Laws of Chemical Combination

Unit 1: Some Basic Concepts in Chemistry

Law of Conservation of Mass (Lavoisier)

In a chemical reaction, mass is neither created nor destroyed. Only rearrangement of atoms takes place.

$$\text{Sum of mass of reactants} = \text{Sum of mass of products}$$

Example: When 4.2 g $NaHCO_3$ is added to a solution of CH_3COOH weighing 10.0 g, it is observed that 2.2 g CO_2 is released into atmosphere. The residue is found to weight 12.0 g.

$$\underset{4.2g}{NaHCO_3} + \underset{10.0g}{CH_3COOH} \longrightarrow \underset{12g}{CH_3COONa} + H_2O + \underset{2.2g}{CO_2}$$

$$\text{Mass of Reactants} = 4.2 + 10.0 = 14.2 \text{ g}$$

$$\text{Mass of Products} = 12 + 2.2 = 14.2 \text{ g}$$

Hence, the mass is conserved.

> In nuclear reactions, the mass is not conserved. Here, the mass gets converted to energy, as explained by Einstein. Therefore, the law is more accurately known as the Law of Conservation of Mass and Energy.

Law of Constant Proportions (Joseph Proust)

For a specific compound, the constituent elements of a compound are always in a constant proportion, irrespective of its source.

Example: Water (H_2O) always has hydrogen and oxygen present in 1 : 8 mass ratio, whether it is tap water, sea water or distilled water.

Law of Multiple Proportions (Dalton)

If two elements form more than one compound, then the different masses of one element, which combine with the fixed mass of the other element, bear a simple whole number ratio.

Example:

$$H_2O \rightarrow H - 2g \quad O - 16g$$

$$H_2O_2 \rightarrow H - 2g \quad O - 32g$$

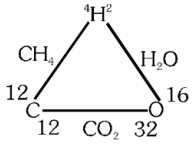
Here, masses of oxygen bears a simple whole number ratio - $16 : 32 = 1 : 2$

- These laws is not applicable in case of compounds formed by different isotopes of the same element.

Law of Reciprocal Proportions (Richter)

The ratio of the weights of two elements A and B which combine separately with a fixed weight of the third element C is either the same or some simple multiple of the ratio of the weights in which A and B combine directly with each other.

Example:



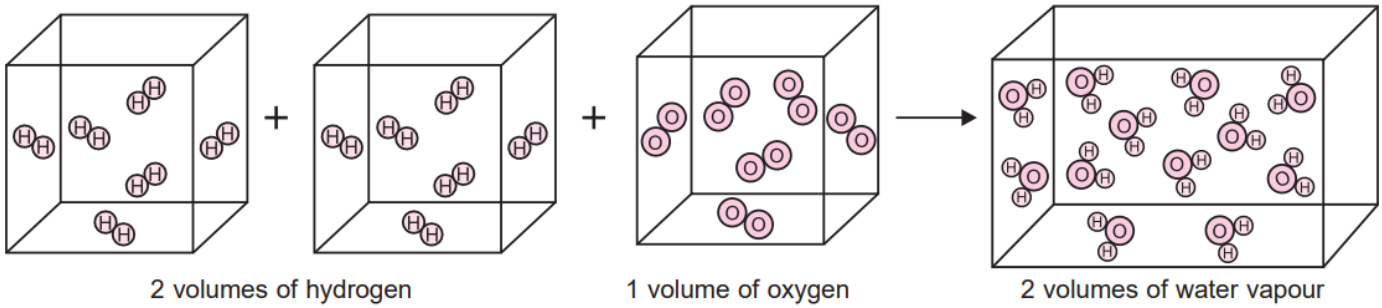
The elements C and O combine separately with the third element H to form CH_4 and H_2O and they combine directly with each other to form CO2. - In CH_4, 4 H combines with 12 C by mass. - In H_2O, 2 H combines with 16 O by mass, or 4 H combines with 32 O by mass. - Thus, a fixed weight of H (4 parts) reacts with C and O in the ratio $12 : 32 = 3 : 8$.

Now, in CO_2, 12 C combines with 32 O. This ratio is same as the one derived above. Hence, the law holds true.

Law of Combining Volumes (Gay Lussac)

When gases react together, they do so in a simple whole number ratio by volume to one another and the products, at S.T.P.

Example:



It has been found, that 2 volumes of hydrogen react with 1 volume of oxygen to produce 2 volumes of water vapour. Thus, the volumes of these gases bear a simple whole number ratio of 2 : 1 : 2.

It might be somewhat counterintuitive to understand that 2 volumes of H and 1 volume of O forms only 2 volumes and not 3 (2+1) volumes. This is because of the fact that gases don't have a fixed volume, and unlike mass, volume is not conserved. Therefore, volumes cannot be added and subtracted like mass.
The reason due to which this above reaction takes place in this volume ratio will be explained later in this unit.

Avogadro's Law (Avogadro)

Under similar conditions of temperature and pressure, equal volumes of all gases contain equal number of molecules.

$$V \propto N$$

Example: 1 L of Hydrogen gas, 1 L of Oxygen gas and 1 L of Chlorine gas all have the same number of molecules.

We can relate Avogadro's Law to Gay Lussac's Law to understand the relations between volume and number of molecules.

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Here, 2 molecules of hydrogen react with 1 molecule of oxygen and form 2 molecules of water.
This can also be written as 2n molecules of H react with n molecules of O to form 2n molecules of H_2O.
From Avogadro's Law, we can say that 2n molecules refer to 2 volumes of the gas, and n molecules refer to 1 volume of the gas. Thus, 2 volumes of hydrogen react with 1 volume of oxygen to produce 2 volumes of water vapour. This result is in agreement to the Gay Lussac's Law.

Questions

1. If 6.3 g of $NaHCO_3$ are added to 15.0 g CH_3COOH solution, the residue is found to weigh 18.0 g. What is the mass of CO_2 released in the reaction?

   (A) 4.5 g
   (B) 3.3 g
   (C) 2.6 g
   (D) 2.8 g

2. 3 g of a hydrocarbon on combustion in excess of oxygen produces 8.8 g of CO_2 and 5.4 g of H_2O. The data illustrates the law of: **[JEE 2010]**

   (A) conservation of mass
   (B) multiple proportions
   (C) constant proportions
   (D) none of these

3. One of the statements of Dalton's atomic theory is given below.
   "Compounds are formed when atoms of different elements combine in a fixed ratio."
   Which of the following laws is not related to this statement? (Multiple Correct Options)

(A) Law of conservation of mass
(B) Law of definite proportions
(C) Law of multiple proportions
(D) Avogadro's Law

4. Two aqueous solutions X and Y containing 0.585 g of sodium chloride and 1.70 g of silver nitrate respectively were mized. The weight of silver chloride formed was found to be 1.432 g and 0.853 g $NaNO_3$ was obtained. Show that these observations confirm the law of chemical conservation of mass.

5. Iron forms two oxides. In the first oxide, 56g Fe reacts with 16g O_2 and in the second oxide 112g Fe reacts with 48g O_2. This data satisfies the law of

(A) Conservation of Mass
(B) Reciprocal Proportions
(C) Multiple Proportion
(D) Combining Volumes

Answers[1] are given below.

[1]Answers: 1-(B) 2-(A) 3-(A,D) 5-(C)