AEP STUDY CIRCLE

SINCE 2001...

IIT-NEET-CBSE

ACCENTS EDUCATIONAL PROMOTERS

24 YEARS OF LEGACY

XI IIT-NEET

CHEMISTRY MOLES CONCEPTS

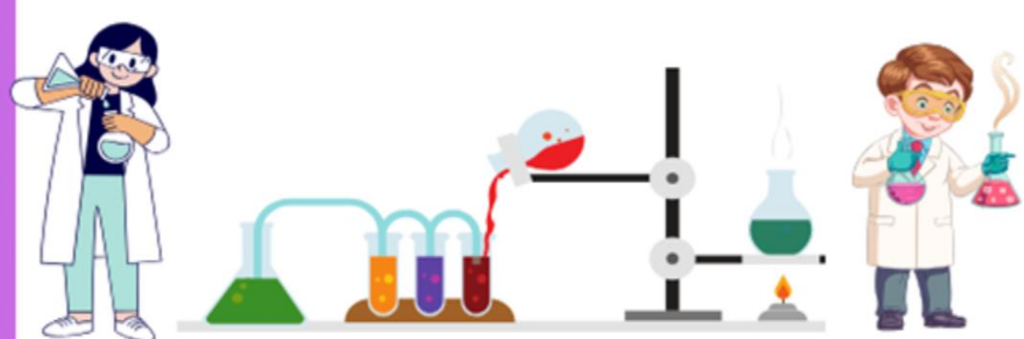
ONLINE-OFFLINE LEARNING ACADEMY

YOUR GATEWAY TO EXCELLENCE IN IIT-JEE, NEET AND CBSE EXAMS

MOLES AND EQUIVALENT CONCEPTS

IIT-NEET CHEMISTRY

IIT-JEE
NEET
CBSE



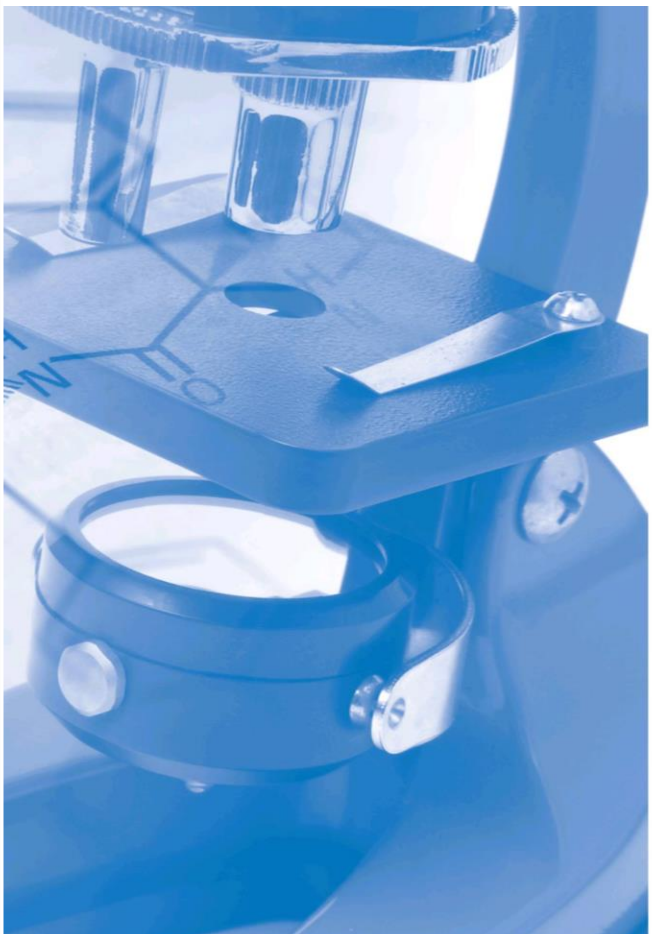
+91-9939586130
+91-9955930311

www.aepstudycircle.com

aepstudycircle@gmail.com

2ND FLOOR, SATKOUDI COMPLEX, THANA CHOWK, RAMGARH - 829122-JH

MOLES CONCEPTS



Remember

Before beginning this chapter, you should be able to:

- understand the concept of matter and atoms
- review the classification of matter and their atomic structure identify the types of chemical reactions

Key Ideas

After completing this chapter, you should be able to:

- understand the kinetic molecular theory and interrelationship among various measurable properties of gases.
- understand mole as the chemical counting unit
- derive ideal gas equation from Gas Laws and draw a comparison between ideal gas and real gas.
- study the behaviour of gases in a mixture and their relative tendency to diffuse.
- understand and to establish quantitative relationship among reactants and products and develop numerical skills with regard to calculations based on chemical equations.

Chemistry is the branch of science which deals with the study of matter in different perceptions. Matter can be basically classified on the basis of molecular composition as elements, compounds and mixtures. The various elements are given names and symbols and the names and formulae of various compounds have been derived based on certain rules. The study of naming these compounds and derivation of formulae for these is the prerequisite for representing chemical reactions in the form of chemical equations. Therefore, the language of chemistry which involves the study of symbols, formulae and chemical equations with respect to the above aspects is of utmost significance.

SYMBOL

All elements are represented by means of their symbols. A symbol represents the atom of an element which may consist of a single letter or a combination of letters derived either from its English name or from its Latin name.
A symbol is the short hand notation which represents a single atom of an element.

Example

H $\Rightarrow$ Hydrogen

Hg $\Rightarrow$ Hydrarg yrum (Latin name for mercury)

He $\Rightarrow$ Helium

FORMULAE

A molecule of an element or a compound is represented by means of a formula. Formula is written with the help of symbols of the respective constituent element(s) along with the actual number of atoms of the respective elements.
A formula is the short hand notation which represents a single molecule of an element or compound.

Example

Cl $\Rightarrow$ one molecule of chlorine consists of two atoms.

$CaCO_3$ $\Rightarrow$ one calcium atom, one carbon atom and three oxygen atoms

Derivation of Formulae of Compounds

A molecule is formed by the combination of a positive radical and a negative radical, but by itself is electrically neutral. Hence the number of positive and negative radicals which form a molecule of the compound depends on the charge(s) on the respective radicals.

Positive Radicals	Negative Radicals	Formulas	Explanation
Na^+	Cl^-	NaCl	One Na^+ neutralizes one Cl^- since both of them are unipositive
H^+	SO_4^{-2}	H_2SO_4	Two H^+ are required to neutralize one SO_4^{-2}
Al^{+3}	CO_3^{-2}	$Al_2(CO_3)_3$	Two Al^{+3} are required to neutralize three CO_3^{-2}
Ca^{+2}	PO_4^{-3}	$Ca_3(PO_4)_2$	Three Ca^{+2} are required to neutralize two PO_4^{-3}

Naming of Inorganic Compounds

Inorganic compounds are classified into three categories, namely, acids, bases and salts. Naming of the respective categories follows certain rules, which we now discuss.

Naming of Acids

Acids usually contain hydrogen ion (H^+) as the positive radical. Hence the name of the acid depends on the constituent(s) of its negative radical.

Types of Acid	Types of Negative Radical	Suffixes
1. Binary acids	Negative radical consists of a single nonmetal Examples: HCl, HBr, etc.	"ic" (prefix hydro) Hydrochloric acid Hydrobromic acid
2. Oxyacid	Negative radical consists of a nonmetal and oxygen. The name of the oxyacid depends on the percentage of the oxygen associated with a specific nonmetal.	
	Acids with comparatively less percentage of oxygen. Examples: H_2SO_3, HNO_3, H_3PO_3, etc.	"ous" Sulphurous acid, nitrous acid, phosphorous acid, etc.
	Acids with comparatively more percentage of oxygen. Examples: H_2SO_4, HNO_3, H_3PO_4, etc.	"ic" Sulphuric acid, nitric acid, phosphoric acid, etc.

If the acid contains lesser number of oxygen atoms than the corresponding "ous" acid, "hypo" prefix is given to the negative radical, whereas "per" prefix is given to the negative radical when the acid contains greater number of oxygen atoms than the corresponding "ic" acid.

Examples

Hypochlorous	acid	$HClO$
Chlorous	acid	$HClO_2$
Chloric	acid	$HClO_3$
Perchloric	acid	$HClO_4$

Naming of Bases

Bases generally contain hydroxyl radical (OH^-) as the negative radical and a metal ion as its positive radical. While writing the name of the base, the name of the metal is written first followed by hydroxide.

Examples

$Ca(OH)_2$	Calcium hydroxide
$Mg(OH)_2$	Magnesium hydroxide
$NaOH$	Sodium hydroxide
$Al(OH)_3$	Aluminium hydroxide

Naming of Salts

The positive radical present in the salt comes from the corresponding base and the negative radical comes from the corresponding acid.

Name of the salts starts with the name of the metal present as a positive radical which is followed by the name of a negative radical. Name of the negative radical depends on the name of the acid from which the salt is produced.

Acids from which the salt is produced	Suffixes and names of the salt
1. "ous" acid Examples: Sulphurous acid (H_2SO_3) Nitrous acid (HNO_2) Phosphorous acid (H_3PO_3)	"ite" $CaSO_3$ → Calcium sulphite $Zn(NO_2)$ → Zinc nitrite $Mg(PO_3)_2$ → Magnesium phosphite
2. "ic" acid Examples: Sulphuric acid (H_2SO_4) Nitric acid (HNO_3) Phosphoric acid (H_3PO_4)	"ate" $ZnSO_4$ → Zinc sulphate $NaNO_3$ → Sodium nitrate $AlPO_4$ → Aluminium phosphate

If NH_4^+ is present as the positive radical in the base or in the salt, ammonium is written in place of the name of the metal.

EXAMPLE

Ammonium hydroxide (base) → NH_4OH

The formula of a metal phosphide is M_3P_2. Identify formulae of the

(a) metal oxide **(b)** metal nitrite **(c)** metal bicarbonate

SOLUTION

Initial condition **Final condition**

Since the formula of metal phosphide is M_3P_2, metal ion is M^{+2}

(a) Formula of metal oxide is $M^{+2}O^{-2} \Rightarrow MO$

(b) Formula of metal nitrite is $M^{+2}NO_2^{-1} \Rightarrow M(NO_2)_2$

(c) Formula of metal bicarbonate is $M^{+2}\ HCO_3^{-1} \Rightarrow M(HCO_3)_2$

EXAMPLE

Ammonium phosphate (salt) → $(NH_4)_3PO_4$

Metal M forms two oxides A and B in which the ratios of number of oxygen atoms to the total number of atoms present in the molecule are 3 : 5 and 1 : 2 respectively. Determine the formulae of A and B.

SOLUTION

Metal ions present in A and B are M^{+a} and M^{+b} respectively,

$\therefore$ Formula of A is $M^{+a}O^{-2} \Rightarrow M_2O_a$

$\therefore$ Ratio $= \dfrac{a}{2+a} = \dfrac{3}{5}$

$\Rightarrow 5a = 6 + 3a \Rightarrow 2a = 6 \Rightarrow a = 3$

$\therefore$ metal oxide A is $M^{+3}O^{-2} \Rightarrow M_2O_3$

Formula of B is $M^{+b}, O^{-2} \Rightarrow M_2O_b$

$\therefore$ Ratio $= \dfrac{b}{2+b} = \dfrac{1}{2}$

$\Rightarrow 2b = 2 + b \Rightarrow b = 2$

$\therefore$ metal oxide B is $M^{+2}, O^{-2} \Rightarrow MO$

Another aspect of the study of matter involves the different physical states of matter, i.e., solids, liquids and gases. Existence of matter in three distinct states entirely depends on the arrangement of molecules.

Molecules are closely packed in solids, comparatively loosely packed in liquids but very loosely packed in gases. This type of molecular arrangement, gives the gas molecules maximum freedom of movement which results in the various unique properties that gases exhibit. The gases neither have a definite shape nor a definite volume due to the random movement of the gas molecules. The unique characteristics of gases can be explained with the help of **kinetic molecular theory**.

KINETIC THEORY OF GASES

(i) All gases are made up of tiny particles known as molecules.

(ii) The huge intermolecular spaces make the forces of attraction between the gas molecules negligible.

(iii) The molecules are in constant random motion. During motion, the molecules collide with each other and also with the walls of the container. These collisions are perfectly elastic. The pressure exerted by a gas is due to the collisions of the molecules with the walls of the container.

(iv) The average kinetic energy of gas molecules is proportional to the absolute temperature of the gas.

Characteristics of Gases

Gases are highly compressible and diffusible. They neither have a definite shape nor definite volume. The gases occupy the entire volume available to them. Therefore, the volume of a gas is taken as the volume of the container.

The study of gases is much simpler than that of solids and liquids because the physical properties of all the gases are found to be identical. For example, the compressibility or thermal expansion of all the gases are the same, but this is not so in case of solids and liquids. The properties of solids and liquids differ widely from substance to substance, but the gases generally obey some common rules known as the **gas laws**.

Gas Laws

Gas laws give the interrelationship among the measurable properties of a gas which have been experimentally established.

Boyle's Law

The volume of a given mass of a gas is inversely proportional to the pressure exerted by the gas at constant temperature.

$$V \propto \frac{1}{P} \text{ (T = constant)}$$

$$V = \frac{K}{P}$$

$$PV = K \text{ (constant)}$$

The product of pressure and volume of a given mass of a gas is constant at constant temperature.

If at constant temperature, a gas occupies a volume V_1 at a pressure P_1 and a volume V_2 at a pressure P_2, then $\mathbf{P_1V_1 = P_2V_2}$ **(T = constant).**

Graphical Representation of Boyle's Law

(i) Volume (V) vs Pressure (P)

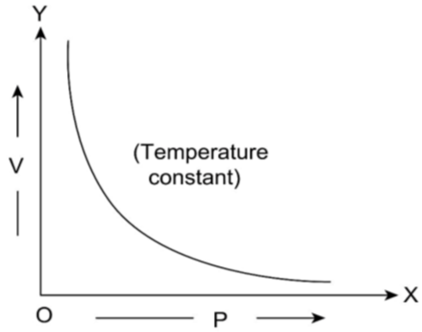


Figure 1.1 Boyle's law graph I

(ii) Volume (V) vs $\frac{1}{\text{Pressure (P)}}$

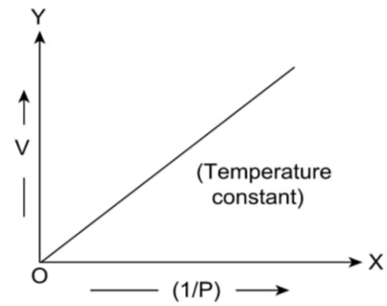


Figure 1.2 Boyle's law graph II

(iii) The product of pressure and volume (PV) vs pressure (P)

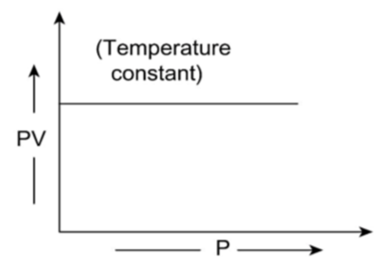


Figure 1.3 Boyle's law graph III

NUMERICAL PROBLEM

1. 5 ℓ of methane gas at 2 atm pressure is compressed to 1.6 ℓ at constant temperature. Calculate the final pressure.

SOLUTION

Initial condition	**Final condition**
$V_1 = 5\ell$	$V_2 = 1.6\,\ell$
$P_1 = 2\,\text{atm}$	$P_2 = ?$

According to Boyle's law, PV = PV

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2} = \frac{5\times2}{1.6} = 6.25\,\text{atm}$$

Final pressure = 6.25 atm

2. The pressure of a certain volume of gas is reduced to half of its initial pressure at constant temperature. Calculate its new volume.

SOLUTION

Initial condition	Final condition
$V_1 = V$	$V_2 = ?$
$P_1 = P\,P_2 = ½P$	

According to Boyle's law,

$$P_1V_1 = P_2V_2$$

$$\Rightarrow V_2 = \frac{V\times P}{\frac{1}{2}P}2V$$

Final volume = 2V

Charle's Law

At constant pressure, the volume of a given mass of a gas increases or decreases by 1/273 of its original volume at 0°C for every 1°C increase or decrease in temperature respectively. If V_0 is the volume of gas at 0°C and V_t is the volume of gas at t°C, (P = constant)

$$V_t = V_0\left[1+\frac{t}{273}\right]$$

$$V_t = V_0\left[\frac{273+t}{273}\right]$$

$$V_t = V_0\left[\frac{T}{273}\right]; T = \text{absolute temperature}$$

$$\frac{V_0}{273} = \text{Constant}$$

$\therefore \quad V \propto T$

If V_1 and V_2 are the volumes occupied by a given mass of gas at temperatures T_1 and T_2

$$\mathbf{\frac{V_1}{T_1} = \frac{V_2}{T_2}\ (P = constant)}$$

Charle's law can otherwise be stated as the volume occupied by a given mass of a gas is directly proportional to the absolute temperature of the gas at constant pressure.

Graphical representation of Charle's Law

(i) Volume (V) vs absolute temperature (T)

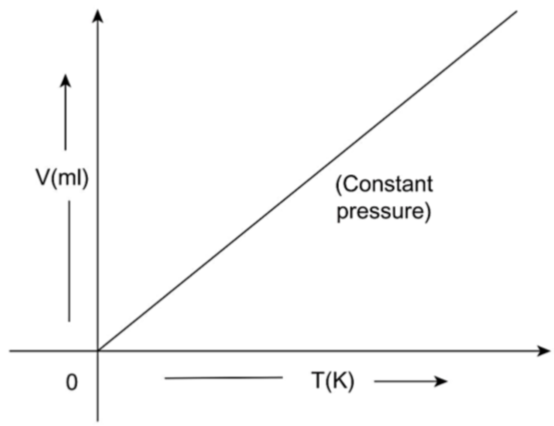


Figure 1.4 Charle's law graph-I

(ii) Volume (V) vs temperature (t) in celsius scale

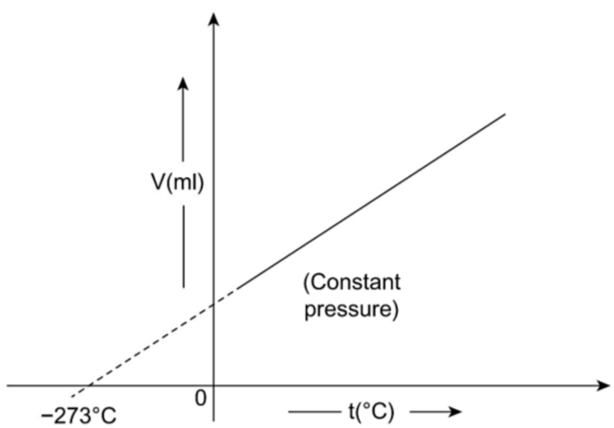


Figure 1.5 Charle's law graph-II

A straight line which intersects the *x*-axis at −273°C is obtained as V = 0 when t = −273°C

Mathematically, volume at –273°C, $V_t = V_0 + \frac{V_0}{273}(-273)$,

$$\therefore \; V_t = V_0\left[\frac{273-273}{273}\right] = 0$$

Absolute Zero

From the graph (ii) V vs t, the straight line intersects the temperature axis at –273°C showing that the gas occupies zero volume at this temperature. That means it is the lowest temperature that can be attained theoretically. Therefore it is called **absolute zero**.

NUMERICAL PROBLEM

1. At a certain pressure, the volume occupied by a given mass of a gas is 10 ℓ at 0°C, calculate the volume occupied by the gas at 91°C at the same pressure.

SOLUTION

Initial condition	Final condition
$V_1 = 10\ell$	$V_2 = ?$
$T_1 = 273K$	$T_2 = (273 + 91)K = 364K$

According to Charle's law, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$\Rightarrow \frac{10}{273} = \frac{V_2}{364} \Rightarrow V_2 = \frac{10 \times 364}{273} = 13.33\ell$$

2. Calculate the temperature at which the volume of a given mass of gas gets reduced to 3/5th of original volume at 10°C without any change in pressure.

Initial condition	Final condition
$V_1 = V$	$V_2 = 3/5V$
$T_1 = (273 + 10)K = 283K$	$T_2 = ?$

According to Charle's law, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

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

$$\Rightarrow T_2 = \frac{3V}{5} \times \frac{283}{V}$$

$$\Rightarrow T_2 = 169.8K \Rightarrow T_2 = -103.2°C$$

The volume of a given mass of gas depends on its temperature and the pressure imposed. Hence in order to define the volume of a gas a **standard temperature and pressure** has been accepted all over the world.

Standard Temperature and Pressure (STP)

The conditions of standard temperature and pressure are given below.

Standard temperature = 0°C = 273 K
Standard pressure = 760 mm of Hg (mercury)
= 76 cm of Hg = 1 atm

Gay-Lussac's law of combining volumes of gases: Gay-Lussac proposed a law pertaining to gaseous reactions which ultimately led to another gas law the Avogadro's law.

Gay-Lussac's law states that when gases chemically react, they do so in volumes which bear a simple whole number ratio to each other and to the volumes of the products, provided the products are also in gaseous state under similar conditions of temperature and pressure.

Explanation

In the reaction of carbon monoxide with oxygen, two volumes of carbon monoxide react with one volume of oxygen to give two volumes of carbon dioxide under similar conditions of temperature and pressure.

$$\underset{2\text{vol}}{CO + CO} + \underset{1\text{vol}}{O_2} \rightarrow \underset{2\text{vol}}{CO_2 + CO_2}$$

The volume ratio of carbon monoxide, oxygen and carbon dioxide is 2 : 1 : 2.

Amedo Avogadro, in 1811, gave his hypothesis to explain Gay-Lussac's law. It was experimentally confirmed later and was established as Avogadro's law.

Avogadro's Law

Avogadro's law states that equal volumes of all gases contain equal number of molecules under similar conditions of temperature and pressure.

If n is the number of molecules present in volume V of any gas at temperature T and pressure P, then $V \propto n$ when T and P are constant.

Example: 1 ℓ of hydrogen, helium and hydrogen chloride contain equal number of molecules in them provided their volumes are measured at the same temperature and pressure.

In chemistry, the mass of any substance irrespective of its state is measured in terms of gram molecular weight or gram molecule and gram atomic weight or gram atom. Atomic weight of a substance expressed in grams is called its **gram atomic weight or gram atom**. Molecular weight of a substance expressed in grams is called its **gram molecular weight or gram molecule**.

Gram Molecular Volume (GMV)

One gram molecule of any dry gas at STP occupies the same volume, i.e., 22.4 ℓ or 22.4 dm^3. This is called gram molar volume or GMV.

Example: 1 gram molecule of dry chlorine gas occupies 22.4 ℓ of volume at STP.

Since GMW of chlorine is 71 g, 71 g of chlorine gas occupies 22.4 l of volume at STP.

Vapour Density

Vapour density (VD) of a gas or vapour is the ratio of the mass of a certain volume of gas or vapour to the mass of the same volume of hydrogen gas when their volumes are measured under similar conditions of temperature and pressure.

Relation Between Molecular Weight or Relative Molecular Mass vand Vapour Density

VD of a gas or vapour at a certain temperature and pressure

$$= \frac{\text{Mass of the certain volume of gas or vapour}}{\text{Mass of the same volume of } H_2 \text{ gas}}$$ [Volume of both the gases are measured at that particular temperature and pressure]

$$= \frac{\text{mass of n molecules of the gas or vapour}}{\text{mass of n molecules of } H_2 \text{ gas}}$$ [By applying Avogadro s law]

$$= \frac{\text{mass of 1 molecule of the gas or vapour}}{\text{mass of 1 molecule of } H_2 \text{ gas}} = \frac{1}{2} \times \frac{\text{mass of 1 molecule of the gas or vapour}}{\text{mass of 1 atom of hydrogen gas}}$$

$= \frac{1}{2} \times$ relative molecular mass (Molecular weight)

$\therefore$ Molecular weight or relative molecular mass = 2 × VD

i.e., relative molecular mass is twice the vapour density of the gas or vapour.

EXAMPLE

Gas laws are universally applicable for all gases whereas such universal laws could not be established for solids and liquids. Comment on this statement.

SOLUTION

Gases differ from solids and liquids in the extent of intermolecular forces of attraction. Since gases are characterized by negligible forces of attraction, the molecules behave independent of the neighbouring molecules. Due to large intermolecular spaces, the coefficient of volume expansion is same for all gases. Moreover, in case of gases the molecules are considered as point masses and hence the volume occupied by the molecules is negligible in comparison to the total volume. Therefore, the physical behaviour of all gases being similar, certain laws could be established which are universally applicable. In case of liquids and solids, the molecules are considered as rigid spheres and the coefficient of volume expansion is not uniform for all substances, such universal laws can not be established.

EXAMPLE

Boyle's law says that pressure and volume are inversely proportional to each other. However, when a balloon is blown, both volume and pressure increase continuously. Justify

SOLUTION

When a balloon is blown continuously, more and more air is forced into the balloon which increases the volume as well as the number of collisions of air molecules on the walls of the balloon that is pressure. Boyle's law is applicable for a given mass of a gas. Hence it is not valid in the above case.

EXAMPLE

Why is Kelvin temperature always positive?

SOLUTION

Absolute zero which is equal to −273°C is the minimum possible temperature for a gas. Any centigrade temperature greater than −273°C will become positive when converted to absolute scale. Since centigrade temperature less than −273°C is not possible, Kelvin temperature cannot have a negative value

EXAMPLE

A certain mass of a gas taken in 1 litre cylinder exerts a pressure of 500 mm Hg at a certain temperature. If the gas is transferred to another cylinder where it exerts 20% more pressure, calculate the volume of the cylinder at the same temperature.

SOLUTION

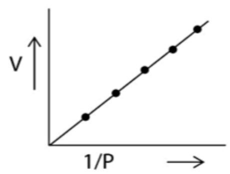
$V_1 = 1000$ cc, $P_1 = 500$ mm of Hg,

$P_2 = P_1 + \frac{20P_1}{100} = 500 + (\frac{20 \times 500}{100}) = 600$ mm of Hg

$P_2V_2 = P_1V_1,\ V_2 = \frac{P_1V_1}{P_2} = \frac{1000 \times 500}{600} = 833$ cc

EXAMPLE

The slope of a given straight line graph with constant temperature is found to be 0.2 ℓ atm at 5 atmospheric pressure. Calculate the volume of gas at that pressure.



SOLUTION

Slope = 0.2 ℓ atm, P = 5 atm.

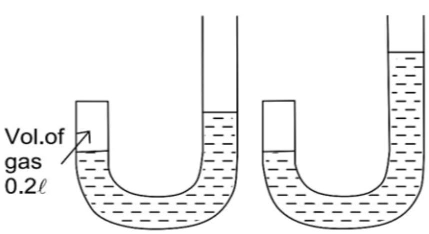
According to Boyle's law,

$P \propto \frac{1}{V}$, $P = \text{constant} \times \frac{1}{V} = \text{slope} \times \frac{1}{V}$; $0.2 \times \frac{1}{V} = 5 \Rightarrow V = \frac{0.2}{5}$

= 0.04 ℓ

EXAMPLE

J-shaped tube closed at one end was used by Boyle to study the relationship between the pressure of the trapped gas and its volume. Such a set up is given here. Initially some amount of gas is taken in the tube and mercury is poured in it. The volume of gas is 0.2 ℓ and the difference in the height of the mercury column is 760 mm of Hg. Now some more amount of mercury is poured and the difference in the height of the mercury column is found to be 1140 mm of Hg. Calculate the new volume of gas considering the temperature constant.



SOLUTION

$V_1 = 0.2$ ℓ $V_2 = ?$

$P_1 = 760$ mm + 760 mm $P_2 = 1140$ mm + 760 mm

According to Boyle's law $P_1 V_1 = P_2 V_2$

$1520 \times 0.2 = 1900 \times V_2 \Rightarrow V_2 = \frac{1520 \times 0.2}{1900} = 0.16\,\ell$

EXAMPLE

A cylinder was filled with a gas at 2 atm pressure at 27°C and can withstand a pressure of 12 atm. At what temperature the cyliner bursts when the building catches fire?

SOLUTION

$P_1 = 2$ atm, $P_2 = 12$ atm

$T_1 = 27 + 273 = 300$ K, $T_2 = ?$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow T_2 = \frac{T_1P_2}{P_1} \Rightarrow T_2 = \frac{12\times300}{2} = 1800\text{ K} = 1527°\text{ C}$$

∴ Cylinder bursts at or above 1527°C

EXAMPLE

After usage for a certain period, a cooking gas cylinder was considered to be empty as no gas was coming out of it. Is the cylinder empty in its true sense? Explain what happens if the cylinder is kept in hot water or shaken vigorously. Explain by applying kinetic molecular theory.

SOLUTION

No. It is not empty in its true sense. In a cooking gas cylinder, the gas was initially at a high pressure. As the gas was drawn out from the cylinder, the amount of gas in the cylinder decreases thereby reducing the pressure inside the cylinder. The gas will come out of the cylinder as long as the pressure of the gas inside the cylinder is more than the atmospheric pressure. When it is kept in hot water or shaken vigorously, kinetic energy of gas molecules increases and number of collisions increases. Thus pressure increases and gas comes out of the cylinder.

Avogadro Number and Mole Concept

Avogadro Number

Scientists experimentally determined that the number of atoms present in 12 g of carbon i.e., 1 g atom of carbon 12 isotope is 6.023×10^{23}.

Different experiments showed that 1 g atom or 1 g molecule of any substance contains the same number (6.023×10^{23}) of elementary particles or chemical units (atoms, molecules or ions). This constant number is called the Avogadro number which is denoted by N_A or L. It also represents the number of molecules present in 1 g molar volume.

The Avogadro number, i.e., 6.023×10^{23} is taken as the unit to measure the amount of substances and is called **mole**.

Mole

A mole is defined as the quantity of substance which contains the same number of elementary particles or chemical units as the number of atoms present in 12 g of C-12 isotope.

Hence, 1 mole of any substance contains the Avogadro number of elementary particles or units. The elementary particles can be atoms, molecules, ions, etc.

Therefore, it can be concluded that

(i) 1 g atom of any substance is equivalent to one mole of atoms of that substance and contains the Avogadro number of atoms.

(ii) 1 g molecule of any substance is equivalent to one mole of molecules of that substance and contains the Avogadro number of molecules.

Examples

1. One mole of hydrogen atoms	6.023×10^{23} hydrogen atoms 1 g atom of hydrogen or 1 g hydrogen
2. One mole of carbon atoms	6.023×10^{23} carbon atoms 1 g atom of carbon or 12 g of carbon
3. One mole of NaCl	6.023×10^{23} Na^+ ions and 6.023×10^{23} Cl^- ions
4. One mole of ammonia gas	1 g molecule of sodium chloride or 58.5 g of NaCl 6.023×10^{23} NH_3 molecules 1 g molecule of ammonia or 17 g of NH_3

Examples

(i) Calculate the number of moles of sodium (Na) atoms present in 11.5 g of sodium.

$$\text{Number of moles of sodium atoms} = \frac{\text{mass of sodium}}{\text{GAW}} = \frac{11.5}{23} = 0.5$$

i.e., 0.5 moles of Na atoms are there in the given 11.5 g sample

(ii) Calculate the number of moles of water (H_2O) present in 4.5 g of water.

$$\text{Number of moles of water molecules} = \frac{\text{mass of water molecules}}{\text{GMW}} = \frac{4.5}{18} = 0.25$$

i.e., 0.25 moles of H_2O are there in 4.5g of water.

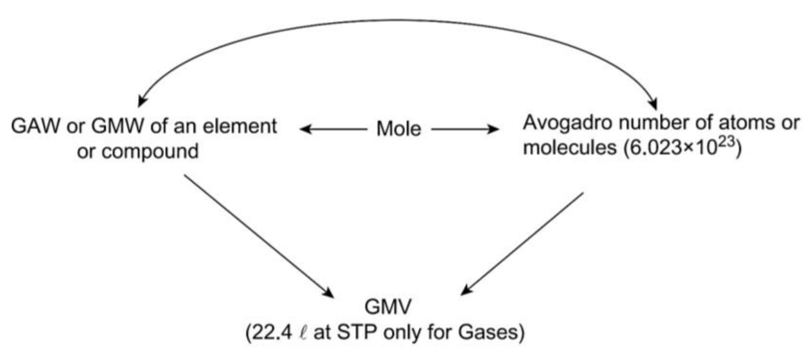
Relation Between GMV, Mole and Avogadro Number

1 g mole of any dry gas occupies 22.4 ℓ volume at STP. Hence 22.4 ℓ of a dry gas at STP contains 6.023×10^{23} molecules, i.e., Avogadro number of molecules.

Example: 32 g or 1 mole of dry oxygen gas occupies 22.4 ℓ volume at STP and contains 6.023×10^{23} molecules of oxygen.

Example: 4 g or 1 mole of dry helium gas occupies 22.4 litres at STP and contains 6.023×10^{23} atoms because helium is a monoatomic gas.

Schematic Representation of Different Relationships for Mole



NUMERICAL PROBLEM

1. Calculate the number of molecules present in 16.8 ℓ of gas "X" at STP. Also determine its gram molecular weight if the above sample weighs 26.625 g.

SOLUTION

Volume of the given gas = 16.8 ℓ at STP

Number of moles present in that volume = 16.8/22.4 = 0.75 mole

Number of molecules in 0.75 moles = $0.75 \times 6.023 \times 10^{23} = 4.52 \times 10^{23}$

Weight of 0.75 moles of the gas X = 26.625 g

Gram molecular weight of "X" = Weight/No. of moles = 26.625/0.75

= 35.5 g

2. Calculate the volume occupied by 200 g of SO_3 gas at STP and the number of molecules present in it.

Weight of SO_3 taken = 200 g

Number of moles of $SO_3 = \dfrac{200}{\text{GMW of } SO_3} = \dfrac{200}{80} = 2.5\,\text{moles}$

Volume occupied by 1 mole of gas is 22.4 ℓ, at STP

Volume occupied by the given amount of gas = 2.5 × 22.4 = 56 ℓ.

Number of molecules present in 1 mole of gas = 6.023×10^{23}

Number of molecules present in the given amount of gas = $2.5 \times 6.023 \times 10^{23} = 15.05 \times 10^{23}$ molecules

3. What is the volume occupied by 30.1×10^{23} molecules of carbon dioxide gas at STP? Calculate the mass of this gas.

Number of molecules = 30.1×10^{23}

Number of moles of gas = $\dfrac{30.1 \times 10^{23}}{6.023 \times 10^{23}} = 5\,\text{moles}$

Volume occupied by 5 moles of gas = 22.4 × 5 = 112 ℓ.

Mass of the given gas = Number of moles × GMW = 5 × 44 = 220 g

Ideal Gas Equation

The behaviour of gases can be described by three laws.

According to Boyle's law, for a given mass of gas, $V \propto \frac{1}{P}$ [T is constant]

According to Charles's law, for a given mass of gas, $V \propto T$ [P is constant]

According to Avogadro's law, $V \propto n$ [P and T are constant]

Combining the three gas laws,

$V \propto \frac{nT}{P}$ [when all the functions vary independently] or $PV \propto nT$

or $PV = nRT$ [R is a constant]

A hypothetical gas called ideal gas obeys the equation under all conditions of temperature and pressure. Hence this equation is called an **ideal gas equation** and R is called universal gas constant.

However, no gas is perfectly ideal. All gases show nearly ideal behaviour under the conditions of low pressure and high temperature and are called real gases.

When one mole of a gas is considered, the equation becomes

PV = RT (∵ n =1 mole). The value of "R" depends upon the units in which pressure and volume are taken.

EXAMPLE

Volume occupied by 16 g of oxygen is same as that occupied by 1 gram of hydrogen under similar conditions of temperature and pressure. Explain.

SOLUTION

Both 16 g of oxygen and 1 g of hydrogen corresponds to 0.5 moles of molecules and hence occupy same volume under similar conditions of temperature and pressure.

EXAMPLE

'X' grams each of nitrogen and carbon monoxide are considered. Draw a comparison with respect to number of moles.

SOLUTION

Nitrogen and carbon monoxide possess equal gram molecular mass. Therefore, equal masses of these two gases possess equal number of moles.

NUMERICAL PROBLEM

1. A gas at a pressure of 2.0 atm is heated from 0°C to 273°C and the volume compressed to 1/4th of its original volume. Find the final pressure.

SOLUTION

Initial condition	**Final condition**
$V_1 = V$	$V_2 = \frac{1}{4}V$
$T_1 = 0°C$ or $273\,K$	$T_2 = 273°C$ (or) $546\,K$
$P_1 = 2\,atm$	$P_2 = ?$

According to gas equation, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$$P_2 = \frac{P_1V_1}{T_1} \times \frac{T_2}{P_2} = \frac{2\times\ V}{273} \times \frac{546}{V} \times 4,\ P_2 = 16\,atm$$

2. If a gas occupies 30 ℓ at 27°C and 1 atm, what volume would it occupy at 227°C and 5 atm?

Initial condition	**Final condition**
$V_1 = 30l$	$V_2 = ?$
$P_1 = 1$ atm	$P_2 = 5$ atm
$T_1 = 27°C = 300\,K$	$T_2 = 227°C = 500\,K$

According to gas equation, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}\ V_2 = \frac{P_1V_1}{T_1} \times \frac{T_2}{P_2} = \frac{30\times 1}{300} \times \frac{500}{5} = 10\ell$

3. What is the volume occupied by 30 g of neon gas at 67°C and 750 mm of Hg?

According to the ideal gas equation

$$PV = nRT \quad (1)$$

n = number of moles = weight/molecular weight = 30/20

Pressure = (750/760) atm [1 atm = 760 mm of Hg]

$$T = (273 + 67)\ K = 340\ K$$

From equation (1),

$$V = nRT/P$$

$$V = \frac{30}{20} \times \frac{0.0821 \times 340}{(750/760)} \left(\frac{g \times \ell.atm / k.mol \times K}{g / mol \times atm} \right) = 42.43\,\ell$$

Dalton's law of partial pressures

The ideal gas equation establishes the relationship among the pressure exerted by a certain number of moles of a gas, its temperature and the volume occupied by it. But the pressure exerted by a mixture of gases present in a container was studied by Dalton. Dalton's law states that "the total pressure exerted by a mixture of non-reacting gases taken in a container at a given temperature is the sum of the practical pressures of the individual gases that each gas would exert if it were taken alone in that container. This statement is known as **Dalton's law of partial pressure**.

Partial pressure is the pressure exerted by each constituent of the gaseous mixture when they are kept individually in the same container.

If the partial pressures of the constituents of the gaseous mixture are p_1, p_2, p_3…… and so on, then according to Dalton's law of partial pressures, the total pressure p = p_1, p_2, p_3 ………..

If n_1 is the number of moles of a constituent of the gaseous mixture take in a container of volume V and p_1 is the pressure exerted by it at temperature T, then

$$P_1 = n_1 \times \frac{RT}{V} \quad \text{(1) (from the ideal gas equation)}$$

Similarly, if P is the total pressure exerted by the gaseous mixture at temperature T, and n is the total number of moles take in the container of volume V, then RT

$$P = n\frac{RT}{V} \quad (2)$$

Dividing equation (1) by equation (2), we obtain

$$\frac{p_1}{p} = \frac{n_1}{n}$$

$$\therefore \quad p_1 = \frac{n_1}{n} \times P$$

∴ Partial pressure (p_1) = Mole fraction (n_1/n) × total pressure of the gas (P)

Mole fraction is the ratio of number of moles of an individual gas to the total number of moles of all gases in a mixture.

Dalton's law of partial pressure is not applicable to gaseous mixture in which the component gases react with each other chemically.

Example: It is not applicable to a mixture of carbon monoxide and oxygen which react with each other to form carbon dioxide at ordinary temperature:

$$2CO + O_2 \rightarrow 2CO_2$$

NUMERICAL PROBLEM

A 2 ℓ flask contains 22 g of carbon dioxide and 1 g of helium at 20°C. Calculate the partial pressure exerted by CO_2 and He if the total pressure is 3 atm.

SOLUTION

$$\text{Number of moles of } CO_2 = \frac{\text{Weight of } Co_2}{\text{Molecular Weight of } Co_2} = \frac{22}{44} = 0.5.$$

$$\text{Number of moles of He} = \frac{1}{4} = 0.25$$

Partial pressure = Mole fraction × total pressure

$$Pco_2 = \frac{0.5}{0.5 + 0.25} \times 3 = 2$$

$$p_{He} = \frac{0.25}{0.75} \times 3 = 1 \text{ atm.}$$

Diffusion is one of the significant properties of gases. The process of spreading out of gas molecules spontaneously is called diffusion. As a result of this, gas molecules uniformly occupy the space available.

The number of gas molecules that pass through a unit area in unit time at a given temperature and pressure is called its **rate of diffusion**. In other words, the volume of the gas that diffuses in unit time at specific temperature and pressure is called its **rate of diffusion**. Rate of diffusion of a gas increases with the increase of temperature while it decreases with the increase of pressure.

Thomas Graham observed that the rate of diffusion of different gases depends on their respective densities provided they are under similar conditions of temperature and pressure. He established a quantitative relationship between the rate of diffusion of gases and their densities.

Graham's Law of Diffusion

Under similar conditions of temperature and pressure, the rates of diffusion of different gases are inversely proportional to the square root of their densities.

i.e., $r \alpha \frac{1}{\sqrt{d}}$ [T and P are constant]

or $\frac{\mathbf{r_1}}{\mathbf{r_2}} = \sqrt{\frac{\mathbf{d_2}}{\mathbf{d_1}}}$ (where r_1 and r_2 are the rate of diffusion of two gases having densities d_1 and d_2, respectively).

Rates of diffusion of gases are also inversely proportional to their molecular weights because equal volume of all gases contains equal number of molecules if the temperature and pressure are kept constant.

$\therefore \frac{\mathbf{r_1}}{\mathbf{r_2}} = \sqrt{\frac{\mathbf{M_2}}{\mathbf{M_1}}}$ where r_1 and r_2 are the rates of diffusion of two gases and their molecular weights are M_1 and M_2, respectively.

NUMERICAL PROBLEM

1. What is the ratio of the rate of diffusion of helium gas to that of oxygen under identical conditions?

SOLUTION

According to Graham's law of diffusion,

$$\frac{r_{He}}{r_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{H_e}}} = \sqrt{\frac{32}{4}}$$

$$\left(\frac{r_{H_e}}{r_{O_2}}\right) = 2\sqrt{2} : 1$$

2. Rate of diffusion of a saturated hydrocarbon is about 1/6th of that of hydrogen under similar conditions of temperature and pressure. What is the molecular formula of that hydrocarbon?

SOLUTION

Let the molecular weight of the hydrocarbon be M_x and its rate of diffusion be r_x

$$\frac{r_{H_2}}{r_x} = \sqrt{\frac{M_x}{M_{H_2}}},\ r_x = 1/6\ r_{H_2}$$

$$\therefore \frac{r_{H_2}}{r_x} = 6 = \sqrt{\frac{M_x}{2}}$$

$$\Rightarrow 36 \times 2 = M_x$$

$$\Rightarrow M_x = 72$$

Molecular weight of the hydrocarbon is 72.

Let the number of carbon atoms present in one molecule of the hydrocarbon be m.

$\because$ the hydrocarbon is saturated, the number of hydrogen atoms present in that hydrocarbon molecule is 2m + 2

$\therefore$ (12 × m) + 2m + 2 = 72

$\Rightarrow$ 14m + 2 = 72 $\Rightarrow$ m = 5

$\therefore$ Molecular formula of the hydrocarbon is C_5H_{12}.

EXAMPLE

A certain amount of oxygen is prepared by the thermal decomposition of potassium chlorate and is collected by downward displacement of water. The pressure of the gas collected is measured with the help of a manometer. The pressure recorded is found to be more than the pressure recorded for the same volume of oxygen cylinder containing same amount of oxygen under the same conditions. How do you account for this deviation?

SOLUTION

When oxygen is prepared, it is collected over water. Since water is in equilibrium with water vapour, the oxygen gas collected is not dry oxygen gas and it is mixed with some amount of water vapour. The total pressure exerted by this moist oxygen gas is the sum of the partial pressures of oxygen and water vapour. The pressure recorded for the same volume of pure and dry oxygen gas is obviously less than the previous case. The pressure of water vapour in the collected gas is called aqueous tension.

Expressing Concentrations of Solutions Using Mole Concept

A solution is a homogenous mixture of two or more components. The solution that contains only two components is called a binary solution. The component which is present in minor proportions is called the solute and the component which is present in major proportions is called the solvent.

The concentration of a solution refers to the relative proportions of solute and solvent present in the solution. The concentrations of solutions can be expressed in various ways by applying the concept of mole.

Molarity

It is the most convenient and commonly used unit for expressing the concentration of a solution.

Molarity can be defined as the number of moles of a solute present in 1 ℓ of a solution. It is denoted by "M."

If n = number of moles of the solute present in the solution

W = Weight of the solute in grams

GMW = Gram molecular weight (mass) of the solute

V = Volume of the solution, then

$$M = \frac{n}{V} = \frac{W}{GMW} \times \frac{1}{V \text{ in}\ell} \text{ or } M = \frac{W}{GMW} \times \frac{1000}{V \text{ in ml}}$$

Example: 0.4 M sodium carbonate solutions means 0.4 moles of sodium carbonate is present in 1000 ml of the solution.

Mole Fraction

Mole fraction of a component in a solution can be defined as the ratio of the number of moles of that component to the total number of moles of all the components of the solution. If "x" represents mole fraction, then

$$x_{solute} = \frac{n_{solute}}{n_{solute} + n_{solvent}}, \text{ where n represents number of moles}$$

$$x_{solvent} = \frac{n_{solvent}}{n_{solute} + n_{solvent}}$$

The sum of mole fractions of all components in a solution is equal to unity.

$$x_{solute} + x_{solvent} = 1$$

The concentration of the solution can also be expressed in terms of weight percentage, volume percentage and weight volume percentage.

Weight Percentage (w/w)

The mass of a solute expressed in grams present in 100 g of a solution is called the weight percentage of the solute in the solution.

$$\textbf{Weight percentage of the solute} = \frac{\textbf{Weight of the solute}}{\textbf{Weight of the solution}} \times \mathbf{100}$$

Example

10% (w/w) sodium hydroxide solution

10 g of sodium hydroxide is present in 100 g of the solution.

Weight/volume of percentage (w/v)

The mass of a solute expressed in grams present in 100 ml of a solution is called the weight/volume percentage of the solute in the solution.

$$\textbf{Weight/volume percentage of the solute} = \frac{\textbf{Mass of the solute (g)}}{\textbf{Total volume of the solution (ml)}} \times 100$$

Example

10% (w/v) Na_2CO_3 solution

10 g of Na_2CO_3 present in 100 ml of the solution.

Volume Percentage (v/V)

The volume of the liquid in millilitre present in a 100 ml solution is called the volume percentage of the solute in the solution.

$$\textbf{Volume percentage of the solute} = \frac{\textbf{Volume of the solute}}{\textbf{Volume of the solution}} \times 100$$

Example

70% (v/v) isopropyl alcohol solution

70 ml isopropyl alcohol is present in 100 ml of the solution.

NUMERICAL PROBLEM

1. What is the molarity of a solution containing 15 g of NaOH dissolved in 500 ml of solution?

SOLUTION

$$\text{Molarity} = \frac{\text{Weight}}{\text{G.M.W}} \times \frac{1000}{\text{V}} = \frac{15}{40} \times \frac{1000}{500} = 0.75\,\text{M}$$

2. A solution is prepared by dissolving 9.8 g of H_2SO_4 in 54 g of water. What is the mole fraction of H_2SO_4?

SOLUTION

Weight of H_2SO_4 = 9.8 g

GMW of H_2SO_4 = 98

Number of moles of H_2SO_4 present in the solution = 9.8/98 = 0.1

Number of moles of H_2O = 54/18 = 3

Mole fraction of H_2SO_4 = 0.1/(0.1+3) = 0.032

3. What is the percentage by weight of sulphuric acid, if 13 g of H_2SO_4 is dissolved to make 78 g of solution?

Weight of H_2SO_4 = 13 g

Weight of solution = 78

$$\left(\frac{\text{w}}{\text{w}}\right)\% \text{ of } H_2SO_4 = \frac{13}{78} \times 100 = 16.6\%$$

4. If 40 g of ethyl alcohol is dissolved in 50 ml of water, then calculate the weight/volume percentage of ethyl alcohol present in the solution. [density of ethyl alcohol = 0.8 g/ml]

Amount of ethyl alcohol = 40 g

Volume of ethyl alcohol $= \frac{40}{0.8} = 50$ ml

Volume of water = 50 ml

Total volume of the solution is 100 ml

$$\left(\frac{w}{v}\right)\% \text{ ethyl alcohol is } \frac{40}{100} \times 100 = 40\%$$

5. What is the molarity of 25% $\left(\frac{w}{v}\right)$ solution of HCl?

25%$\left(\frac{w}{v}\right)$ solution of HCl corresponds to 25g of HCl present in 100 ml of solution.

Amount of HCl present in 1000 ml of solution = 250 g

Molarity $= \frac{250}{36.5} \times \frac{1000}{1000} = 6.85\,M$ [GMW of HCl = 36.5]

EXAMPLE

Specific gravity of 84% (w / W) pure HNO_3 is 1.54. What volume of HNO_3 is required to prepare one litre of 0.5M HNO_3 solution?

SOLUTION

specific gravity of HNO_3 = 1.54

$M = \frac{w}{GMM} \times \frac{1000}{V} \Rightarrow 0.5 = \frac{x}{63} \times \frac{1000}{1000} \Rightarrow x = 31.5$ g

31.5 g of HNO_3 is present in 1 ℓ of solution.

84 g is present in 100 g of solution

31.5 g is present in ? g of solution

$= \frac{31.5 \times 100}{84} = 37.5\,g$

Density = $^{weight}/_{volume} \Rightarrow 1.54 = {}^{37.5}/_{volume} \Rightarrow V = {}^{37.5}/_{1.54} = 24.35$ m ℓ

$V_1 M_1 = V_2 M_2$ 24.35ml of given HNO_3 is required.

Stoichiometry

The word stoichiometry is derived from the Greek word "stoicheion" meaning element and "metron" meaning measurement. It is the area of study where we learn about the quantity of the reactants(s) required to get specific quantity of product(s).

In order to understand the quantitative relation between the reactants and products, knowledge of the composition of the reactants and the products is required. This composition also helps us to determine the formulae of the molecules of the reactants and products.

Percentage Composition of a Compound

Percentage composition is the mass of each constituent element present in 100 g of a compound.

$$\text{Percentage of an element present in a compound} = \frac{\text{Weight of the element in one mole of the compound}}{\text{GMW of the compound}} \times 100$$

Empirical formula weight = 12 + (1× 2) + 16 = 30

Vapour density = 90

Molecular weight = VD × 2 = 180

Molecular formula = (empirical formula)$_n$

$$n = \frac{\text{Molecular weight}}{\text{Empirical formula weight}} = \frac{180}{30} = 6$$

Thus, molecular formula = $(CH_2O)_6 = C_6H_{12}O_6$

In stoichiometry, we find out the quantitative relationship between the reactants and the products on the basis of balanced chemical equation.

EXAMPLE

What is meant by 22 carrat gold in terms of percentage purity?

SOLUTION

24 carrat gold is considered to have 999.99 parts of gold per 1000 g. Therefore one carrat is taken as one part of 24. That means 22 carrat gold is 22 parts per 24 parts. Accordingly, parts of gold in 1000 g of 22 carrat gold can be calculated. From this, percentage can be found out.

Amount of gold in 1000 g of 22 carrat gold = $\frac{22}{24} \times 1000 = 916.3$ g

Percentage of gold = 91.6%

Balanced Chemical Equation

A balanced chemical equation is the one in which the number of atoms of each element are equal in its reactants and products.

Examples:

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

The information that can be obtained from a balanced chemical equation include the following:

(i) The nature and chemical composition of the reactants and the products in a chemical reaction.

(ii) The number of moles of various reactants and products involved in a chemical reaction.

The balanced chemical equation is called the stoichiometric equation.

The quantitative relationship between the various reactants and products can be established based on either the weight of the substances or the volume of the substances in case of gases.

Calculations Based on Chemical Equations

Three types of relationships can be established between the chemical substances involved in the chemical reaction.

(i) Weight–weight relationship of the reactants and products.

(ii) Weight–volume relationship in reactions involving at least one gaseous substance.

(iii) Volume–volume relationship in case of reactions involving all gaseous substances.

Calculation Based on Weight–Weight Relationship

Example: Calculate the weight of zinc required for the liberation of 10 g of hydrogen gas on reaction with H_2SO_4.

Solution

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$
$$\text{1 mole} \qquad\qquad \text{1 mole}$$

Atomic weight of zinc is 65.5

1 mole of hydrogen = 2 g of hydrogen

10 g of hydrogen $= \frac{10}{2} = 5$ moles

1 mole of H_2 gas is produced from 1 mole of zinc

5 moles of H_2 gas are produced from 5 moles of zinc.

1 mole of zinc = 65.5 g

5 mole of zinc = 65.5 × 5 = 327.5 g

Calculations Based on Weight–Volume Relationship

Example: Calculate the weight of sodium bicarbonate to be dissociated to give 0.56 ℓ of CO_2 gas.

Solution

$$2NaHCO_3 \rightarrow NaCO + HO + CO$$
$$\text{2 moles} \qquad\qquad\qquad\qquad \text{1 mole}$$

GMW of $NaHCO_3$ = 84 g

1 mole of CO_2 occupies 22.4 ℓ

22.4 ℓ of CO_2 is produced from 2 × 84 g of $NaHCO_3$

0.56 ℓ of CO_2 is produced from $\frac{0.56 \times 2 \times 84}{22.4} \times 4.2\,g$

Calculations Based on Volume–Volume Relationship

Example: Calculate the volume of carbon monoxide gas required to react with oxygen to give 11.2 ℓ of CO_2 gas.

Solution

$$2CO + O_2 \rightarrow 2CO_2$$
$$\text{2 moles} \qquad \text{2 moles}$$

2 × 22.4 ℓ CO_2 gas is produced from 2 × 22.4 ℓ CO gas.

11.2 ℓ CO_2 gas is produced from 11.2 ℓ CO gas.

Calculations Involving Percentage Purity of Compounds

Percentage purity of a chemical compound is the actual amount of pure substance present in a sample of compound when it contains certain amount of impurities. For example, a sample of 90% pure limestone contains 90% calcium carbonate and 10 g of impurities for every 100 g of limestone.

Example: Calculate the weight of 80% pure limestone required to produce 11 g of CO_2 gas.

Solution

$$CaCO_3 \rightarrow CaO + CO_2$$

1mole 1 mole

44 g of CO_2 is produced from 100 g of $CaCO_3$

$\therefore$ 11 g of CO_2 is produced from $\frac{100}{44} \times 11 = 25\,g$ of $CaCO_3$

As the limestone is 80% pure, the weight of impure limestone required $= \frac{100}{80} \times 25\ g = 31.2\,g$.

Calculations Involving Limiting Reagent

The reactant which decides the amount of products formed in a reaction is called the limiting reagent.

NUMERICAL PROBLEM

Calculate the amount of sodium oxide formed when 2.3 g of sodium reacts with 3.2 g of oxygen.

SOLUTION

$$4Na + O_2 \rightarrow 2Na_2O$$

4 moles 1 mole 2 moles

4×23 g of sodium reacts with 32 g of O_2

2.3 g of sodium reacts with $= \frac{2.3 \times 32}{4 \times 23} = 0.8\,g$

As the amount of oxygen present is 3.2 g, all the oxygen is not utilized for formation of sodium oxide. The amount of sodium oxide formed is determined by sodium. 4×23 g of sodium produces 2×62 g of sodium oxide.

$$2.3 \text{ g of sodium produces } = \frac{2.3 \times 2 \times 62}{4 \times 23} = 3.1\,g$$

Amount of sodium oxide formed = 3.1 g

EXAMPLE

A mixture of sodium carbonate and sodium bicarbonate was subjected to heating. Some loss in weight was found. How does this information help us to find out the composition of mixture?

SOLUTION

Between sodium carbonate and sodium bicarbonate, only sodium bicarbonate decomposes to given sodium carbonate, CO_2 and H_2O. The gaseous products (CO_2 and H_2O) escape out into the atmosphere. Therefore, an apparent loss in weight occurs during the reaction.

This loss in weight corresponds to the amount of gaseous products formed. From the mass of gaseous products formed, amount of sodium bicarbonate in the mixture can be obtained and thus composition of the mixture can be found out.

EXAMPLE

In an apparatus 16.8 g of sodium bicarbonate was subjected to heating till it undergoes complete decomposition, what is the expected loss in weight? When the same apparatus was fitted to a condenser, the loss in weight was different from the earlier loss in weight. Justify the difference.

SOLUTION

$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

2 moles $NaHCO_3 \rightarrow$ 2 moles of gaseous product (CO_2 and H_2O)

Number of moles of $NaHCO_3 = \frac{16.8}{84 \times 2} = 0.1$

0. 1 moles $NaHCO_3 \rightarrow$ 0.2 moles gaseous product $\rightarrow$ 0.1 moles CO_2 + 0.1 moles H_2O.

$\rightarrow$ 4.4 g CO_2 + 1.8 g H_2O

Expected loss in weight = 4.4 + 1.8 = 6.2 g.

Actual loss in weight = Amount of CO_2 formed = 4.4 g.

The difference is due to the condensation of water vapour.

EXAMPLE

At STP, a certain amount of hydrogen is produced by the reaction of 550 g of impure zinc with excess amount of HCl. The same volume of hydrogen at S.T.P. reduces Fe_3O_4 and produces 336 g of iron. Find the percentage purity of zinc.(Atomic mass of Zn is 65)

SOLUTION

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$; $4H_2 + Fe_3O_4 \rightarrow 4H_2O + 3Fe$

Amount of iron produced = 336 g $\Rightarrow$ number of moles of iron $= \frac{336}{56} = 6$

To produce 6 moles of iron it requires 8 moles of hydrogen which further requires 8 moles of Zn.

Weight of Zn = 8 × 65.5 = 524 g; % purity $= \frac{524}{550} \times 100 = 95.27\%$

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. What is an ideal gas? Under what conditions does a real gas behave ideally?
2. The volume occupied by 7 g of nitrogen gas at STP is __________.
3. Why do the gases exert pressure?
4. What is meant by critical temperature?
5. Find out the number of molecules in 2.5 moles of water.
6. 2 moles of CO_2 gas contain the same number of atoms as __________ moles of CO.
7. Calculate the volume occupied by 0.01 moles of helium gas at STP.
8. What is the amount of H_2SO_4 (in grams) present in 0.2 moles of sulphuric acid?
9. The percentage of sulphur in SO_2 is __________ and __________ in SO_3.
10. What is the molarity of HCl solution containing 0.4 moles in 200 ml of the solution?
11. Calculate the volume occupied by 11 g of CO_2 gas at STP.
12. If the pressure exerted on a gas is increased by 4 times and temperature is increased by 9 times, what will be the change in volume occupied by the gas?
13. The vapour density of SO_2 gas is __________ the vapour density of O_2 gas.
14. If the mole fraction of a solute in a binary solution is 0.3, what could be the mole fraction of the solvent in the solution?
15. Calculate the ratio of the rate of diffusion of sulphur dioxide gas to helium gas.
16. Find out the number of moles constituted by 1.4 g of carbon monoxide.

    Number of moles $= \dfrac{\text{Weight}}{\text{GMW}}$
17. The empirical formula of a compound is CH_2O. If the vapour density is 60, what would be the molecular formula of the compound?
18. When 4 ℓ of nitrogen completely reacts with hydrogen, what would be the volume of ammonia gas formed?
19. The molecular formula of a gas with vapour density 15 and empirical formula CH_3 is __________.
20. What is the amount of calcium oxide formed by the dissociation of 25 g of calcium carbonate?
21. State Avogadro's law.
22. Define amu.
23. The vapour density of a substance is 24. What is the gram molecular weight of the substance?
24. Calculate the weight of CO_2, which occupies a volume of 11.2 dm^3 at STP.
25. The mass of N molecules of helium is the same as the mass of __________ molecules of methane.
26. Percentage of calcium in calcium carbonate is ______.
27. Calculate the percentage of chlorine present in calcium chloride.
28. Define molarity.
29. State Graham's law of diffusion.
30. How many litres of oxygen at STP are required for the combustion of 4 g of methane gas? Also calculate the volume of CO_2 gas produced at STP.

Short Answer Type Questions

31. State and explain Charle's law.
32. Explain the significance of absolute zero.
33. (a) Define molarity.
    (b) Calculate the molarity of sodium carbonate solution containing 0.53 g of sodium carbonate dissolved in 200 ml of the solution.
34. Calculate the weight of
    (a) single atom of nitrogen
    (b) single atom of carbon
    (c) 1.5×10^{21} atoms of sodium
    (d) single molecule of carbon monoxide
35. What is the volume of oxygen at STP liberated when 12.25 g of potassium chlorate is subjected to heating?

36. Calculate the total number of atoms present in 0.49 grams of H_2SO_4.

37. What is meant by mole fraction? Find out the mole fraction of sodium hydroxide solution containing 4 g of solute in 90 g of water.

38. What is the volume of 50% (w/v) H_2SO_4 required for the liberation of 5.6 l of hydrogen gas at STP on its reaction with magnesium?

39. Calculate the percentage composition of glucose.

40. Empirical formula of a compound is CH_3N.
If the empirical formula weight is equal to one-fourth of its vapour density, find out the molecular formula of the compound.

41. Calculate the number of atoms in

(a) 4.5 g atoms of potassium
(b) 0.2 g atoms of chlorine
(c) 1.2 g molecules of nitrogen

42. How many litres of oxygen at STP are required for the combustion of 4 g of methane gas? Also calculate the volume of CO_2 gas produced at STP.

43. Find out the relative rates of diffusion of methane and sulphur dioxide under similar conditions of temperature and pressure.

44. 1.8 g of oxalic acid ($H_2C_2O_4$) is dissolved in 200 ml of a solution. Find out the molarity of the resultant solution.

45. A gaseous hydrocarbon with a vapour density of 14 contains 85.2% carbon. Calculate its molecular formula.

Essay Type Questions

46. State and explain the postulates of kinetic molecular theory of gases.

47. State and explain Graham's law of diffusion. 120 cc of SO_2 gas is diffused through a porous membrane in 40 min. Under similar conditions, 360 cc of another gas is diffused in 30 min. What is the molecular weight of the other gas?

48. State and explain

(a) Boyle's law
(b) Charle's law with graphical representation

49. Derive the ideal gas equation on the basis of laws of Boyle, Charle and Avogadro. Calculate the volume occupied by an ideal gas at STP, if 0.25 ℓ of the gas is present at a pressure of 700 mm of Hg and 273°C.

50. Explain the relation between vapour density and molecular mass.

CONCEPT APPLICATION

Level 1

***Direction for questions from 1 to 7*: State whether the following statements are true or false.**

1. Doubling the pressure of a gas at constant temperature doubles the volume occupied by the gas.

2. When a 200 ml gas, in a closed vessel, is heated to 50°C from 25°C, the volume becomes doubled.

3. The rate of diffusion of methane is double the rate of diffusion of sulphur dioxide gas.

4. 1 g atom of nitrogen contains 6.023×10^{23} atoms of nitrogen.

5. Gay-Lussac's law of combining volumes is applicable to the reaction, $2C + O_2 \rightarrow 2CO_2$.

6. Gases show deviations from ideal behaviour at high temperatures and high pressures.

7. The greater the critical temperature of a gas, the easier is the liquefaction of the gas.

***Direction for questions from 8 to 14*: Fill in the blanks.**

8. The ratio of the volumes of 11 g of CO_2 and 28 g of CO at STP is __________.

9. The number of oxygen molecules required for the complete combustion of 5 moles of methane is __________.

10. The volume of CO_2 liberated at STP is __________ on thermal decomposition of 84 g of sodium bicarbonate.

PRACTICE QUESTIONS

11. "ous" acid of a nonmetal "X" has 2 "O" atoms. Per acid of the same nonmetal has the formula ______.

12. The ratio of the gram atomic weight of nitrogen and oxygen is __________.

13. Pressure exerted by water vapour in moist gas is called _____.

14. Mole fraction of NaOH in an aqueous solution is 0.3. Mole fraction of water is _________.

***Direction for question 15*: Match the entries given in Column A with appropriate ones in Column B.**

15.

A. Empirical formula of glucose	( )	a. Less intermolecular forces
B. Percentage of carbon in methane	( )	b. 75%
C. Ideal gas	( )	c. 17.6%
D. High critical temperature	( )	d. Large intermolecular forces of attraction
E. Percentage of hydrogen in ammonia	( )	e. CH_2O
F. Empirical formula of oxalic acid	( )	f. CHO_2

***Direction for questions from 16 to 30*: Select the correct alternative from the given choices.**

16. The number of oxygen atoms present in 2 moles of a compound, which consists of a bivalent metal and a perchlorate ion is
(a) 4 N (b) 6 N
(c) 8 N (d) 16 N

17. When one mole each of CO and O_2 are made to react at STP, the total number of moles at the end of the reaction is
(a) 1.5 moles (b) 1 mole
(c) 4 moles (d) 2 moles

18. When 180 g of glucose is subjected to combustion, the volume of CO_2 liberated at STP is
(a) 22.4 ℓ (b) 67.2 ℓ
(c) 44 ℓ (d) 134.4 ℓ

19. 20 cc of a hydrocarbon on complete combustion gave 80 cc of CO_2 and 100 cc of H_2O at STP. The empirical formula of that compound is
(a) C_2H_5 (b) C_2H_6
(c) C_3H_8 (d) C_4H_{10}

20. How many molecules would be there in 0.01 moles of sodium hydroxide?
(a) 6.023×10^{23} (b) 6.023×10^{21}
(c) 6.023×10^{22} (d) 6.023×10^{20}

21. 44 g of CO_2 contains
(a) 2 moles of oxygen atoms
(b) 1 mole of oxygen atoms
(c) 1.5 moles of oxygen atoms
(d) 2 moles of oxygen molecules

22. 0.1225 g of potassium chlorate decomposes completely. Write the possible chemical equation and the amount of oxygen liberated.
(a) $4KClO_3 \rightarrow 4KCl + 6O_2$, 0.048 g
(b) $4KClO_3 \rightarrow 4KCl + 5O_2$, 0.48 g
(c) $2KClO_3 \rightarrow 2KCl + 3O_2$, 0.048 g
(d) $2KClO_3 \rightarrow 2KCl + 3O_2$, 0.48 g

23. The ratio by mass of sulphur and oxygen in SO_2 is
(a) 1 : 2 (b) 2 : 1
(c) 1 : 1 (d) 1 : 4

24. Critical temperatures of the gases A, B, C and D are
(a) 5.2 K (b) 33.2 K
(c) 126.3 K (d) 191.1 K

Arrange them in the ascending order of intermolecular forces of attraction.
(a) C, B, D, A (b) A, B, C, D
(c) D, C, B, A (d) A, C, B, D

25. Which of the following pairs of gases corresponds to the ratio of the rates of diffusion as $\sqrt{2} : 1$?
(a) H_2 and He (b) He and CH_4
(c) H_2 and CH_4 (d) CH_4 and SO_2

26. When ammonia gas is subjected to sudden expansion from a region of high pressure into a region of low pressure, which of the following changes is expected to take place?
(a) decrease in kinetic energy and potential energy
(b) conversion of kinetic energy to potential energy
(c) conversion of potential energy to kinetic energy
(d) increase in kinetic energy and potential energy

27. Dalton's law of partial pressures cannot hold good for
(a) $NO_2 + O_2$ (b) $H_2 + Cl_2$
(c) $CO_2 + O_2$ (d) $NH_3 + He$

PRACTICE QUESTIONS

28. A 600 ml vessel containing oxygen at 800 mm and a 400 ml vessel containing nitrogen at 600 mm at the same temperature are joined to each other. The final pressure of the mixture is
(a) 1400 mm (b) 1000 mm
(c) 720 mm (d) 700 mm

29. It is found that with an increase in temperature by 40%, the volume decreases by 20% with change in pressure. Find the percentage change in pressure.
(a) 40% decrease (b) 60% decrease
(c) 75% increase (d) 80% increase

30. 23 g of NO_2 contains same number of molecules as
(a) 8 g of oxygen
(b) 28 g of carbon monoxide
(c) 16 g of SO_2
(d) 22 g of CO_2

***Directions for questions from 31 to 45*: Select the correct alternative from the given choices.**

31. Which of the following is in the correct order according to metal reactivity series?
(a) Al < Fe < Na< Ca (b) Fe < Ca< Al < Na
(c) Fe< Al< Ca< Na (d) Na < Ca< Al< Fe

32. Arrange the following compounds in the correct order of percentage of metallic element.
(a) potassium hydroxide
(b) potassium carbonate
(c) potassium bicarbonate
(d) potassium sulphide
(a) a > b > c > d (b) b > a > c> d
(c) c > b > a > d (d) d > a > b > c

33. Empirical formula of a compound is A_2B_4. If its empirical formula weight is half of its vapour density, determine the molecular formula of the compound.
(a) A_4B_8 (b) A_8B_{16}
(c) A_2B_4 (d) A_3B_6

34. The number of oxygen atoms present in 2 moles of a compound, which consists of a bivalent metal and a perchlorate ion is
(a) 4 N (b) 6 N
(c) 8 N (d) 16 N

35. $KMnO_4 + H_2SO_4 + FeSO_4 \rightarrow K_2SO_4 + MnSO_4 + Fe_2(SO_4)_3 + H_2O$
Coefficients of sulphuric acid and ferric sulphate in the balanced equation of above reaction are ___ and ____ respectively
(a) 8, 4 (b) 5, 8
(c) 4, 3 (d) 8, 5

36. A certain mass of a gas occupies a volume of 600 ml at a certain temperature and pressure. If the temperature is increased by 80% what will be the volume occupied by the same mass of gas at the same pressure?
(a) 1080 ml (b) 108 ml
(c) 120 ml (d) 102 ml

37. The weight of an empty china dish is 39 g and when a saturated solution of potassium nitrate is poured into it, its weight is 108 g at 50°C. After evaporating the solution to dryness, if the weight of the dish along with the crystals is 72 g then the solubility of potassium nitrate at 50°C is _____.
(a) 83.9 (b) 95.6
(c) 91.6 (d) 87.4

38. If 15 mg of N_2O_3 is added to 4.82×10^{20} molecules of N_2O_3 the total volume occupied by the gas at STP is
(a) 0.044 ℓ (b) 0.022 ℓ
(c) 0.22 ℓ (d) 0.44 ℓ

39. In a 2.5 ℓ flask at 27°C temperature, the pressure of a gas was found to be 8 atm. If 2.41×10^{23} molecules of the same gas are introduced into the container, the temperature changed to T_2. The pressure of gas is found to be 10 atm. Find out the value of T_2.
(a) 253 K (b) 347 K
(c) 230 K (d) 370 K

40. A certain mass of a gas occupies a volume of 600 ml at a certain temperature and pressure. If pressure is decreased by 40% what will be the volume occupied by the same mass of the gas at the same temperature?
(a) 240 ml (b) 1000 ml
(c) 300 ml (d) 120 ml

41. Calculate the molarity of a solution obtained by mixing 250 ml of 0.5 M HCl with 750 ml of 2 M HCl.
(a) 1.8 (b) 2.0
(c) 1.6 (d) 0.8

42. 40% w/W $Ca(OH)_2$ solution has a molarity of 7.8 M. Calculate the density of the solution.
(a) 1.03 g/cc (b) 1.04 g/cc
(c) 1.54 g/cc (d) 1.44 g/cc

43. Which one of the following is different from the others with respect to valency?
(a) potassium (b) ammonium
(c) barium (d) lithium

44. Plumbous ion is represented as
(a) Pb^{+2} (b) Pb^{+4}
(c) Pb^{+3} (d) Pb^{+1}

45. 0.5 moles of a salt contains "3N" oxygen atoms. Identify the formula of the salt.
(a) MXO_3 (b) MX_2O_3
(c) M_2XO_3 (d) $M(XO_3)_2$

Level 2

1. Balloons of 2 ℓ capacity are to be filled with hydrogen at a pressure of 1 atm and 27°C temperature from an 8 ℓ cylinder containing hydrogen at 10 atm, at the same temperature. Calculate the number of balloons that can be filled.

2. When both pressure and temperature of a given mass of a gas are increased by "n" times, the volume occupied by the same mass of the gas remains the same. Justify with respect to kinetic molecular theory.

3. A gas cylinder is filled with helium at 2000 mm. Due to leakage, the pressure dropped to 1500 torr in 40 min. When the same cylinder is filled with another gas at the same pressure the pressure dropped from 2000 mm to 1500 mm in 200 min. What is the molecular weight of the gas?

4. A cation A^{+4x} and an anion B^{-2x} combine to form a compound. Similarly, C^{+2x} and D^{-4x} also combine to form a compound. When the molten compounds are subjected to electrolysis, the gaseous products obtained are in equimolar amounts. What should be the mole ratio of the compounds taken respectively?

5. A sample of a mixture of Na_2CO_3 and $NaHCO_3$ is subjected to heating till there is no further loss in weight. Assuming that the loss in weight of the sample is 22% of the initial weight of the mixture due to the evolution of CO_2, find out the relative percentages of the two components in the mixture.

6. Calculate the mass of aluminium oxide which contains double the number of oxygen atoms in 192 g of oxygen gas.

7. A vessel contains equal number of moles of helium and methane. Due to a hole in the vessel half of the gaseous mixture effused out. What is the ratio of the number of moles of helium and methane remaining in the vessel?

8. A vessel contains double the number of moles of hydrogen than oxygen. Due to a hole in the vessel, one-fourth of the gaseous mixture is effused out. What is the ratio of the number of moles of hydrogen and oxygen remaining in the vessel?

9. A salt is formed between a bivalent metal cation and an oxyacid of a nonmetal. The -ous acid of the nonmetal has two oxygen atoms per molecule. If the salt contains a radical of per acid of the same nonmetal, calculate the number of atoms of various elements present in 0.5 moles of the salt.

10. Specific gravity of 84% (w/w) pure HNO_3 is 1.54. What volume of HNO_3 is required to prepare 1 l of 0.5 M HNO_3 solution?

11. At STP, a certain amount of hydrogen is produced by the reaction of 550 g of impure zinc with excess amount of HCl. The same volume of hydrogen at STP reduces Fe_3O_4 and produces 336 g of iron. Find the percentage purity of zinc. (atomic weight of Zn is 65)

12. The percentage of oxygen in a metallic oxide of a bivalent metal is 20.1%. The molecular weight of the compound is 79.5. Write the molecular formula of the compound considering the symbol of the metal as M and find out the atomic weight of the metal.

13. A hydrocarbon on combustion gives CO_2 and H_2O in a volume ratio of 2 : 1 under similar conditions of temperature and pressure. What is the empirical formula of the hydrocarbon?

14. An aqueous solution is prepared by dissolving 90 g of acetic acid in water to make a 1000 ml solution. Density of solution is 0.99. Calculate the molarity of solution and mole fraction of solute in the solution.

15. A vessel contains equal masses of hydrogen, helium and methane. Find out the fractions of the partial pressures in the mixture.

Directions for questions from 16 to 25: **Application-Based Questions**

16. The molecular mass of a salt of oxyacid of chlorine of a divalent metal which contains more number of oxygen atoms than its corresponding "-ic" acid is 239. What will the molecular masses of its
(a) phosphate (b) iodide
(c) bisulphate be?

17. Represent the following chemical changes in the form of chemical equations and balance them.
(a) A copper coin is placed in a solution of corrosive sublimate, mercuric chloride. The products obtained are cupric chloride and mercury.
(b) A piece of (a) sulphur, (b) charcoal burns vigorously when dropped in molten potassium nitrate, because potassium nitrate decomposes to form potassium nitrite and oxygen and this oxygen helps to burn charcoal and sulphur giving out carbon dioxide and sulphur dioxide respectively.
(c) Aqueous ammonium hydroxide solution is made to react with aqueous copper sulphate solution and a bluish white precipitate of cupric hydroxide and ammonium sulphate are formed.

18. The percentage of metal in two metal oxides A and B is 74.2% and 59%, respectively. Show that the law of multiple proportions is obeyed.

19. A sample of air contains nitrogen and oxygen saturated with water vapour. The total pressure is 640 mm. The vapour pressure of water vapour is 40 mm and molar ratio of nitrogen and oxygen is 4 : 1. Find out the partial pressures of N_2 and O_2.

20. Calculate the partial pressures of each gas present in a mixture of 8 g of oxygen and 6 g of hydrogen present in 2 ℓ container at 27°C.

21. A particular compound contains only nitrogen and hydrogen. The percentage of nitrogen in the compound is 87.5%. Further, 96 g of the compound contains 18×10^{23} molecules of the substance. Find out the molecular formula of the compound.

22. When a sample of KNO_3 is subjected to heating, the volume of oxygen liberated was sufficient for the combustion of one mole of ethylene. For giving same amount of oxygen, what is the amount of lead nitrate required to be decomposed? Also find out the volume occupied by the gaseous products at STP during this decomposition.

23. Brass is an alloy of copper and zinc. A sample of brass weighing 5.793 g when treated with excess of dil H_2SO_4 gave 336 ml of hydrogen gas at 136.5 K and 785 mm pressure. If the hydrogen gas is collected over water and pressure of water vapour under the given conditions is 25 mm, find out the percentage weight of copper in the alloy.

24. 50 ml of a gaseous hydrocarbon is mixed with excess of oxygen and burnt and cooled to the laboratory temperature. The reduction in volume was found to be 150 ml. The gas is then passed into caustic potash when there is a further reduction in the volume of 150 ml. Provided all the volumes are measured at the same conditions of temperature and pressure, find out the molecular formula of the hydrocarbon.

25. X g of CO_2 is prepared by the reaction of $CaCO_3$ and HCl. How many grams of oxygen will be liberated if X grams of CO_2 completely take part in the process of photosynthesis? 144 g of water is produced in the first reaction.

Equation for photosynthesis is $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$

Level 3

1. When a fully blown balloon is subjected to sudden bursting, what do you observe? Justify your observation.

2. Under what conditions, gases deviate to a large extent from ideal behaviour? Justify with respect to kinetic molecular theory.

PRACTICE QUESTIONS

PRACTICE QUESTIONS

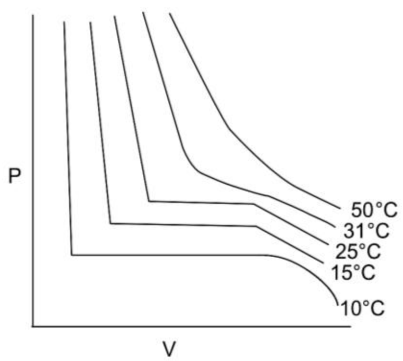
3. The vapour pressure of a solution is always less than that of the pure solvent, when the temperature of both the solution and solvent are the same with the same external pressure acting over them. Explain.

4. The experimental values of the mass (in grams) of 1 l of CO_2, NH_3 and CH_3Cl, at STP are given below:

CO_2 → 1.9767 g
NH_3 → 0.7712 g
CH_3Cl → 2.3076 g

Arrange them in the ascending order of their deviation from the behaviour of ideal gas with appropriate reasons.

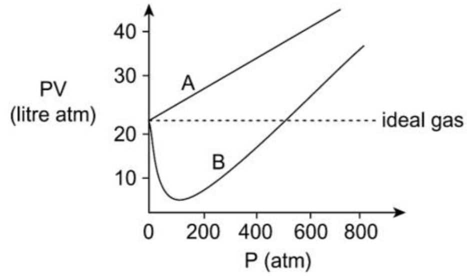
5. In the P vs V graph of CO_2 gas given below, account for the reduction in the horizontal portion of the graph with increase in temperature.



***Directions for questions from 6 to 10*: Application-Based Questions**

6. After usage for a certain period, a cooking gas cylinder was considered to be empty as no gas was coming out of it. Is the cylinder empty in its true sense? Explain what happens if the cylinder is kept in hot water or shaken vigorously. Explain by applying kinetic molecular theory.

7. From the graph given below compare the intermolecular forces of attraction in A and B.



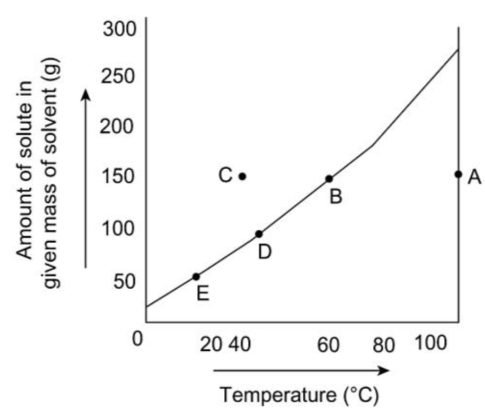
8. The various conditions required for the liquefaction of gases A, B, C and D are given below:

Gas	Temperature	Pressure
A	–4°C	10 atm
B	–4°C	5 atm
C	25°C	5 atm
D	25°C	4 atm

Arrange these gases in the ascending order of their deviation from ideal behaviour. Give reason in support of your answer.

9. The reduction of acidified solution of ferric ions by hydrogen gas takes place in the presence of zinc. Explain.

10. In the graph given below, identify the states of solution at the various points A, B, C, D and E. If the solution is cooled from point "A" at which temperature, precipitation normally starts? Also find out the amount of solute precipitated at 40°C at A and the amount of solute in the solution at point "E." What would be the maximum amount of solute that can be precipitated in the process?



CONCEPT APPLICATION

Level 1

True or false

1. False
2. False
3. True
4. True
5. False
6. False
7. True

Fill in the blanks

8. 1 : 4
9. 6.023×10^{24} molecules
10. 11.2 ℓ
11. HXO_4
12. 7 : 8
13. aqueous tension
14. 0.7

Match the following

15. A : e
B : b
C : a
D : d
E : c
F : f

Multiple choice questions

16. d
17. a
18. d
19. a
20. b
21. a
22. c
23. c
24. b
25. a
26. b
27. b
28. c
29. c
30. d

Solutions for questions from 31 to 45:

31. According to the metal reactivity series, the increasing order of the reactivates of the given metals is

$$Fe < Al < Ca < Na$$

32. (a) potassium hydroxide → KOH

$$\% \text{ of potassium} = \frac{39}{56} \times 100 = 69.64\%$$

(b) potassium carbonate → K_2CO_3

$$\% \text{ of potassium} = \frac{78}{138} \times 100 = 56.52\%$$

(c) potassium bicarbonate → $KHCO_3$

$$\% \text{ of potassium} = \frac{39}{100} \times 100 = 39\%$$

(d) potassium sulphide → K_2S

$$\% \text{ of potassium} = \frac{39 \times 2}{110} \times 100 = 70.90\%$$

∴ increasing order is (d) > (a) > (b) > (c)

33. Let the vapour density of compound be x

Empirical formula weight = x/2

Molecular formula weight = 2x

$$n = \frac{\text{Molecular formula weight}}{\text{Empirical formula weight}} = \frac{2x}{\left(\frac{x}{2}\right)} = 4$$

Molecular formula = $4 \times A_2B_4 = A_8B_{16}$

34. Let the bivalent metal ion be M^{+2}, then the formula of the compound formed will be $M(ClO_4)_2$.

1 mole of compound contains 8 N oxygen atoms.

$\therefore$ 2 moles of compound contain 16 N oxygen atoms.

Choice (d)

35. $2KMnO_4 + 8H_2SO_4 + 10FeSO_4 \rightarrow 5Fe_2(SO_4)_3 + K_2SO_4 + 2MnSO_4 + 8H_2O$

36. Initial volume, $V_1 = 600$ ml

Initial temperature, $T_1 = x$

Final temperature, $T_2 = \frac{180x}{100}$

Final volume, $V_2 = ?$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \text{ as per Charles's law}$$

$$\frac{600}{x} = \frac{V_2 \times 100}{180x} = V_2 = 1080\,\text{ml}$$

37. The weight of saturated solution = 108 – 39 = 69 g

The weight of KNO_3 crystals = 72 – 39 = 33 g

The weight of water in saturated solution = 69 – 33 = 36 g

$$\therefore \text{Solubility of } KNO_3 = \frac{\text{Weight of } KNO_3}{\text{Weight of water}} \times 100$$

$$= \frac{33}{36} \times 100 = 91.6 \text{ at } 50°C$$

38. Gram molecular weight of N_2O_3 is 76 g and 76 g of N_2O_3 contains 6.023×10^{23} molecules

$\therefore$ Weight of 4.82×10^{20} molecules

$$= \frac{76 \times 4.82 \times 10^{20}}{6.023 \times 10^{23}}\,g = 0.061\,g$$

15 mg of N_2O_3 = 0.015 g

$\therefore$ Total weight of N_2O_3 = 0.061 + 0.015

= 0.076 g

76 g occupies 22.4 l at STP.

0.076 g occupies ? l at STP.

$$= \frac{0.076 \times 22.4}{76} = 0.022\ell$$

39. 6.023×10^{23} molecules correspond to 1 mole

2.41×10^{23} molecules correspond to?

$$= \frac{2.41 \times 10^{23}}{6.023 \times 10^{23}} = 0.4\,\text{moles}$$

Case (i)

$_1V_1 = n_1.R_1.\quad T_1$

$8(2.5) = n_1\,(0.08).(300)$

$$n_1 = \frac{8(2.5)}{(0.08)(300)}$$

$n_1 = 0.833$ moles

Total moles, $n_2 = 0.833 + 0.4$

$n_2 = 1.233$

Case (ii)

$P_2V_2 = n_2R\,T_2$

$10\,(2.5) = 1.233\,(0.08).T_2$

$T_2 = 253.4$ K

40. Initial volume, $V_1 = 600$ ml

Let initial pressure be $P_1 = x$

Final pressure, $P_2 = \frac{60x}{100}$

Final volume, V_2

As per Boyle's law, $P_1V_1 = P_2V_2 \Rightarrow V_2 = \frac{P_1V_1}{P_2}$

$$V_2 = \frac{x \times 600 \times 100}{60x}$$

$$V_2 = 1000\,\text{ml}$$

41. $$N_{\text{Mixture}} = \frac{N_1V_1 + N_2V_2}{V_1 + V_2}$$

$$= \frac{(0.5)250 + (2 \times 750)}{250 + 750} = 1.625\,N$$

$\therefore$ Molarity = 1.625 N (as HCl is monobasic acid)

42. Let the density of solution be = xg/cc

Molarity = 7.8 M

Molecular mass of $Ca(OH)_2 = 40 + 34 = 74$

Mass of solute = 40 g

$$\text{Molarity} = \frac{\text{mass of solute}}{\text{molecular mass of solute}} \times \frac{1000}{\left(\frac{100}{x}\right)} 3$$

$$\left(\because v = \frac{m}{d}\right)$$

$$7.8 = \frac{40}{74} \times \frac{1000}{100} \times x$$

43. Barium's valency is 2, whereas the valency of rest of the elements is 1.

44. Suffix "ous" denotes lower valency exhibited by the metal when compared with suffix "ic" which denotes higher valency of the metal. Hence, plumbous is Pb^{+2}.

45. 0.5 moles of salt contains 3N oxygen atoms.

$\therefore$ 1mole of salt contains $= \frac{1 \times 3N}{0.5}$

= 6 N oxygen atoms

$\therefore$ The salt is $M(XO_3)_2$.

Level 2

1. (i) application of ideal gas equation
(ii) calculation of volume at 1 atmospheric pressure
(iii) determination of number of balloons
(iv) 40 balloons

2. (i) change in arrangement of molecules with increase in temperature
(ii) change in arrangement of molecules with increase in pressure
(iii) comparison of these changes

3. (i) relation between drop in pressure and rate of diffusion
(ii) relation between the rate of diffusion and molecular weight of gases
(iii) 100

4. (i) application of criss-cross method
(ii) derivation of the formulae of both the compounds
(iii) determination of the ratio of the number of atoms of B and D present in the respective molecule
(iv) determination of molar ratio of the compounds taken
(v) 1 : 2

5. (i) action of heating on the compounds Na_2CO_3 and $NaHCO_3$.
(ii) determination of the mass of Na_2CO_3 and $NaHCO_3$ from the mass of CO_2 produced
(iii) 84% $NaHCO_3$
16% Na_2CO_3

6. (i) atomicity of oxygen
(ii) chemical composition of Al_2O_3
(iii) determination of mass of Al_2O_3
(iv) 408 g

7. (i) relation between molecular weight and rate of effusion
(ii) determination of the ratio of the number of molecules of helium and methane which are effused out
(iii) calculation of the ratio of the remaining molecules
(iv) $\frac{2x}{3}$ moles

8. (i) relation between number of moles of gases
(ii) relation between number of moles of gases effused and molecular weight
(iii) comparison of number of moles of H_2 and O_2 effused
(iv) calculation of number of moles of H_2 and O_2 left over
(v) 28 : 17

9. (i) identification of acidic radical and formula of salt
(ii) determination of the formula of the "per" acid radical
(iii) determination of the formula of the salt
(iv) determination of the number of atoms of each constituent element present in one molecule of the salt
(v) determination of the number of atoms of each constituent element present in 5 moles of the salt
(vi) 4 N oxygen atoms

N chlorine atoms

10. (i) amount of HNO_3 present in 0.5 M HNO_3
(ii) calculation of volume based on given data and above amount
(iii) calculation of molarity
(iv) 20.5 ml

11. (i) reaction between Fe_3O_4 and hydrogen and weight–volume relationship between reactants and product
(ii) calculation of number of moles of iron
(iii) calculation of the corresponding number of moles of hydrogen consumed from the balanced chemical equation
(iv) calculation of number of moles of zinc taken part in the reaction
(v) calculation of percentage purity of zinc
(vi) 95.27%

12. (i) calculate the number of atoms of oxygen present in the compound
(ii) calculation of the number of atoms of oxygen present in one molecule of the metallic oxide from the percentage of oxygen given
(iii) determination of the formula of the compound
(iv) calculation of atomic weight of the metal
(v) 63.5

13. (i) relation between the ratio of the volumes and ratio of the number of moles
(ii) determination of the empirical formula based on the molar ratio of the product
(iii) CH

14. (i) number of moles of solute
(ii) calculation of weight of solution, solvent
(iii) calculation of number of moles of solvent
(iv) calculation of mole fraction and molarity
(v) 1.5 M, 0.03

15. (i) fraction of number of moles of CH_4, H_2 and He in the mixture
(ii) relation between mole fraction and total pressure
(iii) $\frac{8P}{13}, \frac{4P}{13}, \frac{P}{13}$

Solutions for questions from 16 to 25:

16. The formula of perchlorate of a divalent metal M is $M(ClO_4)_2$.

Molecular mass of $M(ClO_4)_2$ is 239.

Let x be the atomic mass of bivalent metal.

$\therefore x + 2[35.5 + 64] = 239 \Rightarrow x = 40$

$\therefore$ The element is calcium.

(a) The formula of its phosphate is $Ca_3(PO_4)_2$.
$\therefore$ Its molecular mass is $(3 \times 40) + 2[31 + 64] = 310$

(b) The formula of its iodide is CaI_2.
$\therefore$ Its molecular mass is $40 + (2 \times 127) = 294$

(c) The formula of bisulphate is $Ca(HSO_4)_2$
$\therefore$ Its molecular mass is $40 + 2[1 + 32 + 64] = 234$

17. (a) The copper displaces the mercury from mercuric chloride and forms cupric chloride and mercury.

$(Cu + HgCl_2 \rightarrow CuCl_2 + Hg)$

(b) $2\ KNO_3 \rightarrow 2\ KNO_2 + O_2$

$S + O_2 \rightarrow SO_2$

$C + O_2 \rightarrow CO_2$

(c) $2NH_4OH + CuSO_4 \rightarrow Cu(OH)_2 + (NH_4)_2SO_4$

18.

Metal Oxides	Percentage of Metal	Percentage of Oxygen
A	74.2	25.8
B	59	41

In A, 74.2 g of metal combines with 25.8 g of oxygen

? combines with 1 g of oxygen

$$= \frac{74.2g}{25.8g} = 2.87g$$

In B, 59 g of metal combines with 41 g of oxygen

? combines with 1 g of oxygen

$$= \frac{59}{41} g = 1.43g$$

∴ The ratio by weight of metal combining with fixed mass of oxygen in A and B

= 2.87 : 1.43 = 2 : 1

Hence, law of multiple proportions is obeyed.

19. Total pressure, $P_{N_2} + P_{O_2} + P_{H_2O} = 640$ mm

Vapour pressure of water vapour = 40 mm

$$\therefore P_{N_{2+}} + P_{O_2} = 640 - 40 = 600\,\text{mm}$$

Mole fraction of nitrogen = 4/5

Mole fraction of oxygen $= \frac{1}{5}$

Partial pressure of N_2 = total pressure ×

$X_{N_2} = 600 \times \frac{4}{5} = 480\,\text{mm}$

Partial pressure of $O_2 = 600 \times \frac{1}{5} = 120\,\text{mm}$

20. No. of moles of oxygen, $n_{o_2} = \frac{8}{32} = 0.25$

No. of moles of hydrogen, $n_{H_2} = \frac{6}{3} = 2$

Total number of moles, n = 0.25 + 2 = 2.25

PV = nRT

2P = 2.25 × 0.08 × 300

P = 27 atm

Partial pressure of oxygen, p_{O2} = (mole fraction of O_2). P

$$= \left(\frac{0.25}{0.25+2}\right)27 = 3\,\text{atm}$$

$$P_{total} = P_{O_2} + P_{H_2}$$

Partial pressure of H_2 = 27 – 3 = 24 atm

21. Number of moles of the given substance $= \frac{18 \times 10^{23}}{6 \times 10^{23}} = 3$

Weight of compound = 96

Gram molecular mass of the compound $= \frac{96}{3} = 32\,\text{g}$

% of N_2 = 87.5%

Number of nitrogen atoms in 1 molecule of the compound $= \frac{87.5 \times 32}{100 \times 14} = 2$

Similarly number of hydrogen atom in 1 molecule of the compound $= \frac{12.5 \times 32}{100 \times 2} = 4$

Molecular formula is N_2H_4

22. $2KNO_3 \rightarrow 2KNO_2 + O_2$

$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$

1 mole of ethylene requires 3 moles of oxygen

$2Pb(NO_3)_2 \rightarrow 2PbO + 4NO_2 + O_2$

6 moles of $Pb(NO_3)_2$ is required to give 3 moles of oxygen

∴ Weight of $Pb(NO_3)_2$ = 6 × 330 = 1980 g

Volume occupied by gaseous (NO_2 and O_2) products

= 15 × 22.4 l at STP = 336 ℓ

23. Among Cu and Zn, only Zn displaces H_2 from H_2SO_4

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

Pressure = 785 – 25 = 760 mm

Temperature = 136.5 K, volume = 336 ml

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

$$\frac{760 \times 336}{136.5} = \frac{760 \times V_2}{273}$$

V_2 = 672 ml

(V_2) Vol. of H_2 liberated at STP = 672 ml

Weight of zinc required $= \frac{65.5 \times 672}{22400} = 1.965\,\text{g}$

Weight of copper in brass = 5.793 – 1.965 = 3.828 g

% of Cu in the alloy $= \frac{3.828}{5.793} \times 100 = 66\%$

24. Chemical reaction equation to combustion reaction is

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

50 ml 150 ml 150 ml

We know volume of gas has same number of moles at same temperature and pressure

50 moles 150 moles 150 moles

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

50 mole 150 mole 150 mole

Given that reduction in volume when the gases mixture is cooled to the laboratory temperature = 150 ml

$$\therefore \frac{y}{2}(50) = 150 \Rightarrow y = 6.$$

and x(50) = 150 ⇒ x = 3

∴ Hydrocarbon is C_3H_6.

25. $CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Number of moles of water formed in the first reaction $= \frac{144}{18} = 8$

Number of moles of CO_2 produced = 8

Number of moles of oxygen produced by using 8 moles CO_2 is 8.

Weight of oxygen liberated = 32 × 8 = 256 g

Level 3

1. (i) sudden expansion of the gas present inside the balloon
(ii) change in energy of the system due to the sudden expansion of the gas
(iii) effect of the change in energy on temperature
(iv) effect of this change in temperature on the surrounding
(v) phase transition of a vapour present in the surrounding

2. (i) requisite for deviation from ideal behaviour
(ii) consequences of high pressure and low temperature
(iii) comparison of actual volume occupied by real gases and ideal gases
(iv) comparison of intermolecular forces of attraction in the above said condition

3. (i) relation between the vapour pressure of the liquid and its intermolecular forces of attraction
(ii) comparison of the constituents of solution and pure solvent
(iii) comparison of the intermolecular force of attraction existing in the solution and that in the existing pure solvent
(iv) effect on vapour pressure

4. (i) calculation of the volumes of the given gases at STP
(ii) comparison of the difference in the volume of the given gases with that of the ideal gas at STP
(iii) relation between the difference in the volume and deviation in the behaviour of the gases from that of the ideal gas
(iv) determination of the ascending order of the extent of deviation of the given gases from the ideal gas

5. (i) difference between real gas and ideal gas
(ii) analysis of the pattern of the curves given in the graph
(iii) analysis of the kind of gradual change in the curves with the change of temperature
(iv) analysis of the change in volume with the change in pressure in case of each curve
(v) analysis of the reason behind the change

Solutions for questions from 6 to 10:

6. No. It is not empty in its true sense. In a cooking gas cylinder, the gas was initially at a high pressure. As the gas was drawn out from the cylinder,

HINTS AND EXPLANATION