

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. [See SP 2.2, 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 milliliters of a 3.00M HCl are required to react with 12.35 g of zinc? Remember molar volume 22.4L = 1 mol 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 0.25M Cr(NO₃)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) HClO₄
- b) HClO₃
- c) HClO₂
- 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 CO₂ (g). A gaseous product mixture is 35.0 mass % CO and 65.0 mass % CO₂. What is the mass % C in the mixture? (level 3)
6. A mixture of morphine (C₁₇H₁₉NO₃) and an inert solid is analyzed by combustion with O₂. The unbalanced equation for the reaction of morphine with O₂ is: (level 3)
- $$\text{C}_{17}\text{H}_{19}\text{NO}_3 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{NO}_2$$
- The inert solid does not react with O₂. If 4.000 g of the mixture yields 8.72 g of CO₂, calculate the percent morphine by mass in the mixture.

Theoretical Yield and Percent Yield:

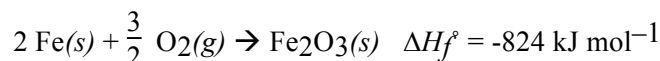
7. Aspirin is obtained via the following reaction: (level 3)
- $$\text{C}_7\text{H}_6\text{O}_3 + \text{C}_4\text{H}_6\text{O}_3 \rightarrow \text{C}_9\text{H}_8\text{O}_4 + \text{C}_2\text{H}_4\text{O}_2$$

What is the theoretical yield of aspirin (C₉H₈O₄) when 2.00 g of salicylic acid (C₇H₆O₃) is heated with 4.00 g of acetic anhydride (C₄H₆O₃)? If the actual yield of aspirin is 1.98 g, what is the percent yield of the reaction?

Hydrates:

8. When a hydrate of CuSO₄ is heated until all the water is removed, it loses approximately 44.1% of its mass. The formula of the hydrate is
- a) CuSO₄·2H₂O
 - b) CuSO₄·3H₂O
 - c) CuSO₄·5H₂O
 - d) CuSO₄·7H₂O
 - e) CuSO₄·11H₂O
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 · n H₂O

Limiting Reactants:



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 O₂(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) O₂(g)
 - b) Identify the limiting reactant when the mixture is heated to produce Fe₂O₃. Support your answer with calculations.
 - c) Calculate the number of moles of Fe₂O₃ 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 O₂ and the volatile gases collected in absorbent traps. The trap for CO₂ increases in mass by 167.6 mg and the trap for H₂O shows a 13.7-mg increase. A second sample of 121.8 mg is treated with concentrated HNO₃ producing Cl₂, 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



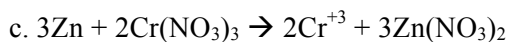
12.35 g Zn	1 mol Zn	2 mol HCl	1 L	1000 mL
	65.39 g	1 mol Zn	3.00 mol HCl	1 L

= 125.9 M HCl



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



.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. $C = 93.7g / 12.011g = 7.80 \text{ mol}$

$H = 6.3 g / 1.01 g = 6.2 \text{ mol}$

$C = 7.80 / 6.2 = 1.25$

$C * 4 = 1.25 * 4 = 5$

C_5

$H = 6.2 / 6.2 = 1.0$

$H * 4 = 1 * 4 = 4$

H_4

a. C_5H_4

b. $128 / 64 = 2 \rightarrow 2(C_5H_4) = C_{10}H_8$

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

4. C because $HClO_2 = 68.5 \text{ g/mol}$

$Cl = 35.5 \text{ g/mol} \rightarrow (35.5 g / 68.5 g) * 100 = 51.8\%$

5. 32.7% C

6. 83.1%

7. $C_7H_6O_3 = 2.00 g / 138.08 g = .0145 \text{ mol}$ ← Limiting Reactant

$C_4H_6O_3 = 4.00 g / 102.04 g = .0392 \text{ mol}$

0.0145 mol	1	180.1 g
	1	1 mol $C_9H_8O_4$

= 2.61 g (Theoretical yield)

$(1.98 g / 2.61 g) * 100 = 75.9\% \text{ yield}$

$$\begin{aligned}
 8. \quad & 44.1 \text{ g H}_2\text{O} / 18.02 \text{ g} = 2.45 \text{ mol H}_2\text{O} \\
 & 55.9 \text{ g CuSO}_4 / 159.61 \text{ g} = 0.350 \text{ mol CuSO}_4 \\
 & 2.45 \text{ mol} / 0.350 \text{ mol} = 7 \quad \boxed{d}
 \end{aligned}$$

$$9. \quad n = 3$$

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

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

$$\frac{(2.66 \text{ atm})(11.5 \text{ L})}{(0.0821 \frac{\text{L atm}}{\text{mol K}})(298 \text{ K})} = 1.25 \text{ mol O}_2$$

$$\text{b) } \text{Fe}; 1.34 \text{ mol Fe} \cdot \frac{\frac{3}{2} \text{ mol O}_2}{2 \text{ mol Fe}} = 1.01 \text{ mol O}_2$$

excess O₂, limiting reagent is Fe

$$\text{c) } 1.34 \text{ mol Fe} \cdot \frac{1 \text{ mol Fe}_2\text{O}_3}{2 \text{ mol Fe}} = 0.671 \text{ mol Fe}_2\text{O}_3$$

11. A conservation of mass requires that all the carbon in the organic compound must be in the CO₂ produced during combustion; thus

$$\begin{aligned}
 167.6 \text{ mg CO}_2 \times 1 \text{ g CO}_2 / 1000 \text{ mg CO}_2 \times 1 \text{ mol C} / 12.01 \text{ g C} &= 1.40 \times 10^{-3} \text{ mol C} \\
 1.40 \times 10^{-3} \text{ mol C} \times 1000 \text{ mg C} / \text{g C} &= 13.7 \text{ mg C} \\
 13.7 \text{ mg C} / 101.3 \text{ mg sample} \times 100 &= 13.5\% \text{ w/w C}
 \end{aligned}$$

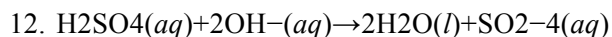
Using the same approach for hydrogen and chlorine, we find that

$$\begin{aligned}
 13.7 \text{ mg H}_2\text{O} \times 1 \text{ g H}_2\text{O} / 1000 \text{ mg H}_2\text{O} \times 2 \text{ mol H} / 2.016 \text{ g H} &= 1.35 \times 10^{-3} \text{ mol H} \\
 1.35 \times 10^{-3} \text{ mol H} \times 1000 \text{ mg H} / \text{g H} &= 1.35 \text{ mg H} \\
 1.35 \text{ mg H} / 101.3 \text{ mg sample} \times 100 &= 1.33\% \text{ w/w H} \\
 262.7 \text{ mg AgCl} \times 1 \text{ g AgCl} / 1000 \text{ mg AgCl} \times 1 \text{ mol Cl} / 143.32 \text{ g Cl} &= 1.83 \times 10^{-3} \text{ mol Cl} \\
 1.83 \times 10^{-3} \text{ mol Cl} \times 1000 \text{ mg Cl} / \text{g Cl} &= 183 \text{ mg Cl} \\
 183 \text{ mg Cl} / 121.8 \text{ mg sample} \times 100 &= 150\% \text{ w/w Cl}
 \end{aligned}$$

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

$$\text{moles C} / \text{moles H} = \text{moles C} / \text{moles Cl} = 0.0376 / 0.0150 = 2.51 \approx 2.5$$

EF: C₅H₂Cl₂.



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

$$6.021 \times 10^{-3} \text{ mol NaOH} \times 1 \text{ mol H}_2\text{SO}_4 / 2 \text{ mol NaOH} = 3.010 \times 10^{-3} \text{ mol H}_2\text{SO}_4$$

produced by bubbling SO₂ through H₂O₂. Because all the sulfur in H₂SO₄ comes from the sulfanilamide, we can use a conservation of mass to determine the amount of sulfanilamide in the sample.

$$\begin{aligned}
 3.010 \times 10^{-3} \text{ mol H}_2\text{SO}_4 \times 1 \text{ mol S} / \text{mol H}_2\text{SO}_4 \times 1 \text{ mol C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} / \text{mol S} &= 3.010 \times 10^{-3} \text{ mol C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} \\
 3.010 \times 10^{-3} \text{ mol C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} \times 168.18 \text{ g C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} / \text{mol C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} &= 0.5062 \text{ g C}_6\text{H}_4\text{N}_2\text{O}_2\text{S}
 \end{aligned}$$

$$0.5062 \text{ g C}_6\text{H}_4\text{N}_2\text{O}_2\text{S} / 0.5136 \text{ g sample} \times 100 = 98.56\% \text{ w/w C}_6\text{H}_4\text{N}_2\text{O}_2\text{S}$$