22.4$ L (b) $V_m < 22.4$ L

(c) $V_m = 22.4$ L (d) $V_m = 44.8$ L

10. The r.m.s. velocity of hydrogen is $\sqrt{7}$ time the r.m.s. velocity of nitrogen. If T is the temperature of the gas, **(2000)**

(a) $T(H_2) = T(N_2)$ (b) $T(H_2) > T(N_2)$

(c) $T(H_2) < T(N_2)$ (d) $T(H_2) = \sqrt{7}\, T(N_2)$

11. A gas will approach ideal behaviour at **(1999)**

(a) low temperature and low pressure

(b) low temperature and high pressure

(c) high temperature and low pressure

(d) high temperature and high pressure

12. According to Graham's law, at a given temperature the ratio of the rates of diffusion r_A/r_B of gases A and B is given by

(Where P and M are pressures and molecular weights of gases A and B respectively) **(1998)**

(a) $(P_A/P_B)(M_A/M_B)^{1/2}$ (b) $(M_A/M_B)(P_A/P_B)^{1/2}$

(c) $(P_A/P_B)(M_B/M_A)^{1/2}$ (d) $(M_A/M_B)(P_B/P_A)^{1/2}$

13. The critical temperature of water is higher than that of O_2 because the H_2O molecule has **(1997)**

(a) fewer electrons than O_2

(b) two covalent bonds

(c) V-shape

(d) dipole moment

14. The compressibility factor for an ideal gas is **(1997)**

(a) 1.5 (b) 1.0

(c) 2.0 (d) ∞

15. The ratio between the root mean square speed of H_2 at 50K and that of O_2 at 800 K is **(1996)**

(a) 4 (b) 2

(c) 1 (d) 1/4

16. Equal weights of ethane and hydrogen are mixed in an empty container at 25°C. The fraction of the total pressure exerted by hydrogen is **(1993)**

(a) 1 : 2 (b) 1 : 1

(c) 1 : 16 (d) 15 : 16

17. At constant volume, for a fixed number of moles of a gas the pressure of the gas increases with rise of temperature due to **(1992)**

(a) increase in average molecular speed

(b) increase rate of collisions amongst molecules

(c) increase in molecular attraction

(d) decrease in mean free path

18. According to kinetic theory of gases, for a diatomic molecule **(1991)**

(a) the pressure exerted by the gas is proportional to mean velocity of the molecule

(b) the pressure exerted by the gas is proportional to the root mean velocity of the molecule

(c) the root mean square velocity of the molecule is inversely proportional to the temperature

(d) the mean translational kinetic energy of the molecule is proportional to the absolute temperature.

19. The rate of diffusion of methane at a given temperature is twice that of a gas X. The molecular weight of X is

(1990)

(a) 64.0 (b) 32.0

(c) 4.0 (d) 8.0

20. The density of neon will be highest at **(1990)**

(a) STP (b) 0ºC, 2 atm

(c) 273º C, 1 atm (d) 273º C, 2 atm

21. The value of van der Waals' constant 'a' for the gases O_2, N_2, NH_3 and CH_4 are 1.360, 1.390, 4.170 and 2.253L^2 atm mol^{-2} respectively. The gas which can most easily be liquified is **(1989)**

(a) O_2 (b) N_2

(c) NH_3 (d) CH_4

22. A bottle of dry ammonia and a bottle of dry hydrogen chloride connected through a long tube are opened simultaneously at both ends, the white ammonium chloride ring first formed will be : **(1988)**

(a) at the centre of the tube

(b) near the hydrogen chloride bottle

(c) near the ammonia bottle

(d) throughout the length of the tube

23. In van der Waals' equation of state for a non-ideal gas, the term that accounts for intermolecular forces is

(1988)

(a) $(V - b)$ (b) RT

(c) $\left(p + \frac{a}{V^2}\right)$ (d) $(RT)^{-1}$

24. The average velocity of an ideal gas molecule at 27°C is 0.3 m/s. The average velocity at 927° C will be **(1986)**

(a) 0.6 m/s (b) 0.3 m/s

(c) 0.9 m/s (d) 3.0 m/s

25. Rate of diffusion of a gas is

(a) directly proportional to its density

(b) directly proportional to its molecular weight

(c) directly proportional to the square root of its molecular weight

(d) inversely proportional to the square root of its molecular weight

26. A liquid is in equilibrium with its vapour at it's boiling point. On the average, the molecules in the two phases have equal **(1984)**

(a) inter-molecular forces (b) potential energy

(c) kinetic energy (d) total energy

27. Equal weights of methane and hydrogen are mixed in an empty container at 25°C. The fraction of the total pressure exerted by hydrogen is **(1984)**

(a) $\frac{1}{2}$ (b) $\frac{8}{9}$

(c) $\frac{1}{9}$ (d) $\frac{16}{17}$

28. When an ideal gas undergoes unrestrained expansion, no cooling occurs because the molecules **(1984)**

(a) are above the inversion temperature

(b) exert no attractive forces on each other

(c) do work equal to loss in kinetic energy

(d) collide without loss of energy

29. Helium atom is two times heavier than a hydrogen molecule At 298 K, the average kinetic energy of a helium atom is **(1982)**

(a) two times that of a hydrogen molecule

(b) same as that of a hydrogen molecule

(c) four times that of a hydrogen molecule

(d) half that of a hydrogen molecule

30. Equal weights of methane and oxygen are mixed in an empty container at 25°C. The fraction of the total pressure exerted by oxygen is **(1981)**

(a) $\frac{1}{3}$ (b) $\frac{1}{2}$

(c) $\frac{2}{3}$ (d) $\frac{1}{3}\times\frac{273}{298}$

31. The temperature at which a real gas obeys the ideal gas laws over a wide range of pressure is **(1981)**

(a) critical temperature (b) Boyle temperature

(c) inversion temperature (d) reduced temperature

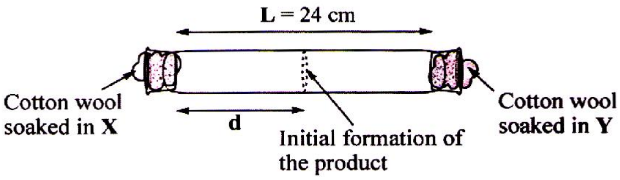
32. The ratio of root mean square velocity to average velocity of a gas molecule at a particular temperature is **(1981)**

(a) 1.086 : 1 (b) 1 : 1.086

(c) 2 : 1.086 (d) 1.086 : 2

Paragraph

X and **Y** are two volatile liquids with molar weights of 10 g mol^{-1} and 40 g mol^{-1} respectively. Two cotton plugs, one socked in **X** and the other soaked in **Y**, are simultaneously placed at the ends of a tube of length **L** = 24 cm, as shown in the figure. The tube is filled with an inert gas at 1 atmosphere pressure and a temperature of 300 K. Vapours of **X** and **Y** react to form a product which is first observed at a distance **d** cm from the plug soaked in X. Take **X** and **Y** to have equal molecular diameters and assume ideal behaviour for the inert gas and the two vapours.



33. The value of **d** in cm (shown in the figure), as estimated from Graham's law, is :

(A) 8 (B) 12

(C) 16 (D) 20

34. The experimental value of **d** is found to be smaller than the estimate obtained using Graham's law. This is due to

(A) larger means free path for **X** as compared to that of **Y.**

(B) larger means free path for **Y** as compared to that of **X.**

(C) increased collision frequency of **Y** with the inert gas as compared to that of **X** with the inert gas.

(D) increased collision frequency of **X** with the inert gas as compared to that of **Y** with the inert gas.

Objective Questions (One or more than one correct option)

35. If a gas is expanded at constant temperature **(1986)**

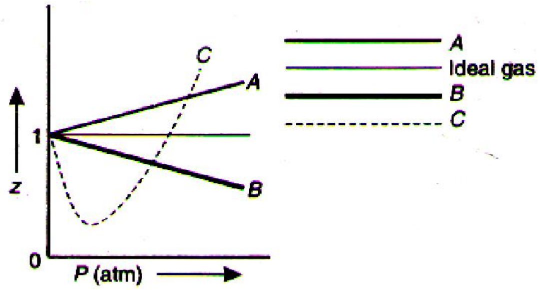
(a) the pressure decreases

(b) the kinetic energy of the molecules remains the same

(c) the kinetic energy of the molecules decreases

(d) the number of molecules of the gas increases

36. The given graph represent the variations of Z (compressibility factor (Z) = $\frac{pV}{nRT}$) versus p, for three real gases A, B and C. Identify the only incorrect statement **(2006)**



(a) For the gas A, a = 0 and its dependence on p is linear at all pressure.

(b) For the gas B, b = 0 and its dependence on p is linear at all pressure.

(c) For the gas C, which is typical real gas for which neither a nor b = 0. By knowing the minima and the point of intersection, with Z = 1, a and b can be calculated.

(d) At high pressure, the slope is positive for all real gases.

37. A gas described by van der Waals' equation **(2008)**

(a) behaves similar to an ideal gas in the limit of large molar volumes

(b) behaves similar to an ideal gas in the limit of large pressures

(c) is characterized by van der Waals' coefficients that are dependent on the identity of the gas but are independent of the temperature

(d) has the pressure that is lower than the pressure exerted by the same gas behaving ideally

Assertion and Reason

(A) If both ASSERTION and REASON are true and reason is the correct explanation of the assertion.

(B) If both ASSERTION and REASON are true but reason is not the correct explanation of the assertion.

(C) If ASSERTION is true but REASON is false.

(D) If both ASSERTION and REASON are false.

(E) If ASSERTION is false but REASON is true.

38. **Assertion :** The value of van der Waals' constant 'a' is larger for ammonia than for nitrogen.

Reason : Hydrogen bonding is present in ammonia.

(1998)

(a) A (b) B (c) C
(d) D (e) E

39. **Assertion :** The pressure of a fixed amount of an ideal gas is proportional to its temperature.

Reason : Frequency of collisions and their impact both increase in proportion to the square root of temperature.

(2000)

(a) A (b) B (c) C
(d) D (e) E

Match the Columns

40. Match the gases under specified conditions listed in **Column I** with their properties/laws in **Column II.**

	Column I	**Column II**
(A)	Hydrogen gas (p = 200 atm, T = 273 K)	(p) compressibility factor ≠ 1
(B)	Hydrogen gas (p ~ 0, T = 273 K)	(q) attractive forces are dominant
(C)	CO_2 (p = 1 atm, T = 273 K)	(r) pV = nRT
(D)	Real gas with very large molar volume	(s) p (V – nb) = nRT

Fill in the Blanks

41. The total energy of one mole of an ideal monatomic gas at 27° C is .... cal.

42. $C_p - C_V$ for an ideal gas is .... **(1984)**

43. The rate of diffusion of a gas is .... proportional to both .... and square root of molecular mass. **(1986)**

44. The value of pV for 5.6L of an ideal gas is .... RT, at NTP. **(1987)**

45. 8g each of oxygen and hydrogen at 27°C will have the total kinetic energy in the ratio of .... **(1989)**

46. The absolute temperature of an ideal gas is .... to/than the average kinetic energy of the gas molecules. **(1997)**

True/False

47. Kinetic energy of a molecule is zero at 0°C. **(1985)**

48. A gas in a closed container will exert nuch higher pressure due to gravity at the bottom than at the top. **(1985)**

49. In the van der Waals' equation $\left(p+\frac{n^2a}{V^2}\right)(V-nb)=nRT$ the constant 'a' reflects the actual volume of the gas molecules.

50. A mixture of ideal gases is cooled up to liquid helium temperature (4.22K) to form an ideal solution. **(1996)**

Subjective Questions

51. Calculate the density of NH_3 at 30°C and 5 atm pressure. **(1978)**

52. 4.215 g of a metallic carbonate was heated in a hard glass tube, the CO_2 evolved was found to measure 1336 mL at 27°C and 700 mm of Hg pressure. What is the equivalent weight of the metal ? **(1979)**

53. 3.7 g of a gas at 25°C occupied the same volume as 0.184g of hydrogen at 17°C and at the same pressure. What is the molecular weight of the gas ? **(1972)**

54. A hydrocarbon contains 10.5g of carbon per gram of hydrogen. 1L of the vapour of the hydrocarbon at 127°C and 1 atm pressure weighs 2.8 g. Find the molecular formula of the hydrocarbon. **(1980)**

55. The pressure in a bulb dropped from 2000 to 1500 mm of mercury in 47 min when the contained oxygen leaked through a small hole. The bulb was then evacuated. A mixture of oxygen and another gas of molecular weight 79 in the molar ratio of 1 : 1 at a total pressure of 4000 mm of mercury was introduced. Find the molar ratio of the two gases remaining in the bulb after a period of 74 min. **(1981)**

56. Calculate the average kinetic energy, in Joule per molecule in 8.0g of methane at 27°C. **(1982)**

57. At room temperature, ammonia gas at 1 atm pressure and hydrogen chloride gas at p atm pressure are allowed to effuse through identical pin holes from opposite ends of a glass tube of one metre length and of uniform cross-section. Ammonium chloride is first formed at a distance of 60 cm from the end through which HCl gas is sent in. What is the value of p ? **(1982)**

58. When 2g of a gas A is introduced into an evacuated flask kept at 25°C, the pressure is found to be one atmosphere, If 3g of another gas B is then added to the same flask, the total pressure becomes 1.5 atm. Assuming ideal gas behaviour, calculate the ratio of the molecular weights $M_A : M_B$. **(1983)**

59. Oxygen is present in one litre flask at a pressure of 7.6×10^{-10} mm Hg. Calculate the number of oxygen molecules in the flask at 0°C. **(1983)**

60. Give reasons for the following in one or two sentences.

(i) A bottle of liquor ammonia should be cooled before opening the stopper. **(1983)**

(ii) Equal volumes of gases contain equal number of moles. **(1984)**

61. Calculate the root mean square velocity of ozone kept in a closed vessel at 20°C and 82 cm mercury pressure. **(1985)**

62. A spherical balloon of 21 cm diameter is to be filled up with hydrogen at NTP from a cylinder containing the gas at 20 atmospheres at 27°C. If the cylinder can hold 2.82 L of water, calculate the number of balloons that can be filled up. **(1987)**

63. The average velocity at T_1 K and the most probable at T_2K of CO_2 gas is 9.0×10^4 cm s^{-1}. Calculate the value of T_1 and T_2. **(1990)**

64. Calculat the volume occupied by 5.0 g of acetylene gas at 50°C and 740 mm pressure. **(1991)**

65. At 27°C, hydrogen is leaked through a tiny hole into a vessel for 20 min. Another unknown gas at the same temperature and pressure as that of hydrogen is leaked through same hole for 20 min. After the effusion of the gases the mixture exerts a pressure of 6 atm. The hydrogen content of the mixture is 0.7 mole. If the volume of the container is 3L. What is the molecular weight of the unknown gas ? **(1992)**

66. At room temperature, the following reaction proceed nearly to completion.

$$2NO + O_2 \rightarrow 2NO_2 \rightarrow N_2O_4$$

The dimer, N_2O_4, solidifies at 262 K. A 250 mL flask and a 100 mL flask are separated by a stopcock. At 300 K, the nitric oxide in the larger flask exerts a pressure of 1.053 atm and the smaller one contains oxygen at 0.789 atm. The gases are mixed by opening the stopcock and after the end of the reaction the flasks are cooled to 220 K. Neglecting the vapour pressure of the dimer, find out the pressure and composition of the gas remaining at 220 K. (Assume the gases to behave ideally). **(1992)**

67. A gas bulb of 1 L capacity contains 2.0×10^{21} molecules of nitrogen exerting a pressure of 7.57×10^3 Nm^{-2}. Calculate the root mean square (rms) speed and the temperature of the gas molecules. If the ratio of the most probable speed to root mean square speed is 0.82, calculate the most probable speed for these molecules at this temperature. **(1993)**

68. A 4 : 1 molar mixture of He and CH_4 is contained in a vessel at 20 bar pressure. Due to a hole in the vessel, the gas mixture leaks out. What is the composition of the mixture effusing out initially ? **(1994)**

69. An LPG (liquified petroleum gas) cylinder weighs 14.8 kg when empty. When full it weighs 29.0 kg and shows a pressure of 2.5 atm. In the course of use at 27ºC, the weight of the full cylinder reduces to 23.2 kg. Find out the volume of the gas in cubic metres used up at the normal usage conditions, and the final pressure inside the cylinder. Assume LPG to the n-butane with normal boiling point of 0ºC. **(1994)**

70. A mixture of ethane (C_2H_6) and ethene (C_2H_4) occupies 40 L at 1.00 atm and at 400 K. The mixture reacts completely with 130 g of O_2 to produce CO_2 and H_2O. Assuming ideal gas behaviour, calculate the mole fractions of C_2H_4 and C_2H_6 in the mixture. **(1995)**

71. The composition of the equilibrium mixture ($Cl_2 \rightleftharpoons 2Cl$) which is attained at 1200ºC, is determined by measuring the rate of effusion through a pin-hole. It is observed that at 1.80 mm Hg pressure, the mixture effuses 1.16 times as fast as krypton effuses under the same conditions. Calculate the fraction of chlorine molecules dissociated into atoms (atomic weight of Kr = 84) **(1995)**

72. A mixture of ideal gases is cooled up to liquid helium temperature (4.22 K) to form an ideal solution. Is this statement true or false ? Justify your answer in not more than two lines. **(1996)**

73. An evacuated glass vessel weighs 50.0g when empty 148.0 g when filled with a liquid of density 0.98g mL^{-1} and 50.5 g when filled with an ideal gas at 760 mm Hg at 300 K. Determine the molar mass of the gas. **(1998)**

74. Using van der Waals' equation, calculate the constant 'a' when two moles of a gas confined in a four litre flask exert a pressure of 11.0 atm at a temperature of 300 K. The value of 'b' is 0.05 L mol^{-1}. **(1998)**

75. (a) One mole of nitrogen gas at 0.8 atm takes 38 s to diffuse through a pin-hole, whereas one mole of an unknown compound of xenon with fluorine at 1.6 atm takes 57 s to diffuse through the same hole. Calculate the molecular formula of the compound.

(b) The pressure exerted by 12 g of an ideal gas at temperature tºC in a vessel of volume V litre is one atm. When the temperature is increased by 10ºC at the same volume, the pressure increases by 10%. Calculate the temperature 't' and volume V. (molecular weight of the gas = 120) **(1999)**

76. Calculate the pressure exerted by one mole of CO_2 gas at 273 K if the van der Waals' constant a = 3.592 dm^6 atm mol^{-2}. Assume that the volume occupied by CO_2 molecules is negligible. **(2000)**

77. The compression factor (compressibility factor) for one mole of a van der Waals' gas at 0ºC and 100 atm pressure is found to be 0.5. Assuming that the volume of a gas molecule is negligible, calculate the van der Waals' constant 'a'. **(2001)**

78. The density of the vapour of a substance at 1 atm pressure and 500 K is 0.36 kg m^{-3}. The vapour effuses through a small hole at a rate of 1.33 times faster than oxygen under the same condition.

(a) Determine, (i) molecular weight (ii) molar volume (iii) compression factor (z) of the vapour and (iv) which forces among the gas molecules are dominating, the attractive or the repulsive ?

(b) If the vapour behaves ideally at 1000 K, determine the average translational kinetic energy of a molecule. **(2002)**

79. The average velocity of gas molecules is 400 m s^{-1}, find the rms velocity of the gas. **(2003)**

80. At 400 K, the root mean square (rms) speed of a gas X (molecular weight = 40) is equal to the most probable speed of gas Y at 60 K. The molecular weight of the gas Y is **(2009)**

81. The diffusion coefficient of an ideal gas is proportional to its mean free path and mean speed. The absolute temperature of an ideal gas is increased 4 times and its pressure is increased 2 times. As a result, the diffusion coefficient of this gas increases x times. The value of x is **(2016)**

82. If the value of Avogadro number is 6.023 × 10^{23} mol^{-1} and the value of Boltzmann constant is 1.380 × 10^{-23} J K^{-1}, then the number of significant digits in the calculated value of the universal gas constant is **(2015)**

83. A closed tank has two compartments A and B, both filled with oxygen (assumed to be ideal gas). The partition separating the two compartments is fixed and is a perfect heat insulator (figure 1). If the old partition is replaced by a new partition which can slide and conduct heat but does NOT allow the gas to leak across (figure 2), the volume (in m^3) of the compartment A after the system attains equilibrium is .... **(2018)**

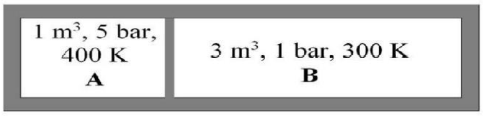


Figure 1

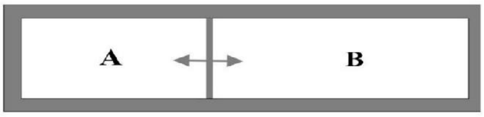


Figure 2

ANSWER KEY

EXERCISE - 1 : (Basic Objective Questions)

1. (d) **2.** (c) **3.** (c) **4.** (d) **5.** (d) **6.** (a) **7.** (b) **8.** (d) **9.** (a) **10.** (a)

11. (a) **12.** (d) **13.** (a) **14.** (c) **15.** (c) **16.** (d) **17.** (c) **18.** (b) **19.** (c) **20.** (b)

21. (b) **22.** (a) **23.** (c) **24.** (b) **25.** (c) **26.** (b) **27.** (c) **28.** (a) **29.** (a) **30.** (b)

31. (a) **32.** (d) **33.** (c) **34.** (c) **35.** (d) **36.** (c) **37.** (a) **38.** (b) **39.** (d) **40.** (c)

41. (d) **42.** (a) **43.** (d) **44.** (b) **45.** (b) **46.** (c) **47.** (d) **48.** (a) **49.** (c) **50.** (a)

51. (a) **52.** (a) **53.** (a) **54.** (a) **54.** (c) **56.** (b) **57.** (c) **58.** (b) **59.** (c) **60.** (a)

61. (d) **62.** (b) **63.** (d) **64.** (c) **65.** (d) **66.** (b) **67.** (d) **68.** (c) **69.** (d) **70.** (a)

71. (c) **72.** (a) **73.** (d) **74.** (b) **75.** (d) **76.** (c) **77.** (d) **78.** (d) **79.** (d) **80.** (a)

81. (c) **82.** (c) **83.** (c) **84.** (d) **85.** (c) **86.** (b) **87.** (b) **88.** (a) **89.** (d)

EXERCISE - 2 : (Previous year JEE Mains Questions)

1. (c) **2.** (d) **3.** (c) **4.** (c) **5.** (c) **6.** (c) **7.** (b) **8.** (d) **9.** (d) **10.** (c)

11. (c) **12.** (a) **13.** (d) **14.** (b)

JEE Mains Online

1. (a) **2.** (d) **3.** (d) **4.** (a) **5.** (c) **6.** (b) **7.** (b) **8.** (c) **9.** (b)

EXERCISE - 3 : (Advanced Objective Questions)

1. (A-r; B – s; C – q; D – p) **2.** (c) **3.** (A – r ; B – s; C – p; D – q) **4.** (0003) **5.** (0010) **6.** (b)

7. (d) **8.** (c) **9.** (bcd) **10.** (abc) **11.** (ad) **12.** (abd) **13.** (b) **14.** (a) **15.** (b)

16. (A → p, s); (B → r, p, s); (C → q); (D → r, p, s) **17.** (b) **18.** (c) **19.** (b) **20.** (d) **21.** (d)

22. (c) **23.** (b) **24.** (c) **25.** (c) **26.** (c) **27.** (d) **28.** (b) **29.** (a) **30.** (c) **31.** (a)

32. (a,c) **33.** (0003) **34.** (0009) **35.** (a,b,c) **36.** (b) **37.** (a) **38.** (a) **39.** (b) **40.** (d) **41.** (ad)

42. (a,b,d) **43.** (b) **44.** (b) **45.** (b) **46.** (c) **47.** (b) **48.** (b) **49.** (a) **50.** (c) **51.** (a)

52. (a,b) **53.** (b) **54.** (d) **55.** (b,c) **56.** (d) **57.** (d) **58.** (d) **59.** (d) **60.** (d) **61.** (b)

62. (c) **63.** (d) **64.** (a,b,c,d) **65.** (0009) **66.** (b,c) **67.** (c) **68.** (d) **69.** (d) **70.** (a,b,c,d)

71. (b) **72.** (c) **73.** (a) **74.** (A – p; B – p; C – q, r; D – s) **75.** (d) **76.** (ac) **77.** (A – r; B – s; C – q; D – q)

78. (a) **79.** (b) **80.** (bcd) **81.** (A → q); (B → r); (C → s); (D →p) **82.** (a)

83. (A – p; B – p, C – q, r; D – s)

EXERCISE - 4 : (Previous year JEE Advanced Questions)

1. (c) **2.** (b) **3.** (a) **4.** (a) **5.** (a) **6. (c)** **7.** (d) **8.** (c) **9.** (b) **10. (c)**

11. (c) **12. (c)** **13.** (d) **14.** (b) **15.** (c) **16.** (d) **17.** (a) **18.** (d) **19.** (a) **20.** (b)

21. (c) **22.** (b) **23.** (c) **24.** (a) **25.** (d) **26.** (c) **27.** (b) **28.** (b) **29.** (b) **30.** (a)

31. (b) **32.** (a) **33.** (c) **34.** (d) **35.** (a, b) **36.** (b) **37.** (a, c) **38.** (a) **39.** (d)

40. A – P, S; B – R; C – P, Q; D – R

41. 900 **42.** R **43.** Inversely, time **44.** 0.25 **45.** 1.16 **46.** less **47.** False **48.** False **49.** False

50. False **51.** 3.42 g L^{-1}. **52.** 12.15 **53.** 41.32g **54.** C_7H_8 **55.** 1 : 1.18 **56.** 6.21×10^{-21} J/molecule

57. 2.20 atm **58.** 1 : 3 **59.** 2.7×10^{10} molecules **61.** 390.2 ms^{-1} **62.** 10

63. 1682.5 K, 2142 K **64.** 5.23 L **65.** M = 1020g mol^{-1} **66.** 0.221 atm **67.** 407 ms^{-1} **68.** 8 : 1

69. 1.48 atm, 2.46 m^3 **70.** 0.34 **71.** 0.14 **73.** 123g mol^{-1} **74.** 6.46 atm L^2 mol^{-2}

75. (a) XeF_6 (b) – 173ºC, 0.82L **76.** 0.99 atm **77.** 1.25 atm L^2 mol^{-2} **79.** 434 ms^{-1} **80.** (4)

81. (4) **82.** (4) **83.** (2.22)