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 <u>Dalton's Atomic Theory</u>.**

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

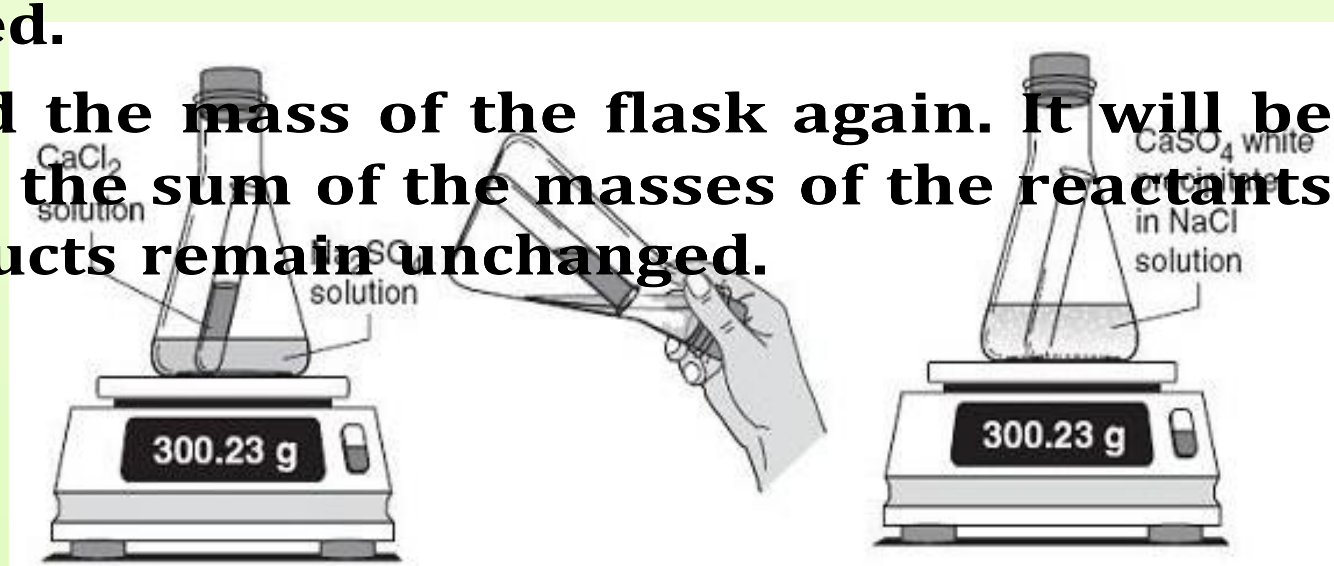
- The law of conservation of mass states that,

“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 pot 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 again. It will be seen that the sum of the masses of the reactants and products remain unchanged.



Law of Conservation of Mass

e.g. Reactant → Product

$2H_2 + O_2 \rightarrow H_2O$

4g 32g 36g

$3H_2 + N_2 \rightarrow 2NH_3$

6g 28g 34g

$C + O_2 \rightarrow CO_2$

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 (H_2O) the ration of mass of H & O will be (2 x 1): (1 x 16) OR 1:8, given that masses of H & O 1u & 16u respectively.
- In a molecule of Ammonia (NH_3) the ratio of mass of H & N will be (3 x 1): (1 x 14) OR 3:14, given that masses of H & N 1u & 14u respectively.
- In a molecule of Carbon dioxide (CO_2) the ratio of mass of C & O will be (1 x 12): (2 x 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 carbon toproduce CO_2. Calculate the amount of oxygen required to react with 4.5g of carbon.

Ans: $C + O_2 \rightarrow CO_2$

By law: 3g 8g

Given 4.5g x

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

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

Amount of Oxygen required = 12g

Numerical Problem (Finding mass of product)

Q. 3g of hydrogen react with 14g of nitrogen to produce ammonia (NH_3). Calculate the amount of ammonia produce when 7.5g of hydrogen react with 21g of nitrogen.

Ans: $H_2 + N_2 \rightarrow NH_3$

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 H_2 is present in excess thus will remain unreacted and N_2 will be completely consumed in the reaction. Thus N_2 will limit the amount of product and should be used for calculating it.

Numerical Problem
(Finding mass of product)

$H_2 + N_2 \rightarrow NH_3$

By law: 14g 17g

Given 21g xg

By law of fixed proportion $\frac{14g}{21g} = \frac{17g}{xg}$

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

Amount of NH_3 produced = 25.5g

John Dalton

- John Dalton was an English chemist, meteor olo-gist and physicist.
- He is best known for his pioneering work in the development of modern atomic theory.
- He also worked oncolour 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?????????????

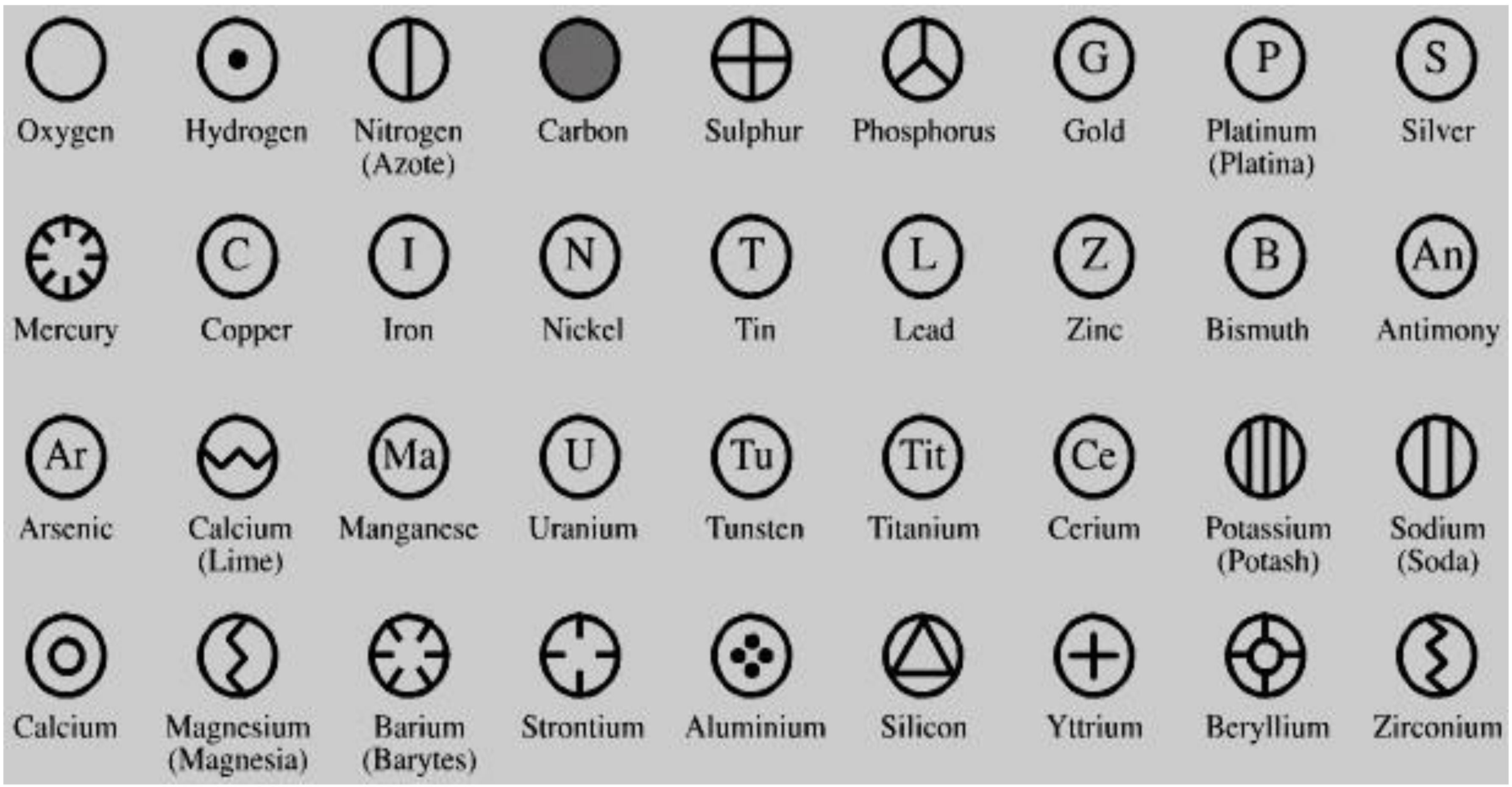
Atoms are very small, they are smaller than anything that we can imagine or compare with.

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.



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	Nobelium	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	Ytterbium	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 easy trade.

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

- 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 1.673×10^{-24} g OR 0.00000000000000000000001673 gram.**
- **Thus for convenience <u>relative atomic mass</u> 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}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 H_2SO_4. The molecular mass for molecule will be:

Molecular mass = (2 x mass of H) + (1 x mass of sulphur) + (4 x mass of O)

= (2 x 1) + (1 x 32) + (4 x 16)

= 2 + 32 + 64

= 98u

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_2), Oxygen (O_2), Nitrogen (N_2), Chlorine (Cl_2), 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_3)

Molecule

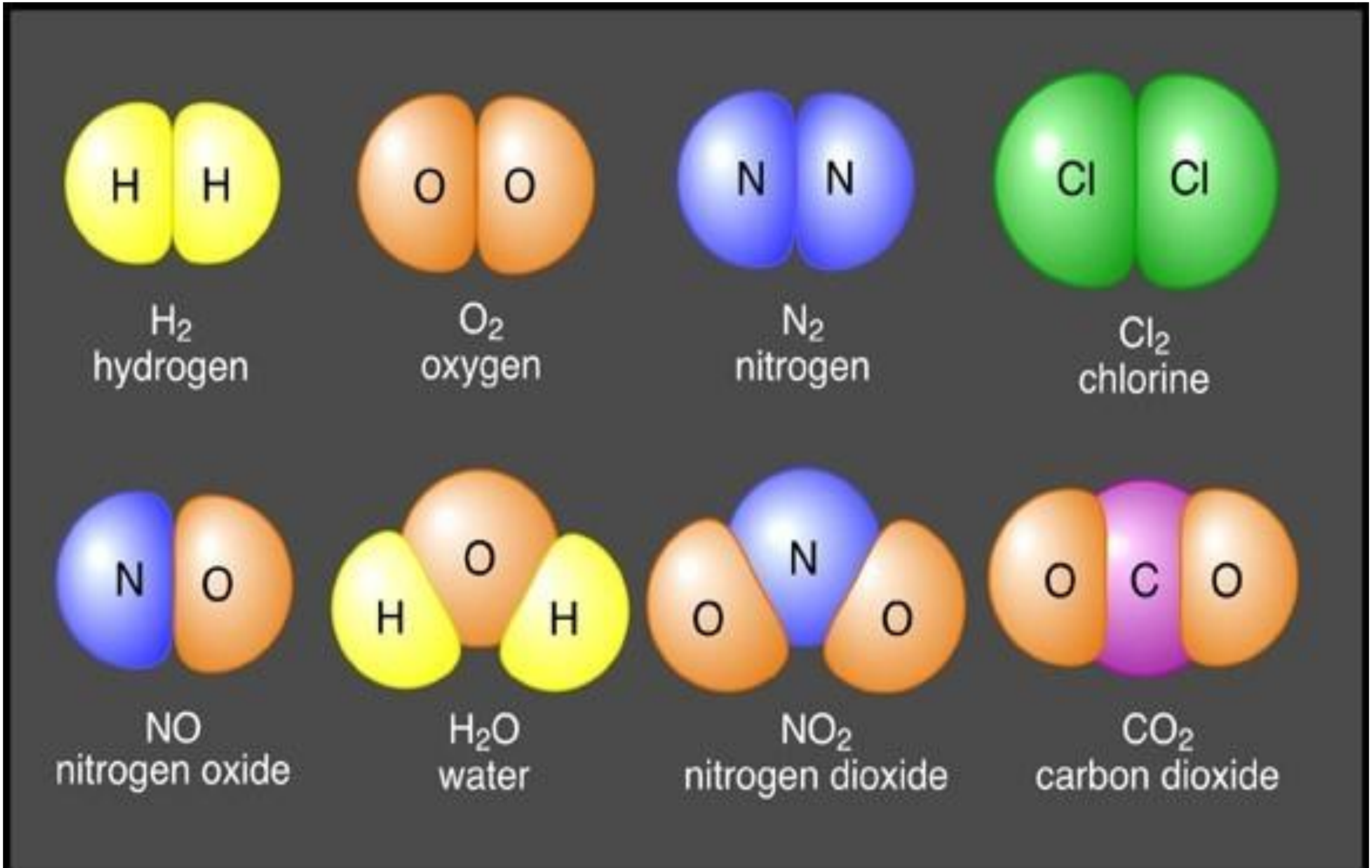
- **Tetra-atomic:-** When molecule is formed by the combination of four atoms it is called tetra-atomic molecule. For example: Phosphorous molecule (P_4)
- **Polyatomic:-** When molecule is formed by the combination of more than two atoms, it is called polyatomic molecule. For example: Sulphur molecule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


H H
H_2
hydrogen
O O
O_2
oxygen
N N
N_2
nitrogen
Cl Cl
Cl_2
chlorine
N O
NO
nitrogen oxide
O H H
H_2O
water
N O O
NO_2
nitrogen dioxide
O C O
CO_2
carbon dioxide

Chemical Formulae

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

  e.g.: H_20 (Water), CaO (Calcium Oxide), NH_3 (Ammonia) , K_2SO_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

Symbol H Cl

Valency 1 1

Formula HCl

ii) Formula of hydrogen sulphide

Symbol H S

Valency 1 2

Formula H_2S

iii) Formula of Magnesium chloride

iv) Formula of Carbon tetrachloride

Symbol	Mg	Cl
Valency	2	1

Symbol	C	Cl
Valency	4	1

Chemical Formulae

v) Formula of Calcium oxide

Symbol Ca O

Valency 2 2

Formula Ca_2O_2 = CaO

vi) Formula of Aluminium oxide

Symbol Al O

Valency 3 2

Formula Al_2O_3

vii) Formula of Sodium nitrate

Symbol/ Na NO_3

Valency 1 1

Formula $NaNO_3$

viii) Formula of Calcium hydroxide

Symbol/ Ca OH

Valency 2 1

$Ca(OH)_2$

ix) Formula of Sodium carbonate

x) Formula of Ammonium sulphate

Symbol/ Na CO_3 Symbol/ NH_4 SO_4

Ions

- Particles carrying positive or negative charges are called ions.

Types of ions:

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

All metals form cations by loosing 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 forrmula instead they are represented by a relative formula e.g. for *sodium chloride crystal it is $NaCl$.*

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 then 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	$CaSO_4$
Ammonium Phosphate	$(NH_4)_3PO_4$
Iron Chloride	$FeCl_2$
Manganese carbonate	$MnCO_3$
Magnesium acetate	$Mg(CH_3COO)_2$
Aluminum fluoride	AlF_3
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) = 6.022×10^{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.**
- ***<u>Mass of 1 mole of a particular substance is always fixed.</u>***
- **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:

Mass of atom = Molar mass/N_A

OR

N_A = 6.022 x 10^{23} = Molar mass/ Mass of atom

Number of moles(N) = Given mass (m)/ Molar mass (M)

Number of particles = Number of moles (N) x N_A

$$= \frac{\text{Given mass (m)} \times N_A}{\text{Molar mass (M)}}$$

Numerical Problem-4
Calculating number of moles

Q. Calculate the number of moles present in

(a) 9g of H_2O (b) 3.3g of CO_2 (c) 6.8g of ammonia

(d) 15g of H_2SO_4 (e) 2.53g of HNO_3

Ans: (a) n = w/M = 9g/18g = 0.5 moles

(b) n = w/M = 3.3g/44g = 0.075 moles

(c) n = w/M = 6.8g/34g = 0.2 moles

Numerical Problem-5

Q. Calculate the number of atoms & molecules present in 7 g of dinitrogen (N_2).

Ans: molar mass of N_2 = 2 x 14 = 28g

Number of N_2 molecules = $\frac{\text{Given mass (m) x } N_A}{\text{Molar mass (M)}}$

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

$= 1.55 \times 10^{23}$

As each molecule contain two atoms

Number of N atoms = Number of N_2 molecules x 2

$= 1.55 \times 10^{23} \times 2 = 3.01 \times 10^{23}$

Numerical Problem-6

Q. Which on 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 =

n_1 = Given mass (m)/ Molar mass (M)

= 100/ 40 = 2.5 moles

Number of moles in 100g Al

n_2 = Given mass (m)/ Molar mass (M)

= 100/ 27 = 3.70 moles

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