LAWS OF CHEMICAL COMBINATION

INTRODUCTION

Chemistry deals with matter and the changes occurring in it. These chemical changes are governed by some empirical laws of chemical combinations. These laws are:

1. Law of conservation of mass
2. Law of constant composition or Law of definite proportion
3. Law of multiple proportions
4. Law of reciprocal proportions.

LAW OF CONSERVATION OF MASS

INTRODUCTION

This law was given by Antonie Lavoiser.

STATEMENT

It states that mass is neither be created nor be destroyed during a chemical reaction. In other words

In any chemical reaction the initial weight of reacting substances is equal to the weight of the products.

OR

Mass is neither be created nor be destroyed during a chemical reaction but it only change from one form to another form.

EXAMPLE

- An iron (Fe) increase in weight on rusting is because of it combination of oxygen from the air and increases in weight is exactly equal to the weight of oxygen combined.

$$4Fe + 3O_2 \longrightarrow 2Fe_2O_3$$

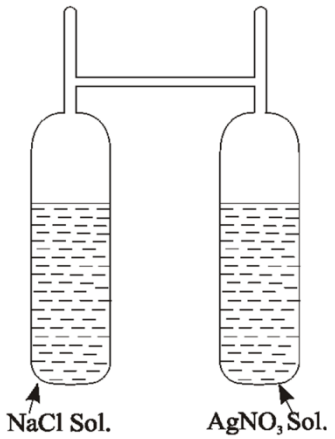
Lavoisier summarized his finding by formulating a law, which is known as law of conservation of mass.

LANDOLT EXPERIMENT FOR THE VERIFICATION OF LAW OF CONSERVATION OF MASS

German Chemist H. Landolt tested the A validity of law of conservation of mass.

PROCEDURE

- He took H- shaped tube as shown in figure
- He filled the two limbs A and B with silver nitrate ($AgNO_3$) in limb A and Hydrochloric acid (HCl) in limb B.
- The tube was sealed so that the material could not escaped outside.
- The tube was weighted initially in a vertical position so that the solutions should not intermix with each other.
- The reactant were mixed by inverting and shaking the tube
- The tube was weighted after mixing (on the formation of white precipitate of AgCl).



OBSERVATION

He observed that weight remains same.

$$AgNO_{3(aq)} + HCl_{(aq)} \longrightarrow AgCl_{(s)} + HNO_{3(aq)}$$

RESULT

Thus total mass of the substance before the reaction is equal to the total mass of the substances after the reaction.

EINSTEIN THEORY ABOUT THE RELATIONSHIP BETWEEN MASS AND ENERGY

EINSTEIN THEORY

The relationship between mass and energy was first proposed by Albert Einstein in 1906. The relationship between mass that is lost and the energy that is released in chemical reaction is given by the equation.

$$E = mC^2$$

Where

E is the energy in ergs

M is the mass in gram

C is the velocity of light in centimeter/second ($3x10^8$ cm/sec)

If follows that for every chemical change there will be a negligible mass change which cannot be detected by weighting technique i-e. There is no detectable gain or loss of mass in a chemical reaction.

LAW OF CONSTANT COMPOSITION

Louis Proust in 1799 proposed the Law of constant proportion.

STATEMENT:

It states that different samples of same compounds always contain the same elements combined together in same proportions by mass.

OR

When different elements combine to give a pure compound, the ratio between the masses of these elements will always remain the same.

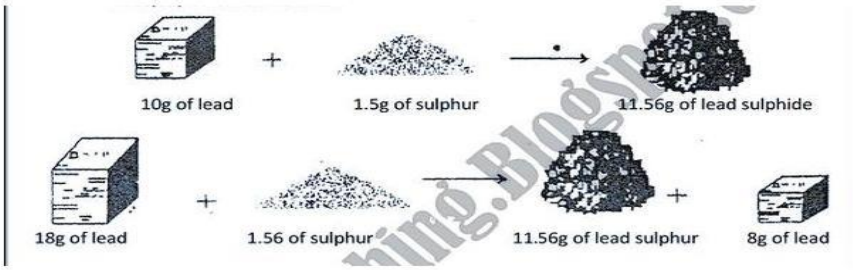
EXPLANATION

Proust proved experimentally that a compound obtained from different sources will always contain the same elements combined together in a fixed proportion. If different samples of pure water from different sources like river, ocean, well, tube well and rain are analyzed, we will always find the ratio between the masses of hydrogen and oxygen to be 1:8.

EXAMPLE

- Every sample of pure water, though prepared in the laboratory or obtained from rain, river or water pump contains one part hydrogen (H) and 8^{th} part oxygen (O) by mass.
  e.g H_2O
  2:16
- Berzelius heated 10g of lead (Pb) with various amount of sulphur (S). he got exactly 11.56g of lead sulphide and the excess of sulphur was left over, when he used 18g of lead

- (Pb) with 1.56g of sulphur(S), he got exactly 11.56g of lead sulphide (PbS) and 8g of lead (Pb) remained used.



LAW OF MULTIPLE PROPORTIONS

1n 1803 John Dalton proposed the law of multiple proportions.

STATEMENT

It states that if two elements combine to form more than one compound. The masses of one element that combine with a fixed mass of the other element are in the same ratio of small whole numbers or simple multiple ratios.

OR

In other words law of multiple proportions stated as

If two elements "X" and "Y", combine to form more than one chemical compound, then the various masses of one element X, which combine separately with a fixed mass of other element Y, will be in a simple multiple ratio.

EXAMPLE

- **Ratio Of Different Masses Of Oxygen And Carbon In CO And CO_2**
  Carbon (C) form two stable compounds with oxygen (O) namely carbon monoxide CO and Carbon dioxide CO_2. The ratio between different masses of oxygen in the two compounds with fixed mass of carbon (12g) is simple [16:32] i.e 1:2, which is simple whole number ratio, and obey the law of multiple proportions.
- **Ratio Of Different Masses Of Oxygen And Hydrogen In H_2O And H_2O_2**
  In water (H_2O) 2g of hydrogen combine with 16g of O_2 while in hydrogen peroxide (H_2O_2) 2g of hydrogen combine with 32g of O_2. According to the law of multiple proportion, these masses of oxygen reacted with fixed mass 2g of hydrogen, will have a simple ratio between each other i.e. 16:32 or 1:2.
- **Ratio Of Different Masses Of Oxygen And Nitrogen In Oxides Of Nitrogen**
  When the elements nitrogen (N) and oxygen (O) combine together to form a series of five oxides of nitrogen, in which these two elements are present in different proportions

Name Of Oxides	Mass of (N)	Mass of (O)	Fixed mass of (N)	Variable Mass of (O)	Ratio of (O)
Nitrous Oxide (N_2O)	28	16	14	8 (1X8)	1
Nitric Oxide (NO)	14	16	14	16 (2X8)	2

Nitrogen tri Oxide (N_2O_3)	28	48	14	24 (3X8)	3
Nitrogen tetra oxide (N_2O_4)	28	64	14	32 (4X8)	4
Nitrogen penta Oxide (N_2O_5)	28	80	14	40 (5X8)	5

By fixing the mass of nitrogen (N), the mass of oxygen (O) in different oxides varies i.e.

8:16:24:32:40

Or 1:2:3:4:5

These figures (in multiple ratio), are according to the law of multiple proportions.

LAW OF RECIPROCAL PROPORTION

STATEMENT

When two different elements A and B combine separately with the fixed mass of the third element E, the proportion in which these combine with E will be either in the same ratio or some simple multiple of it.

EXAMPLE

- **Ratio Of C and O In CO_2**

  When two elements C and O separately combine with H to form methane (CH_4) and water (H_2O) respectively.

  i. In CH_4 ratio between carbon and hydrogen is 12:4 = 3:1

  ii. In H_2O ratio between hydrogen and Oxygen is 16:2 = 1:8

  When C and O combine with each other to form CO_2, they do so in the same proportion i.e. 12:32 = 3:8 parts by mass.

  CH_4 12:4 3:1 — H 1g — H_2O 2:16 1:8

  3g — 8g

  CO_2 12:32 3:8

- **Ratio Of C and S In CS_2**

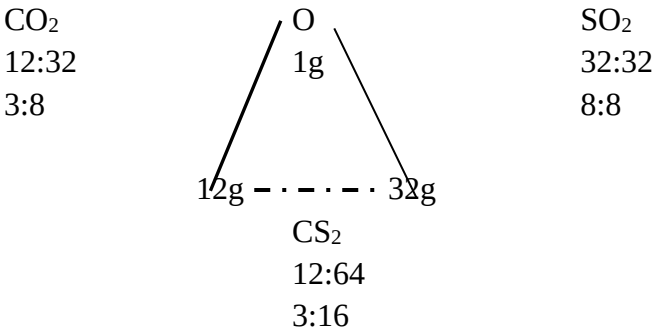
  When two elements C and S separately combine with O to form carbon dioxide (CO_2) and sulphurdioxide (SO_2) respectively.

  i. In CO_2 ratio between carbon and oxygen is 12:32 = 3:8

  ii. In SO_2 ratio between sulphur and Oxygen is 32:32 = 8:8

  According to the law of reciprocal proportion when C and S combine with each other to form CS_2, the proportion in which they combine with each other shall be

either in the same ratio 3:8 or some multiple of it i.e. 12:64 = 3:16 which is simple multiple of 3:8.



ATOMIC MASS

DEFINITION

The sum of number of protons and neutrons in an atom is called atomic mass.

ATOMIC MASS UNIT

One atomic mass unit is defined as a mass exactly equal to one twelfth the mass of C-12 atom.

EXAMPLE

- Naturally occurring carbon is composed of 98.889% C-12 and 1.111% C-13. Thus average atomic mass of C-atom becomes 12.011a.m.u.
- The atomic mass of sodium atom is 23a.m.u. It means that one atom of sodium is 23 times heavier than a hydrogen atom. Similarly the atomic mass of Oxygen is 16a.m.u. and that of sulphur is 32a.m.u .

ATOM

Definition

The smallest particle of an element which can or cannot exist in Free State and can enter into a chemical reaction is called atom

MOLECULE

Definition

The smallest particle of a compound which can exist independently and show all the properties of the substance is called molecule.

RADICAL

Definition

A radical is a group of atoms usually charged which can keepitself intact and behaves like a unit in a chemical reaction.

Example:

Hydroxide ion OH^-, ammonia ion NH_4^+ compound containing more than one radicals are $(NH_4)_2SO_4$ and $Ca(OH)_2$.

VALENCY

The combining power of an element with other elements is called valency.

VARIABLE VALENCY

Same elements show more than one valency which is termed as variable valency.

Example:

Oxygen shows valency of 2, but in H_3O^+ ion it shows its valency 3.

CHEMICAL FORMULA

Definition

Chemical formula is a formula which is used to represent an element or a compound in terms of symbols. A chemical formula also represents the number and type of atoms of elements present in the smallest unit of that substance.

Example:

The chemical formula of hydrogen sulphide is H_2S and it shows the number and type of different atoms present in its molecule. The chemical formula of hydrogen, nitrogen, oxygen and ozone are H_2, N_2, and O_3 respectively.

SYMBOL

Symbol represents an element or an atom of an element in short form by letters.

Example:

- Symbol for Hydrogen is H
- Symbol for calcium is Ca

FORMULA

A formula is a combination of symbols for atoms or ions, that are held together chemically in a compound. Formula also indicates the ratios in which the atoms are combined.

Example

- Formula for water is H_2O
- Formula for carbon dioxide is CO_2

EMPIRICAL FORMULA

Definition

The formula which shows the simplest ratio of atoms of different elements present in a compound is called empirical formula.

Example:

Benzene

Empirical formula of benzene (C_6H_6) is CH

Glucose:

Empirical Formula of glucose ($C_6H_{12}O_6$) is CH_2O

Hydrogen Peroxide:

Empirical formula of hydrogen peroxide is (H_2O_2) is HO

Water:

Empirical formula of water is (H_2O) is H_2O.

<u>Compounds Having Same Empirical Formula</u>

- Acetylene (C_2H_2) and Benzene (C_6H_6) have same empirical formula CH
- Acetic acid (CH_3COOH) and Glucose ($C_6H_{12}O_6$) have same empirical formula CH_2O.

MOLECULAR FORMULA

Molecular formula of an element or a compound represents the actual number and type of atoms present in molecule. It can either be same as empirical formula or some multiple of it.

Example:

Carbon dioxide:

Molecular formula of carbon dioxide is CO_2. It represents the true composition of compound.

Glucose:

Molecular formula of glucose is $C_6H_{12}O_6$ that is equal to $(CH_2O)_6$ or six times to empirical formula (CH_2).

Water:
Molecular Formula of water is H_2O

DETERMINATION OF MOLECULAR FORMULA:

Molecular formula of a compound may be calculated by multiplying a whole number (n) with the empirical formula of that compound.

Molecular Formula (M.F) = (E.F) n

Where

$$n = \frac{\text{M.F.weight}}{\text{E.F.weight}}$$

MOLECULAR FORMULA MASS

Definition
Molecular formula mass is the sum of the atomic masses of all the atoms present in molecular formula of a substance.
Example:
Molecular Formula Mass of CO_2:
The atomic mass of C is 12a.m.u and that of O is 16a.m.u

C = 12 X 1 = 12a.m.u
O = 16 X 2 = 32a.m.u

Molecular formula Mass of CO_2 = 12+32 = 44a.m.u
Molecular formula Mass of Ozone (O_3)
The atomic mass of O is 16a.m.u.

O = 16 X 3

Molecular formula Mass of O_3 = 48a.m.u.

Molecular formula Mass of H_2O
Molecular formula mass of water (H_2O) =1 X 2 + 16 = 18a.m.u.

FORMULA MASS

Formula mass of a substance is the sum of the atomic masses of all atoms in a formula unit of the substance.
Example:
Formula mass of sodium chloride NaCl

Na = 23 X 1 = 23a.m.u.
Cl = 35.5 X 1 = 35.5a.m.u.

Formula mass of sodium chloride = 58.5a.m.u

MOLAR MASS

Molar mass of a substance is its relative mass molecular mass expressed in grams. It has a fixed unit.
Example:
Molar Mass Of Carbon
1 mole of (C) is equal to its atomic mass expressed in grams.

Molar mass of C = 12
C = 1X12g = 12g

Molar Mass of NH_3

N=1 X 14g = 14g
H= 3X 1g = 3g

Molar Mass of NH_3 = 17g

Relative molar mass of NH_3 = 17a.m.u

MOLE

Definition

Mole can be defined as "*the molecular mass, atomic mass and formula mass of a substance expressed in grams."*

Thus

1 mole of C = 12 g
1 mole of Mg = 24g
1 mole of H_2O = 18g
1 mole of CO_2 = 44g
1 mole of $CaCO_3$ = 100g
1 mole of FeO_3 = 160g

By Formula

$$\text{No: of moles} = \frac{\text{Given mass of substances}}{\text{Atomic mass or Formula mass or Molecular mass}}$$

AVOGADRO'S NUMBER

Definition

The number of atoms or molecules present in one mole of a substance is constant and is equal to 6.023X 10^{23} particles. This number is called Avogadro's number and represented by N_A.

Example

Consider the following reaction

C	+	O	⟶	CO
12g		16g		28g
(1mole)		(1mole)		(1mole)

1 mole of C = 12g = 6.023X10^{23} atoms of carbon
1 mole of Mg = 24g = 6.023X10^{23} atoms of magnesium
1 mole of H_2O = 18g = 6.023X10^{23} molecules of water
1 mole of CO_2 = 44g = 6.023X10^{23} molecules of CO_2
1 mole of $CaCO_3$ = 100g = 6.023X10^{23} molecules of $CaCO_3$
1 mole of NaCl = 58.5g = 6.023X10^{23} molecules of NaCl
1 mole of Na^+ = 23g = 6.023X10^{23} ions of Na^+
1 mole of Cl^- = 44g = 6.023X10^{23} ions of Cl^-

CHEMICAL REACTION OR CHEMICAL CHANGES

Definition:

Chemical reaction is any change which alters the composition of substance.

TYPES OF CHEMICAL REACTION

There are five main types of reactions.

- Decomposition reaction
- Addition reaction
- Single displacement reaction
- Double displacement reaction
- Combustion reaction

➢ DECOMPOSITION REACTION

The reaction in which a chemical substance decomposes into two or simpler substances upon heating is called decomposition reaction.

General Equation:

$$AB \longrightarrow A+B$$

Example:

- ✓ Commercial preparation of carbon dioxide involves the decomposition of lime stone at high temperature

$$CaCO_3 \xrightarrow{\text{high temp}} CO_{2(g)} + CaO_{(s)}$$

- ✓ Laboratory preparation of oxygen gas involves the decomposition of potassium chlorate on heating.

$$2KClO_{3(g)} \xrightarrow{\text{high temp}} 2KCl_{(g)} + 3O_2$$

- ✓ Metal nitrate like $Zn(NO_3)_2$ decomposes on heating.

$$2Zn(NO_3)_{2(s)} \xrightarrow{\text{heat}} 2ZnO_{(s)} + 4NO_{2(g)} + O_{2(g)}$$

➢ ADDITION REACTION

When two or more substances react together to form a single substance, the reaction is called an addition reaction.

General Equation:

$$A+B \longrightarrow AB$$

Examples:

- ✓ Reaction between metal and nonmetal

$$2Mg_{(s)} + O_{2(g)} \longrightarrow 2MgO$$
$$2Na_{(s)} + Cl_{2(g)} \longrightarrow 2NaCl_{(s)}$$

- ✓ Reaction between two nonmetals

$$H_{2(s)} + Cl_{2(g)} \longrightarrow 2HCl_{(g)}$$

- ✓ Reaction between two compounds

$$CaO_{(s)} + CO_{2(g)} \longrightarrow CaCO_{3(g)}$$

➢ SINGLE DISPLACEMENT REACTION

The reaction in which an atom or group of atoms is replaced by another atom or group of atoms is called displacement reaction.

General Equation:

$$A+BC \longrightarrow AC+B$$

Example:

- ✓ When a mixture of iron fillings and copper oxide is turned red on heating. The pink colored copper metal is formed on cooling.

$$Fe_{(s)} + CuO_{(s)} \longrightarrow Cu_{(s)} + FeO_{(s)}$$

- ✓ Magnesium is more reactive than copper, so it displaces copper.

$$Mg + CuSO_4 \longrightarrow Cu_{(s)} + MgSO_4$$

- ✓ Some metals react with acids, bases or even water to displace hydrogen gas.

$$2Na(s) + 2H_2O_{(l)} \longrightarrow 2NaOH_{(aq)} + H_{2(g)}$$
$$Zn\,(s) + 2HCl \longrightarrow ZnCl_2 + H_{2(g)}$$

- ✓ Nonmetals can displace a nonmetal.

$$Cl_{2(g)} + 2KBr_{(aq)} \longrightarrow 2KCl_{(aq)} + Br_{2(aq)}$$

➢ DOUBLE DISPLACEMENT REACTION

The reaction in which both the reactants are decomposed and exchange their partners, to form two new compounds, is called double displacement reaction. There is an exchange of ionic radicals in double displacement reaction.

General Equation:

$$AB + CD \longrightarrow AD + CB$$

Example:

- ✓ When aqueous solution of NaCl and $AgNO_3$ are react, they exchange their partners to form two different compounds silver chloride AgCl and sodium nitrate ($NaNO_3$)

$$NaCl_{(aq)} + AgNO_{3\,(aq)} \longrightarrow NaNO_{3(aq)} + AgCl_{(s)}$$

- ✓ When calcium chloride $CaCl_2$ is react with sodium carbonate Na_2CO_3 exchange their partners to form two new compounds silver sodium chloride (NaCl) and calcium carbonate ($CaCO_3$)

$$CaCl_{2(aq)} + Na_2CO_{3(aq)} \longrightarrow CaCO_{3(s)} + 2NaCl_{(aq)}$$

➢ COMBUSTION REACTION

A reaction in which substances react with either free oxygen or oxygen of the air, with rapid release of heat and flame, is called combustion reaction.

- ✓ When methane (CH_4) gas burns in air it forms carbon dioxide (CO_2), water (H_2O) and heat.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \Delta H_{(heat)}$$

- ✓ When carbon (C) burns in air it produces carbon dioxide (CO_2), and heat

$$C + O_2 \longrightarrow CO_2 + \Delta H_{(heat)}$$

CHEMICAL EQUATION

Definition:

Chemical equation is a short hand method of expressing the chemical reaction, in terms of symbols and formulae of the substances involved in a chemical reaction.

OR

The representation of a chemical change in terms of symbols and formula is called chemical equation.

COMPONENTS OF CHEMICAL EQUATION

Reactant:

The starting substances which react with each other to form a new substance are called reactants.

Products:

Substances formed by chemical reaction are called products.

Arrow:

The reactant and products are separated from each other by using the single arrow (→) or double headed ( ), depending upon the kind of reaction.

Example:

When two molecules of hydrogen (H_2) combine with one molecule of oxygen (O_2) to give two molecule of water (H_2O), instead of writing the full name of substance, chemist represented this chemical reaction in the form of the following equation.

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

Co-Efficient:

The number in front of formula in a chemical equation is called co-efficient.

They show the number of molecules that react with each other. Where no co-efficient appears, only one number is considered.

Expression:

The expression (g), (l) and (s) placed sometimes as subscript after the formulae of the reactants and products, indicating the state, gaseous, liquid and solid of reactant and product.

$$C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$$

CONDITIONS OF REACTION

Sometimes reaction conditions are written over the arrow.

Example:

- When reactants are heated, a capital Greek letter delta (Δ) may be placed over the arrow

$$CaCO_{3\,(s)} + CaO_{(s)} \xrightarrow{\Delta} CO_2$$

- If catalyst is used, this catalyst is shown over the arrow.

$$2SO_{2\,(g)} + O_{2\,(g)} \xrightarrow{pt} 2SO_{3\,(g)}$$

- If the reactants are heated in the presence of catalyst, both the symbols are placed on the arrow.

$$2KClO_{3\,(s)} \xrightarrow[\text{Catalyst}]{\Delta} 2KCl_{3\,(s)} + 3O_{2\,(g)}$$

POINTS FOR WRITING A CHEMICAL EQUATION

- The composition of all reactants and products should be known.
- Knowing the formulae of all reactants and products, equation is balanced.
- A chemical equation must obey the law of conservation of mass.
- The formulae of elements and compounds must be written correctly.
- Number of atoms of each element must be same on both sides of the arrow in a chemical equation.
- A chemical equation must point out the direction of the reaction.
- A chemical equation should show normal physical state of reactant and products Solid, liquid and gas are symbolized by s, l and g respectively.

Example:

- When Zn reacts with sulphuric acid to form zinc sulphate and hydrogen gas.

$$Zn_{(s)} + H_2SO_{4\,(l)} \longrightarrow ZnSO_{4(l)} + H_{2\,(g)}$$

- Where the arrow is read as "gives", "produces", "yields" or "form".
- The (+) sign on the left side of equation appears for "reacts with".
- The (+) sign on the right side of equation is read as "and:
- The reaction is assumed to proceed from left to right, as the arrow indicates.

IMPORTANCE OF CHEMICAL EQUATION

The chemical equation gives following important information's about the chemical reaction.

- The nature of reactants and products.
- The relative number of each i.e. reactants and products.

BALANCED EQUATION

A chemical equation which contains equal number of atoms of each element on both sides of the equation is called balanced equation.

Balancing A Chemical Equation:

Balancing a chemical equation is the equating the atoms of reactants with those of products. The method of balancing the chemical equation is called inspection method or trial and error method.

STEPS

- ***Writing The Correct Formulae:***

Write the correct formulae of all the reactants on the left side and all the products on the right side.

- ***Balancing The Number Of Atoms:***

Balance the number of atoms on each side.

- ***Multiplying By Co-efficient:***

Balance the equation by inspection method for this multiply the formula by co-efficient so as to make the number of atoms same on both sides of the equation.

- ***Writing Diatomic Molecules As It Is:***

Write the diatomic molecules e.g. H_2, O_2, N_2 and Cl_2 as such in chemical equation.

- ***Rechecking Of Balnced Equation:***

Finally recheck the balanced equation to be sure that the number and kind of atoms are the same on both sides of equations.

MOLE RATIO BASED ON BALANCED CHEMICAL EQUATION:

We know that the reactants needed by chemical reaction cannot be determined by counting molecules directly and counting is always be done by weighing while co-efficient in a chemical equation represents the number of moles (molecules) and not masses of molecules.

STEPS CALCULATING THE AMOUNT OF REACTANTS OR PRODUCTS:

Following steps will help in calculating the amount of reactant and products.

I. Balancing The Equation:
Balance the chemical equation for the given reaction.

II. Finding Mole Ratio:
Use the co-efficient in the balanced equation to get the mole ratio.

III. Calculating Number Of Moles:
Use the mole ratio to calculate the number of moles of required reactants or products.

IV. Converting The Moles Into Mass:
Convert the mole of reactants or products into mass, if required by the problem.

DIFFERENTIATIONS

❖ ATOM	❖ MOLECULE
Atom is the smallest particle of an element.	A molecule contains two or more atoms held together by strong forces of attraction.
Atoms have incomplete outer most shell except in Noble gases.	Molecules have complete outer most shell.
Atom may or may not exist independently.	Molecules can exist independently.
❖ SYMBOL	**❖ FORMULA**
Symbol represents the element in short form.	A formula is a combination of symbols of atoms or ions, that are held together chemically in a compound.
Symbol represents an atom of an element.	Formula represents a molecule.
❖ EMPIRICAL FORMULA	**❖ MOLECULAR FORMULA**
The formula that gives only the relative number of each type of atoms present in a molecule is called empirical formula.	A formula is that which indicates the actual number and type of atoms in a molecule. It can either be same as empirical formula or some simple multiple of it.

Empirical formula is derived by the chemical analysis	Molecular formula is derived by the following equation M.F= n (E.F)
❖ **MOLECULAR MASS**	❖ **FORMULA MASS**
Molecular mass of substance is the sum of the atomic masses of all atoms present in the molecular formula of a substance or molecule.	Formula mass of a substance is the sum of the atomic masses of all atoms in a formula unit of the substance.
❖ **MOLE**	❖ **MASS**
It is defined as the molecular mass, atomic mass, formula mass of a substance expressed in grams or the quantity of the substance containing $6.022X10^{23}$ particles is called a mole	The molar mass of a substance is its relative molecular mass expressed in grams. It has a fixed unit.