Learning objective 1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively. [*See* **SP 7.1;Essential knowledge 1.A.3**]

Learning objective 3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [SeeSP2.2, 5.1;Essential knowledge 3.A.2]

Learning objective 3.4 The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [See SP 2.2, 5.1, 6.4; Essential knowledge 3.A.2]

Concept Review:

You can calculate the molecular formula of a compound from:

1. Moles of each atom and molar mass
2. Mass % of each element and the total # of atoms in a given sample of the compound (calculate empirical formula, get total number of atoms in EF, then divide the total number of atoms in the compound by the total number of atoms in EF, this value will be the multiplier for EF to get the MF)
3. Mass % of each element and the number of atoms of one of the elements in a molecule of that compound. (calculate EF, then divide # of atoms of one element in the molecule by # of atoms of that element in EF, this will give the multiplier for EF to get the MF)

Level 1: #5, 15, 20, 22, 27, 31, 35, 40, 49, 51, 55, 67, 73, 95 from textbook (Recommended for Phy or Chem students)

Stoichiometry (Percent Composition, EF, MF) Level 2 and 3

1. Solve the following stoichiometric relationships (level 2)

   a) Zinc reacts with hydrochloric acid to produce zinc chloride and hydrogen gas. How many milliters of a 3.00*M* HCl are required to react with 12.35 g of zinc? Remember molar volume 22.4L= 1mol of any gas @STP

   b) How many liters of oxygen gas at STP are required to react with 65.3 g of aluminum in the production of aluminum oxide?

   c) Zinc metal reacts with chromium (III) nitrate in a single replacement reaction. How many grams of zinc are required to react with 425 mL of 0.25*M* $Cr(NO_3)_3$? First, write a balanced equation and draw a particulate level drawing for this reaction.

2. Naphthalene, used in moth balls is composed of 93.7% carbon and 6.3% hydrogen. (level 2)
   a) What is the empirical formula of naphthalene?
   b) If naphthalene has a molar mass of 128 g/mol, what is its molecular formula?

3. Nicotine contains 74.9% carbon, 8.7% hydrogen and 17.3% nitrogen. It is known that this compound contains two nitrogen atoms per molecule. What are the empirical and molecular formulas of nicotine? (level 3)

Mass Percent

4. In which of the following is the percent of chlorine in the compound approximately 51.8%? (level 2)

   a) $HClO_4$

   b) $HClO_3$

   c) $HClO_2$

   d) HClO

   e) HCl

5. When carbon-containing compounds are burned in a limited amount of air, some CO(g) is produced as well as CO_2 (g). A gaseous product mixture is 35.0 mass % CO and 65.0 mass % CO_2. What is the mass % C in the mixture? (level 3)

6. A mixture of morphine ($C_{17}H_{19}NO_3$) and an inert solid is analyzed by combustion with O_2. The unbalanced equation for the reaction of morphine with O_2 is: (level 3)

$$C_{17}H_{19}NO_3 + O_2 \rightarrow CO_2 + H_2O + NO_2$$

The inert solid does not react with O_2. If 4.000 g of the mixture yields 8.72 g of CO_2, calculate the percent morphine by mass in the mixture.

Theoretical Yield and Percent Yield:

7. Aspirin is obtained via the following reaction: (level 3)

$C_7H_6O_3 + C_4H_6O_3 \rightarrow C_9H_8O_4 + C_2H_4O_2$

What is the theoretical yield of aspirin ($C_9H_8O_4$) when 2.00 g of salicylic acid ($C_7H_6O_3$) is heated with 4.00 g of acetic anhydride ($C_4H_6O_3$)? If the actual yield of aspirin is 1.98 go, what is the percent yield of the reaction?

Hydrates:

8. When a hydrate of $CuSO_4$ is heated until all the water is removed, it loses approximately 44.1% of its mass. The formula of the hydrate is

a) $CuSO_4*2H_2O$

b) $CuSO_4*3H_2O$

c) $CuSO_4*5H_2O$

d) $CuSO_4*7H_2O$

e) $CuSO_4*11H_2O$

9. Narceine is a narcotic in opium. It crystallizes from water solution as a hydrate that contains 10.8 mass % water. If the molar mass of narceine hydrate is 499.52 g/mol, determine n in Narceine $\cdot$ *n* H_2O

Limiting Reactants:

$$2\ Fe(s) + \frac{3}{2}\ O_2(g) \rightarrow Fe_2O_3(s) \quad \Delta Hf^\circ = -824\ kJ\ mol^{-1}$$

10. Iron reacts with oxygen to produce iron(III) oxide as represented above. A 75.0 g sample of Fe*(s)* is mixed with 11.5 L of O_2*(g)* at 2.66 atm and 298 K.

a) Calculate the number of moles of each of the following before the reaction occurs.

(i) Fe*(s)*

(ii) O_2*(g)*

b) Identify the limiting reactant when the mixture is heated to produce Fe_2O_3. Support your answer with calculations.

c) Calculate the number of moles of Fe_2O_3 produced when the reaction proceeds to completion.

Lab Questions:

11. A 101.3-mg sample of an organic compound containing chlorine is combusted in pure O_2 and the volatile gases collected in absorbent traps. The trap for CO_2 increases in mass by 167.6 mg and the trap for H_2O shows a 13.7-mg increase. A second sample of 121.8 mg is treated with concentrated HNO_3 producing Cl_2, which subsequently reacts with Ag^+, forming 262.7 mg of AgCl. Determine the compound's composition, as well as its empirical formula.

12. The purity of a pharmaceutical preparation of sulfanilamide, $C_6H_4N_2O_2S$, is determined by oxidizing sulfur to SO_2 and bubbling it through H_2O_2 to produce H_2SO_4. Assume that sulfanilamide and H_2SO_4 react in a 1:1 mole ratio . The acid is titrated to the bromothymol blue end point with a standard solution of NaOH. Calculate the purity of the preparation given that a 0.5136-g sample requires 48.13 mL of 0.1251 M NaOH.

Answers

1) a. $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

12.35 g Zn	1 mol Zn	2 mol HCl	1 L	1000 mL
	65.39 g	1 mol Zn	3.00 mol HCl	1 L

= 125.9 M HCl

b. $3O_2 + 4Al \rightarrow 2Al_2O_3$

65.3 g Al	1 mol Al	3 mol O_2	22.4 L
	26.98 g	4 mol Al	1 mol

= 40.7 L O_2

c. $3Zn + 2Cr(NO_3)_3 \rightarrow 2Cr^{+3} + 3Zn(NO_3)_2$

.25 M * .425 L = .11 moles

.11 moles	3 mol Zn	65.39 g
	2 mol $Cu(NO_3)_3$	1 mol Zn

= 11 g Zn

2. C = 93.7g/12.011g= 7.80 mol
H= 6.3 g/1.01 g = 6.2 mol

C= 7.80/6.2 =1.25 H=6.2/6.2=1.0
C*4= 1.25*4 = 5 H*4=1 * 4= 4
C_5 H_4

a. C_5H_4
b. 128/64 = 2 -----> $2(C_5H_4) = C_{10}H_8$

3. C_5H_7N; $C_{10}H_{14}N_2$

4. C because $HClO_2$= 68.5 g/mol
Cl=35.5 g/mol -→ (35.5 g/68.5 g) * 100 = 51.8%

5. *32.7% C*
6. 83.1%
7. $C_7H_6O_3$ = 2.00 g/138.08 g = .0145 mol ←Limiting Reactant

$C_4H_6O_3$ = 4.00 g/ 102.04 g = .0392 mol

0.0145 mol	1	180.1 g
	1	1mol $C_9H_8O_4$

= 2.61 g(Theoretical yield)

(1.98 g/ 2.61 g) * 100 = 75.9% yield

8. 44.1g H_2O/ 18.02 g =2.45 mol H_2O
55.9 g $CuSO_4$/ 159.61 g = 0.350 mol $CuSO_4$
2.45 mol / .350 mol = 7 d

9. *n = 3*

10. a) (i) $75.0 \text{ g Fe} \times \frac{1 \text{ mol}}{55.85 \text{ g}} = 1.34 \text{ mol Fe}$

(ii) PV = nRT, $n = \frac{PV}{RT}$

$$\frac{(2.66 \text{ atm})(11.5 \text{ L})}{(0.0821 \frac{\text{L atm}}{\text{mol K}})(298 \text{ K})} = 1.25 \text{ mol } O_2$$

b) Fe; $1.34 \text{ mol Fe} \times \frac{\frac{3}{2} \text{ mol } O_2}{2 \text{ mol Fe}} = 1.01 \text{ mol } O_2$

excess O_2, limiting reagent is Fe

c) $1.34 \text{ mol Fe} \times \frac{1 \text{ mol } Fe_2O_3}{2 \text{ mol Fe}} = 0.671 \text{ mol } Fe_2O_3$

11. A conservation of mass requires that all the carbon in the organic compound must be in the CO_2 produced during combustion; thus

$$167.6\text{mgCO2}\times\frac{1\text{gCO2}}{1000\text{mgCO2}}\times\frac{1\text{molC}}{44.011\text{gCO2}}\times\frac{12.011\text{gC}}{\text{molC}}\times\frac{1000\text{mgC}}{\text{gC}}=45.74\text{mgC}$$

$$\frac{45.74\text{mgC}}{101.3\text{mgsample}}\times 100=45.15\%\text{w/w C}$$

Using the same approach for hydrogen and chlorine, we find that

$$13.7\text{mgH2O}\times\frac{1\text{gH2O}}{1000\text{mgH2O}}\times\frac{2\text{molH}}{18.015\text{gH2O}}\times\frac{1.008\text{gH}}{\text{molH}}\times\frac{1000\text{mgH}}{\text{gH}}=1.533\text{mgH}$$

$$\frac{1.533\text{mgH}}{101.3\text{mgsample}}\times 100=1.51\%\text{w/w H}$$

$$262.7\text{mgAgCl}\times\frac{1\text{gAgCl}}{1000\text{mgAgCl}}\times\frac{1\text{molCl}}{143.32\text{gAgCl}}\times\frac{35.453\text{gCl}}{\text{molCl}}\times\frac{1000\text{mgCl}}{\text{gCl}}=64.98\text{mgCl}$$

$$\frac{64.98\text{mgCl}}{121.8\text{mgsample}}\times 100=53.35\%\text{w/w Cl}$$

Adding together the weight percents for C, H, and Cl gives a total of 100.01%; thus, the compound contains only these three elements. To determine the compound's empirical formula we note that a gram of sample contains 0.4515 g of C, 0.0151 g of H and 0.5335 g of Cl. Expressing each element in moles gives 0.0376 moles C, 0.0150 moles H and 0.0150 moles Cl. Hydrogen and chlorine are present in a 1:1 molar ratio. The molar ratio of C to moles of H or Cl is

$$\frac{\text{molesC}}{\text{molesH}}=\frac{\text{molesC}}{\text{molesCl}}=\frac{0.0376}{0.0150}=2.51\approx 2.5$$

EF:$C_5H_2Cl_2$.

12. $H2SO4(aq)+2OH-(aq)\rightarrow 2H2O(l)+SO2-4(aq)$

Using the titration results, there are $0.1251 \text{ M NaOH}\times 0.04813 \text{ L NaOH}=6.021\times 10-3 \text{ mol NaOH}$

$$6.021\times 10-3 \text{ mol NaOH}\times\frac{1 \text{ mol H2SO4}}{2 \text{ mol NaOH}}=3.010\times 10-3 \text{ mol H2SO4}$$

produced by bubbling SO_2 through H_2O_2. Because all the sulfur in H_2SO_4 comes from the sulfanilamide, we can use a conservation of mass to determine the amount of sulfanilamide in the sample.

$$3.010\times 10-3 \text{ mol H2SO4}\times\frac{1 \text{ mol S}}{\text{mol H2SO4}}\times\frac{1 \text{ mol C6H4N2O2S}}{\text{mol S}}\times\frac{168.18 \text{ g C6H4N2O2S}}{\text{mol C6H4N2O2S}}$$

$$=0.5062 \text{ g C6H4N2O2S}$$

$$\frac{0.5062 \text{ g C6H4N2O2S}}{0.5136 \text{ g sample}}\times 100=98.56\% \text{ w/w C6H4N2O2S}$$