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}C "weighs" 12 amu

On this scale.

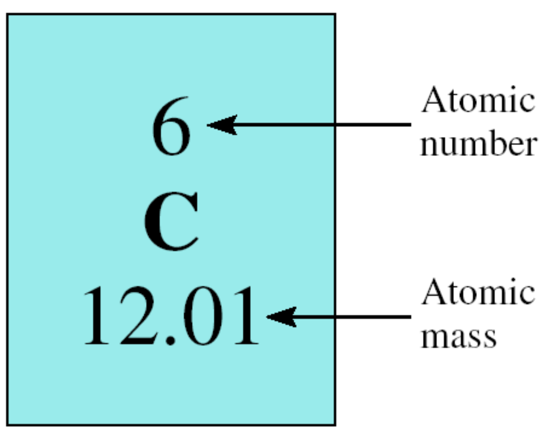
^{1}H = 1.008 amu

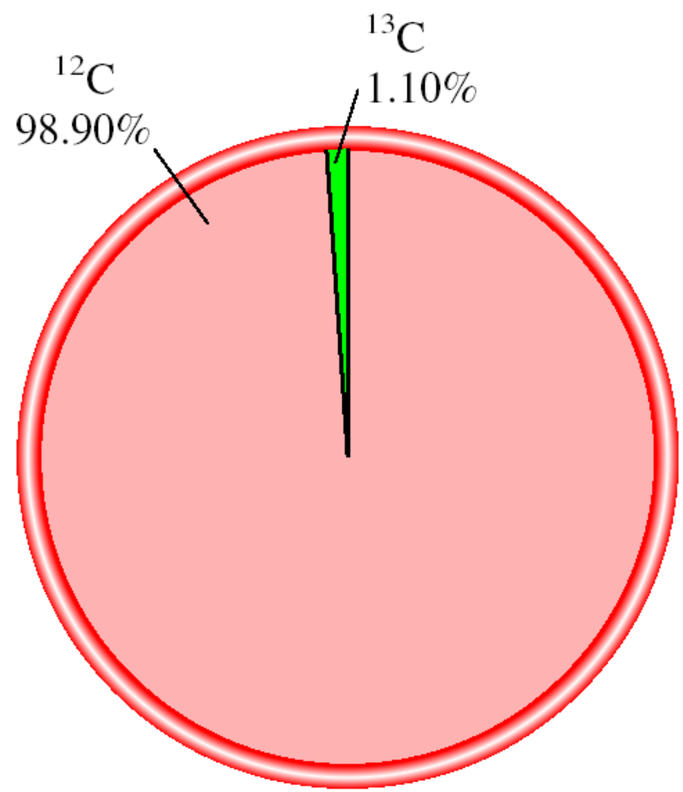
^{16}O = 16

1 atom of ^{12}C =12
Experimentally, ^{1}H weighs 8.40% of ^{12}C.
Weight/Mass of H= (8.40 x 12)/ 100
= 1.008 amu

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}C is = 98.90%

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

Atomic mass of ^{12}C = 12.00

Atomic mass of ^{13}C = 13.00335

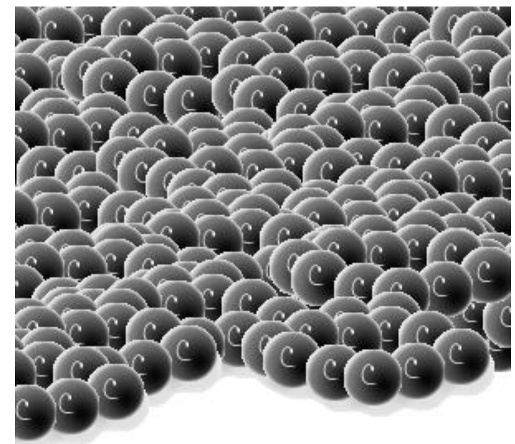
Average atomic mass is = (0.9890x12amu)+(.0110x13.00335amu) = 12.01 amu

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}C .
- **Mole:** is the unit to count the number of particles in SI system.
- The actual number of atoms that12 gram ^{12}C contains has experimentally been determined.
- The number is called the <u>Avogadro's number</u>, which is,

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

Avogadro's Number



1 Dozen = 12 pieces

1 mol = 6.022×10^{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 mol ^{12}C atoms = 6.022×10^{23} atoms = 12.00 g

1 ^{12}C atom = 12.00 amu

1 mol ^{12}C atoms = 12.00 g ^{12}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 6.022×10^{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	**(1 / 4.003) X 6.46** mol
				= 1.61 mol

- 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).

$$\text{grams of S} \longrightarrow \text{moles of S} \longrightarrow \text{number of S atoms}$$

The conversion factors are:

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

We can combine these conversions in one step as follows:

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

Thus, there are 3.06×10^{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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of sulfur(S)? [1 mol = 32.06g]

= 1 mole of Sulfur contains
6.022x10^23 atoms

So, 5.10 moles of Sulfur will have=
5.10 X 6.022X10^23
= 3.07x1024

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 mol Au=197.0g

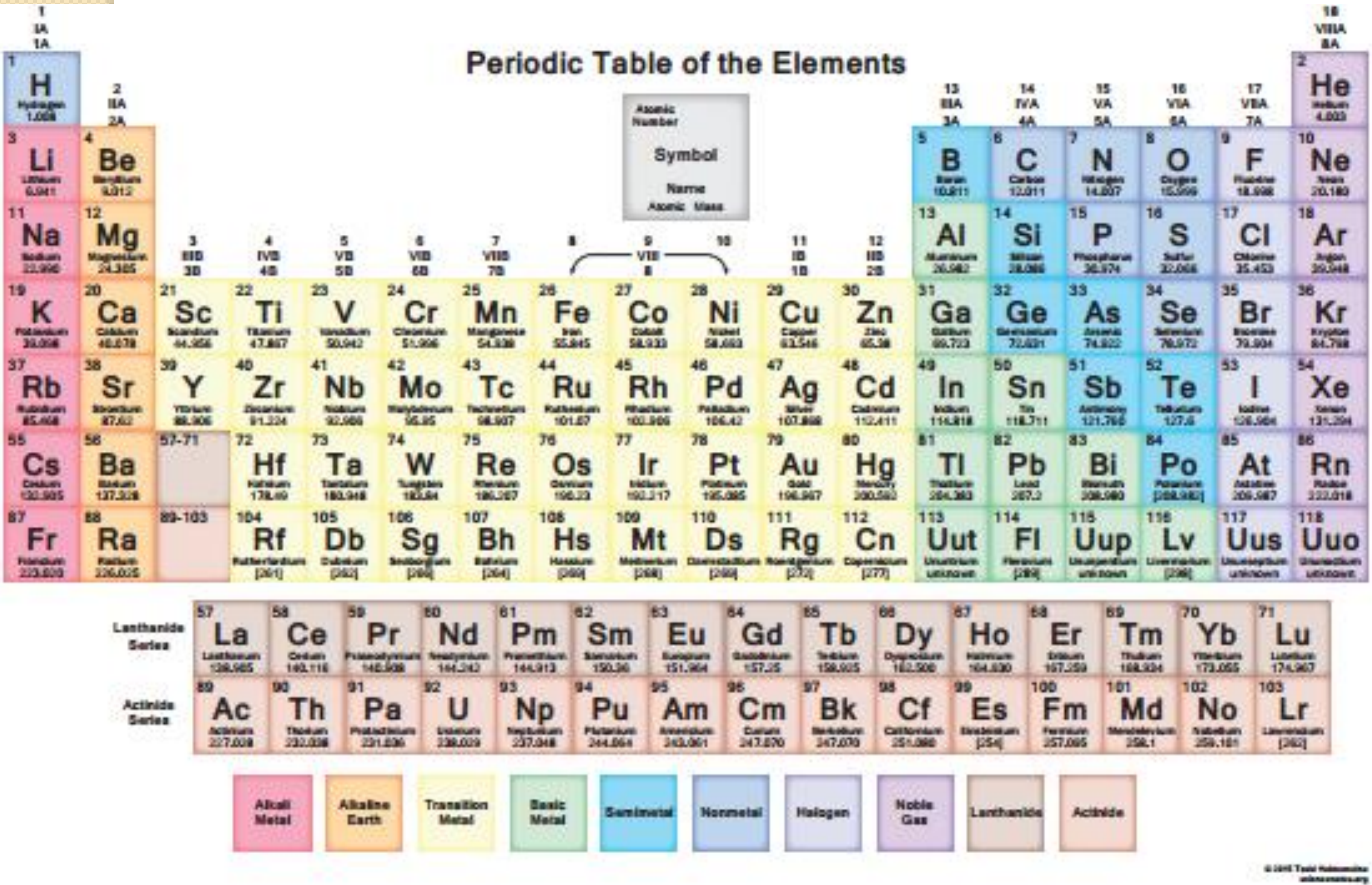
1mole of Au = 197.0 g

15.3 moles of Au = (197.0 g/1mol)x 15.3 mol

= 3014.0 g

=3.01×10^3 g

Periodic Table



Molecular Mass

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

S = 32.07 amu

2O = 2x 16.00 amu

SO_2 = 64.07 amu

For any molecule

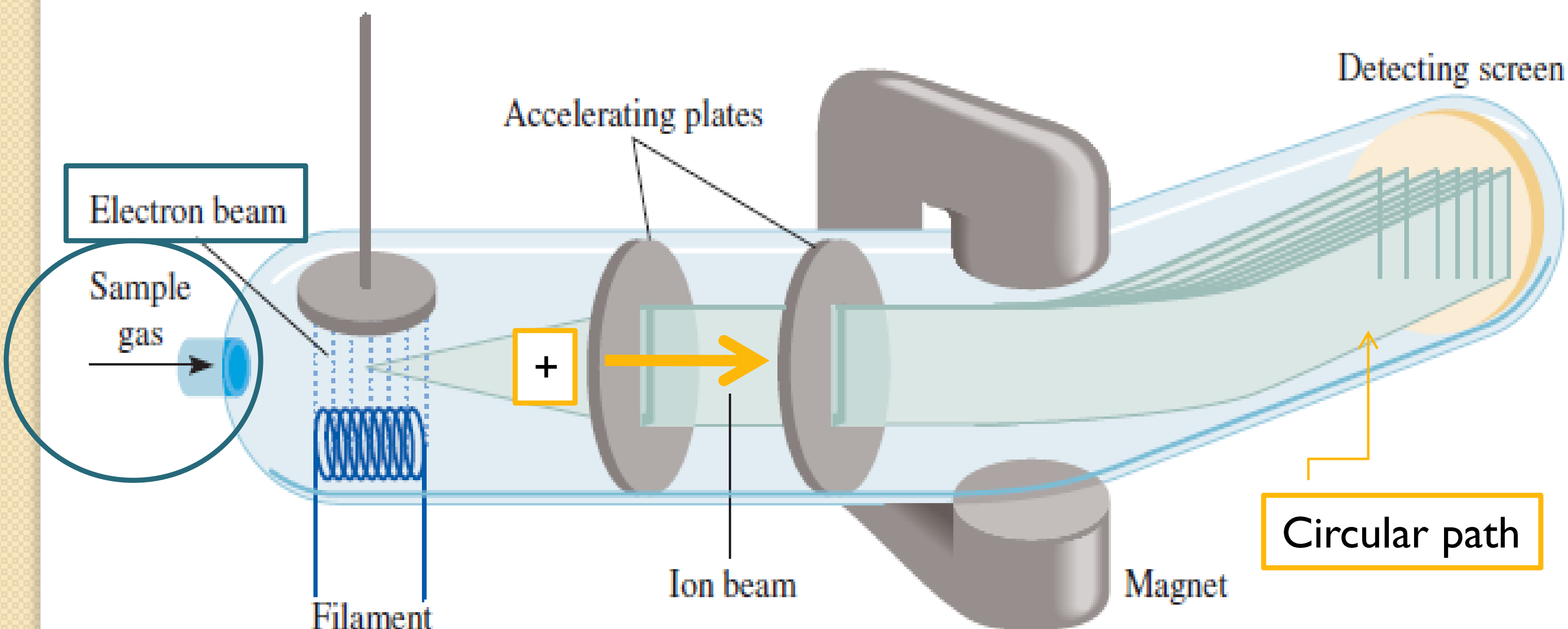
Molecular mass (amu) = molar mass (grams)

1 molecule SO_2 = 64.07 amu

A mol SO_2 = 64.07 g SO_2

The Mass Spectrometer

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



The Mass Spectrometer

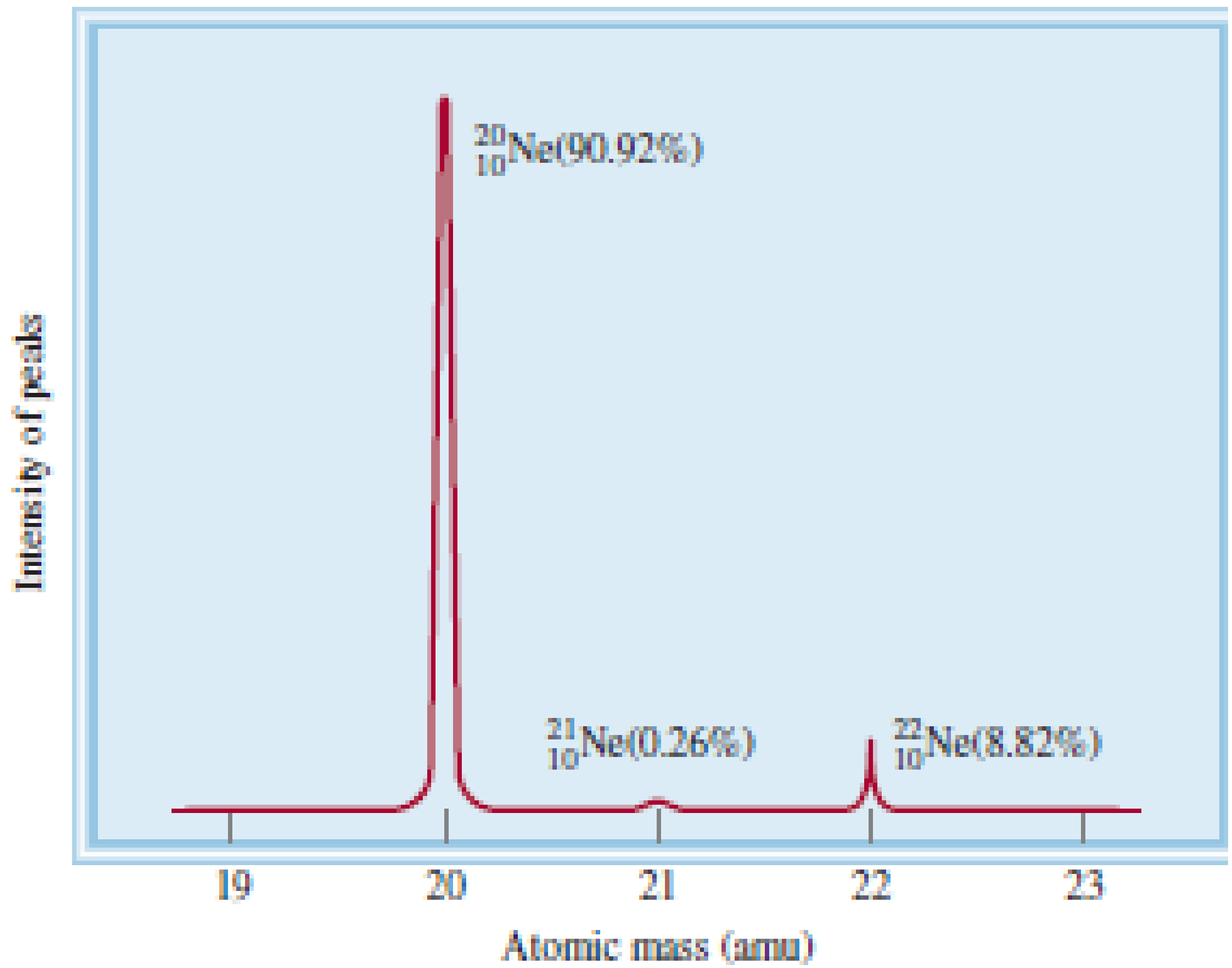


Figure: *The mass spectrum of the three isotopes of neon.*

Percent Composition of Compounds

- The percent composition is the (%) by <u>mass</u> 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: $\mathbf{H_2O_2}$

Molar mass of H = 1.008g
Molar mass of O = 16g
Molar mass of $\mathbf{H_2O_2}$ = 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 H2O2,

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

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

The sum of the percentages is,

5.926 % + 94.06 % = 99.99 %

Phosphoric acid (H_3PO_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 H_3PO_4 is 97.99 g. The percent by mass of each of the elements in H_3PO_4 is calculated as follows:

$$\%H = \frac{3(1.008 \text{ g}) \text{ H}}{97.99 \text{ g } H_3PO_4} \times 100\% = \boxed{3.086\%}$$

$$\%P = \frac{30.97 \text{ g P}}{97.99 \text{ g } H_3PO_4} \times 100\% = \boxed{31.61\%}$$

$$\%O = \frac{4(16.00 \text{ g}) \text{ O}}{97.99 \text{ g } H_3PO_4} \times 100\% = \boxed{65.31\%}$$

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 :C_6H_6 ; Water: H_2O

Empirical Formula

is the ratio of elements present in the compound. The empirical formula is also known as the simplest formula. Ex: Benzene CH, Water: H_2O

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 g Mg x (1 mol Mg/24.3 g Mg) = 2.97 mol Mg
for N: 27.8 g N x (1 mol N/14.0 g N) = 1.99 mol N

(3) Divide by small:
for Mg: 2.97 mol / l.99 mol = 1.49
for N: 1.99 mol / l.99 mol = 1.00

(4) Multiply 'til whole:
for Mg: 2 x 1.49 = 2.98 (i.e., 3)
for N: 2 x 1.00 = 2.00

and the formula of the compound is Mg3N2.

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 per oxide has an empirical formula of HO. What is the molecular formula?

- Given the molar mass of hydrogen per oxide 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 $C_8H_{10}N_4O_2$?

C8H10N4O2.

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]

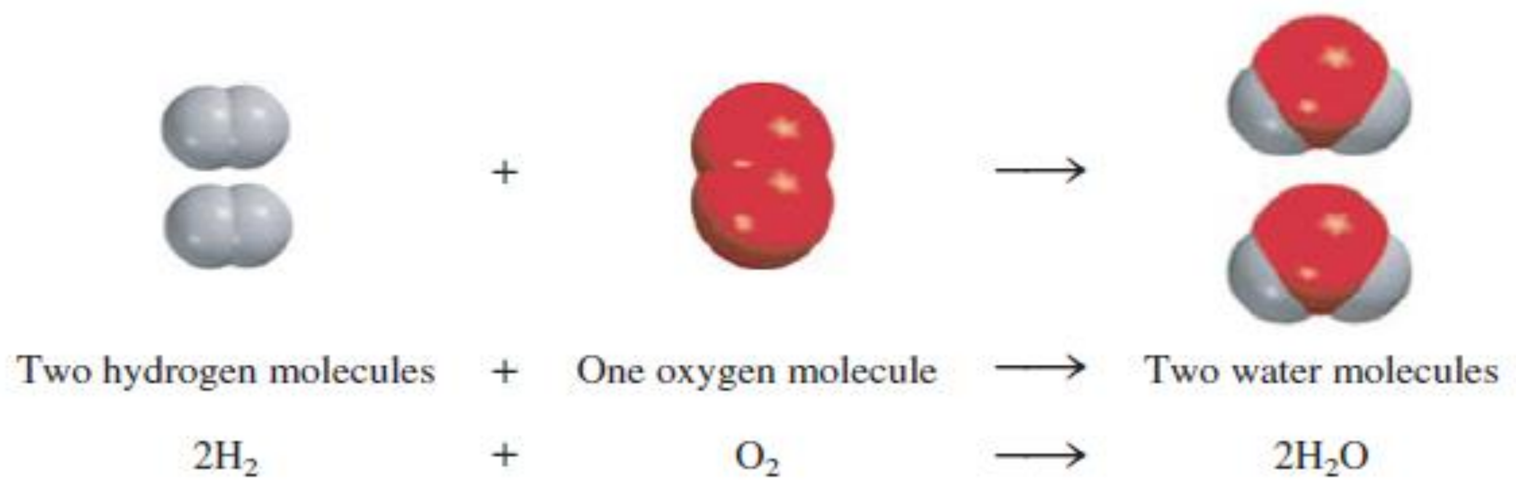
$C_3H_4O_3$

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 → Products

<u>3 ways of representing the reaction of H_2 with O_2 to form H_2O</u>



How to read Chemical Equations

$$2\,Mg + O_2 \longrightarrow 2MgO$$

- 2 atoms Mg + 1 molecule O_2 makes 2 formula units MgO
- 2 moles Mg + 1 mole O_2 makes 2 moles MgO
- 48.6 grams Mg + 32.0 grams O2 makes 80.6 g MgO

NOT

- 2 grams Mg + 1 gram O2 makes 2 grams MgO

Balancing Chemical Equations

- Write the correct formula (s) for the reactants on the left side an 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

$$KClO_3 \longrightarrow \underline{KCl} + O_2$$

- 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 $KClO_3$ and a 3 in front of O_2.

$$2KClO_3 \rightarrow KCl + 3O_2$$

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

$$2KClO_3 \rightarrow 2KCl + 3O_2$$

(a) $2N_2O_5 \rightarrow 2N_2O_4 + O_2$

(b) $2KNO_3 \rightarrow 2KNO_2 + O_2$

(c) $NH_4NO_3 \rightarrow N_2O + 2H_2O$

(d) $NH_4NO_2 \rightarrow N_2 + 2H_2O$

(e) $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$ 2

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.*

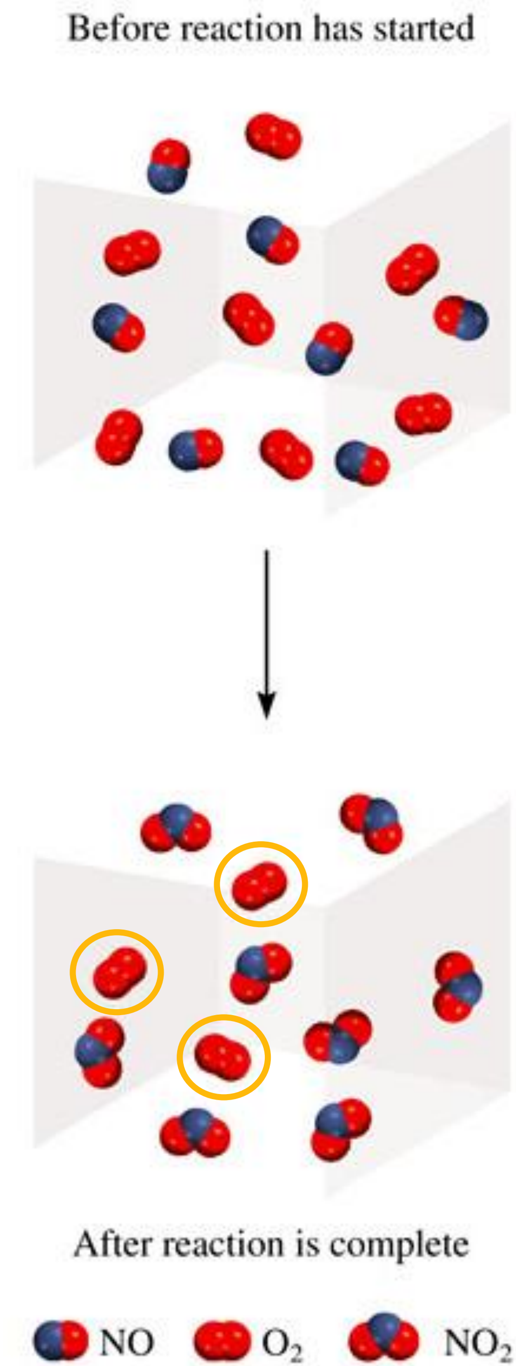
Limiting Reagent

Reactant used up first in the reaction.

$$2NO + O_2 \longrightarrow 2NO_2$$

NO is the limiting reagent

O_2 is the excess reagent



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