

# **ATOMS AND MOLECULES**

# History

- Democritus (460-370 BC): Atoms are indivisible particles .
- Plato and Aristotle challenged this view believing that matter was continuous.
- Newton (1642-1727 AD) proposed the idea of invisible particles in the air called atoms.
- Antoine Lavoisier (1743-1794 AD) conducted experiments demonstrating mass of products = mass of reactants
- John Dalton (1766-1844 AD) proposed a model of matter as Dalton's Atomic Theory.

# **Dalton's Atomic Theory**

Postulates are:

- i) Matter is made up of tiny particles called atoms.**
- ii) Atoms are indivisible and cannot be created or destroyed in a chemical reaction**
- iii) Atoms of a given element are similar in mass and properties.**
- iv) Atoms of different elements have different masses and properties.**
- v) Atoms combine in small whole number ratios to form compounds.**
- vi) In a given compound the relative number and kind of atoms are constant.**

# Father of Modern Chemistry

## *Antoine L. Lavoisier*

- **Lavoisier** was a French alchemist central to the 18th-century Chemical Revolution.
- He worked in both chemistry and biology.
- He laid the foundation of modern day chemical sciences by establishing two important laws of chemical combination.



# Laws of Chemical Combination

***“Laws of chemical combination are laws followed by different chemical reactions.”***

There are two basic laws of chemical combination.

- Law of Conservation of Mass.
- Law of Constant Proportions.

# Law of Conservation of Mass

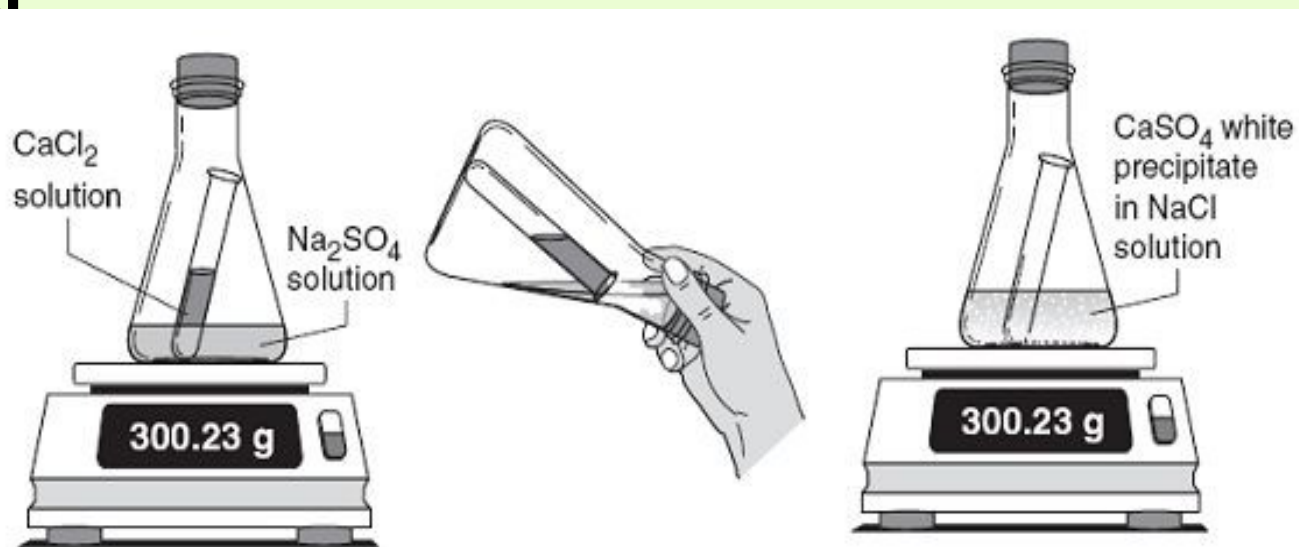
- The law of conservation of mass states that,

***“Mass can neither be created nor destroyed in a chemical reaction”.***

- The law is applicable to chemical reactions only and excludes nuclear and other such reactions.
- **This means that during a chemical reaction the sum of the masses of the reactants and products remain unchanged.**

# Activity:

- Take some sodium sulphate solution in a conical flask and some barium chloride solution in an ignition tube.
- Hang the ignition tube in the flask by a thread and put a cork on the flask. Find the mass of the flask on a balance.
- Then tilt the flask. A chemical reaction takes place and sodium chloride and barium sulphate are formed.
- Then find the mass of the flask and see that it is the same as before and produce a white precipitate.



# Law of Conservation of Mass

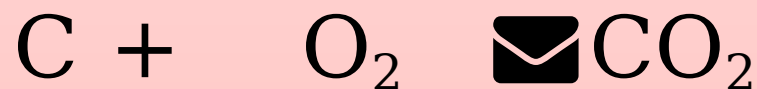
e.g. Reactant                       Product



4g            32g            36g



6g            28g            34g



12g            32g            44g

# Law of Constant Proportion

- Law of Constant Proportion states that  
**“A chemical compound always contains exactly the same proportion of elements by mass.”**
- This law is also known as Law of definite proportions.
- Joseph Louis Proust gave this law hence, this law is also known as Proust's Law.

# Law of Constant Proportion

For example:

- ❖ In a molecule of water ( $\text{H}_2\text{O}$ ) the ratio of mass of H & O will be  $(2 \times 1) : (1 \times 16)$  OR 1:8, given that masses of H & O 1u & 16u respectively.
- ❖ In a molecule of Ammonia ( $\text{NH}_3$ ) the ratio of mass of H & N will be  $(3 \times 1) : (1 \times 14)$  OR 3:14, given that masses of H & N 1u & 14u respectively.
- ❖ In a molecule of Carbon dioxide ( $\text{CO}_2$ ) the ratio of mass of C & O will be  $(1 \times 12) : (2 \times 16)$  OR 3:8, given that masses of C & O 12u & 16u respectively.

## Numerical Problem (Finding mass of other reactant)

Q. 3g of carbon react with 8 g of oxygen to produce  $\text{CO}_2$ . Calculate the amount of oxygen required to react with 4.5g of carbon.

Ans:  $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$

By law: 3g      8g

Given      4.5g      x

By law of fixed proportion       $\frac{3\text{g}}{4.5\text{g}} = \frac{8\text{g}}{x\text{g}}$

$$x = (8 \times 4.5)/3 = 12\text{g}$$

**Amount of Oxygen required = 12g**

## Numerical Problem (Finding mass of product)

Q. 3g of hydrogen react with 14g of nitrogen to produce ammonia ( $\text{NH}_3$ ). Calculate the amount of ammonia produce when 7.5g of hydrogen react with 21g of nitrogen.

Ans:  $\text{H}_2 + \text{N}_2 \rightarrow \text{NH}_3$

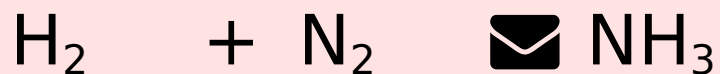
By law: 3g 14g 17g

Given 7.5g 21g xg

Calculate H/N ratio for given amount i.e.  $7.5/21 = 5/14$

Ratio indicate that  $\text{H}_2$  is present in excess thus will remain unreacted and  $\text{N}_2$  will be completely consumed in the reaction. Thus  $\text{N}_2$  will limit the amount of product and should be used for calculating it.

# Numerical Problem (Finding mass of product)



By law:                      14g              17g

Given                              21g              xg

By law of fixed proportion              14g = 17g

                                    21g              xg

$$x = (17 \times 21)/14 = 25.5\text{g}$$

***Amount of NH<sub>3</sub> produced = 25.5g***

# John Dalton

- **John Dalton** was an English chemist, meteorologist and physicist.
- He is best known for his pioneering work in the development of modern atomic theory.
- He also worked on colour blindness.
- He received Noble Prize for **Daltons atomic theory** in 1902.



# Main points of Dalton's atomic theory.

- Elements are made of extremely small particles called atoms.
- Atoms of a given element are identical in size, mass, and other properties;
- Atoms of different elements differ in size, mass, and other properties.
- Atoms cannot be subdivided, created, or destroyed.

***“This postulate is a result of law of conservation of mass.”***

- Atoms of different elements combine in simple whole-number ratio by mass to form chemical compounds.

***“This postulate is a result of law of fixed proportion.”***

- In chemical reactions, atoms are combined, separated, or rearranged

# What is an Atom?

- Atom can be defined as the smallest particle of matter that takes part in a chemical reaction.

How big are  
Atoms??????????

Atoms are very small, they are smaller than anything that we can imagine or compare with.

# Characteristics of Atom

- Atom is the smallest particle of matter.
- All elements are made of tiny particles called atom.
- Atoms are very small and cannot be seen through naked eyes.
- Atoms generally do not exist in free-state in nature.
- Atom is the chemical & material unit that takes part in a chemical reaction.
- The properties of a matter depend upon the characteristics of atoms.
- Dalton considered atom as indivisible.

# Dalton's Symbols

- By Dalton and earlier alchemist pictographic symbols were used to symbolize elements known since ancient times.
- Many symbols for compounds was also used at that times.

|                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                      |                                                                                       |                                                                                       |                                                                                       |                                                                                       |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |    |    |    |    |    |    |    |    |
| Oxygen                                                                              | Hydrogen                                                                            | Nitrogen<br>(Azote)                                                                 | Carbon                                                                              | Sulphur                                                                              | Phosphorus                                                                            | Gold                                                                                  | Platinum<br>(Platina)                                                                 | Silver                                                                                |
|    |    |    |    |    |    |    |    |    |
| Mercury                                                                             | Copper                                                                              | Iron                                                                                | Nickel                                                                              | Tin                                                                                  | Lead                                                                                  | Zinc                                                                                  | Bismuth                                                                               | Antimony                                                                              |
|   |   |   |   |   |   |   |   |   |
| Arsenic                                                                             | Calcium<br>(Lime)                                                                   | Manganese                                                                           | Uranium                                                                             | Tunsten                                                                              | Titanium                                                                              | Cerium                                                                                | Potassium<br>(Potash)                                                                 | Sodium<br>(Soda)                                                                      |
|  |  |  |  |  |  |  |  |  |
| Calcium                                                                             | Magnesium<br>(Magnesia)                                                             | Barium<br>(Barytes)                                                                 | Strontium                                                                           | Aluminium                                                                            | Silicon                                                                               | Yttrium                                                                               | Beryllium                                                                             | Zirconium                                                                             |

# Symbols for Different Elements

- Modern alphabetic notation was introduced in 1814 by **Jöns Jakob Berzelius**.
- In this notation the first letter of English (sometimes Greek or Latin) name of element followed by second or any following alphabet is used as symbol.
- The first letter is mandatory and is always written in **UPPERCASE**.
- Letters following it are added if required and are always written in **lowercase**.
- Symbols for few elements are given in next slide.

# Symbols for Different Elements

|             |    |              |    |              |    |
|-------------|----|--------------|----|--------------|----|
| Actinium    | Ac | Hafnium      | Hf | Praseodymium | Pr |
| * Aluminum  | Al | * Helium     | He | Promethium   | Pm |
| Americium   | Am | Holmium      | Ho | Protactinium | Pa |
| Antimony    | Sb | * Hydrogen   | H  | Radium       | Ra |
| * Argon     | Ar | Indium       | In | Radon        | Rn |
| Arsenic     | As | * Iodine     | I  | Rhenium      | Re |
| Astatine    | At | Iridium      | Ir | Rhodium      | Rh |
| * Barium    | Ba | * Iron       | Fe | * Rubidium   | Rb |
| Berkelium   | Bk | Krypton      | Kr | Ruthenium    | Ru |
| * Beryllium | Be | Lanthanum    | La | Samarium     | Sm |
| * Bismuth   | Bi | Lawrencium   | Lr | Scandium     | Sc |
| * Boron     | B  | * Lead       | Pb | Selenium     | Se |
| * Bromine   | Br | * Lithium    | Li | * Silicon    | Si |
| * Cadmium   | Cd | Lutetium     | Lu | * Silver     | Ag |
| * Calcium   | Ca | * Magnesium  | Mg | * Sodium     | Na |
| Californium | Cf | * Manganese  | Mn | * Strontium  | Sr |
| * Carbon    | C  | Mendelevium  | Md | * Sulfur     | S  |
| Cerium      | Ce | * Mercury    | Hg | Tantalum     | Ta |
| * Cesium    | Cs | * Molybdenum | Mo | Technetium   | Tc |
| * Chlorine  | Cl | Neodymium    | Nd | Tellurium    | Te |
| * Chromium  | Cr | * Neon       | Ne | Terbium      | Tb |
| * Cobalt    | Co | Neptunium    | Np | * Thallium   | Tl |
| * Copper    | Cu | * Nickel     | Ni | Thorium      | Th |
| Curium      | Cm | Niobium      | Nb | Thulium      | Tm |
| Dysprosium  | Dy | * Nitrogen   | N  | * Tin        | Sn |
| Einsteinium | Es | Nobellium    | No | Titanium     | Ti |
| Erbium      | Er | Osmium       | Os | Tungsten     | W  |
| Europium    | Eu | * Oxygen     | O  | Uranium      | U  |
| Fermium     | Fm | Palladium    | Pd | Vanadium     | V  |
| * Fluorine  | F  | * Phosphorus | P  | Xenon        | Xe |
| Francium    | Fr | * Platinum   | Pt | Ytterblum    | Yb |
| Gadolinium  | Gd | Plutonium    | Pu | Yttrium      | Y  |
| Gallium     | Ga | Polonium     | Po | * Zinc       | Zn |
| Germanium   | Ge | * Potassium  | K  | Zirconium    | Zr |
| Gold        | Au |              |    |              |    |

# Symbols for Different Elements

- Some elements like sodium, potassium, mercury and others get their symbols from latin name due to assure easiness.

| Common Name | Symbol    | Latin Name        |
|-------------|-----------|-------------------|
| antimony    | <i>Sb</i> | <i>stibnum</i>    |
| copper      | <i>Cu</i> | <i>cuprum</i>     |
| gold        | <i>Au</i> | <i>aurum</i>      |
| iron        | <i>Fe</i> | <i>ferrum</i>     |
| lead        | <i>Pb</i> | <i>plumbum</i>    |
| mercury     | <i>Hg</i> | <i>hydragyrum</i> |
| potassium   | <i>K</i>  | <i>kalium</i>     |
| silver      | <i>Ag</i> | <i>argentum</i>   |
| sodium      | <i>Na</i> | <i>natrium</i>    |
| tin         | <i>Sn</i> | <i>stannum</i>    |

- Tungsten get symbol 'W' from German name 'Wolfram' as a political compromise between European countries.

# Atomic Mass

- Mass of atom is called atomic mass.
- Mass of an atom is very small e.g. the actual mass of one atom of hydrogen is equal to  $1.673 \times 10^{-24}$  g OR 0.0000000000000000000000001673 gram.
- Thus for convenience **relative atomic mass** is used.
- In earlier times oxygen (relative atomic mass = 16) was used as standard for calculating atomic masses. This was due to following reasons:
  - It form oxides with maximum elements which were used to calculate the atomic mass of an element.
  - The relative mass of maximum other elements was obtained in whole number.

# Atomic Mass

- Later oxygen was replaced by carbon as standard for relative atomic mass.
- The mass of one carbon atom is taken as 12u where u is unified atomic mass unit.
- Thus 1u is equal to  $1/12$  of the mass of a carbon atom.

***“Atomic mass of an element from a specified source is the ratio of the average mass per atom of the element to  $1/12$  of the mass of an atom of  $^{12}\text{C}$ .”***

- For a molecule, molecular mass is used which is the sum of masses of all the atoms present in a molecule.
- For ionic compounds relative molecular mass is calculated on basis of chemical formula.

# Molecular Mass

***“Molecular mass can be defined as the sum of atomic mass of all atoms present in a molecule.”***

- The unit for atomic mass was also amu as the values are only summed up.
- Later the unit **amu** was replaced by unified **mass ‘u’** to eliminate terms atom or molecule hereby providing a unit that is same for representing and calculating mass of atoms and molecules.

# Calculating Molecular Mass

For example the molecular formula for sulphuric acid is  $\text{H}_2\text{SO}_4$ . The molecular mass for molecule will be:

$$\begin{aligned}\text{Molecular mass} &= (2 \times \text{mass of H}) + (1 \times \text{mass of sulphur}) + (4 \times \text{mass of O}) \\ &= (2 \times 1) + (1 \times 32) + (4 \times 16) \\ &= 2 + 32 + 64 \\ &= 98\text{u}\end{aligned}$$

# Molecule

- A molecule is a group of two or more atoms that are chemically bonded together.
- **Mono-atomic:** When a molecule is formed by single atom only, it is called mono-atomic molecule. Generally noble gases form mono-atomic molecules. For example: Helium (He), Neon (Ne),
- **Di-atomic:** When a molecule is formed by the combination of two atoms it is called diatomic molecule. For example: Hydrogen (H<sub>2</sub>), Oxygen (O<sub>2</sub>), Nitrogen (N<sub>2</sub>), Chlorine (Cl<sub>2</sub>), etc.
- **Tri-atomic:** When molecule is formed by the combination of three atoms it is called tri-atomic molecule. For example: molecule of ozone (O<sub>3</sub>)

# Molecule

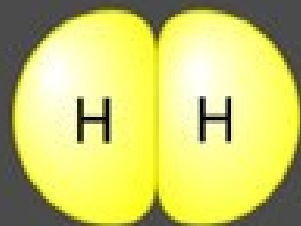
- **Tetra-atomic:-** When molecule is formed by the combination of four atoms it is called tetra-atomic molecule. For example: Phosphorous molecule ( $P_4$ )
- **Polyatomic:-** When molecule is formed by the combination of more than two atoms, it is called polyatomic molecule. For example: Sulphur molecule ( $S_8$ )

***“Atomicity is defined as the number of atoms present in the molecule of an element.”***

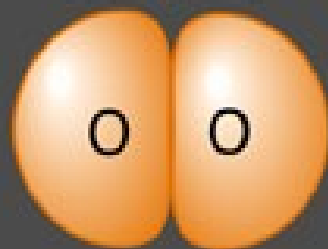
Thus we can say that

- ✓ *All metals are mono-atomic i.e. atomicity =1.*
- ✓ *Gases are generally di-atomic i.e. atomicity =2.*
- ✓ *Atomicity can vary with number of atoms in a molecule e.g. for  $O_2$  &  $O_3$  atomicity are 2 & 3 resp.*

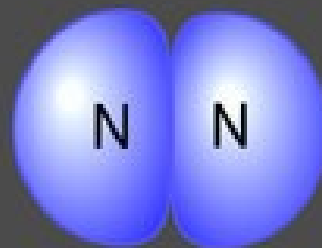
# Molecule



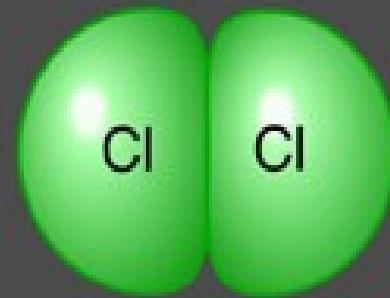
$\text{H}_2$   
hydrogen



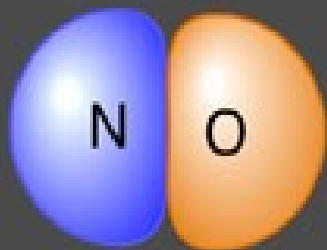
$\text{O}_2$   
oxygen



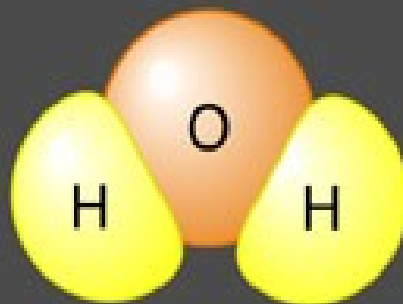
$\text{N}_2$   
nitrogen



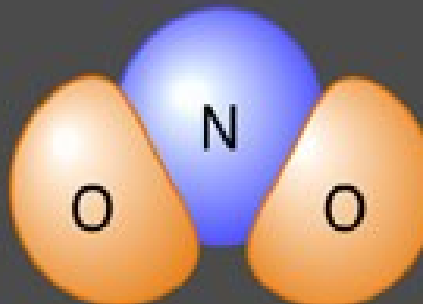
$\text{Cl}_2$   
chlorine



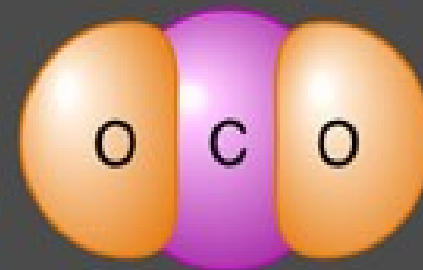
$\text{NO}$   
nitrogen oxide



$\text{H}_2\text{O}$   
water



$\text{NO}_2$   
nitrogen dioxide



$\text{CO}_2$   
carbon dioxide

# Chemical Formulae

- The chemical formula of a compound is a symbolic representation of its molecular composition.

e.g.:  $\text{H}_2\text{O}$  (Water),  $\text{CaO}$  (Calcium Oxide),  $\text{NH}_3$  (Ammonia) ,  $\text{K}_2\text{SO}_4$  (Potassium sulphate) etc.

# Writing Chemical Formulae

i) Write the symbols / formula of the elements or ions so that the symbol of the metal or positive ion is on the left and symbol / formula of the non metal or negative ion is on the right.

ii) Write the valencies of the elements or ions below the elements or ions.

iii) Cross over the valencies of the combining ions.

iv) Polyatomic ions should be enclosed in bracket before writing the formula.

**Examples :-**

i) Formula of hydrogen chloride  
sulphide

Symbol H Cl

Valency 1 1

Formula HCl

iii) Formula of Magnesium chloride  
tetrachloride

Symbol Mg Cl

Valency 2 1

ii) Formula of hydrogen

Symbol H S

Valency 1 2

Formula H<sub>2</sub>S

iv) Formula of Carbon

Symbol C Cl

Valency 4 1

# Chemical Formulae

v) Formula of Calcium oxide

Symbol ~~Ca~~ O

Valency 2 2

Formula  $\text{Ca}_2\text{O}_2 = \text{CaO}$

vii) Formula of Sodium nitrate hydroxide

Symbol/ ~~Na~~ ~~NO<sub>3</sub>~~

Valency 1 1

Formula ~~NaNO<sub>3</sub>~~

ix) Formula of Sodium carbonate sulphate

Symbol/ Na CO<sub>3</sub>

vi) Formula of Aluminium

~~Symbol~~ Al O

Valency 3 2

Formula Al<sub>2</sub>O<sub>3</sub>

viii) Formula of Calcium

~~Symbol/~~ Ca OH

Valency 2 1

Ca(OH)<sub>2</sub>

x) Formula of Ammonium

Symbol/ NH<sub>4</sub> SO<sub>4</sub>

# Ions

- Particles carrying positive or negative charges are called ions.

Types of ions:

1. **Cations:** Positively charged ions E.g.:  $\text{Al}^{3+}$ ,  $\text{Ca}^{2+}$
2. **Anions:** Negatively charged ions E.g.:  $\text{Cl}^-$ ,  $\text{Br}^-$

*All metals form cations by losing electrons.*

*All non-metals form anions by gaining electrons.*

*Compounds made up of ions are called ionic compounds. They do not form a molecule thus don't have a molecular formula instead they are represented by a relative formula e.g. for sodium chloride crystal it is  $\text{NaCl}$ .*

# Valency

*“Valency can be defined as the combining capacity of an atom.”*

The valency for an atom can vary from one molecule to another depending upon the pattern in which atoms are bonded within molecule.

In simpler terms it can also be defined as the number of chemical bonds formed by an atom within a molecule.

In ionic compounds charge is used instead of valency.

# Writing the chemical formulae

- ❖ Balancing is done to balance the valencies or charges on the ion as molecule/ crystal must be electrically neutral.
- ❖ When a compound consists of a metal and a non-metal, the name or symbol of the metal is written first. For example: calcium oxide (CaO), sodium chloride (NaCl), iron sulphide (FeS), copper oxide (CuO) etc., where oxygen, chlorine, sulphur are non-metals and are written on the right, whereas calcium, sodium, iron and copper are metals, and are written on the left.
- ❖ Polyatomic ion is enclosed in a bracket if more than one are present in molecule.
- ❖ The number of atom or ion is written after symbol of atom & outside bracket for a polyatomic ion.
- ❖ Number of atom/ ion are always written in subscript ( $X_{\text{subscript}}$ ).

# Writing the chemical formulae

❖ Chemical formula & name of some molecular or ionic compounds are:

Sodium Chloride      NaCl

Calcium Sulphate      CaSO<sub>4</sub>

Ammonium Phosphate (NH<sub>4</sub>)<sub>3</sub>PO<sub>4</sub>

Iron Chloride      FeCl<sub>2</sub>

Manganese carbonate      MnCO<sub>3</sub>

Magnesium acetate      Mg(CH<sub>3</sub>COO)<sub>2</sub>

Aluminum fluoride      AlF<sub>3</sub>

Potassium hydroxide      KOH

Hydrogen bromide      HBr

# Mole Concept

- One mole of any entity is equal to number of atoms present in 12 g of carbon-12 isotope.
- 1 mole (of anything) =  $6.022 \times 10^{23}$  in number
- This figure (1 mole) was named as Avogadro's number after the name of an Italian scientist Amedeo Avogadro.
- It is denoted by  $A_o$  or  $N_A$ .
- Mass of 1 mole of a particular substance is always fixed.
- One mole of an atom or molecule have mass numerically equal to atomic or molecular mass respectively.

# Mole Concept: Formulae

- In mole concept following values are related as:

$$\text{Mass of atom} = \text{Molar mass}/N_A$$

OR

$$N_A = 6.022 \times 10^{23} = \text{Molar mass} / \text{Mass of atom}$$

$$\text{Number of moles}(N) = \text{Given mass (m)} / \text{Molar mass (M)}$$

$$\begin{aligned} \text{Number of particles} &= \text{Number of moles (N)} \times N_A \\ &= \frac{\text{Given mass (m)} \times N_A}{\text{Molar mass (M)}} \end{aligned}$$

## Numerical Problem-4

### Calculating number of moles

Q. Calculate the number of moles present in

(a) 9g of  $\text{H}_2\text{O}$       (b) 3.3g of  $\text{CO}_2$       (c) 6.8g of ammonia

(d) 15g of  $\text{H}_2\text{SO}_4$     (e) 2.53g of  $\text{HNO}_3$

Ans: (a)  $n = w/M = 9\text{g}/18\text{g} = 0.5$  moles

(b)  $n = w/M = 3.3\text{g}/44\text{g} = 0.075$  moles

(c)  $n = w/M = 6.8\text{g}/34\text{g} = 0.2$  moles

# Numerical Problem-5

Q. Calculate the number of atoms & molecules present in 7 g of dinitrogen ( $\text{N}_2$ ).

Ans: molar mass of  $\text{N}_2 = 2 \times 14 = 28\text{g}$

Number of  $\text{N}_2$  molecules =  $\frac{\text{Given mass (m)} \times N_A}{\text{Molar mass (M)}}$

$$= \frac{7\text{g} \times 6.022 \times 10^{23}}{28\text{g}}$$

$$= 1.55 \times 10^{23}$$

As each molecule contain two atoms

$$\begin{aligned}\text{Number of N atoms} &= \text{Number of } \text{N}_2 \text{ molecules} \times 2 \\ &= 1.55 \times 10^{23} \times 2 = 3.01 \times 10^{23}\end{aligned}$$

# Numerical Problem-6

Q. Which one has more number of atoms 100g of Ca or 100g of Al.

Ans: molar mass of Ca = 40g                      molar mass of Al  
= 27g

Number of moles in 100g Ca =

$$\begin{aligned} n_1 &= \text{Given mass (m)} / \text{Molar mass (M)} \\ &= 100 / 40 = 2.5 \text{ moles} \end{aligned}$$

Number of moles in 100g Al

$$\begin{aligned} n_2 &= \text{Given mass (m)} / \text{Molar mass (M)} \\ &= 100 / 27 = 3.70 \text{ moles} \end{aligned}$$

$n_1 < n_2$  so 100 g Al has more number of particles.