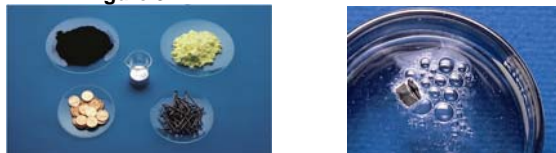


# Mass Relationships in Chemical Reactions

## Chapter 3

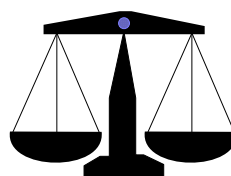
Figure 3.1



### 3.1 Atomic Mass

Micro World atoms & molecules  $\longrightarrow$  Macro World grams

**Atomic mass** - mass of an atom in atomic mass units (amu)



By definition:  
1 atom  $^{12}\text{C}$  "weighs" 12 amu

On this scale  
 $^1\text{H} = 1.008$  amu  
 $^{16}\text{O} = 16.00$  amu

## HW, CH 3, Due Jan. 28

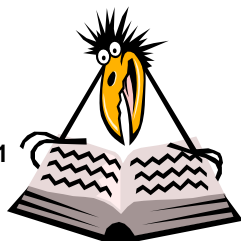
Read from Chapter 3 Chang:

and

Work End-of-Chapter 3 problems:

2, 5-8, 9, 11, 12-22 (even), 23,  
24-30 (even), 35, 39, 40, 43,  
44-54 (even), 59, 60, 63,  
64-68 (even), 69, 74, 78, 81,  
82-86 (even), 90, 92, 96, 102, 111

WebAssign CH3 Due: Feb. 8  
Exam 1: Feb. 7 (8-9:15 PM)



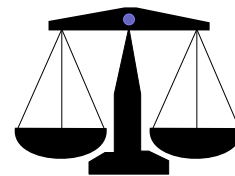
Naturally occurring lithium is a mixture of 2 isotopes:

7.42%  $^6\text{Li}$  (6.015 amu)

92.58%  $^7\text{Li}$  (7.016 amu)

**Average atomic mass of Li:**

$$\frac{7.42 \times 6.015 + 92.58 \times 7.016}{100} = 6.941 \text{ amu}$$



1A																		18A													
1	H																	2	He												
1.008																		4.003													
3	Li	4	Be																	5	B	6	C	7	N	8	O	9	F	10	Ne
6.941		9.012																		10.81	12.01	14.01	16.00	19.00	20.18						
Average atomic mass (6.941)																															
11	Na	12	Mg	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18												
22.99	24.31	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	26.98	28.09	30.97	32.07	35.45	39.95														
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36														
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr														
39.10	40.08	44.96	47.88	50.94	52.00	54.94	55.85	58.93	58.69	63.55	65.39	69.72	72.59	74.92	78.96	79.90	83.80														
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54														
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
85.47	87.62	88.91	91.22	92.91	95.94	(99)	101.1	102.9	106.4	107.9	112.4	114.8	118.7	121.8	127.6	126.9	131.3														
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86														
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn														
132.9	137.3	138.9	178.5	180.9	183.9	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	(210)	(210)	(222)														
87	88	89	104	105	106	107	108	109	110	111	112																				
Fr	Ra	Ac	Rf	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn													
(223)	(226)	(227)	(261)	(262)	(263)	(263)	(265)	(266)																							
Metals																															
Metalloids																															
Nonmetals																															

**Molar mass** is the mass of 1 mole of **eggs shoes marbles atoms** in grams

1 mole <sup>12</sup>C atoms = 6.022 x 10<sup>23</sup> atoms = 12.00 g

1 <sup>12</sup>C atom = 12.00 amu

OR

1 amu =  $\frac{1}{12}$  • mass of 1 <sup>12</sup>C atom (g)

1 mole <sup>12</sup>C atoms = 12.00 g <sup>12</sup>C

1 mole lithium atoms = 6.941 g Li

**For any element**  
**atomic mass (amu) = molar mass (grams)**

**3.2 Avogadro's Number and the Molar Mass of an Element**

The **mole (mol)** - amount of a substance that contains as many particles as there are atoms in exactly 12.00 grams of <sup>12</sup>C

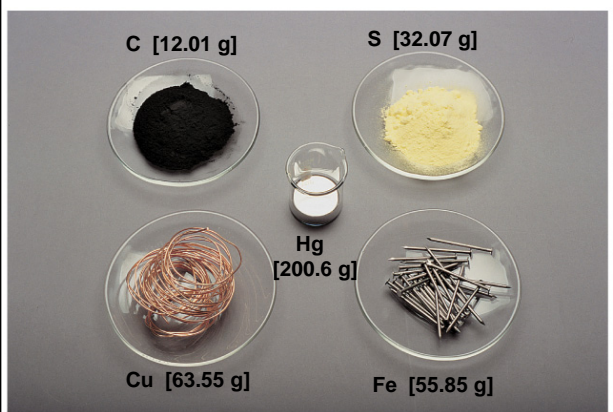
1 mol = N<sub>A</sub> = 6.0221367 x 10<sup>23</sup>

Avogadro's number (N<sub>A</sub>)

Note: N<sub>A</sub> is very large because atoms are so small

1 mol [things] = 6.02 x 10<sup>23</sup> [things]

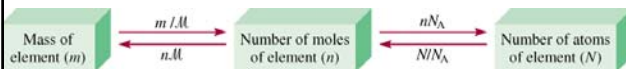
**Figure 3.1 How Much is a Mole of an Element?**



**Figure 3.2 Mass, Moles, Avogadro's Number, and Number of Atoms**

$$\frac{1 \text{ }^{12}\text{C atom}}{12.00 \text{ amu}} \times \frac{12.00 \text{ g}}{6.022 \times 10^{23} \text{ }^{12}\text{C atoms}} = \frac{1.66 \times 10^{-24} \text{ g}}{1 \text{ amu}}$$

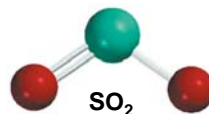
$$1 \text{ amu} = 1.66 \times 10^{-24} \text{ g} \text{ or } 1 \text{ g} = 6.022 \times 10^{23} \text{ amu}$$



Where:  $m$  = mass in grams       $M$  = molar mass in g/mol  
 $n$  = number moles               $N_A$  = Avogadro's number  
 $N$  = number atoms

### 3.3 Molecular Mass

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



$$\begin{array}{r} 1\text{S} \quad 32.07 \text{ amu} \\ 2\text{O} \quad + 2 \times 16.00 \text{ amu} \\ \hline \text{SO}_2 \quad 64.07 \text{ amu} \end{array}$$

For any molecule  
**molecular mass (amu) = molar mass (grams)**

$$\begin{array}{l} 1 \text{ molecule SO}_2 = 64.07 \text{ amu} \\ 1 \text{ mole SO}_2 = 64.07 \text{ g SO}_2 \end{array}$$



### Do You Understand Molar Mass?

How many atoms are in 0.551 g of potassium (K) ?

$$1 \text{ mol K} = 39.10 \text{ g K}$$

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

$$0.551 \text{ g K} \times \frac{1 \text{ mol K}}{39.10 \text{ g K}} \times \frac{6.022 \times 10^{23} \text{ atoms K}}{1 \text{ mol K}} =$$

$$8.49 \times 10^{21} \text{ atoms K}$$



### Do You Understand Molecular Mass?

How many H atoms are in 72.5 g of C<sub>3</sub>H<sub>8</sub>O ?

$$1 \text{ mol C}_3\text{H}_8\text{O} = (3 \times 12) + (8 \times 1) + 16 = 60 \text{ g C}_3\text{H}_8\text{O}$$

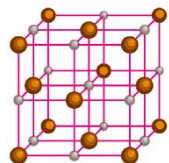
$$1 \text{ mol C}_3\text{H}_8\text{O molecules} = 8 \text{ mol H atoms}$$

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

$$72.5 \text{ g C}_3\text{H}_8\text{O} \times \frac{1 \text{ mol C}_3\text{H}_8\text{O}}{60 \text{ g C}_3\text{H}_8\text{O}} \times \frac{8 \text{ mol H atoms}}{1 \text{ mol C}_3\text{H}_8\text{O}} \times \frac{6.022 \times 10^{23} \text{ H atoms}}{1 \text{ mol H atoms}} =$$

$$5.82 \times 10^{24} \text{ atoms H}$$

**Formula mass** is the sum of the atomic masses (in amu) in a formula unit of an ionic compound.



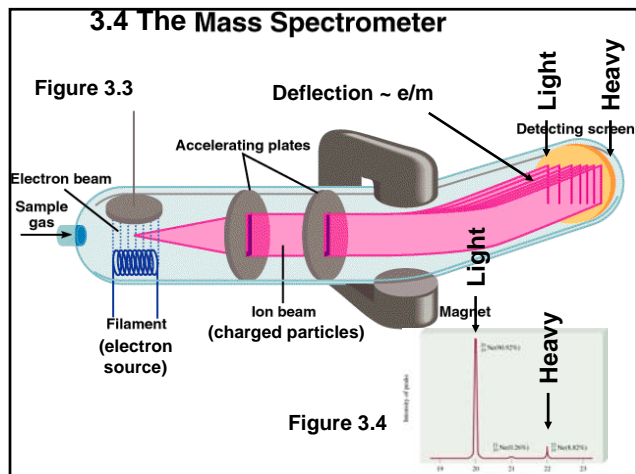
NaCl

$$\begin{array}{r} 1\text{Na} \quad 22.99 \text{ amu} \\ 1\text{Cl} \quad + \quad 35.45 \text{ amu} \\ \hline \text{NaCl} \quad 58.44 \text{ amu} \end{array}$$

For any ionic compound  
formula mass (amu) = molar mass (grams)

$$\begin{array}{l} 1 \text{ formula unit NaCl} = 58.44 \text{ amu} \\ 1 \text{ mole NaCl} = 58.44 \text{ g NaCl} \end{array}$$

### 3.4 The Mass Spectrometer



### Do You Understand Formula Mass?

What is the formula mass of  $\text{Ca}_3(\text{PO}_4)_2$  ?

1 formula unit of  $\text{Ca}_3(\text{PO}_4)_2$

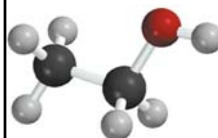
$$\begin{array}{r} 3 \text{ Ca} \quad 3 \times 40.08 \\ 2 \text{ P} \quad 2 \times 30.97 \\ 8 \text{ O} \quad + \quad 8 \times 16.00 \\ \hline 310.18 \text{ amu} \end{array}$$

### 3.5 Percent Composition of Compounds

What is **Percent composition** of element in a compound?

$$\frac{n \times \text{molar mass of element}}{\text{molar mass of compound}} \times 100\%$$

$n$  = number moles of element in **1 mole** of the compound



$\text{C}_2\text{H}_6\text{O}$

$$\% \text{C} = \frac{2 \times (12.01 \text{ g})}{46.07 \text{ g}} \times 100\% = 52.14\%$$

$$\% \text{H} = \frac{6 \times (1.008 \text{ g})}{46.07 \text{ g}} \times 100\% = 13.13\%$$

$$\% \text{O} = \frac{1 \times (16.00 \text{ g})}{46.07 \text{ g}} \times 100\% = 34.73\%$$

$$52.14\% + 13.13\% + 34.73\% = 100.0\%$$

Or  $\text{CH}_3\text{CH}_2\text{OH}$  (ethanol)

### Percent Composition and Empirical Formulas

Mass percent

Convert to grams and divide by molar mass

Moles of each element

Divide by the smallest number of moles

Mole ratios of elements

Change to integer subscripts

Empirical formula

**Determine the empirical formula of a compound that has the following percent composition by mass: K 24.75, Mn 34.77, O 40.51 percent.**

$$n_K = 24.75 \text{ g K} \times \frac{1 \text{ mol K}}{39.10 \text{ g K}} = 0.6330 \text{ mol K}$$

$$n_{Mn} = 34.77 \text{ g Mn} \times \frac{1 \text{ mol Mn}}{54.94 \text{ g Mn}} = 0.6329 \text{ mol Mn}$$

$$n_O = 40.51 \text{ g O} \times \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.532 \text{ mol O}$$

### 3.6 Experimental Determination of Empirical Formulas

Typically use a technique called combustion analysis

$$\text{excess O}_2 + 2 \text{ C}_2\text{H}_6\text{O} \longrightarrow 6 \text{ H}_2\text{O} + 2 \text{ CO}_2$$

Mass gain proportional to amount of ethanol, H<sub>2</sub>O, and CO<sub>2</sub>!

### Percent Composition and Empirical Formulas

Mass percent

Convert to grams and divide by molar mass

Moles of each element

Divide by the smallest number of moles

Mole ratios of elements

Change to integer subscripts

Empirical formula

$n_K = 0.6330$ ,  $n_{Mn} = 0.6329$ ,  $n_O = 2.532$

$$\text{K} : \frac{0.6330}{0.6329} \approx 1.0$$

$$\text{Mn} : \frac{0.6329}{0.6329} = 1.0$$

$$\text{O} : \frac{2.532}{0.6329} \approx 4.0$$

**KMnO<sub>4</sub>**

Name = potassium permanganate

### How to Determine Molecular Formulas: Ethanol

Combust 11.5 g ethanol      Collect 22.0 g CO<sub>2</sub> and 13.5 g H<sub>2</sub>O

$$\text{g CO}_2 \longrightarrow \text{mol CO}_2 \longrightarrow \text{mol C} \longrightarrow \text{g C} \quad 6.0 \text{ g C} = 0.5 \text{ mol C}$$

$$\text{g H}_2\text{O} \longrightarrow \text{mol H}_2\text{O} \longrightarrow \text{mol H} \longrightarrow \text{g H} \quad 1.5 \text{ g H} = 1.5 \text{ mol H}$$

$$\text{g of O} = \text{g of sample} - (\text{g of C} + \text{g of H}) \quad 4.0 \text{ g O} = 0.25 \text{ mol O}$$

Empirical formula C<sub>0.5</sub>H<sub>1.5</sub>O<sub>0.25</sub>

Divide by smallest subscript (0.25)

Empirical formula C<sub>2</sub>H<sub>6</sub>O

$$\text{O}_2 (\text{xs}) + 2 \text{ C}_2\text{H}_6\text{O} \longrightarrow 6 \text{ H}_2\text{O} + 2 \text{ CO}_2$$

### 3.7 Chemical Reactions and Chemical 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

3 ways of representing the reaction of H<sub>2</sub> with O<sub>2</sub> to form H<sub>2</sub>O

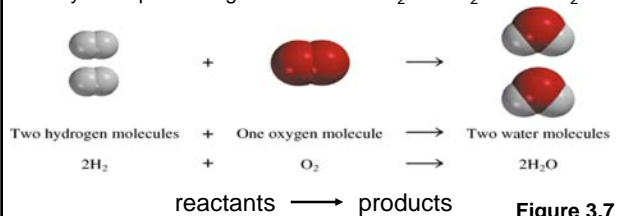


Figure 3.7

### Balancing Chemical Equations

1. 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.

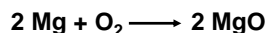
Ethane reacts with oxygen to form carbon dioxide and water



2. 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 subscripts.**



### How to “Read” Chemical Equations



2 atoms Mg + 1 molecule O<sub>2</sub> makes 2 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

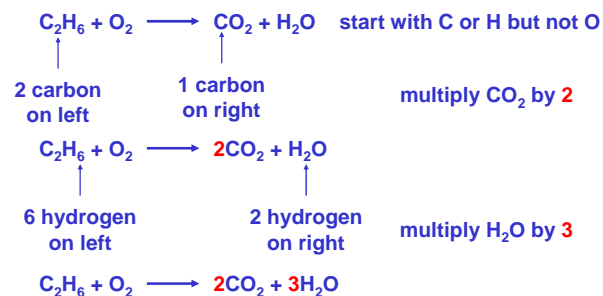


IS NOT

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

### Balancing Chemical Equations

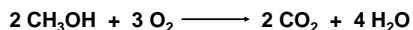
3. Start by balancing those elements that appear in only one reactant and one product.







Methanol burns in air according to the equation



If 209 g of methanol are used up in the combustion, what mass of water is produced?

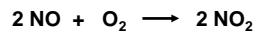
grams  $\text{CH}_3\text{OH}$   $\longrightarrow$  moles  $\text{CH}_3\text{OH}$   $\longrightarrow$  moles  $\text{H}_2\text{O}$   $\longrightarrow$  grams  $\text{H}_2\text{O}$

molar mass  
 $\text{CH}_3\text{OH}$       coefficients  
chemical equation      molar mass  
 $\text{H}_2\text{O}$

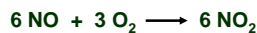
$$209 \text{ g } \text{CH}_3\text{OH} \times \frac{1 \text{ mol } \text{CH}_3\text{OH}}{32.0 \text{ g } \text{CH}_3\text{OH}} \times \frac{4 \text{ mol } \text{H}_2\text{O}}{2 \text{ mol } \text{CH}_3\text{OH}} \times \frac{18.0 \text{ g } \text{H}_2\text{O}}{1 \text{ mol } \text{H}_2\text{O}} =$$

235 g  $\text{H}_2\text{O}$

### Limiting Reagents



Means same as:



$\text{NO}$  is the limiting reagent  
(used up)

$\text{O}_2$  is the excess reagent  
(lots left over)

Before reaction starts



After reaction - incomplete



### 3.9 Limiting Reagents

Many reactions do not go to completion and/or an error in measuring reagents was made

Some of reagent will remain after reaction stops

Reagent you have fewest moles of called *limiting reagent*

Determines the maximum yield of a reaction



### Do You Understand Limiting Reagents?

In a reaction, 124 g of Al are reacted with 601 g of  $\text{Fe}_2\text{O}_3$



Calculate the mass of  $\text{Al}_2\text{O}_3$  formed.

g Al  $\longrightarrow$  mol Al  $\longrightarrow$  mol  $\text{Fe}_2\text{O}_3$  needed  $\longrightarrow$  g  $\text{Fe}_2\text{O}_3$  needed

OR

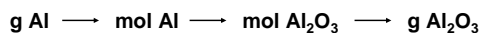
g  $\text{Fe}_2\text{O}_3$   $\longrightarrow$  mol  $\text{Fe}_2\text{O}_3$   $\longrightarrow$  mol Al needed  $\longrightarrow$  g Al needed

$$124 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \times \frac{1 \text{ mol } \text{Fe}_2\text{O}_3}{2 \text{ mol Al}} \times \frac{160. \text{ g } \text{Fe}_2\text{O}_3}{1 \text{ mol } \text{Fe}_2\text{O}_3} = 367 \text{ g } \text{Fe}_2\text{O}_3$$

Start with 124 g Al  $\longrightarrow$  need 367 g  $\text{Fe}_2\text{O}_3$

Have more  $\text{Fe}_2\text{O}_3$  (601 g) so Al is limiting reagent

Use limiting reagent (Al) to calculate amount of product that can be formed.



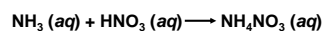
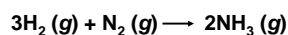
$$124 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \times \frac{1 \text{ mol Al}_2\text{O}_3}{2 \text{ mol Al}} \times \frac{102 \text{ g Al}_2\text{O}_3}{1 \text{ mol Al}_2\text{O}_3} = 234 \text{ g Al}_2\text{O}_3$$



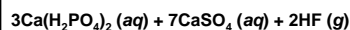
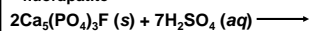
## Chemistry In Action: Chemical Fertilizers



Plants need: N, P, K, Ca, S, & Mg



fluorapatite



### 3.10 Reaction Yield

**Theoretical Yield** is the amount of product that would result if all the limiting reagent reacted. (aka perfect world)

**Actual Yield** is the amount of product actually obtained from a reaction. (aka real life)

Ratio relating actual to theoretical yield (out of 100%)

$$\% \text{ Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$