



# GENERAL CHEMISTRY

## CHE 101

Lecture : Mass Relationship in Chemical Reactions

# Mass Relationship in Chemical Reactions:

- Atomic Mass
- Avogadro's Atomic Mass
- Avogadro's Number
- Molar Mass
- Molecular Mass
- The Mass Spectrometry
- Percent composition of compounds
- Empirical formulas
- Chemical reaction and equation
- Limiting reagents and Reaction Yield

# Atomic Mass

- Mass of an atom, depends on the number of electrons, protons and neutrons.
- Exact weight measurement of this sub atomic particles is not possible.
- We do it by comparing with a standard value.
- By international agreement, atomic mass/atomic weight is the mass of the atom in atomic mass units(amu).

# Atomic Mass

One atomic mass unit(amu) is defined as a mass exactly equal to one-twelfth( $1/12$ ) the mass of one carbon-12 atom.

By definition,

1 atom  $^{12}\text{C}$  “weighs” 12 amu

On this scale.

$$^1\text{H} = 1.008 \text{ amu}$$

$$^{16}\text{O} = 16$$

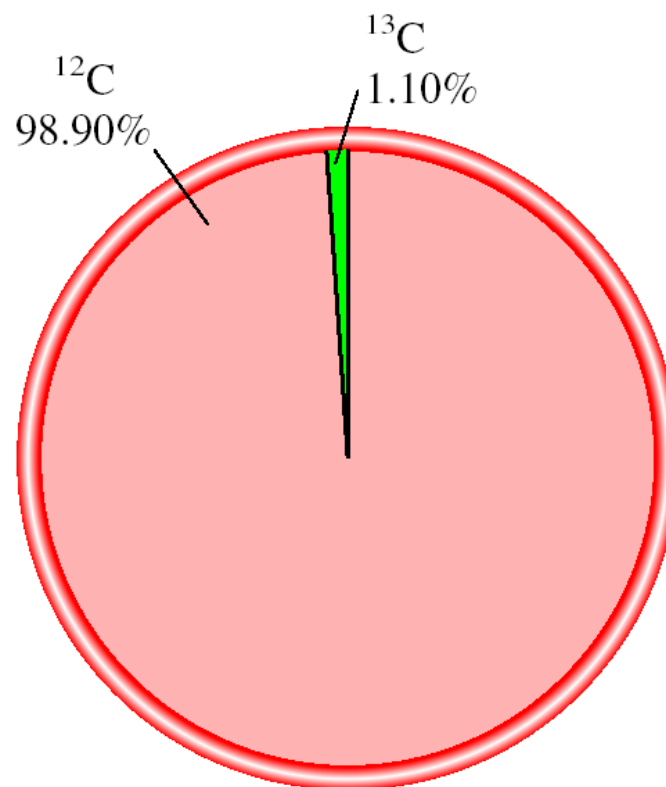
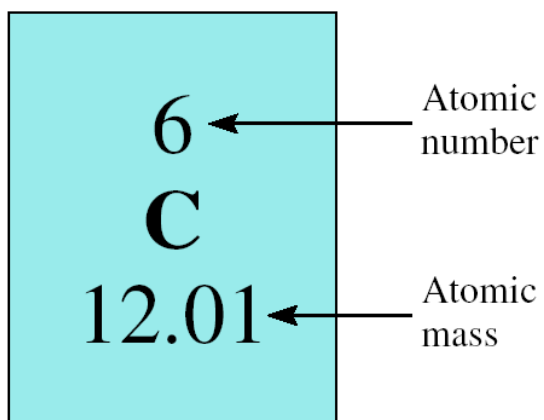
1 atom of  $^{12}\text{C} = 12$

Experimentally,  $^1\text{H}$  weighs 8.40% of  $^{12}\text{C}$ .

$$\begin{aligned}\text{Weight/Mass of H} &= (8.40 \times 12) / 100 \\ &= 1.008 \text{ amu}\end{aligned}$$

# Average Atomic Mass

The **average atomic mass** is the weighted average of all of the naturally occurring isotopes of the element.



# Average Atomic Mass

Example:

Abundances of naturally occurring  $^{12}\text{C}$  is = 98.90%

Abundances of naturally occurring  $^{13}\text{C}$  is = 1.10%

Atomic mass of  $^{12}\text{C}$  = 12.00

Atomic mass of  $^{13}\text{C}$  = 13.00335

Average atomic mass is =  
 $(0.9890 \times 12\text{amu}) + (0.0110 \times 13.00335\text{amu}) =$   
12.01 amu

# Avogadro's Number

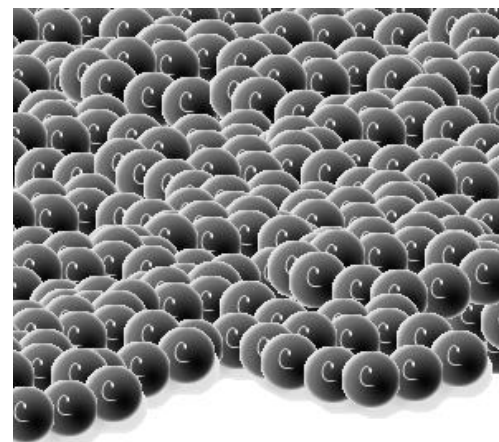
- **Mole** (mol) is the amount of a substance that contains as many elementary entities (atoms, molecules, other particles) as there are in 12 gram of  $^{12}\text{C}$ .
- **Mole:** is the unit to count the number of particles in SI system.
- The actual number of atoms that 12 gram  $^{12}\text{C}$  contains has experimentally been determined.
- The number is called the Avogadro's number, which is,

$$N_A = 6.0221367 \times 10^{23}$$

# Avogadro's Number



1 Dozen = 12 pieces



1 mol =  $6.022 \times 10^{23}$  atoms



# Molar Mass

- **Molar mass** is the mass of 1 mol of X in grams.
- Molar mass is exactly same as the atomic mass but in grams, not in amu.

$$1 \text{ mol } ^{12}\text{C atoms} = 6.022 \times 10^{23} \text{ atoms} = 12.00 \text{ g}$$

$$1 \text{ } ^{12}\text{C atom} = 12.00 \text{ amu}$$

$$1 \text{ mol } ^{12}\text{C atoms} = 12.00 \text{ g } ^{12}\text{C}$$

What is the unit of molar mass (M)?

**g/mol**

# Calculating the mass of atom in grams

Knowing the molar mass and Avogadro's number, we can calculate the mass of a single atom in grams.

For example, we know the molar mass of carbon-12 is 12.00 g and there are  $6.022 \times 10^{23}$  carbon-12 atoms in 1 mole of the substance; therefore,

The mass of one carbon-12 atom is given by,

$$\frac{12.00 \text{ g carbon-12 atoms}}{6.022 \times 10^{23} \text{ carbon-12 atoms}}$$

$$= 1.993 \times 10^{-23} \text{ g}$$

# Class work

□ How many moles of He atoms are in 6.46 g of He?

1 mol He = 4.003 g He

4.003 g	He	are	in	1 mol
1 g	He	are	in	1 / 4.003 mol
6.46 g	He	are	in	<b>( 1 / 4.003 ) X 6.46 mol</b>
				<b>= 1.61 mol</b>

- How many atoms are in 16.3g of S?

Molar Mass of S = 32.07 g/mol

**Solution** We need two conversions: first from grams to moles and then from moles to number of particles (atoms).

grams of S  $\longrightarrow$  moles of S  $\longrightarrow$  number of S atoms

The conversion factors are:

$$\frac{1 \text{ mol S}}{32.07 \text{ g S}} \quad \text{And} \quad \frac{6.022 \times 10^{23} \text{ S atoms}}{1 \text{ mol S}}$$

We can combine these conversions in one step as follows:

$$16.3 \text{ g S} \times \frac{1 \text{ mol S}}{32.07 \text{ g S}} \times \frac{6.022 \times 10^{23} \text{ S atoms}}{1 \text{ mol S}} = 3.06 \times 10^{23} \text{ S atoms}$$

Thus, there are  $3.06 \times 10^{23}$  atoms of S in 16.3 g of S.

# Classwork:

- How many atoms are there in 5.10 moles of sulfur(S)? [ 1 mol = 32.06g]

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- How many atoms are there in 5.10 moles of sulfur(S)? [ 1 mol = 32.06g]

= 1 mole of Sulfur contains  
 $6.022 \times 10^{23}$  atoms

So, 5.10 moles of Sulfur will have=  
 $5.10 \times 6.022 \times 10^{23}$   
 $= 3.07 \times 10^{24}$

# Classwork:

- How many grams of gold (Au) are there in 15.3 moles of Au? [ 1 mol Au = 197.0g]

# Classwork:

- How many grams of gold (Au) are in 15.3 moles of Au?  $1 \text{ mol Au} = 197.0 \text{ g}$

$$1 \text{ mole of Au} = 197.0 \text{ g}$$

$$\begin{aligned} 15.3 \text{ moles of Au} &= (197.0 \text{ g/1mol}) \times 15.3 \text{ mol} \\ &= 3014.0 \text{ g} \\ &= \mathbf{3.01 \times 10^3 \text{ g}} \end{aligned}$$



# Periodic Table

Periodic Table of the Elements																					
<div><div>Atomic Number</div><div>Symbol</div><div>Name</div><div>Atomic Mass</div></div>																					
1 H Hydrogen 1.008																	2 He Helium 4.003				
3 Li Lithium 6.941	4 Be Beryllium 9.012															5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 B Boron 10.811	4 Be Beryllium 9.012	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948				
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 83.798				
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29				
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.225	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon 222.018				
87 Fr Francium 223.019	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [293]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown				
<div><div>Lanthanide Series</div><div>57 La Lanthanum 138.905</div><div>58 Ce Cerium 140.116</div><div>59 Pr Praseodymium 140.908</div><div>60 Nd Neodymium 144.242</div><div>61 Pm Promethium 144.913</div><div>62 Sm Samarium 150.36</div><div>63 Eu Europium 151.964</div><div>64 Gd Gadolinium 157.25</div><div>65 Tb Terbium 158.925</div><div>66 Dy Dysprosium 162.500</div><div>67 Ho Holmium 164.930</div><div>68 Er Erbium 167.259</div><div>69 Tm Thulium 168.934</div><div>70 Yb Ytterbium 173.055</div><div>71 Lu Lutetium 174.967</div></div>																					
<div><div>Actinide Series</div><div>89 Ac Actinium 227.028</div><div>90 Th Thorium 232.038</div><div>91 Pa Protactinium 231.036</div><div>92 U Uranium 238.029</div><div>93 Np Neptunium 237.048</div><div>94 Pu Plutonium 244.064</div><div>95 Am Americium 243.061</div><div>96 Cm Curium 247.070</div><div>97 Bk Berkelium 247.070</div><div>98 Cf Californium 251.080</div><div>99 Es Einsteinium [254]</div><div>100 Fm Fermium 257.085</div><div>101 Md Mendelevium 258.1</div><div>102 No Nobelium 259.101</div><div>103 Lr Lawrencium [262]</div></div>																					
<div><div>Alkali Metal</div><div>Alkaline Earth</div><div>Transition Metal</div><div>Basic Metal</div><div>Semimetal</div><div>Nonmetal</div><div>Halogen</div><div>Noble Gas</div><div>Lanthanide</div><div>Actinide</div></div>																					

# Molecular Mass

- Molecular mass (or molecular weight) is the sum of the atomic masses (in amu) in a molecule.

$$\text{S} = 32.07 \text{ amu}$$

$$2\text{O} = 2 \times 16.00 \text{ amu}$$

$$\text{SO}_2 = 64.07 \text{ amu}$$

**For any molecule**

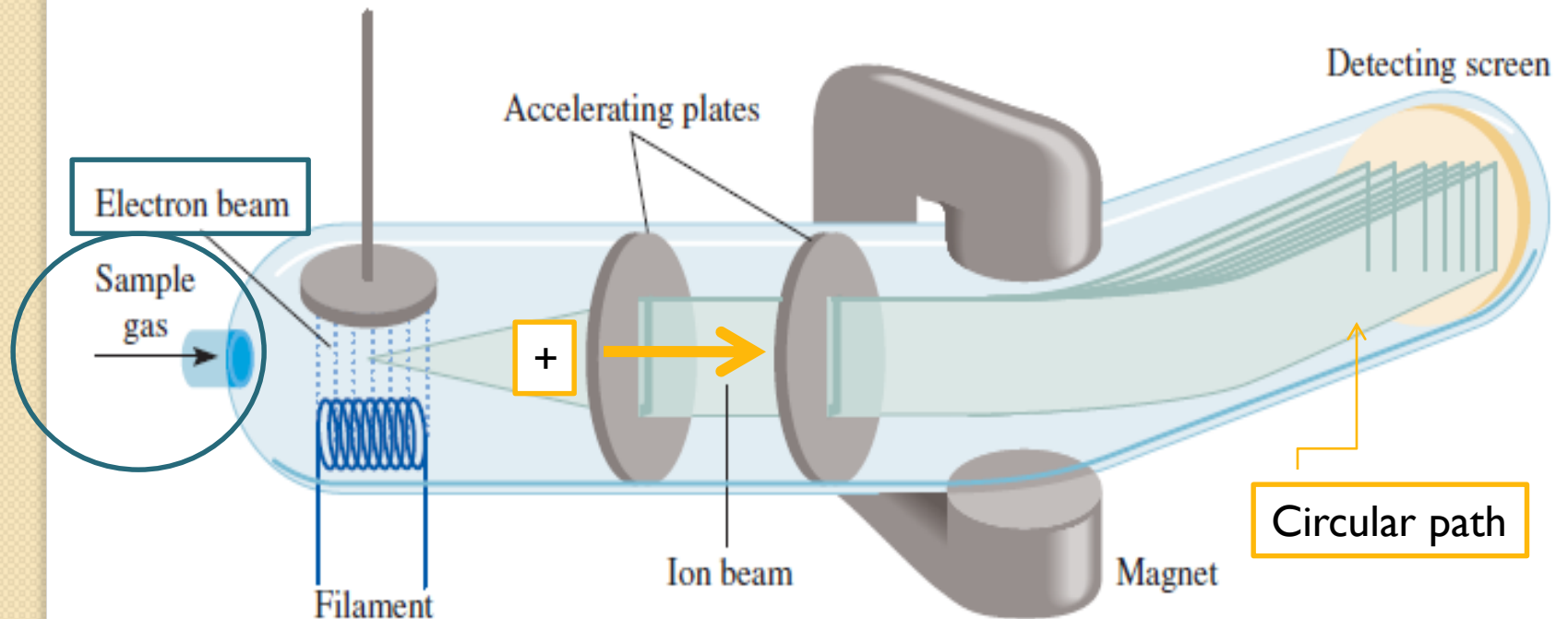
$$\text{Molecular mass (amu)} = \text{molar mass (grams)}$$

$$1 \text{ molecule SO}_2 = 64.07 \text{ amu}$$

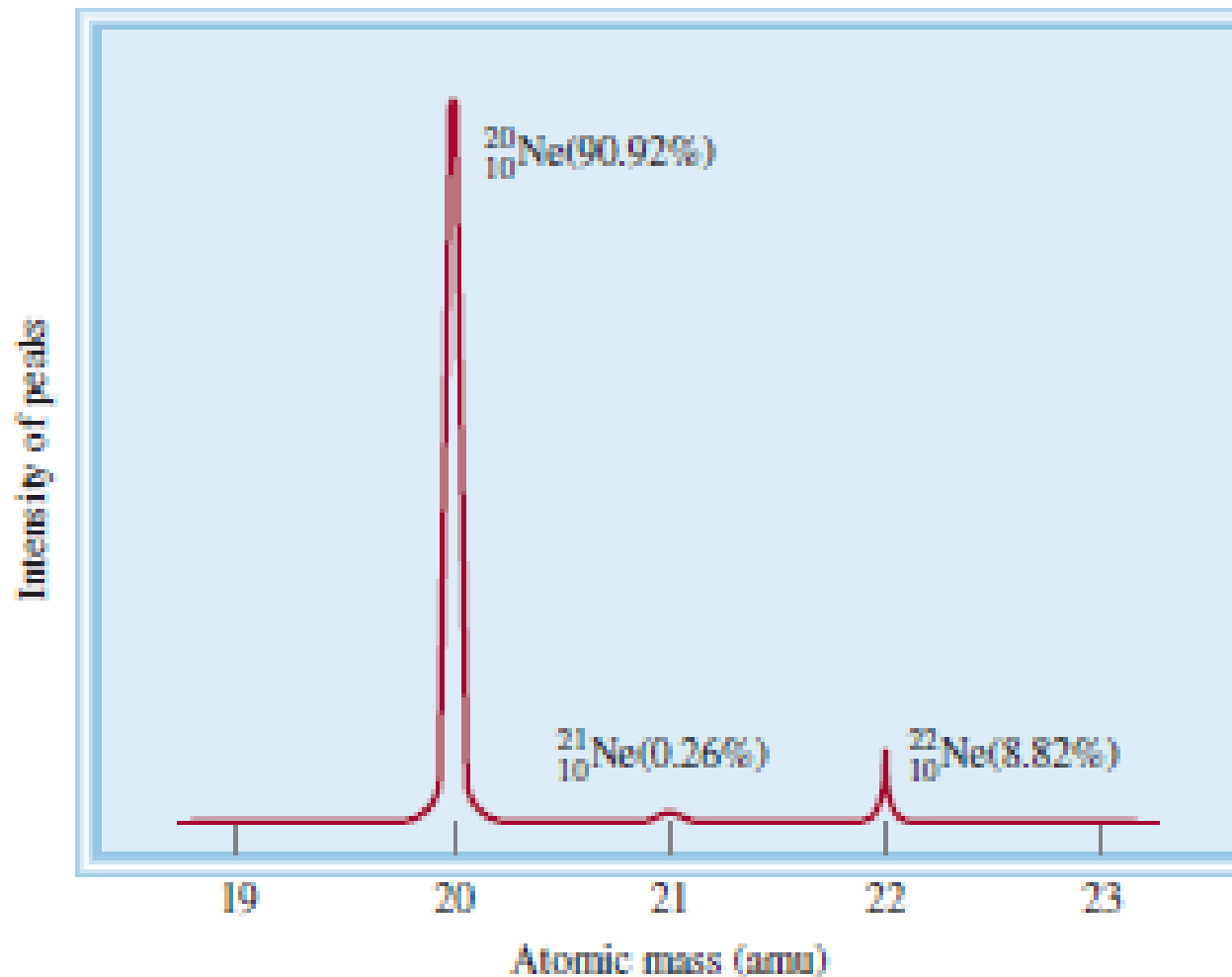
$$1 \text{ mol SO}_2 = 64.07 \text{ g SO}_2$$

# The Mass Spectrometer

Most direct and accurate method to measure atomic and molecular mass.



# The Mass Spectrometer



**Figure:** The mass spectrum of the three isotopes of neon.

# Percent Composition of Compounds

- The percent composition is the (%) by mass of each element in a compound.

$$\text{percent composition of an element} = \frac{n \times \text{molar mass of element}}{\text{molar mass of compound}} \times 100\%$$

Example: **H<sub>2</sub>O<sub>2</sub>**

Molar mass of H = 1.008g

Molar mass of O = 16g

Molar mass of **H<sub>2</sub>O<sub>2</sub>** = 34.02g

Count percent composition of the elements.

# Percent Composition of Compounds

$$\text{percent composition of an element} = \frac{n \times \text{molar mass of element}}{\text{molar mass of compound}} \times 100\%$$

In H<sub>2</sub>O<sub>2</sub>,

$$\% \text{H} = \frac{2 \times 1.008 \text{ g}}{34.02 \text{ g}} \times 100\% = 5.926\%$$

$$\% \text{O} = \frac{2 \times 16.00 \text{ g}}{34.02 \text{ g}} \times 100\% = 94.06\%$$

The sum of the percentages is,

$$5.926\% + 94.06\% = 99.99\%$$

Phosphoric acid ( $\text{H}_3\text{PO}_4$ ) is a colorless, syrupy liquid used in detergents, fertilizers, toothpastes, and in carbonated beverages for a “tangy” flavor. Calculate the percent composition by mass of H, P, and O in this compound.

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**Solution** The molar mass of  $\text{H}_3\text{PO}_4$  is 97.99 g. The percent by mass of each of the elements in  $\text{H}_3\text{PO}_4$  is calculated as follows:

$$\% \text{H} = \frac{3(1.008 \text{ g}) \text{ H}}{97.99 \text{ g } \text{H}_3\text{PO}_4} \times 100\% = 3.086\%$$

$$\% \text{P} = \frac{30.97 \text{ g P}}{97.99 \text{ g } \text{H}_3\text{PO}_4} \times 100\% = 31.61\%$$

$$\% \text{O} = \frac{4(16.00 \text{ g}) \text{ O}}{97.99 \text{ g } \text{H}_3\text{PO}_4} \times 100\% = 65.31\%$$



# Molecular and Empirical Formula

## Molecular Formula

is the **number** and **type** of atoms that are present in a single molecule of a substance.

Ex: Benzene :  $\text{C}_6\text{H}_6$ ; Water:  $\text{H}_2\text{O}$

## Empirical Formula

is the **ratio of elements** present in the compound. The empirical formula is also known as the simplest formula. Ex: Benzene  $\text{CH}$ , Water:  $\text{H}_2\text{O}$

You can find Empirical formula from the percent(%) composition.

- *If the % composition of any compound is given, then do the following steps;*
  - Percent to mass
  - Mass to mole
  - Divide by small
  - Multiply 'til whole

# Empirical formula from the *percent(%) composition*.

A compound consists of 72.2% magnesium and 27.8% nitrogen by mass.  
What is the empirical formula?

(1) Percent to mass:

Assume 100 g of the substance, then 72.2 g magnesium and 27.8 g nitrogen.

(2) Mass to moles:

for Mg:  $72.2 \text{ g Mg} \times (1 \text{ mol Mg} / 24.3 \text{ g Mg}) = 2.97 \text{ mol Mg}$

for N:  $27.8 \text{ g N} \times (1 \text{ mol N} / 14.0 \text{ g N}) = 1.99 \text{ mol N}$

(3) Divide by small:

for Mg:  $2.97 \text{ mol} / 1.99 \text{ mol} = 1.49$

for N:  $1.99 \text{ mol} / 1.99 \text{ mol} = 1.00$

(4) Multiply 'til whole:

for Mg:  $2 \times 1.49 = 2.98$  (i.e., 3)

for N:  $2 \times 1.00 = 2.00$

and the formula of the compound is  $\text{Mg}_3\text{N}_2$ .

# Determine the molecular formula

- Actual numbers of atoms are given in molecular formula.
- To determine the molecular formula:

Steps:

1. Find empirical molar mass of the compound
2. Molar mass is known.
3. Divide molar mass with empirical molar mass.
4. If it is a simple integer, multiply the subscripts of empirical formula with the result.

Hydrogen peroxide has an empirical formula of HO. What is the molecular formula?

- Given the molar mass of hydrogen peroxide is 32.02g.
- Empirical molar mass of HO =  $(1.008 + 16)g$   
 $= 17.008g$

$$\frac{\text{Empirical molar mass}}{\text{Molar mass}} = \frac{32.02g}{17.008g} = 1.88 \sim 2$$

Molecular formula of HO =  $(HO)_2 = H_2O_2$

# Class work

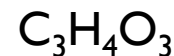
1. What are the empirical formulas of the compounds with the following compositions? 20.2 %Al, 79.8 % Cl. [Al= 26.98g; Cl= 35.45g]

2. The molar mass of caffeine is 194.19 g. Is the molecular formula of caffeine  $C_4H_5N_2O$  or  $C_8H_{10}N_4O_2$  ?

**$C_8H_{10}N_4O_2$ .**

Ascorbic acid (vitamin C) cures scurvy. It is composed of  
40.92 percent carbon (C),  
4.58 percent hydrogen (H), and  
54.50 percent oxygen (O) by mass.  
Determine its empirical formula.

[C=12.01g, H=1.008g, O=16g]



# Chemical Reactions & Equations

- A process in which one or more substances is changed into one or more new substances is a **chemical reaction**.
- A **chemical equation** uses chemical symbols to show what happens during a chemical reaction.

Reactants  $\rightarrow$  Products

3 ways of representing the reaction of  $\text{H}_2$  with  $\text{O}_2$  to form  $\text{H}_2\text{O}$



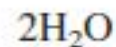
Two hydrogen molecules + One oxygen molecule  $\longrightarrow$  Two water molecules



+



$\longrightarrow$





# How to read Chemical Equations



- 2 atoms Mg + 1 molecule O<sub>2</sub> makes 2 formula units MgO
- 2 moles Mg + 1 mole O<sub>2</sub> makes 2 moles MgO
- 48.6 grams Mg + 32.0 grams O<sub>2</sub> makes 80.6 g MgO

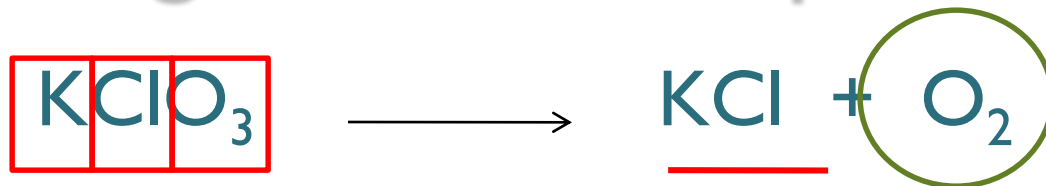
**NOT**

- 2 grams Mg + 1 gram O<sub>2</sub> makes 2 grams MgO

# Balancing Chemical Equations

- Write the correct formula (s) for the reactants on the left side and the correct formula (s) for the product(s) on the right side of the equation.
- Change the numbers in front of the formulas (coefficients) to make the number of atoms of each element the same on both sides of the equation. Do not change the subscript.
- Start by balancing those elements that appear in only one reactant and one product.
- Balance those elements that appear in two or more reactants or products.
- Check to make sure that you have the same number of each type of atom on both sides of the equation.

# Balancing Chemical Equations



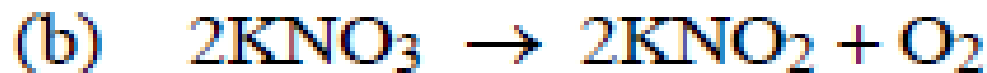
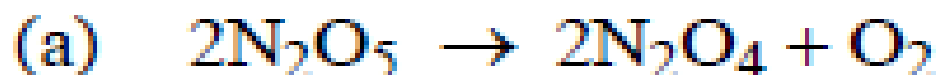
- All three elements (K, Cl, and O) appear only once on each side of the equation.

we can balance the O atoms by placing a 2 in front of  $\text{KClO}_3$  and a 3 in front of  $\text{O}_2$ .



Finally, we balance the K and Cl atoms by placing a 2 in front of KCl:



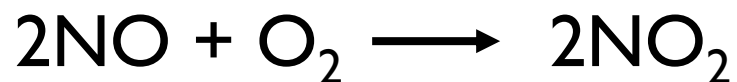


# Limiting Reagents

- ❑ *The reactant used up first in a reaction is called the limiting reagent, because the maximum amount of product formed depends on how much of this reactant was originally present.*
- ❑ *Excess reagents are the reactants present in quantities greater than necessary to react with the quantity of the limiting reagent.*

# Limiting Reagent

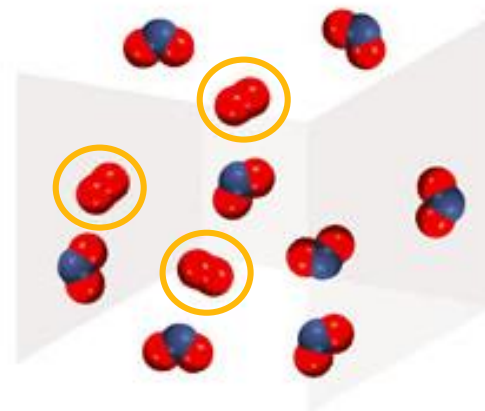
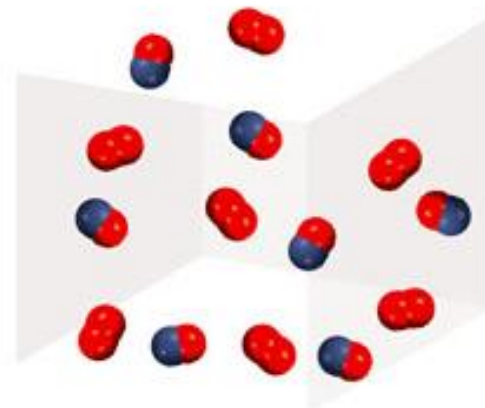
Reactant used up first in the reaction.



NO is the limiting reagent

O<sub>2</sub> is the excess reagent

Before reaction has started



After reaction is complete



# Reaction Yield

- Theoretical Yield: The amount of product that would result if *all the limiting reagents* reacted.
- Actual Yield: The amount of product actually obtained from a reaction.
- Reaction Yield: The proportion of the actual yield to the theoretical yield.

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$



**THANK YOU**