Mole Concept and Stoichiometry

Boyle's Law and Charle's Law

Boyle’s Law

- Relation between pressure (*p*) and volume (*V*)
- Statement − At constant temperature, the pressure of a fixed amount (number of moles, *n*) of a gas is inversely proportional to its volume.
- Explanation − Based on kinetic theory:
- Number of particles and their average kinetic energy is constant for a given mass of gas.
- When volume of a certain mass of gas is reduced to half, the particles have lesser space to move around.
- The number of collision of the particles with the walls of the container doubles, thus increasing the pressure to twice the original value.
- Mathematically,

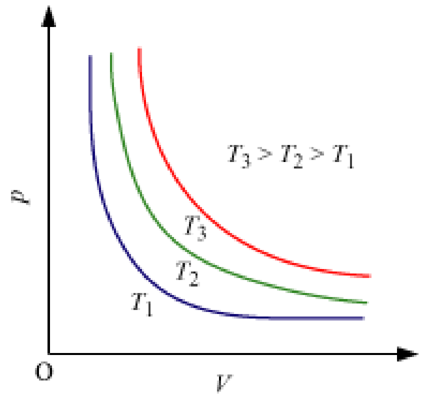
$$p \propto \frac{1}{V} \text{(at constant } T \text{ and } n\text{)}$$

$\Rightarrow p = k_1 \frac{1}{V}$, where k_1 = Proportionality constant

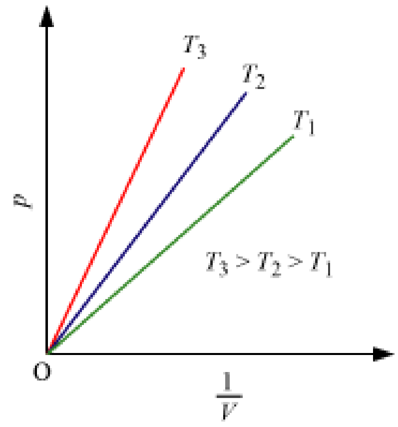
$$\Rightarrow pV = k_1$$

- From the above equation, it is found that at constant temperature, the product of pressure and volume of a fixed amount of a gas is constant.
- The value of k_1 depends upon
  - amount of the gas
  - temperature of the gas
  - units of *p* and *V*

Graphical representation of Boyle's law



p vs V graph



p vs $\frac{1}{V}$ graph

- Each line is called isotherm (at constant temperature plot).

- If at constant temperature,

  V_1 = Volume of a gas at pressure p_1

  V_2 = Volume of the same gas at pressure p_2

  Then,

  $p_1V_1 = p_2V_2$ = Constant

  $$\Rightarrow \frac{p_1}{p_2} = \frac{V_2}{V_1}$$

- Relationship between density (d) and pressure (p):

  We know that,

  $$d = \frac{m}{V}$$

  Where, m = Mass of a gas

  V = Volume of the gas

$$\Rightarrow d = \left(\frac{m}{k_1}\right)p \quad \left(\text{since } p = k_1 \frac{1}{V}\right)$$
$$\Rightarrow d = k'p$$
$$\Rightarrow d \propto p$$

- From the above equation, it is known that density is proportional to the pressure of a fixed amount of a gas.
- Significance of Boyle's law:
- Mountaineers carry oxygen cylinders with them as at higher altitudes as the pressure is low.

Example

Rita has two cylinders. One is empty and the other contains compressed nitrogen at 25 atm. She wants to distribute the gas in the two cylinders. To do so, she connects the two cylinders. If the volume of the cylinder containing the gas is 50 L and that of the empty one is 80 L, then what will be the pressure inside the two cylinders?

Solution:

According to Boyle's law,

$$p_1V_1 = p_2V_2$$

Given, p_1 = 25 atm

V_1 = 50 L

V_2 = (50 + 80) L = 130 L

Now, 25 atm × 50 L = p_2 × 130 L

$$\Rightarrow p_2 = \frac{25 \times 50}{130} \text{atm}$$
$$= 9.62 \text{ atm}$$

Hence, the pressure inside the cylinders is 9.62 atm.

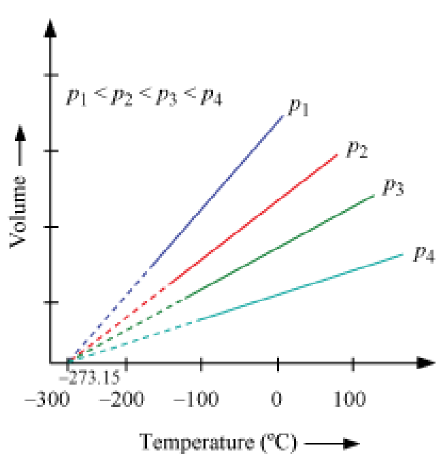
Charles' Law

- Relation between temperature (*T*) and volume (*V*)
- Statement − At constant pressure, the volume of a fixed amount of a gas is directly proportional to its absolute temperature.
- Explanation − On the basis of kinetic theory
- Average kinetic energy of the particles of a gas is directly proportional to the absolute temperature of the gas
- When temperature is increased at constant pressure, the kinetic energy of the particles increases.
- The number and intensity of collisions with the walls of the container increase, thereby increasing the volume at constant pressure.
- Mathematically,

  $V \propto T$

  $\Rightarrow V = k_2 T$, where k_2 = Proportionality constant

- The value of k_2 depends upon
  - pressure of the gas
  - amount of the gas
  - unit of volume
- Graphical representation



- Straight line
- Interception on zero volume at 273.15°C
- Each line is called isobar (constant pressure plot).

- Derivation

For each degree rise in temperature, volume of a gas increases by $\frac{1}{273.15}$ of the original volume of the gas at 0°C.

Suppose, V_0 = Volume of a gas at 0°C

V_t = Volume of the same gas at t°C

Then,

$$V_t = V_0 + \frac{t}{273 \cdot 15} V_0$$
$$\Rightarrow V_t = V_0 \left(1 + \frac{t}{273 \cdot 15}\right)$$
$$\Rightarrow V_t = V_0 \left(\frac{273 \cdot 15 + t}{273 \cdot 15}\right) \qquad \text{(i)}$$

According to Kelvin temperature scale (also called absolute temperature scale or thermodynamic scale),

T = 273.15 + t

T_0 = 273.15

From equation (i), we obtain

$$V_t = V_0 \left(\frac{T_t}{T_0}\right)$$
$$\Rightarrow \frac{V_t}{V_0} = \frac{T_t}{T_0}$$

Or, we can write

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

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

$$\Rightarrow \frac{V}{T} = \text{constant} = k_2$$

$$\Rightarrow V = k_2 T$$

- Significance of Charle's law:
- Hot air is filled in the balloons used for meteorological purposes.

Example

It is desired to increase the volume of 5 L of a gas by 40% without changing the pressure. To what temperature should the gas be heated if its initial temperature is 298 K?

Solution:

Desired increase in the volume of gas = 40% of 5 L

$$= \frac{40}{100} \times 5 \text{ L}$$

= 2 L

Therefore, final volume of the gas = (5 + 2) L = 7 L

Applying Charles' law,

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

Now, V_1 = 5 L

T_1 = 298 K

V_2 = 7 L

Therefore, $\frac{5\ \text{L}}{298\ \text{K}} = \frac{7\ \text{L}}{T_2}$

$$\Rightarrow T_2 = \frac{7\ \text{L} \times 298\ \text{K}}{5\ \text{L}}$$
$$= 417.2\ \text{K}$$

Standard Temperature and Pressure(STP)

The pressure and temperature of the gas keeps varying frequently. Hence, we choose a standard value for temperature and pressure to which the gas volumes can be referred. The standard value chosen are 0°0°C or 273K for temperature and 1 atm or 760 mm of Hg for pressure and are commonly known as **S.T.P.**

Diffusion

Diffusion is defined as the random movement of gaseous molecules from regions of higher concentration to regions of lower concentration. It is a physical process and can only occur if the gases do not react with each other.

Graham's Law of Diffusion:

It states that the rate of diffusion of gas is inversely proportional to the square root of its density at the given temperature and pressure.

$$r \propto \frac{1}{\sqrt{\mathrm{d}}}$$
$$\mathrm{r} = \frac{\mathrm{K}}{\sqrt{\mathrm{d}}} \text{ or } \mathrm{K} = \mathrm{r}\sqrt{\mathrm{d}}$$
$$\mathrm{r} = \text{ rate of diffusion}$$
$$\mathrm{d} = \text{density of gas}$$
$$\mathrm{K} = \text{ proportionality constant}$$
$$\text{Relationship between diffusion and mass}$$
$$\mathrm{r} = \frac{\mathrm{K}}{\sqrt{\mathrm{d}}}$$
$$\mathrm{r} \propto \frac{\mathrm{K}}{\sqrt{\frac{\mathrm{m}}{\mathrm{v}}}} \qquad \text{as } \mathrm{d} = \frac{\mathrm{m}\ (\text{mass})}{\mathrm{v}\ (\text{volume})}$$
$$\text{Hence, } \mathrm{r} = \mathrm{K}\sqrt{\frac{\mathrm{v}}{\mathrm{m}}} \quad \text{or} \quad \mathrm{r} \propto \frac{1}{\sqrt{\mathrm{m}}}$$

It means that the rate of diffusion is inversely proportional to the square root of mass of the gas.

The Mole Concept

The Mole Concept: A Brief Overview

Mole defines the quantity of a substance.

One mole of any substance will always contain **6.022×10^{23}** particles, no matter what that substance is.

Therefore, we can say:

- 1 mole of sodium atoms (Na) contains 6.022×10^{23} sodium atoms.
- 1 mole of sodium ions (Na^+) contains 6.022×10^{23} sodium ions.
- 1 mole of hydrogen atoms (H) contains 6.022×10^{23} hydrogen atoms.
- 1 mole of hydrogen molecules (H_2) contains 6.022×10^{23} hydrogen molecules.

The word ‘mole’ is derived from the Latin word ‘moles’ which means ‘heap’ or ‘pile’. It was first used by the German chemist Wilhelm Ostwald in 1896. It was accepted universally much later, in 1967, as a way of indicating the number of atoms or molecules in a sample.

Thus, mole can be defined as **a unit of measurement used for determining the number of atoms or molecules or ions in a given sample. It is also used to express the number of reactants and products in a chemical reaction**.

The Mole Concept: A Brief Overview

Consider the formation of water by the combination of hydrogen and oxygen.

$2H_2 + O_2 \rightarrow 2H_2O$

This reaction implies that 2 moles of hydrogen molecules combine with 1 mole oxygen molecules to form 2 moles of water molecules.

When carbon (C) reacts with oxygen (O), carbon dioxide is produced. **Can you write the chemical equation for the same?**

The chemical equation for the reaction is:

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{O_2} \rightarrow \underset{\text{Carbon dioxide}}{CO_2}$$

In this reaction, one atom of carbon combines with one molecule (or two atoms) of oxygen to form one molecule of carbon dioxide. We can also say that in this chemical reaction, 12 u of carbon combines with 32 u of oxygen to give 44 u of carbon dioxide. Clearly, we can represent the quantities of substances in terms of their masses.

However, a chemical equation only indicates the numbers of atoms or molecules taking part in the chemical reaction. Therefore, it is easier to represent the quantities of substances involved in a chemical reaction by the numbers of their atoms or molecules rather than their masses. In order to do the same, the concept of mole is used.

Mole Concept

In 1909, the French physicist Jean Perrin found that one gram atom of any element contains the same number of atoms and one gram molecule of any substance contains the same number of molecules, which is equal to $\mathbf{6.022 \times 10^{23}}$.

He proposed naming this number in honour of the Italian physicist Amedeo Avogadro. Hence, $\mathbf{6.022 \times 10^{23}}$ is known as **Avogadro's number** (or Avogadro's constant) and the amount of a substance containing $\mathbf{6.022 \times 10^{23}}$ atoms/molecules/ions is called a **mole**.

Mole is a counting unit in chemistry as it is used to express large numbers of atoms or molecules. One mole of any substance can be defined as the amount of a substance that contains as many particles (atoms, molecules or ions) as there are atoms in 12 g of carbon-12 isotope. So,

1 mole of oxygen atoms (O) = 6.022×10^{23} oxygen atoms

1 mole of oxygen molecules (O_2) = 6.022×10^{23} oxygen molecules

Know Your Scientist

Jean Perrin (1870-1942) was a French physicist. He was awarded the Nobel Prize in Physics in 1962, for his contribution to the establishment of the atomic nature of matter, while conducting research on Brownian motion. In 1895, he showed that cathode rays are made up of negatively charged particles. He is also known for explaining the origin of solar energy through thermonuclear reaction of hydrogen (nuclear fusion) in the sun.

In 1908, he studied Brownian motion using an ultramicroscope and gave experimental confirmation to the hypothesis that the random motion of suspended particles is due to the particulate nature of matter and the inter-particle interactions. He is also credited with estimating the size of a water molecule and the number of molecules of water present in a given amount of water.

Amedeo Avogadro (1776-1856) was an Italian lawyer; however, his interest in the natural sciences led him to study physics and mathematics privately. In 1809, while teaching the natural sciences in Vercelli, he hypothesized that under the same conditions of temperature and pressure, equal volumes of gases contain the same number of particles. This hypothesis later came to be known as Avogadro’s law.

Mole Concept

The molar mass of a substance can be defined as the mass of one mole of a substance in grams. It is numerically equal to atomic/molecular/formula unit mass in u.

$$\text{Molar mass} = \frac{\text{Mass of substance}}{\text{Number of moles}}$$

The mass of one atom is called **atomic mass** and its unit is unified mass (u), while the mass of one mole of atoms is called **molar mass of atoms** and its unit is gram (g). Molar mass of atoms is also called **gram atomic mass**.

For example, the atomic mass of nitrogen (N) is 14 u, while its gram atomic mass is 14 g. So, while 14 u of nitrogen contains only 1 atom of nitrogen, 14 g of nitrogen contains 1 mole of nitrogen atoms, i.e., 6.022×10^{23} nitrogen atoms.

The mass of one molecule is called **molecular mass** and its unit is unified mass (u), while the mass of one mole of molecules is called **molecular mass** and its unit is gram (g). When molecular mass is expressed in grams, it is called **gram molecular mass** or **gram molecule**.

For example, the molecular mass of oxygen (O_2) is 32 u, while its gram molecular mass is 32 g. So, while 32 u of oxygen contains only 1 molecule of oxygen, 32 g of oxygen contains 1 mole of oxygen molecules, i.e., 6.022×10^{23} oxygen molecules.

The volume of one mole of any substance is called its **molar volume**.

The molar volume of a gas at **STP** is numerically equal to 22.4 L.

Mole Concept

Solved Examples

Easy

Example 1:

Calculate the mass of 3.3 moles of ammonia molecule.

Solution:

Molar mass of ammonia molecule (NH_3) = 17 g

Number of moles of ammonia molecule = 3.3

We know that:

$$\text{Molar mass} = \frac{\text{Mass of substance}}{\text{Number of moles}}$$

So,

$$17\text{ g} = \frac{\text{Mass of ammonia molecule}}{3.3}$$

$$\Rightarrow \text{Mass of ammonia molecule} = \left(17 \times 3.3\right)\text{ g} = 56.1\text{ g}$$

Medium

Example 2:

Calculate the volume of 14 g of nitrogen gas at STP.

Solution:

Mass of nitrogen gas (N_2) = 14 g

Molar mass of nitrogen gas = 28 g

We know that:

$$\text{Molar mass} = \frac{\text{Mass of substance}}{\text{Number of moles}}$$

So,

$$28\,g = \frac{14\text{ g}}{\text{Number of moles}}$$

$$\Rightarrow \text{Number of moles} = \frac{14\text{ g}}{28\text{ g}} = 0.5$$

The volume of 1 mole of a gas at STP is 22.4 L.

Therefore,

Volume of 0.5 mole of nitrogen gas at STP = $\frac{22.4\,L}{1} \times 0.5 = 11.2\,L$

Avogadro's Law

In 1811, Avogadro hypothesized that under the same conditions of temperature and pressure, equal volumes of all gases contain an equal number of moles. For example, at the same temperature and pressure, the two gases, oxygen and nitrogen possessing the same volume contain the same number of molecules. This hypothesis is named Avogadro's law. The mole concept provides the following information.

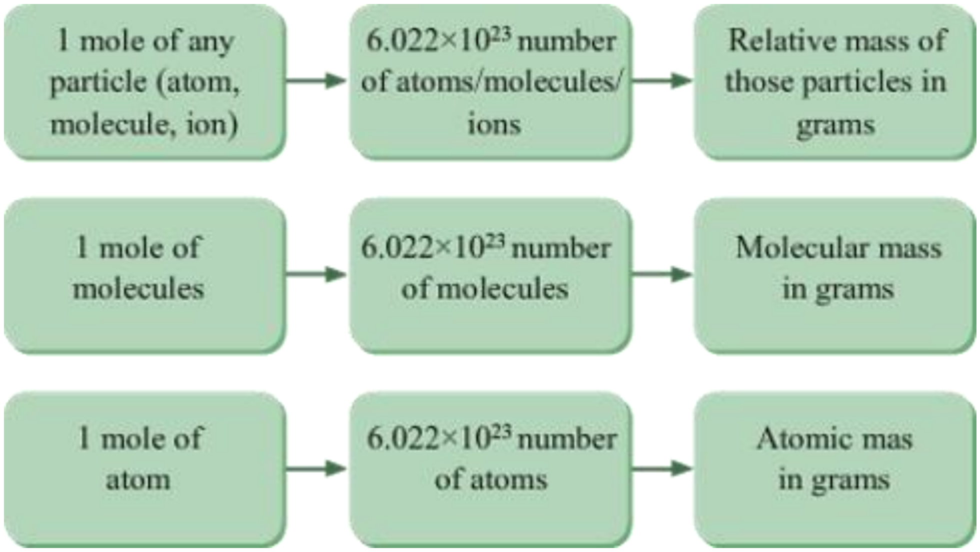
- If one mole of a substance (atoms, molecules or ions) is present, then the number of elementary particles present in that substance is equal to 6.022×10^{23}.
- The mass of one mole of a substance (atoms, molecules or ions) is equal to its molar mass.
- While carrying out reactions, scientists require the number of atoms and molecules. This requirement is fulfilled by the use of the mole concept as follows:

1 mole = 6.022×10^{23} = Relative mass in grams.

Avogadro's Law

Relationship between Mole, Avogadro's Number and Mass

The relationship between mole, Avogadro’s number and mass is summarized in the given figure.



Applications of Avogadro's Law

- It provides an explanation for Gay-Lussac's law.

  The volumes of different combining gases bear a simple ratio to one another because according to Avogadro's law at constant temperature and pressure equal volumes of gases contain the same number of molecules.

- It helps in determination of atomicity of gases.

  Consider the formation of hydrogen chloride gas by the direct combination of hydrogen and chlorine gases:

  $H_2 + Cl_2 \rightarrow 2\ HCl$

  According to Avogadro's law:

  1 molecule of H_2 + 1 molecule of Cl_2 → 2 molecules of HCl

  Or, 1/2 molecule of H_2 + 1/2 molecule of Cl_2 → 1 molecule of HCl

  As atoms are indivisible, therefore, half a molecule of H_2 and Cl_2 indicate they both contain two atoms per molecule.

- It helps in determination of molecular formula of a gas.

Consider the formation of hydrogen chloride gas by the direct combination of hydrogen and chlorine gases:

$H_2 + Cl_2 \rightarrow 2\ HCl$

According to Avogadro's law:

1 molecule of H_2 + 1 molecule of Cl_2 → 2 molecules of HCl

Or, 1/2 molecule of H_2 + 1/2 molecule of Cl_2 → 1 molecule of HCl
Or, 1 atom of H + 1 atom of Cl → 1 molecule of HCl

Hydrogen chloride gas has one atom of hydrogen and one atom of chlorine. Therefore, its molecular formula is HCl.

- It helps in the establishment of the relationship between molecular mass and vapour density (VD).

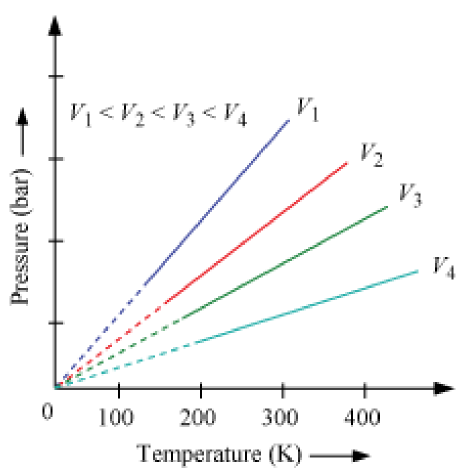
$$2 \times \mathrm{VD} = \frac{\text{Mass of 1 molecule of a gas}}{\text{Mass of 1 atom of hydrogen}}$$

- It provides the relation between gram molecular mass and gram molecular volume.

Molar volume of a gas = 22.4 L

Gram molecular mass of a gas occupies 22.4 L and contains 6.02×10^{23} molecules/atoms of the gas.

Gay-Lussac's Law



This law gives the relationship between pressure and temperature. According to this law, *at constant volume, the pressure of a fixed amount of a gas is directly proportional to the temperature*. It can be represented mathematically as, Mathematically,

$p \propto T$

$\Rightarrow \frac{p}{T}$ **=** constant = k_3

If at constant volume,

p_1 = Pressure of a gas at T_1

p_2 = Pressure of the same gas at T_2

Then,

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Mole Concept and Molar Masses

- 1 mole of any substance can be defined as:
- Amount of a substance that contains as many particles (atoms, molecules or ions) as there are atoms in 12 g of the ^{12}C isotope
- Avogadro number or Avogadro constant (N_A); it is equal to 6.022×10^{23} particles
- Example − 1 mole of oxygen atoms = 6.022×10^{23} atoms of oxygen

  1 mole of carbon dioxide molecules = 6.022×10^{23} molecules of carbon dioxide

  1 mole of sodium chloride = 6.022×10^{23} formula units of sodium chloride

- **Relative atomic mass:** Relative atomic mass of an element is the ratio of the average mass of one atom of an element to one-twelfth of the mass of an atom of carbon-12.

$$\text{Relative atomic mass} = \frac{\text{Average mass of Atom}}{\frac{1}{12} \times \text{Mass of carbon}\left(C^{12}\right)}$$

Molar mass of a substance can be defined as:

- Mass of one mole of a substance in grams

- Numerically equal to atomic/molecular/formula mass in u.

- Example − Molar mass of CO_2 = 44.011 g mol−1
- **Relative molecular mass:** It is defined as the ratio of the mass of a molecule to the atomic mass unit of the molecule. It is a unitless quantity.

$$\text{Relative molecular mass} = \frac{\text{Average mass of Molecule / Compound}}{\frac{1}{12} \times \text{Mass of carbon}\left(C^{12}\right)}$$

Molar mass of NaCl = 58.5 g mol^{-1}

Examples

1. What number of moles contains 3.011×10^{23} molecules of glucose?

Solution:

1 mole of glucose is equivalent to 6.022×10^{23} molecules of glucose.

Hence, 3.011×10^{23} molecules of glucose will be present in

$= \frac{1 \times 3.011 \times 10^{23}}{6.022 \times 10^{23}}$ mol = 0.5 mol (of glucose)

Thus, 0.5 mole of glucose contains 3.011×10^{23} molecules of glucose.

2. What is the mass of a fluorine molecule?

Solution:

1 mole of fluorine molecule contains 6.022×10^{23} molecules and weighs 38 g.

Therefore, mass of a fluorine molecule = $\frac{38}{6.022 \times 10^{23}}$ g

= 6.31×10^{-23} g

Atomicity

- It is defined as the total number of atoms of constituent elements which combine to form a molecule.

- One molecule of hydrogen combines with one molecule of chlorine to form two molecules of hydrogen chloride.
- One molecule of hydrogen or chlorine contains two atoms of each.

Percentage Composition

Mass percent of an element = $\frac{\text{Mass of that element in the compound} \times 100\%}{\text{Molar mass of the compound}}$

Example

What is the mass percent of oxygen in potassium nitrate? (Atomic mass of K = 39.10 u, atomic mass of N = 14.007 u, atomic mass of O = 16.00 u)

Solution:

Atomic mass of K = 39.10 u (Given)

Atomic mass of N = 14.007 u (Given)

Atomic mass of O = 16.00 u (Given)

Therefore, molar mass of potassium nitrate (KNO_3)

= 39.10 + 14.007 + 3(16.00)

= 101.107 g

Therefore, mass percent of oxygen in KNO_3

$= \frac{\text{Mass of oxygen in } KNO_3 \times 100\%}{\text{Molar mass of } KNO_3}$

$= \frac{3 \times 16.00}{101.107} \times 100\%$

= 47.47% (approx)

- Empirical formula and molecular formula:

Empirical formula	Molecular formula
Represents the simplest whole number ratio of various atoms present in a compound	Represents the exact number of different types of atoms present in a molecule of a compound

- Empirical formula is determined if mass % of various elements are known.
- Molecular formula is determined from empirical formula if molar mass is known.

Example

A compound contains 92.26% carbon and 7.74% hydrogen. If the molar mass of the compound is 26.038 g mol^{-1}, then what are its empirical and molecular formulae?

Solution:

Mass percent of carbon (C) = 92.26% (Given)

Mass percent of hydrogen (H) = 7.74% (Given)

Therefore, 100 g of the compound contains 92.26 g and 7.74 g of of hydrogen

Number of moles of carbon present in the compound = $\frac{92.26}{12.011}$

= 7.68 mol

Number of moles of hydrogen present in the compound $= \frac{7.74}{1.008}$

= 7.68 mol

Thus, in the given compound, carbon and hydrogen are present in the ratio C : H = 7.68 : 7.68

= 1 : 1

Therefore, the empirical formula of the compound is CH.

Empirical formula mass of CH = (12.011 + 1.008)g

= 13.019 g

Molar mass of the compound = 26.038 g (Given)

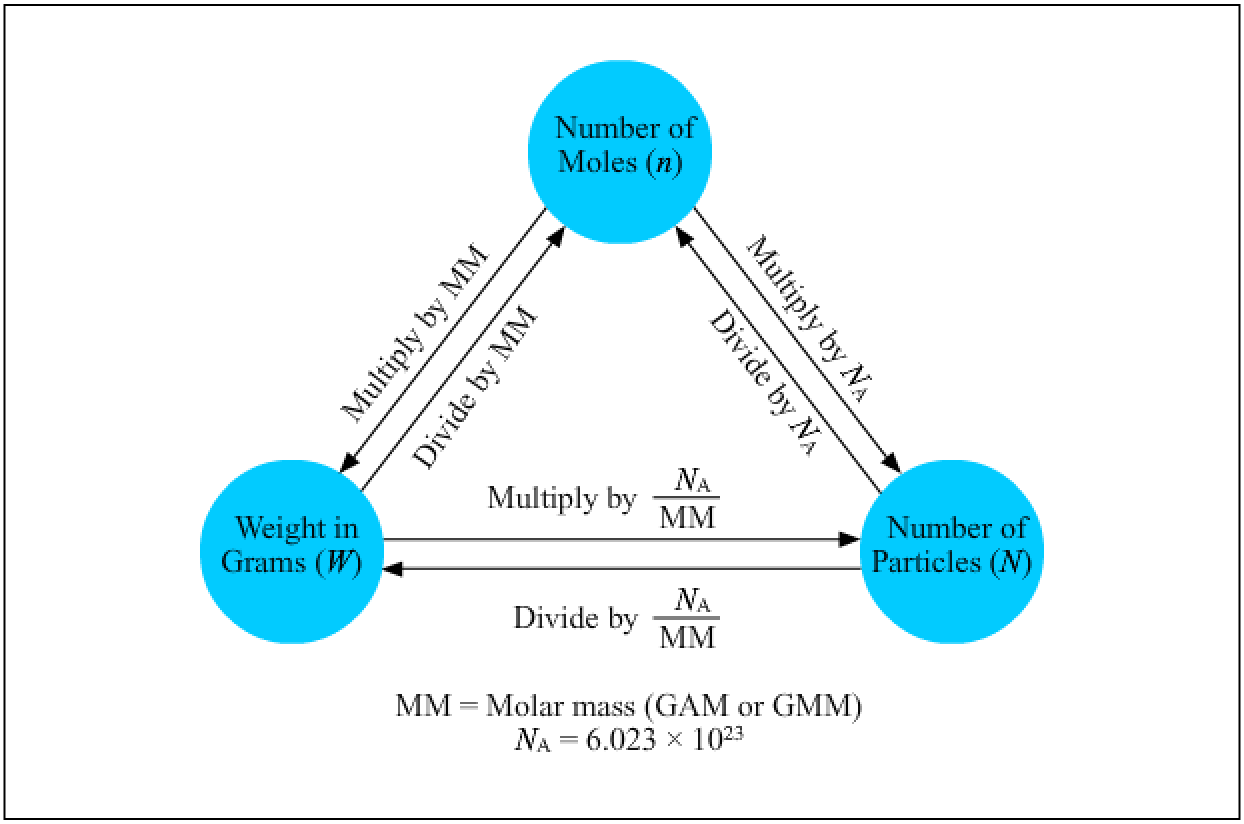
Therefore, $n = \frac{\text{Molar Mass}}{\text{Empirical formula mass}}$

$= \frac{26.038 \text{ g}}{13.019 \text{ g}}$

= 2

Hence, the molecular mass of the compound is $(CH)_n$, i.e., $(CH)_2$ or C_2H_2.

Interconversion Among Number of Moles, Mass and Number of Molecules



Stoichiometric Calculations in Balanced Chemical Equations

- An example of a balanced chemical equation is given below.

$$C_3H_{8(g)} + 5O_{2(g)} \longrightarrow 3CO_{2(g)} + 4H_2O_{(l)}$$

From the above balanced chemical equation, the following information is obtained:

- One mole of C_3H_8(g) reacts with five moles of O_2(g) to give three moles of CO_2(g) and four moles of H_2O(l).

- One molecule of C_3H_8(g) reacts with five molecules of O_2(g) to give three molecules of CO_2(g) and four molecules of H_2O(l).

- 44 g of C_3H_8(g) reacts with (5 × 32 = 160) g of O_2(g) to give (3 × 44 = 132) g of CO_2(g) and (4 × 18 = 72) g of H_2O(l).

- 22.4 L of C_3H_8(g) reacts with (5 × 22.4 = 112) L of O_2(g) to give (3 × 22.4 = 67.2) L of CO_2(g) and (4 × 22.4 = 89.6) L of H_2O(l).

Example

Nitric acid (HNO_3) is commercially manufactured by reacting nitrogen dioxide (NO_2) with water (H_2O). The balanced chemical equation is represented as follows:

$$3NO_{2(g)} + H_2O_{(l)} \longrightarrow 2HNO_{3(aq)} + NO_{(g)}$$

Calculate the mass of NO_2 required for producing 5 moles of HNO_3.

Solution:

According to the given balanced chemical equation, 3 moles of NO_2 will produce 2 moles of HNO_3.

Therefore, 2 moles of HNO_3 require 3 moles of NO_2.

Hence, 5 moles of HNO_3 require $= \frac{3}{2} \times 5$ moles of NO_2

= 7.5 moles of NO_2

Molar mass of NO_2 = (14 + 2 × 16) g mol^{-1}

= 46 g mol^{-1}

Thus, required mass of NO_2 = (7.5 × 46) g

= 345 g

- Limiting reagent or limiting reactant:
- Reactant which gets completely consumed when a reaction goes to completion
- So called because its concentration limits the amount of the product formed

Example

Lead nitrate reacts with sodium iodide to give lead iodide and sodium nitrate in the following manner:

$$Pb(NO_3)_2 + 2NaI \longrightarrow PbI_2 + 2NaNO_3$$

What amount of sodium nitrate is obtained when 30 g of lead nitrate reacts with 30 g of sodium iodide?

Solution:

Molar mass of $Pb(NO_3)_2 = 207 + \left[\{14 + (16 \times 3)\} \times 2\right]$

= 331 g mol^{-1}

Molar mass of NaI = (23 + 127) = 150 g mol^{-1}

According to the given equation, 1 mole of $Pb(NO_3)_2$ reacts with 2 moles of NaI, i.e.

331 g of $Pb(NO_3)_2$ reacts with 300 g of NaI to give PbI_2 and $NaNO_3$

Thus, 30 g of $Pb(NO_3)_2$ will react with (30 × 300) / 331 g of NaI = 27.19g of NaI

However, we have 30 g of NaI. So, NaI is present in excess and $Pb(NO_3)_2$ is the limiting reagent.

Now, number of moles in 30 g of $Pb(NO_3)_2$ 30 g $= \frac{30}{331} = 0.09$ mole

According to the equation, 1 mole of $Pb(NO_3)_2$ gives 2 moles of $NaNO_3$. So

0.09 moles of $Pb(NO_3)_2$ will give (2 × 0.09) moles of $NaNO_3$ = 0.18 moles of $NaNO_3$.

- **Reactions in solutions:**

  Ways for expressing the concentration of a solution −

- Mass per cent or weight per cent (w/w%)

Mass per cent $= \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100\%$

Example

4.4 g of oxalic acid is dissolved in 200 mL of a solution. What is the mass per cent of oxalic acid in the solution? (Density of the solution = 1.1 g mL^{-1})

Solution:

Density of the solution = 1.1 g mL^{-1}

So the mass of the solution = (200 mL) × (1.1 g mL^{-1})

= 220 g

Mass of oxalic acid = 4.4 g

Therefore, mass per cent of oxalic acid in the solution

$$= \frac{\text{Mass of oxalic acid}}{\text{Mass of the solution}} \times 100\%$$
$$= \frac{4.4\text{g}}{220\text{g}} \times 100\%$$
$$= 2\%$$

- Mole fraction:

  If a substance 'A' dissolves in a substance 'B', then mole fraction of A $= \frac{\text{Number of moles of A}}{\text{Number of moles of the solution}}$

  $$= \frac{n_A}{n_A + n_B}$$

  Mole fraction of B $= \frac{\text{Number of moles of B}}{\text{Number of moles of the solution}}$

$$= \frac{n_B}{n_A + n_B}$$

n_A − Number of moles of A

n_B − Number of moles of B

Example

A solution is prepared by dissolving 45 g of a substance **X** (molar mass = 25 g mol^{-1}) in 235 g of a substance **Y** (molar mass = 18 g mol^{-1}). Calculate the mole fractions of **X** and **Y**.

Solution:

Moles of X, $n_X = \frac{45}{25}$

= 1.8 mol

Moles of Y, $n_Y = \frac{235}{18}$

= 13.06 mol

Therefore, mole fraction of X, $n_X = \frac{1.8}{1.8+13.06}$

$$= \frac{1.8}{14.86}$$
$$= 0.121$$

And, mole fraction of Y, $n_Y = 1 - n_X$

= 1 − 0.121

= 0.879

- Molarity:

Number of moles of solute in 1 L of solution

Molarity (M) = $\frac{\text{Number of moles of solute}}{\text{Volume of solution in litres}}$

For a given solution, the molarity equation is as follows:

$M_1V_1 = M_2V_2$

M_1 = Molarity of a solution when its volume is V_1

M_2 = Molarity of the same solution when its volume is V_2

Examples

1. 10g of HCl is dissolved in enough water to form 500 mL of the solution. Calculate the molarity of the solution.

Solution:

Molar mass of HCl = 36.5 g mol^{-1}

So the moles of HCl = $\frac{10}{36.5}$ mol

= 0.274 mol

Volume of the solution = 500 mL = 0.5 L

Therefore, molarity = $\frac{\text{Number of moles of HCl}}{\text{Volume of solution in litres}}$

$= \frac{0.274 \text{ mol}}{0.5 \text{ L}}$

= 0.548 M

2. Commercially available concentrated HCl contains 38% HCl by mass. What volume of concentrated HCl is required to make 2.5 L of 0.2 M HCl? (Density of the solution = 1.19 g mL^{-1})

Solution:

38% HCl by mass means that 38g of HCl is present in 100 g of the solution.

Moles of HCl = $\frac{38}{36.5} = 1.04 \text{ mol}$

Volume of the solution $= \frac{\text{Mass}}{\text{Density}}$

$= \frac{100\text{g}}{1.19\text{g mL}^{-1}}$

= 84.03 mL

= 0.08403L

Therefore, molarity of the solution = $\frac{1.04}{0.08403 \text{ L}}$

= 12.38 M

According to molarity equation,

$M_1V_1 = M_2V_2$

Here,

M_1 = 12.38 M

M_2 = 0.2 M

V_2 = 2.5 L

Now, $M_1V_1 = M_2V_2$

$$\Rightarrow V_1 = \frac{M_2V_2}{M_1}$$

$$= \frac{0.2 \times 2.5}{12.38}$$

$$= 0.0404 \text{ L} \quad \text{(approx)}$$

Hence, required volume of HCl = 0.0404 L

- Molality:

Number of moles of solute present in 1 kg of solvent

Molality (m) = $\dfrac{\text{Number of moles of solute}}{\text{Mass of solvent in kg}}$

Example

What is the molality of a solution of glucose in water, which is labelled as 15% (w/w)?

Solution:

15% (w/w) solution means that 15 g of glucose is present in 100 g of the solution, i.e. (100 − 15) g = 85 g of water = 0.085 kg of water

Moles of glucose = $\dfrac{15\text{g}}{180\,\text{g mol}^{-1}}$

= 0.083 mol

Therefore, molality of the solution $= \dfrac{0.083\,\text{mol}}{0.085\text{ kg}}$

= 0.976 m