Atoms and Molecules

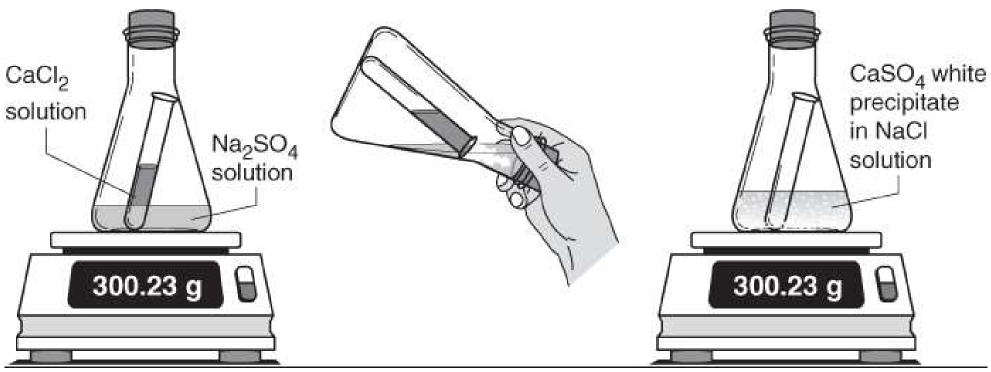
Laws of Chemical Combination

Law of Conservation of Mass

PRINCIPLE: The Law of Conservation of Mass states that mass can neither be created nor destroyed in a chemical reaction.

Total Mass of the Reactant = Total Mass of the Product

DIAGRAM:



TECHNIQUE:

- Take a solution of calcium chloride in a flask labelled A and a solution of sodium sulphate in a test tube labelled B.
- Tie a thread to the test tube and carefully lower it into the flask. Seal the flask with a cork to make it airtight.
- Weigh the flask on a balance. It weighs around 300.23 grams.
- Tilt and swirl the flask and allow the contents of the test tube to come in contact with the contents of the flask.

OBSERVATION:

- Calcium chloride reacts with sodium sulphate to form a white precipitate of calcium sulphate and a solution of sodium chloride.
- Weigh the flask again. There will be no change in the weight of the flask. It is found to weigh 300.23 grams.

CONCLUSION:

- Scientists noticed that if chemical reactions were carried out in a closed container, there was no change in the mass.
- The total mass of the reactants was equal to the total mass of the products.

Law of Constant Proportion

- According to the Law of Constant Proportion, in a chemical substance, elements are always present in a definite proportion by mass.
- For example, water obtained from any source will have the same two elements, namely hydrogen and oxygen present in it.

- 2 grams of hydrogen and 16 grams of oxygen form a molecule of water. The proportion of hydrogen and oxygen is 1 : 8 by mass. This proportion will always remain the same, irrespective of the source of water.
- Similarly, carbon dioxide obtained from any source will contain the same two elements, carbon and oxygen.
- 12 grams of carbon and 32 grams of oxygen form a molecule of carbon dioxide. Carbon dioxide obtained from any source will always have the proportion of masses of carbon and oxygen as 3 : 8.

Dalton's Atomic Theory

Dalton’s theory is the basic theory about the nature of matter. According to his theory, all matter, whether a solid, liquid or gas or an element, compound or mixture, is composed of small particles called atoms.

The Postulates of Dalton's Atomic Theory

- All matter is made up of very tiny particles called atoms.
- Atoms are indivisible particles, which can neither be created nor destroyed in a chemical reaction.
- The atoms of a given element are identical in mass and chemical properties.
- Atoms of different elements have different masses and chemical properties.
- Atoms combine in the ratio of small whole numbers to form compounds.
- The relative number and types of atoms are constant in a given compound.

The Atom: Its Size, Mass and Symbol

- An atom is very small in size and consists of subatomic particles protons, neutrons and electrons.
- About one million atoms stacked up one over the other would roughly equal the thickness of a sheet of a paper.

Atomic radius is measured in nanometers.

$$\frac{1}{10^9}\text{ m} = 1\text{ nm}$$

$$1\text{ m} = 10^9\text{ nm}$$

Modern Day Symbols of Atoms of Different Elements

- Dalton was the first scientist to use symbols for elements. He used circles to represent elements.
- Berzelius suggested that the symbols of the elements can be made from one to two letters of the name of the element.
- Now, we use names and symbols as stated by IUPAC i.e. the International Union of Pure and Applied Chemistry.
- Many symbols are the first letter or the first two letters of the name of the element.

Name	Symbol
Carbon	C
Nitrogen	N
Calcium	Ca
Aluminium	Al

- The symbols of some elements are formed from the first letter of the name and a letter appearing later in the name.

Name	Symbol
Ch**l**orine	Cl
Ma**g**nesium	Mg

- The symbols for some elements were derived from their Latin, German or Greek names.

English name of the element	Latin name of the element	Symbol
Sodium	**Na**trium	Na
Potassium	**K**alium	K
Iron	**Fe**rrum	Fe
Copper	**Cu**prum	Cu
Silver	**Ag**entum	Ag
Gold	**Au**rum	Au
Mercury	**H**ydrar**g**yrum	Hg
Lead	**Pl**um**b**um	Pb
Tin	**S**ta**n**num	Sn

Modern Symbols of Elements

The modern symbols of elements are derived from their English or Latin names, which are made up of either the first letter, the first and second letter or the first letter and a letter appearing later in the name of the element.

Name of element	Symbol	Latin Name	Name of element	Symbol	Latin Name
Hydrogen	H	—	Nickel	Ni	—
Oxygen	O	—	Manganese	Mn	—
Boron	B	—	**Ca**lcium	Ca	—
Carbon	C	—	**Cl**orine	Cl	—
Fluorine	F	—	**Br**omine	Br	—
Iodine	I	—	**Chr**omium	Cr	—
Nitrogen	N	—	**Co**balt	Co	—
Phosphorus	P	—	Lead	Pb	**P**lum**b**um
Sulphur	S	—	Mercury	Hg	**H**ydrar**g**yrum
Barium	Ba	—	Phosphorus	P	—
Iron	Fe	**Fe**rrum	Sodium	Na	**Na**trium
Gold	Au	**Au**rum	Potassium	K	**K**alium
Silver	Ag	**Arg**entum	Tin	Sn	**St**a**n**num
Tungsten	W	**W**olfram (German name)	**U**ranium	U	—
Lithium	Li	—	Zinc	Zn	—

Significance of Symbol of an Element

The symbol of an element signifies
(1) The name of the element.
(2) An atom of the element.

For example-
The symbol N stands for,
(1) The element nitrogen.
(2) An atom of the element nitrogen.

Atomic Mass

- Earlier, hydrogen was taken as a standard for measuring the atomic masses of elements.
- Later, carbon-12 isotope was chosen as a standard for measuring the atomic masses of elements.
- Similarly, the relative atomic mass of the atom of an element is defined as the average mass of the atom, as compared to $\frac{1}{12}$th the mass of one carbon-12 atom.
- The masses of all other atoms are determined relative to the mass of an atom of carbon–12 as the standard.
- Carbon–12 atom has been assigned an atomic mass of exactly 12 atomic mass units, abbreviated as amu, i.e. 12 amu. Recently, the unit of atomic mass, **amu** was replaced by **u**, meaning **unified mass**.
- Now, since carbon–12 atom has been assigned an atomic mass of 12 amu, therefore, the atomic mass unit should be equal to $\frac{1}{12}$th (one twelfth) of the mass of a carbon–12 atom.

1 atomic mass unit (amu) or 1 u = $\frac{1}{12}$th the mass of carbon–12 atom

Definition of the atomic mass unit (amu or u):
One atomic mass unit is a mass unit equal to exactly one twelfth $\frac{1}{12}$th the mass of one atom of carbon–12.

How do Atoms Exist?

- Atoms of a few elements such as noble gases like helium, neon, argon and krypton etc. exist in the free state, that is as single atoms.
- But most elements, being chemically reactive, do not exist in the free state. They either exist as molecules or ions.
- For example, an iodine crystal is a collection of many iodine molecules. These molecules are so tiny that they are not visible to the naked eye. But, what is visible is the entire iodine crystal.
- Similarly, in sodium chloride, the sodium ions and chloride ions being very tiny are not visible. But, we see the compound sodium chloride as a white powder which is made up of several sodium and chloride ions.

Molecule

- A molecule is a group of two or more atoms chemically bonded together. A molecule is the smallest particle of an element or a compound which has properties of the element or the compound and can exist in a free state.
- Molecules can be formed either by the combination of atoms of the same element or of different elements.
- Thus, there are two types of molecules — **molecules of elements** and **molecules of compounds.**

Molecules of Elements

- A molecule of an element contains two or more similar atoms combined together.
- They are classified as diatomic, triatomic, tetra-atomic and poly-atomic molecules, depending on the number of atoms present in them.

Atomicity

Atomicity is the total number of atoms present in one molecule.

Table showing atomicity of some elements

Name	Formula of molecule	Atomicity	
Helium	He	1	Monoatomic
Hydrogen	H_2	2	Diatomic
Nitrogen	N_2	2	Diatomic
Ozone	O_3	3	Triatomic
Phosphorous	P_4	4	Tetra-atomic
Sulphur	S_8	8	Poly-atomic

Molecules of Compounds

- A molecule of a compound contains two or more different types of atoms, chemically combined together.
- The atoms of different elements join together in definite proportions to form the molecules of compounds.

Compound	Molecular Formula	Combining Elements	Simplest ratio
Water	H_2O	Hydrogen, oxygen	1 : 8
Ammonia	NH_3	Nitrogen, hydrogen	14 : 3
Carbon dioxide	CO_2	Carbon, oxygen	3 : 8

Ions and Radicals

An atom or a group of atoms can exist independently with charge(s). These are formed by the loss or gain of electron(s). They are called radicals or more commonly ions.

Types of Ions or Radicals

Ions are either positively charged or negatively charged.
Positively charged ions are called cations. Example: Sodium ion (Na^+)

$$\underset{\text{Sodium atom}}{Na} \xrightarrow{-\,1\text{ electron}} \underset{\substack{\text{Sodium ion}\\ \text{(A cation)}}}{Na^+}$$

$$Na \xrightarrow{-\,1\text{ electron}} Na^+$$

sodium atom	sodium ion
Protons = 11(+charge)	Protons = 11(+charge)
Electrons = 11(-charge)	Electrons = 10(-charge)
Overall charge = 0	Overall charge = 1+

Formation of a Sodium ion

Negatively charged ions are called anions. Example: Chloride ion (Cl^-)

$$\underset{\text{chlorine atom}}{Cl} \xrightarrow{+1\text{ electron}} \underset{\substack{\text{chloride ion}\\ \text{(an anion)}}}{Cl^-}$$

$$Cl \xrightarrow{+1\text{ electron}} Cl-$$

chlorine atom	chloride ion (an anion)
protons = 17 (+ charge)	protons = 17 (+ charge)
electrons = 17 (-charge)	electrons = 18 (-charge)
Overall charge = 0	Overall charge = 1-

Formation of a Chloride ion

- Sometimes, groups of atoms also give or accept electrons forming positive or negative groups of ions. Such groups of atoms having a positive or negative charge are called **radicals**

What does the charge indicate?

The charge indicates the valency of an ion.

Magnesium ion is written as Mg^{2+}, where the 2+ charge indicates that its valency is +2.

Sulphate ion is written as SO_4^{2-}, where the 2- charge indicates that its valency is -2.

The valencies of ions and radicals are useful in writing the chemical formulae of the compounds.

Variable Valency

Sometimes, the same element may exhibit one valency in one compound and another valency in some other compound. This property is called variable valency.

Example

Element	Symbol	Valencies exhibited (variable valencies)	
Copper	Cu	1, 2	Cu^{+1}, Cu^{+2}
Silver	Ag	1, 2	Ag^{+1}, Ag^{+2}
Gold	Au	1, 3	Au^{+1}, Au^{+3}
Iron	Fe	2, 3	Fe^{+2}, Fe^{+3}

Writing Chemical Formulae

Step 1 : Write the symbol of a basic radical (element with a positive valency) on the left hand side and that of the acidic radical (element with a negative valency) on the right hand side.
Step 2 : Write the valency number/charge of each of the respective ions at the bottom of its symbol.
Step 3 : Interchange the valency number. Ignore the (+) and (-) sign.
Step 4 : Write the interchanged number.
Step 5 : Write the compound's formula.
Step 6: Cross the reduced valencies. If 1 appears, ignore it. And if a group of atoms receives a valency number more than 1, enclose it within brackets.

Formulae of Simple Compounds

Using the valency of ions, we can write the formulae of compounds.

1. **Formula of Aluminum chloride**

Symbols Al Cl

Valency 3+ 1-

Formula **$AlCl_3$**

2. **Formula of Carbon dioxide**

Symbols C O

Valency 4+ 2-

Formula C_2O_4 = **CO_2**

3. **Formula of Sodium phosphate**

Symbols	Na	PO_4
Valency	1+	3-
Formula	**Na_3PO_4**	

4. **Formula of Magnesium sulphate**

Symbols	Mg	SO_4
Valency	2+	2-
Formula	$Mg_2(SO_4)_2$ = **$MgSO_4$**	

5. **Formula of Ammonium bicarbonate**

Symbols	NH_4	HCO_3
Valency	1+	1-
Formula	**NH_4HCO_3**	

6. **Formula of Ammonium sulphate**

Symbols	NH_4	SO_4
Valency	1+	2-
Formula	**$(NH_4)_2SO_4$**	

As we know that, if a group of atoms receives a valency number more than 1, we enclose it within brackets. Therefore, the molecular formula of ammonium sulphate is **$(NH_4)_2SO_4$**.

Significance of Molecular Formula

The molecular formula of a compound has a quantitative significance. It represents the following:
(1) The name of the substance.
(2) Both, the molecule and the molecular mass of the compound.
(3) The respective numbers of different atoms present in one molecule of a compound.
(4) The ratios of the respective masses of the elements present in the compound.
Let us consider an example of carbon dioxide.
The formula CO_2 means that
(1) It represents carbon dioxide.

(2) The molecular formula of carbon dioxide is CO_2.
(3) Each molecule contains one carbon atom joined by chemical bonds with two oxygen atoms.
The molecular mass of carbon dioxide is 44, given that the atomic mass of carbon is 12 and that of oxygen is 16.

Molecular Mass and Mole Concept

Molecular Mass

- The molecular mass of a substance is the sum of all the atoms present in one molecule of the substance. It is expressed in atomic mass unit (u).

How to determine molecular mass?

Example: Let us determine the molecular mass of water.
The molecular mass of water (H_2O) is the sum of the masses of two hydrogen atoms and one oxygen atom.
Therefore, the molecular mass of water (H_2O) = 2 × (Atomic mass of hydrogen) + 1 × (Atomic mass of oxygen).
We know that the atomic mass of hydrogen is 1 unit and that of oxygen is 16 units.

$$= 2 \times (1) + 1 \times (16)$$
$$= 2 + 16$$
$$= 18 \text{ u}$$

Therefore, the molecular mass of water is **18 u**.

Formula Unit Mass

- The formula unit mass of a substance is the sum of the atomic masses of all the atoms in a formula unit of a compound.
- We do not use term molecular mass for **ionic compounds**. Thus, we use term formula unit for those substances whose constituent particles are **ions**.

How to determine formula unit mass?

The formula unit mass is calculated in the same manner as we calculate the molecular mass. The only difference is that we use the term formula unit for those substances whose constituent particles are **ions**.

Mole Concept

- We know that a dozen is a collection of 12 substances, a century is a collection of 100 substances and a gross is a collection of 144 substances.
- We use the terms dozen, century, gross etc. to express a certain quantity of a substance.
- Similarly, a mole is a word used to describe a collection of particles i.e. atoms, molecules or ions.

Definition of a Mole

1 mole of a substance is equal to its atomic mass or molecular mass expressed in grams.

- The atomic mass expressed in grams is the gram atomic mass.
- The molecular mass expressed in grams is the gram molecular mass.

For example

- The atomic mass of sodium is 23 grams.
  Therefore, 23 grams of sodium is equal to one mole of sodium atoms.
- Similarly, the molecular mass of oxygen (O_2) = 2 × Atomic mass of oxygen
  = 2 × 16 **= 32 g**

Avogadro experimentally found that one mole of any substance always contained 6.022×10^{23} particles. This number is called the Avogadro's number, denoted by N_0.

$$\boxed{\text{1 mole (of anything)} = 6.022 \times 10^{23} \text{ in number}}$$

For Example

How many molecules will be present in 2 grams of hydrogen gas (H_2)?

1 mole of hydrogen molecules = molecular mass of hydrogen
= 2 grams

We know that 1 mole of hydrogen molecules contains 6.022×10^{23} hydrogen molecules.

∴ 2 grams of hydrogen gas will also contain 6.022×10^{23} hydrogen molecules.

Important Formulae

Number of moles = n

Given mass = m

Molar mass = M

Given number of particles = N

Avogadro number of particles = N_0

(1) The number of moles(n) = $\dfrac{\text{Given mass}}{\text{Molar mass}} = \dfrac{m}{M}$

(2) (For the problems based on Avogadro number)

The number of moles(n) = $\dfrac{\text{Given number of particles}}{\text{Avogadro number}} = \dfrac{N}{N_0}$

(3) To find mass

Mass (m) = Molar mass(M) × Number of moles (n)

(4) To find the number of atoms when Avogadro number is given in the question

$$\text{The number of atoms} = \frac{\text{Given mass} \times \text{Avogadro number}}{\text{Molar mass}}$$

$$N = \frac{m \times N_0}{M}$$

(5) The number of particles (atoms) = Number of moles of particles × Avogadro number

$$N = n \times N_0$$