* Chapter 3: Stoichiometry

* Lesson 9 : Emperical, Molecular, & Structural formulas

* Compounds are made of elemental atoms held together by chemical bond; Compounds have two or more elements.

Q. what is the chemical bond?

A. Chemical bonds are the forces of attraction between the atoms. which Come from the attraction between protons & electrons.

Types of Chemical bonds

Covalent

It is formed by equal sharing of electrons between the two atoms

e.g. H_2O (water) is Covalent Compound

H_2O
(2 : 1)

* Covalent Compounds may have Single, double or triple bonds.

e.g.

H–H   O=O   N≡N

Ionic

It is formed by tranfer of one or more electrons from one atom to the other forming Cation and anion

e.g. Sodium Na^{11} Chlorine Cl^{17}

2,8,1 → 2,8,7

Na^+: 2,8 Cl^-: 2,8,8

So, Na^+Cl^-
ionic Compound.

* The properties of the formed Compound are completely different from its elements

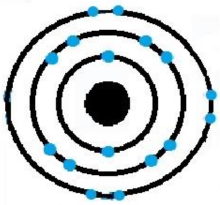
Property	H_2	O_2	H_2O Water molecule
* B.p.	$-253\ ^\circ C$	$-183\ ^\circ C$	$100\ ^\circ C$
* State	Gas	Gas	Liquid
* flammability	Explosive	Necessary for Combustion	used to extinguish flame

* Octet rule :

Atoms, of main-group elements, tend to Combine in such way that each atom has 8 electrons in its valence shell (as the nearest noble gas).

Thus;

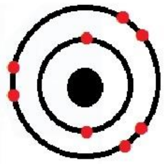
In Covalent Compounds, two non metals of same electron affinity Combine by equal sharing of electrons and fill their valence shell with 8 electrons to be stable.

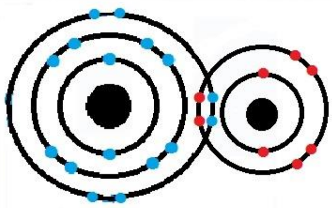


^{16}S : 2, 8, 6

By sharing of two electrons

^{8}O : 2, 6





S^{2-} : 2, 8, 8

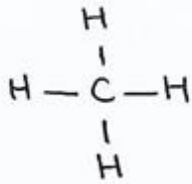
O^{2-} : 2, 8

(*) Representing Compounds:

Compounds are generally represented by chemical formula, where the chemical formulas show the elements that are in the compound and use the Letter symbol of the element.

e.g.

Methane CH_4



Molecular formula | Structural formula | Ball-stick model

* Molecular Formula:

It shows the actual number of atoms of each element present in the compound.

e.g.

H_2O : 2H 1O ; K_2SO_4 : 2K 1S 4O ; $Mg(NO_3)_2$: Mg 2N 6O

Some Complex ions: SO_4^{--} ; NH_4^{+} ; NO_3^{-} (polyatomic ions)
(Sulfate) (Ammonium) (Nitrate)

* Emperical Formula:

It shows only the simplest ratio of atoms of each element in the compound.

e.g. Molecular Formula: H_2O_2 ; C_6H_6 ; $\underbrace{C_2H_4 , C_3H_6 ; C_4H_8}_{CH_2}$

Emperical Formula: HO ; CH ; CH_2

* Structural Formula:

It uses lines to represent the Covalent bonds and shows how the atoms in the molecule are Connected.

Where;

Shape of Line	No. of Shared e^-	Name of Covalent bond
Single line —	1 pair = 2 e^-	Single H—H
Double line =	2 pairs = 4 e^-	double O=O
Triple line ≡	3 pairs = 6 e^-	Triple N≡N

Q. What is the difference between atomic element and molecular element?

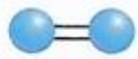
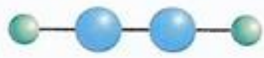
A.

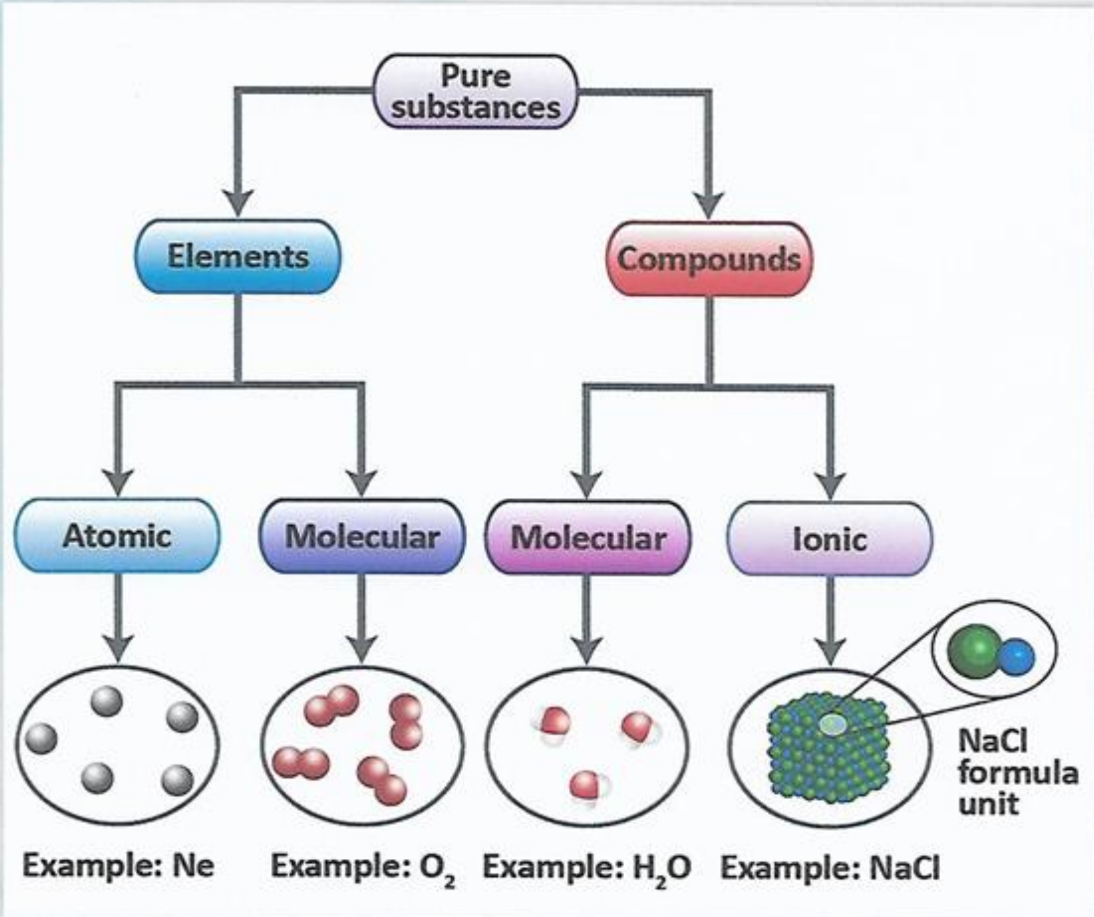
Atomic element Composed of single type of atoms. e.g. C ; He.

Molecular element is Composed of multi-atom molecules (with more than one atom). e.g.

diatomic molecules like O_2 and Cl_2.

polyatomic molecules like S_8 and P_4.

Chemical Formula	Structural Formulas	
H_2	H—H	
O_2	O=O	
H_2O	H—O—H	
H_2O_2	H—O—O—H	



« Ch 3: Stoichiometry »

Lesson 10 : Compound Formulas and Naming

* Introduction :

Sodium Chloride (NaCl) is made of sodium and Chlorine atoms. it has a common name : Table salt and scientific name : Sodium Chloride.

Most of the Compounds don't have Common names, so they are named according to scientific rules (Scientific names).

* Ionic compounds (Formulas & Names)

Ionic Compound = (+ve metal Cation) + (−ve nonmetal Anion)

the formula unit of ionic Compound must have an equal number of +ve and −ve charges, so the formula unit has net charge = Zero

$$\underbrace{Na^{+}\quad Cl^{-}}_{0} \qquad\qquad \underbrace{Br^{-}\quad Mg^{2+}\quad Br^{-}}_{0}$$

$$NaCl \qquad\qquad\qquad MgBr_2$$

⇒ How to write the formula of ionic Compound Aluminum oxide ?

e.g. 1

Aluminum Oxide
- Al (Metal) → Group 3A → Al^{3+}
- O (Nonmetal) → Group 6A → O^{2-}

Al^{3+} O^{2-}

Al_2O_3

e.g. 2

Calcium Chloride
- Ca → Group 2A → Ca^{2+}
- Cl → Group 7A → Cl^{-}

Ca^{2+} Cl^{-}

$CaCl_2$

* Formula-to-Name Rules for Ionic Compounds :

* For Cations:

- **A** Metal (with invariant charge) → Name of metal
- **B** Metal (with variable charge) → Name of metal + Charge
- polyatomic ion → Name of polyatomic ion

* For Anions :

- For Nonmetal → Stem of nonmetal name + ide
- polyatomic ion → Name of polyatomic ion

N.B. polyatomic ions are several atoms attached together by Covalent bonds as one ion.

* Metal ions with variable charge (can have more than one possible charge) are named as:

Name of metal + Roman numeral charge

e.g.

$Fe^{2+} \longrightarrow$ Iron (II) ; $Cu^{+} \longrightarrow$ Copper (I)

N.B. the charge can be determined from the charge of anion.

* Metal ions with invariant charge (can have only one possible charge) so, they are named without the oxidation number (charge)

e.g.

$Li^{+} \longrightarrow$ Lithium ; $Ca^{2+} \longrightarrow$ Calcium

Variable Change Examples			
Metal	**Ion**	**Name**	**Older name***
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	Chromium(III)	Chromic
Iron	Fe^{2+}	Iron(II)	Ferrous
	Fe^{3+}	Iron(III)	Ferric
Cobalt	Co^{2+}	Cobalt(II)	Cobaltous
	Co^{3+}	Cobalt(III)	Cobaltic
Copper	Cu^{+}	Copper(I)	Cuprous
	Cu^{2+}	Copper(II)	Cupric
Invariant Change Examples			
Metal	**Ion**	**Name**	**Group number**
Li	Li^{+}	Lithium	1A
Na	Na^{+}	Sodium	1A
K	K^{+}	Potassium	1A
Mg	Mg^{2+}	Magnesium	2A
Ca	Ca^{2+}	Calcium	2A
Al	Al^{3+}	Aluminum	3A
Zn	Zn^{2+}	Zinc	*
Ag**	Ag^{+}	Silver	*

* Naming of Binary Ionic Compounds:

① Binary Ionic Compound = Metal Cation + Nonmetal Anion

② Name the metal cation firstly, then the name of nonmetal anion.

③ For metal cation:

Cation

Invariant Charge → Name of metal

Variant → Name of metal + Charge

④ For nonmetal anion:

Name of nonmetal + end (ide)

(For metals with invariant Charge)

Name of cation (metal)	Base name of anion (nonmetal)+ *-ide*
Cesium $Cs = Cs^+$ Because it is group 1A	Fluorine $F = F^-$ Because it is group 7A
Cs^+ = Cesium	F^- = fluoride

Cesium fluoride

⇒ Naming binary ionic Compound with variable charge metal : (Transition element)

e.g. CuF_2

1) Metal Cation + Nonmetal Anion
   Cu F

2) Group No. of F is 7A ; so it will be F^-
   Thus; Cu must be Cu^{2+} (to balance 2 F ions)

3) Name Cation : Cu^{2+} = Copper (II)

4) Name Anion : F^- = Fluoride

5) Final Name : Copper (II) Fluoride

⇒ Naming the Compounds Containing polyatomic ions :

- Polyatomic ions are single ions that contain more than-one atom.
- Name the ionic Compound : name of Cation + name of anion

* Remmber well :

- Carbonate : CO_3^{2-}
- Bicarbonate : HCO_3^-
- Hydroxide : OH^-
- Nitrate : NO_3^-
- Nitrite : NO_2^-
- Sulfate : SO_4^{2-}
- Sulfite : SO_3^{2-}
- Ammonium : NH_4^+

* Naming Molecular Compounds :

* Molecular Compounds are composed of two or more nonmetals.

Rules :

1) Write the name of element with the smallest group number first.

2) If the two elements are in the same group, write the name of element with the greatest row number first.

3) Use the prefixes that indicate the number of atoms present.

Name : Prefix – Name of the 1^{st} element + Prefix – Name of the 2^{nd} element + ide

➢ If there is only one atom for the first element, don't use the prefix "mono".

Prefix	No.
mono	1
di	2
tri	3
tetra	4
penta	5
hexa	6
hepta	7
octa	8
nona	9
deca	10

examples;

NI_3 : nitrogen triiodide

PCl_5 : phosphorus pentachloride

P_4S_{10} : tetraphosphorus decasulfide

* Naming Acids :

- Acids are molecular compounds that produce H^+ when dissolved in water e.g. $HCl_{(aq.)}$; $H_2SO_{4\,(aq.)}$
- Acids have sour taste and can dissolve many metals. such as Zn, Fe, or Mg but not Au, Ag & Pt.

Types of Acids

Binary acids	Oxyacids
(H^+) + (nonmetal anion)	(H^+) + Poly atomic anion
e.g. HCl	e.g. HNO_3 , H_2SO_4

* Acids are produced by adding H^+ ion to anion;

$$\underset{}{H^+} + \underset{\text{Nitrate}}{NO_3^-} \longrightarrow \underset{\text{Nitric acid}}{HNO_3}$$

$$\underset{}{H^+} + \underset{\text{Chloride}}{Cl^-} \longrightarrow \underset{\text{Hydrochloric acid}}{HCl}$$

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Ch. 3. : Stoichiometry

Lesson 11 : Composition of Compounds & Chemical equations

* Introduction :

Chemical formula, e.g. H_2O , is useful to Know the no. of atoms and their ratio. Also, the chemical formulas are used to show the reactions in the form of "Chemical equations".

Q. What is the molecular mass or molecular weight ?

A.

It is the mass of an individual molecule (formula unit).

i.e. the mass of a molecule is the sum of the masses of the atoms that make it up (expressed in amu).

example; water has formula unit : H_2O

$$\therefore \text{Molecular mass} = \sum \text{No. of element atoms} \times \text{its atomic mass}$$

Given: H = 1 ; O = 16

$$\therefore \underset{(H_2O)}{\text{Molecular mass}} = \underbrace{(2 \times 1)}_{H} + \underbrace{(1 \times 16)}_{O} = 18 \text{ amu (atomic mass unit).}$$

So Molar mass of water is 18 g/mol .

* Mass Percent Composition :

It is the mass percent of one element to the total mass of all elements in the molecule.

$$\% \text{ Mass of element } (Z) = \frac{\text{Mass of element } (Z)}{\text{Molar mass of Compound}} \times 100$$

Example;

Calculate the mass % of hydrogen in water ?

A.

From Periodic Table

Water has formula unit (H_2O) $\because$ H = 1 ; O = 16

$$\% \text{ Mass (H)} = \frac{\text{Mass of H}}{\text{Molar mass of } H_2O} \times 100$$

$$= \frac{2 \times 1}{18} \times 100 = 11.1\%$$

Examples; Calculate the molar mass of each of the following:

1) K_2S

Molar mass = 2 X Atomic mass(K) + 1 X Atomic mass (S)

$= (2 \times 39.1) + (1 \times 32.1) = 110.3$ g/mol

2) $Ca_3(PO_4)_2$

Molar mass $= (3 \times 40.1) + 2\,[(1 \times 31) + (4 \times 16)]$

$= 120.3 + 2\,[31 + 64]$

$= 120.3 + 2\,(95) = 120.3 + 190$

$= 310.3$ g/mol.

Q. Calculate the mass % of oxygen in $HOCH_2CH_2OH$?

A.

firstly; $HOCH_2CH_2OH \Rightarrow C_2H_6O_2$

From Periodic Table
$C = 12$
$H = 1$
$O = 16$

$\therefore$ Molar mass $= (2 \times 12) + (6 \times 1) + (2 \times 16) = 62$ g/mol

$$\% \text{Mass}(O) = \frac{\text{Mass of O}}{\text{Molar Mass}} \times 100 = \frac{2 \times 16}{62} \times 100 = 51.6\%$$

* Emperical Formula :

It is the simplest whole-number ratio of the atoms in a compound.

- Emperical formula can be calculating by knowing the mass percent of each element in the compound.

(**) A compound contains 28% nitrogen and 72% oxygen. Calculate its emperical formula ?

A.

1. Assuming the given percent as part of 100 g of compound. (Mass).
   so, 28 g nitrogen and 72 g oxygen.

2. Convert the mass to moles for each element.

$$\text{moles}(N) = \frac{\text{Mass}}{\text{Atomic mass}} = \frac{28}{14} = 2 \text{ mol}$$

$$\text{moles}(O) = \frac{72}{16} = 4.5 \text{ mol}$$

Now; $N_2O_{4.5}$ is not accepted. (fraction ??)

3. Multiply all mole ratios by the suitable number to get whole numbers for all elements.

so, multiply with 2 : $2\,(N_2O_{4.5}) \Rightarrow N_4O_9$

∴ Emperical formula of the Compound is N_4O_9.

Q. A Compound contains 60% Carbon, 4.48 g hydrogen and 35.52% oxygen. Calculate its emperical formula?

H = 1
C = 12
O = 16

A.

Step 1: Assuming % as Mass (g)

	C	H	O
% Percent:	60	4.48	35.52
Mass :	60	4.48	35.52

Step 2: Convert Mass to moles

C	H	O
$\frac{60}{12}$	$\frac{4.48}{1}$	$\frac{35.52}{16}$
5 mol	4.48 mol	2.22 mol

To

Step 3: Divide by the smallest number (2.22)

C	H	O
$\frac{5}{2.22}$	$\frac{4.48}{2.22}$	$\frac{2.22}{2.22}$
2.25	2	1

Now; $C_{2.25}\ H_2\ O_1$

It is not accepted (fraction).

Step 4: Multiply with the suitable number to get all whole-number ratio.

so, Multiply by 4: $C_9\ H_8\ O_4$

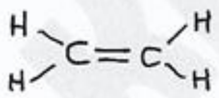
Decimal	Multiply by
0.20	5
.25	4
.33	3
.50	2

Now;

Q. What is the difference between emperical and molecular formulas?

"Emperical Formula"

It is the simplest whole-number ratio of the atoms of the elements in the compound.

e.g.  C_2H_4

$\therefore$ Emperical formula: CH_2

"Molecular Formula"

It is the actual number of atoms of elements in the compound. It is a multiple of the emperical formula.

Molecular formula = Emperical formula X No.

so, if we have an emperical formula CH_2

so, Molecular formula may be:

CH_2 , C_2H_4 , C_3H_6 , C_4H_8 or .....

* Chemical Reactions and Equations :

- Chemical reactions involve rearrangement of atoms to produce new molecules.
- Chemical equations are a shorthand way to describe the chemical reactions.

* Chemical equations give basic information about the reaction :

- Formulas of reactants and products.
- States of reactants and products (s), (l), (g) or (aq.) — Solid, Liquid, gas, aqueous
- Relative numbers of reactants and products in the reaction.
- Weights of reactants and products.
- Required Conditions : Δ (heat) ; $h\nu$ (light) ; ......etc.

* Balanced chemical equations :

Chemical equation must be balanced, in such way that an equal number of atoms of each element on both sides of the arrow.

e.g.

$$CH_{4(g)} + 2\,O_{2(g)} \longrightarrow CO_{2(g)} + 2\,H_2O_{(g)}$$

1C, 4H, 4O — 1C, 4H, 4O

Q. Balance the following chemical equation :

$$Al_{(s)} + O_{2(g)} \longrightarrow Al_2O_{3(s)} \quad ?$$

A.

$$4\,Al_{(s)} + 3\,O_{2(g)} \longrightarrow 2\,Al_2O_{3(s)}$$

4Al, 6O — 4Al, 6O