9 STOICHIOMETRY

PLANNING GUIDE

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9.1 The Arithmetic of Equations **Objectives** ▸ Calculate the amount of reactants required or product formed in a nonchemical process ▸ Interpret balanced chemical equations in terms of interacting moles, representative particles, masses, and gas volume at STP	**Discover It!** *How Much Can You Make,* p. 236 **Sample Problems** 9-1 through 9-2	**Review Module** (Chapters 9–12) ▸ Section Review 9.1 ▸ Practice Problems ▸ Quizzes **Laboratory Manual,** Experiment 12: *Quantitative Analysis*
9.2 Chemical Calculations **Objectives** ▸ Construct mole ratios from balanced chemical equations and apply these ratios in mole-mole stoichiometric calculations ▸ Calculate stoichiometric quantities from balanced chemical equations using units of moles, mass, representative particles, and volumes of gases at STP	**CHEMath** *Dimensional Analysis,* p. 243 **Link to Forensic Chemistry** *Chemistry in Crime Fighting,* p. 246 **Link to Agriculture** *Ammonia in the Nitrogen Cycle,* p. 247 **Small-Scale Lab** *Analysis of Baking Soda,* p. 251 **Sample Problems** 9-3 through 9-7	**Review Module** ▸ Section Review 9.2 ▸ Practice Problems ▸ Quizzes **Laboratory Recordsheet** 9-1 **Laboratory Manual,** Experiment 12: *Quantitative Analysis* **Small-Scale Chemistry Lab Manual** ▸ Experiment 10: *Titration: Determining How Much Acid is in a Solution* ▸ Experiment 11: *Weight Titrations: Measuring Molar Concentrations*
9.3 Limiting Reagent and Percent Yield **Objectives** ▸ Identify and use the limiting reagent in a reaction to calculate the maximum amount of product(s) produced and the amount of excess reagent ▸ Calculate theoretical yield, actual yield, or percent yield given appropriate information	**Mini Lab** *Limiting Reagents,* p. 259 **Chemistry Serving. . . the Environment** *Flat Tires for Recyclers,* p. 260 **Chemistry in Careers** *Quality Control Chemist,* p. 260 **Sample Problems** 9-8 through 9-10	**Review Module** ▸ Section Review 9.3 ▸ Practice Problems ▸ Interpreting Graphics ▸ Vocabulary Review 9 ▸ Chapter 9 Tests and Quizzes **Laboratory Recordsheet** 9-2 **Laboratory Manual,** Experiment 13: *Balanced Chemical Equations* **Laboratory Practicals** 9-1 and 9-2 **Solutions Manual for Chapter Reviews**

PLANNING GUIDE continued

TECHNOLOGY RESOURCES

Internet Connections
Within this chapter, you will see the chemSURF logo. If you and your students have access to the Internet, the following URL address will provide various Internet connections that are related to topics and features presented in this chapter.

http://www.chemsurf.com

You can also find relevant chapter material at **The Chemistry Place address: http://www.chemplace.com**

CD-ROMs

Chem ASAP! CD-ROM
- Chapter 9

ResourcePro CD-ROM
- Chapter 9

ActivChemistry CD-ROM
- Stoichiometry

Assessment Resources CD-ROM

Videodiscs and Videotapes

Chemistry Alive! Videodisc
- Carbide Cannon

Overhead Transparencies
- #16: Formation of Ammonia
- #17: Stoichiometric Calculations
- #18: Limiting Reagents

PLANNING FOR ACTIVITIES

STUDENT EDITION

Discover It! p. 236
- metal paper clips
- vinyl-coated paper clips
- plastic sandwich bags

Small-Scale Lab, p. 251
- baking soda
- soda straws
- plastic cups
- pipettes of HCl, NaOH, and thymol blue
- balances

Mini Lab p. 259
- graduated cylinders
- balances
- 250-mL Erlenmeyer flasks
- rubber balloons
- magnesium ribbons
- hydrochloric acid

TEACHER'S EDITION

Teacher Demo, p. 240
- 2 tsp lemon juice
- sweetener
- one small bottle of carbonated water
- small water cups

Teacher Demo, p. 241
- mass of a strip of Mg approx. 2.5 cm to 3.5 cm long
- 50 mL of 1*M* HCl(*aq*)
- 100-mL beaker

Teacher Demo, p. 245
- prepared 0.1*M* solutions of potassium iodide and lead (II) nitrate
- 50.0 mL of $Pb(NO_3)_2$
- 150 mL of KI
- two 250-mL beakers

Teacher Demo, p. 253
- 15 plastic bottles
- 30 plastic caps to fit bottles
- 6 containers to hold 5 caps each

Activity, p. 257
- 3 Styrofoam™ cups for each group
- thermometer
- 100 mL of 1.0*M* HCl
- 200 mL of 1.0*M* NaOH
- safety goggles

ASSESSMENT

Student Edition
- Section Reviews 9.1–9.3
- Chapter 9 Review, pp. 261–264
- Alternative Assessment, p. 265

Technology
Chem ASAP! CD-ROM
- Assessment 9.1–9.3

Assessment Resources CD-ROM
- Chapter 9 Tests

Teacher's Resource Package
Review Module (Chap. 9–12)
- Vocabulary Review
- Chapter 9 Test A and Test B
- Chapter 9 Quizzes

Name ______________________ Class __________ Date __________

9.1 THE ARITHMETIC OF EQUATIONS

SECTION REVIEW

Objectives

- Calculate the amount of reactants required or product formed in a nonchemical process
- Interpret balanced chemical equations in terms of interacting moles, representative particles, masses, and gas volume at STP

Key Terms

- stoichiometry

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The coefficients of a balanced chemical equation indicate the relative number of ___1___ of reactants and products. All stoichiometric calculations begin with a ___2___. Only ___3___ and ___4___ are conserved in every reaction; moles, volumes, and representative particles may not be.

In solving stoichiometric problems, conversion factors relating moles of reactants to ___5___ of products are used.

If you assume ___6___, the equation also tells you about the volume of gases.

1. ________________
2. ________________
3. ________________
4. ________________
5. ________________
6. ________________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 7. The coefficients in a balanced chemical equation can be used to form mole ratios relating reactants to products.

________ 8. The coefficients in a balanced chemical equation tell the relative volumes of reactants and products, expressed in any suitable unit of volume.

________ 9. To calculate the mass of a molecule in grams, you can use the molar mass and Avogadro's number.

Name ______________________ Class __________ Date __________

______ 10. Because the mass of the reactants equals the mass of the products of a reaction, the number of moles will be conserved.

______ 11. If the ratio of molecules in the reaction $2A_2 + B_2 \rightarrow 2A_2B$ is 2:1:2, we can predict that when 4 molecules of A_2 react with 2 molecules B_2, to produce 4 molecules of A_2B.

______ 12. One mole of any gas occupies a volume of 22.4 L.

Part C Matching

Match each description in Column B to the correct term in Column A.

	Column A	Column B
______	13. stoichiometry	a. Avogadro's number
______	14. product	b. the calculations of quantities in chemical reactions
______	15. coefficient	c. STP
______	16. 6.02×10^{23}	d. a substance formed in a chemical reaction
______	17. 0° C, 101.3 kPa	e. mole ratio
______	18. 2 moles O_2/4 moles H_2O	f. gives the relative number of molecules involved in a reaction

Part D Questions and Problems

Answer the following in the space provided. Show your work.

19. Interpret the following equation using moles, molecules, and volumes (assume STP). Compare the mass of the reactants to the mass of the product.

$$2N_2(g) + 3O_2(g) \rightarrow 2N_2O_3(g)$$

20. How many moles of chlorine gas will be required to react with sufficient iron to produce 14 moles of iron(III) chloride?

$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(g)$$

Name ______________________ Class ______________ Date ______________

9.2 CHEMICAL CALCULATIONS

SECTION REVIEW

Objectives

- Construct mole ratios from balanced chemical equations and apply these ratios in mole-mole stoichiometric calculations
- Calculate stoichiometric quantities from balanced chemical equations using units of moles, mass, representative particles, and volumes of gases at STP

Key Equations

- mole-mole relationship used in every stoichiometric calculation:

$$aG \longrightarrow bW$$

(given quantity) (wanted quantity)

- $$x \text{ mol } G \times \frac{b \text{ mol } W}{a \text{ mol } G} = \frac{xb}{a} \text{ mol } W$$

Given Mole Ratio Calculated

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Mole ratios from balanced equations may be used to solve problems with other units such as numbers of ___1___ and ___2___ of gases at STP. The ___3___ from the balanced equation are used to write conversion factors called ___4___. These conversion factors are used to calculate the numbers of moles of ___5___ from a given number of moles of ___6___. In mass-mass calculations, the molar mass is used to convert mass to ___7___.

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________
6. ______________________
7. ______________________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 8. In mass-mass calculations, the molar mass is used to convert mass to moles.

________ 9. The mole ratio 2 mol HF/1 mole SnF_2 can be used to determine the mass of SnF_2 produced according to the equation: $Sn(s) + 2HF(g) \rightarrow SnF_2(s) + H_2(g)$

______ **10.** In a volume-volume problem, the 22.4 L/mol factors always cancel out.

______ **11.** In stoichiometric problems, volume is expressed in terms of liters.

______ **12.** For a mass-mole problem, the first conversion from mass to moles is skipped.

______ **13.** For a mass-mass problem, the first conversion is from moles to mass.

______ **14.** Because mole ratios from balanced equations are exact numbers, they do not enter into the determination of significant figures.

Part C Matching

Match each conversion problem in Column A to the correct conversion factors in Column B.

Column A	Column B
______ **15.** moles $O_2 \rightarrow$ grams O_2	**a.** molecules $\times \frac{\text{mol}}{6.02 \times 10^{23}\text{ molecules}} \times \frac{18.0\text{ g}}{\text{mol}}$
______ **16.** liters $SO_2 \rightarrow$ grams SO_2 at STP	**b.** liters $\times \frac{\text{mol}}{22.4\text{ L}} \times \frac{64.1\text{ g}}{\text{mol}}$
______ **17.** molecules He $\rightarrow$ liters He(g) at STP	**c.** mol $\times \frac{32.0\text{ g}}{\text{mol}}$
______ **18.** grams Sn $\rightarrow$ molecules Sn	**d.** molecules $\times \frac{\text{mol}}{6.02 \times 10^{23}\text{molecules}} \times \frac{22.4\text{ L}}{\text{mol}}$
______ **19.** molecules $H_2O \rightarrow$ grams H_2O	**e.** grams $\times \frac{\text{mol}}{119\text{ g}} \times \frac{6.02 \times 10^{23}\text{ molecules}}{\text{mol}}$

Part D Questions and Problems

Answer the following questions in the space provided.

20. How many liters of carbon monoxide (at STP) are needed to react with 4.8 g of oxygen gas to produce carbon dioxide?

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

21. What mass of ammonia, NH_3, is necessary to react with 2.1×10^{24} molecules of oxygen?

$$4NH_3(g) + 7O_2(g) \rightarrow 6H_2O(g) + 4NO_2(g)$$

Name ______________________ Class ____________ Date ____________

9.3 LIMITING REAGENT AND PERCENT YIELD

SECTION REVIEW

Objectives

- Identify and use the limiting reagent in a reaction to calculate the maximum amount of product(s) produced and the amount of excess reagent
- Calculate theoretical yield, actual yield, or percent yield given the appropriate information

Key Terms

- limiting reagent
- excess reagent
- theoretical yield
- actual yield
- percent yield

Key Equations

- $\text{percent yield} = \dfrac{\text{actual yield}}{\text{theoretical yield}} \times 100$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Whenever quantities of two or more reactants are given in a stoichiometric problem, you must identify the ___1___. This is the reagent that is completely ___2___ in the reaction. The amount of limiting reagent determines the amount of ___3___ that is formed.

When an equation is used to calculate the amount of product that will form during a reaction, the value obtained is the ___4___. This is the ___5___ amount of product that could be formed from a given amount of reactant. The amount of product that forms when the reaction is carried out in the laboratory is called the ___6___.

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 7. Normally, the actual yield in a chemical reaction will be equal to or less than the theoretical yield.

________ 8. The actual yield of a chemical reaction can be calculated using mole ratios.

_______ **9.** The amount of product can be determined from the amount of excess reagent.

_______ **10.** The percent yield of a product is 100%.

_______ **11.** If you had 100 steering wheels, 360 tires, and enough of every other part needed to assemble a car, the limiting reagent would be tires.

_______ **12.** The theoretical yield is the maximum amount of product that could be formed.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_______ **13.** actual yield	**a.** the ratio of the actual yield to the theoretical yield $\times$ 100
_______ **14.** limiting reagent	**b.** the amount of product formed when a reaction is carried out in the laboratory
_______ **15.** theoretical yield	**c.** the reactant that determines the amount of product that can be formed in a reaction
_______ **16.** percent yield	**d.** a quantity of a reactant left after the limiting reagent is used up
_______ **17.** excess reagent	**e.** the maximum amount of product that can be formed during a reaction

Part D Questions and Problems

Answer the following in the space provided.

18. a. What is the limiting reagent when 3.1 mol of SO_2 react with 2.7 mol of O_2 according to the equation:

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

b. Calculate the maximum amount of product that can be formed and the amount of unreacted excess reagent.

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9 STOICHIOMETRY

PRACTICE PROBLEMS

In your notebook, solve the following problems.

SECTION 9.1 THE ARITHMETIC OF EQUATIONS

Use the 3-step problem-solving approach you learned in Chapter 4.

1. An apple pie needs 10 large apples, 2 crusts (top and bottom), and 1 tablespoon of cinnamon. Write a balanced equation that fits this situation. How many apples are needed to make 25 pies?
2. Two moles of potassium chloride and three moles of oxygen are produced from the decomposition of two moles of potassium chlorate, $KClO_3(s)$. Write the balanced equation. How many moles of oxygen are produced from twelve moles of potassium chlorate?
3. Using the equation from problem 2, how many moles of oxygen are produced from 14 moles of potassium chlorate?
4. Two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. How many molecules of water are produced from 2.0×10^{23} molecules of oxygen? How many moles of water are produced from 22.5 moles of oxygen?

SECTION 9.2 CHEMICAL CALCULATIONS

1. Calculate the number of moles of hydrogen chloride produced from 10 moles of hydrogen.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

2. Calculate the number of moles of chlorine needed to form 14 moles of iron(III)chloride.

$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$$

3. Calculate the number of grams of nitrogen dioxide that are produced from 4 moles of nitric oxide.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

4. Calculate the mass of oxygen produced from the decomposition of 75.0 g of potassium chlorate.

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

5. Calculate the mass of silver needed to react with chlorine to produce 84 g of silver chloride. *Hint:* Write a balanced equation first.
6. How many liters of carbon monoxide at STP are needed to react with 4.80 g of oxygen gas to produce carbon dioxide?

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

7. Calculate the number of liters of oxygen gas needed to produce 15.0 liters of dinitrogen trioxide. Assume all gases are at the same conditions of temperature and pressure.

$$2N_2(g) + 3O_2(g) \rightarrow 2N_2O_3(g)$$

8. A volume of 7.5 L of hydrogen gas at STP was produced from the single-replacement reaction of zinc with nitric acid. Calculate the mass of zinc needed for this reaction.

SECTION 9.3 LIMITING REAGENT AND PERCENT YIELD

1. How many moles of water can be made from 4 moles of oxygen gas and 16 moles of hydrogen gas? What is the limiting reagent?
2. Calculate the mass of water produced from the reaction of 24.0 g of H_2 and 160.0 g of O_2. What is the limiting reagent?
3. The burning of 18.0 g of carbon produces 55.0 g of carbon dioxide. What is the theoretical yield of CO_2? Calculate the percent yield of CO_2.
4. Calculate the percent yield of $Cl_2(g)$ in the electrolytic decomposition of hydrogen chloride if 25.8 g of HCl produces 13.6 g of chlorine gas.
5. One method for reclaiming silver metal from silver chloride results in a 94.6% yield. Calculate the actual mass of silver that can be produced in this reaction if 100.0 g of silver chloride is converted to silver metal.

$$2AgCl(s) \rightarrow 2Ag(s) + Cl_2(g)$$

6. What is the actual amount of magnesium oxide produced when excess carbon dioxide reacts with 42.8 g of magnesium metal? The percent yield of MgO(*s*)for this reaction is 81.7%.

$$2Mg(s) + CO_2(g) \rightarrow 2MgO(s) + C(s)$$

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9 INTERPRETING GRAPHICS

USE WITH SECTION 9.3

Preparation of Salicylic Acid

Student #1

mass of flask	37.820 g
flask + $C_7H_6O_3$	39.961 g
volume of $C_4H_6O_3$	5.0 mL
mass of watch glass	22.744 g
watch glass + $C_9H_8O_4$	24.489 g

Student #2

mass of flask	37.979 g
flask + $C_7H_6O_3$	40.010 g
volume of $C_4H_6O_3$	5.0 mL
mass of watch glass	21.688 g
watch glass + $C_9H_8O_4$	24.197 g

Two students prepared aspirin according to the following reaction in which acetic anhydride, $C_4H_6O_3$, reacts with salicylic acid, $C_7H_6O_3$, to form aspirin, $C_9H_8O_4$, and acetic acid, $C_2H_4O_2$.

$$C_7H_6O_3 + C_4H_6O_3 \rightarrow C_9H_8O_4 + C_2H_4O_2$$

The procedure involved heating the reaction mixture in a water bath for 15 minutes at 75 °C, not to exceed 80 °C. The mixture was removed from the water bath and distilled water was added to decompose any unreacted acetic anhydride. The mixture was then placed in an ice bath for 5 minutes to facilitate the formation of aspirin crystals. The aspirin crystals were collected using filtration. The aspirin crystals were dried and then transferred to a watch glass and massed.

Because their grades were partially based on accuracy, both students used their very best lab technique. Which student got the better grade and why?

1. Determine the molar masses of:

   a. acetic anhydride, $C_4H_6O_3$. ______________

   b. salicylic acid, $C_7H_6O_3$. ______________

   c. aspirin, $C_9H_8O_4$. ______________

2. How many moles of salicylic acid were added to the reaction mixture?

Student 1 ______ Student 2 ______

3. Given the density of acetic anhydride to be 1.05 g/mL, what was the mass of the acetic anhydride added to the reaction? How many moles of acetic acid were added?

Student 1 ______ Student 2 ______

______ ______

4. According to the mole ratios in the given reaction, what is the limiting reagent in this reaction?

______

5. What is the theoretical yield, in grams, of aspirin in each reaction?

Student 1 ______ Student 2 ______

6. What was the actual yield, in grams, of aspirin in each reaction?

Student 1 ______ Student 2 ______

7. What was the percent yield in each reaction?

Student 1 ______ Student 2 ______

8. Evaluate your answers. Which student got the better grade and why?

______

______

Name ____________________ Class __________ Date __________

9 VOCABULARY REVIEW

Match the correct vocabulary term to each numbered statement Write the letter of the correct term on the line provided.

	Column A	Column B
______	1. the starting materials in an equation	a. a mole
______	2. the amount of substance in grams or moles	b. stoichiometry
______	3. the maximum amount of product that could be formed in a reaction	c. mass-mass calculations
______	4. Avogadro's number of particles	d. reactants
______	5. the substance completely used up in a chemical reaction	e. excess reagent
______	6. the ratio of how much product is produced compared to how much is expected	f. theoretical yield
______	7. the calculations of quantities in a chemical reaction	g. limiting reagent
______	8. the actual amount of product in a chemical reaction	h. quantity
______	9. the substance left over after a reaction takes place	i. actual yield
______	10. determining the mass of products from the given mass of reactants	j. percent yield

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9 STOICHIOMETRY

Quiz for CHAPTER 9

Fill in the word(s) that will make each statement true.

1. The __1__ in a balanced chemical equation also reveal the mole ratios of the substances involved. 1. ______________ *9.1*

2. The number of moles of a product can be calculated from a given number of moles of __2__. 2. ______________ *9.1*

3. In mass-mass calculations, the gram formula mass is used to convert mass to __3__. 3. ______________ *9.2*

4 In addition to mass, the only quantity conserved in every chemical reaction is __4__. 4. ______________ *9.2*

5. According to the equation: 5. ______________ *9.2*

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g),$$

22.4 L of O_2 will react with __5__ L of NO at STP.

Classify each of these statements as always true, AT, sometimes true, ST, or never true, NT.

________ 6. The excess reagent determines the amount of product formed in a reaction. *9.3*

________ 7. In the reaction: $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, using 4 moles of CO to react with 1 mole of O_2 will result in the production of 4 moles of CO_2. *9.3*

________ 8. To calculate the percent yield of a reaction, you use the relationship: *9.3*

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

________ 9. The total mass of the excess reagent and the limiting reagent is equal to the total mass of the products. *9.3*

________ 10. The actual yield is equal to the theoretical yield. *9.3*

Name ________________ Class ________ Date ________

9 STOICHIOMETRY
CHAPTER TEST A

A. Matching

Match each description in Column B with the correct term in Column A. Write the letter of the correct definition in the blank provided.

	Column A	Column B
______	1. actual yield	a. the ratio of the actual yield to the theoretical yield
______	2. limiting reagent	b. the amount of product formed when a reaction is carried out in the laboratory
______	3. theoretical yield	c. the reactant that determines the amount of product that can be formed in a reaction
______	4. stoichiometry	d. a quantity of a reactant that is more than enough to react with a limiting reagent
______	5. percent yield	e. the calculated amount of product that might be formed during a reaction
______	6. excess reagent	f. the calculation of quantities in chemical equations

B. Multiple Choice

Write the letter of the best answer in the blank.

______ 7. Which of these expressions is an *incorrect* interpretation of the balanced equation?

$$2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$$

a. 2 atoms S + 3 molecules $O_2 \rightarrow$ 2 molecules SO_3
b. 2 g S + 3 g $O_2 \rightarrow$ 2 g SO_3
c. 2 mol S + 3 mol $O_2 \rightarrow$ 2 mol SO_3
d. none of the above

______ 8. In a chemical reaction, the mass of the products:
a. is less than the mass of the reactants.
b. is greater than the mass of the reactants.
c. is equal to the mass of the reactants.
d. has no relationship to the mass of the reactants.

______ 9. How many liters of oxygen are required to react completely with 1.2 liters of hydrogen to form water?

$$2H_2(g) + O_2(g) \rightarrow 2H_2(g)$$

a. 1.2 L
b. 0.6 L
c. 2.4 L
d. 4.8 L

______ **10.** How many molecules of NO_2 are produced when 2.0×10^{20} molecules of N_2O_4 are decomposed according to the equation:

$$N_2O_4(g) \rightarrow 2NO_2(g)$$

a. 4
b. 1.0×10^{20}
c. 2.0×10^{20}
d. 4.0×10^{20}

______ **11.** How many liters of $CO(g)$ at STP are produced when 68.0 g of $CaCO_3(s)$ is heated according to the equation:

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

a. 0.679 L
b. 15.2 L
c. 68.0 L
d. 30.4 L

______ **12.** A reaction that has been calculated to produce 60.0 g of $CuCl_2$ actually produces 50.0 g of $CuCl_2$. What is the percent yield?

a. 0.833%
b. 96.1%
c. 83.3%
d. 120%

______ **13.** When 0.2 mol of calcium is mixed with 880 g of water, 4.48 L of hydrogen gas forms (at STP). How would the amount of hydrogen produced change if the mass of water were decreased to 220 g?

a. Only one-half of the volume of hydrogen would be produced.
b. The volume of hydrogen produced would be the same.
c. The volume of hydrogen produced would double.
d. No hydrogen would be produced.

______ **14.** The equation for the complete combustion of methane is:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

To calculate the number of grams of CO_2 produced by the reaction of 29.5 g of CH_4 with O_2, the first conversion factor to use is:

a. $\frac{1 \text{ mol } CH_4}{16.0 \text{ g } CH_4}$
b. $\frac{2 \text{ mol } O_2}{1 \text{ mol } CO_2}$
c. $\frac{16.0 \text{ g } CH_4}{1 \text{ mol } CH_4}$
d. $\frac{29.5 \text{ g } CH_4}{2 \text{ mol } CO_2}$

______ **15.** In any chemical reaction the quantities that are conserved are:

a. the number of moles and the volumes.
b. the number of molecules and the volumes.
c. mass and number of atoms.
d. mass and moles.

Questions 16, 17, and 18 refer to the following equation:

$$3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(s) + 2NO(g) + 4H_2O(l)$$

______ **16.** Calculate the number of moles of water produced when 3.3 mol of $Cu(NO_3)_2$ are formed in the reaction.

a. 4.4 mol
b. 6.6 mol
c. 4.9 mol
d. 8.8 mol

______ **17.** How many grams of Cu would be needed to react with 2.0 mol HNO_3?

a. 95.3 g
b. 63.5 g
c. 47.6 g
d. 1.50 g

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______ 18. If you could drop 12 atoms of copper into a beaker containing nitric acid, how many molecules of NO would be produced?

a. 2
b. 4
c. 8
d. 12

C. Problems

Solve the following problems in the space provided. Show your work.

19. What is the limiting reagent when 49.84 g of nitrogen react with 10.7 g of hydrogen according to this balanced equation?

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

20. How many grams of CO are needed to react with an excess of Fe_2O_3 to produce 558 g Fe? The equation for the reaction is:

$$Fe_2O_3(s) + 3CO(g) \rightarrow 3CO_2(g) + 2Fe(s)$$

21. How many grams of butane (C_4H_{10}) must be burned in an excess of O_2 to produce 15.0 g of CO_2?

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$

22. a. If 4.0 g of H_2 are made to react with excess CO, how many grams of CH_3OH can theoretically be produced according to the following equation?

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

b. If 28.0 g of CH_3OH are actually produced, what is the percent yield?

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D. Essay

Write a short essay for the following.

23. What is the importance of the coefficients in a balanced chemical equation?

E. Additional Problems

Solve the following problems in the space provided. Show your work.

24. A 5.00×10^2 g sample of $Al_2(SO_4)_3$ is made to react with 450 g of $Ca(OH)_2$. A total of 596 g of $CaSO_4$ is produced. The balanced equation is:

$$Al_2(SO_4)_3(aq) + 3Ca(OH)_2(aq) \rightarrow 2Al(OH)_3(s) + 3CaSO_4(s)$$

a. What is the limiting reagent in this reaction?

b. How many moles of excess reagent are unreacted?

25. How many liters of O_2 are needed to react completely with 10.0 L of H_2S at STP according to the following reaction?

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$

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26. The decomposition of potassium chlorate gives oxygen gas according to the reaction:

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

How many grams $KClO_3$ are needed to produce 5.00 L of O_2 at STP?

27. Suppose that the reaction described in question 26 produces 4.80 L of O_2 in the laboratory. What is the percent yield?

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9 STOICHIOMETRY
CHAPTER TEST B

A. Matching

Match each term in Column B with the correct description in Column A. Write the letter of the correct term in the blank provided.

	Column A	Column B
______	1. the substance that determines the amount of product that can be formed in a reaction	a. percent yield
______	2. the amount of product that forms when a reaction is carried out in the laboratory	b. limiting reagent
______	3. the calculation of quantities in chemical equations	c. theoretical yield
______	4. the ratio of the actual yield to the theoretical yield expressed as a percent	d. stoichiometry
______	5. the substance that is present in enough quantity to react with a limiting reagent	e. actual yield
______	6. the maximum amount of products that could be formed from given amounts of reactants	f. excess reagent

B. Multiple Choice

Choose the best answer and write its letter in the blank.

______ 7. In a chemical reaction:

a. mass is conserved.
b. atoms are conserved.
c. moles are conserved.
d. both mass and atoms are conserved.

______ 8. Which of the following is a correct interpretation of this balanced equation?

$$2Al(s) + 3Pb(NO_3)_2(aq) \rightarrow 2Al(NO_3)_3(aq) + 3Pb(s)$$

a. 2 atoms Al + 3 molecules $Pb(NO_3)_2 \rightarrow$ 2 molecules $Al(NO_3)_3$ + 3 atoms of Pb
b. 2 grams Al + 3 grams $Pb(NO_3)_2 \rightarrow$ 2 grams $Al(NO_3)_3$ + 3 grams Pb
c. 2 moles Al + 3 moles $Pb(NO_3)_2 \rightarrow$ 2 moles $Al(NO_3)_3$ + 3 moles Pb
d. both a and c

______ 9. If 3.0 moles of HCl are consumed in the reaction below, how many moles of $FeCl_3$ are produced?

$$6HCl + Fe_2O_3 \rightarrow 2FeCl_3 + 3H_2O$$

a. 0.50 mol
b. 1.0 mol
c. 2.0 mol
d. 4.0 mol

________ **10.** Given the equation $2H_2O \rightarrow 2H_2 + O_2$, how many moles of H_2O would be required to produce 2.5 moles of O_2?
a. 2.0 mol **c.** 4.0 mol
b. 2.5 mol **d.** 5.0 mol

________ **11.** If 3.00 mol of $CaCO_3$ undergo decomposition to form CaO and CO_2, how many grams of CO_2 are produced?
a. 3.00 g **c.** 88.0 g
b. 44.0 g **d.** 132 g

________ **12.** If $CuO + H_2 \rightarrow Cu + H_2O$, how many moles of H_2O are produced when 240 grams of CuO react?
a. 1.0 mol **c.** 18 mol
b. 3.0 mol **d.** 54 mol

________ **13.** Given the balanced equation $16HCl + 2KMnO_4 \rightarrow 2KCl + 2MnCl_2 + 5Cl_2 + 8H_2O$, if 1.0 mol of $KMnO_4$ reacts, how many moles of H_2O are produced?
a. 0.50 mol **c.** 4.0 mol
b. 2.0 mol **d.** 8.0 mol

________ **14.** Based on the equation in question 13, how many grams of KCl are produced when 1.0 mol of $KMnO_4$ reacts?
a. 1.0 g **c.** 150 g
b. 75 g **d.** 158 g

________ **15.** If 110 grams of HCl are used in the reaction $6HCl + Fe_2O_3 \rightarrow 2FeCl_3 + 3H_2O$, how many moles of $FeCl_3$ are produced?
a. 1.0 mol **c.** 3.0 mol
b. 2.0 mol **d.** 6.0 mol

________ **16.** In the reaction $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$, how many grams of H_2SO_4 are required to produce 1.0 gram of H_2?
a. 1.0 g **c.** 49 g
b. 2.0 g **d.** 98 g

________ **17.** If 18 grams of carbon react with oxygen to produce carbon dioxide, how many molecules of oxygen would be required?
a. 1.5 molecules **c.** 9.0×10^{23} molecules
b. 48 molecules **d.** 3.2×10^{24} molecules

________ **18.** Given the reaction $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$, if 6.5 L of O_2 react at STP, how many liters of NO_2 are produced?
a. 6.5 L **c.** 26 L
b. 3.2 L **d.** 13 L

________ **19.** Given the reaction $Zn + 2HCl \rightarrow ZnCl_2 + H_2$, if 2.0 mol Zn and 5.0 mol HCl are allowed to react:
a. Zn is the limiting reagent. **c.** 1.0 mol of $ZnCl_2$ is produced.
b. HCl is the limiting reagent. **d.** 5.0 mol of H_2 is produced.

______ **20.** Once the reaction in question 19 is completed, how many moles of excess reactant remain?

a. 3.0 mol
c. 4.0 mol
b. 1.0 mol
d. 2.0 mol

______ **21.** Given the reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$, if 50.0 g of $CaCO_3$ react to produce 20.0 g of CO_2, what is the percent yield of CO_2?

a. 66.7 %
c. 90.9%
b. 40.0%
d. 250%

C. Problems

Solve the following problems in the space provided. Show your work.

22. Ammonia, NH_3, is a typical ingredient in household cleaners. It is produced through a combination reaction involving $N_2(g)$ and $H_2(g)$. If 12.0 mol of $H_2(g)$ react with excess $N_2(g)$, how many moles of ammonia are produced?

23. The compound tin(II) fluoride, or stannous fluoride, once was a common ingredient in toothpaste. It is produced according to the following reaction:

$$Sn(s) + 2HF(g) \rightarrow SnF_2(s) + H_2(g)$$

If 45.0 grams of HF react with Sn, how many grams of stannous fluoride are produced?

24. The combustion of methane, $CH_4(g)$, can be described by the following equation:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

If 150 moles of carbon dioxide are produced, what mass, in grams, of methane is required?

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25. If aluminum reacts with oxygen according to the following equation:

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

what mass, in grams, of the product would be produced if 625 mL of oxygen react at STP?

26. Given the following reaction:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g),$$

if 50.8 grams of $CaCO_3$ react to produce 26.4 grams of CaO, what is the percent yield of CaO?

D. Essay

Write a short essay for the following.

27. Based on the following general reaction, if 1.0 mole of A is allowed to react with 2.0 moles of B, which reactant is the limiting reactant and what amount of A_2B_3 can be produced?

$$2A + 3B \rightarrow A_2B_3$$

____

____

____

____

____

____

Name ______________________ Class ______________ Date ______________

E. Additional Problems

Solve the following problems in the space provided. Show your work.

28. In photosynthesis, plants use energy from the sun in combination with carbon dioxide and water to form glucose ($C_6H_{12}O_6$) and oxygen. If 4.50 moles of water react with carbon dioxide, what mass of glucose is produced?

29. Acetylene gas (C_2H_2) is used in welding and produces an extremely hot flame according to the reaction:

$$2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g)$$

If 5.00×10^4 g of acetylene burn completely, how many grams of carbon dioxide are produced?

30. Given the following reaction:

$$3H_2SO_4(aq) + Ca_3(PO_4)_2(s) \rightarrow 3CaSO_4(s) + 2H_3PO_4(aq),$$

if 1.25×10^5 kg of $H_2S)_4$ react, how many kilograms of H_3PO_4 are produced?

31. Ammonia and copper(II) oxide react according to the following:

$$2NH_3(g) + 3CuO(s) \rightarrow N_2(g) + 3Cu(s) + 3H_2O(g)$$

If 57.0 g of ammonia are combined with 290.0 g of copper(II) oxide:

a. Identify the limiting reactant.

b. How much of the excess reactant remains, in moles?

c. What mass of nitrogen gas is produced, in grams?

32. If ammonia reacts according to the following equation, how many kilograms of NO could be produced from 10.0 kg of NH_3 if the percent yield of NO is 80.0%?

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$

Section Review 9.1

Part A Completion

1. moles/molecules
2. balanced equation
3. mass/atoms
4. atoms/mass
5. moles
6. STP (standard temperature and pressure)

Part B True-False

7. AT
8. ST
9. AT
10. ST
11. AT
12. ST

Part C Matching

13. b
14. d
15. f
16. a
17. c
18. e

Part D Questions and Problems

19. moles $N_2 = 2$
moles $O_2 = 3$
moles $N_2O_3 = 2$
molecules $N_2 = 2$
molecules $O_2 = 3$
molecules $N_2O_3 = 2$
volume $N_2 = 2 \times 22.4\ L = 44.8\ L$
volume $O_2 = 3 \times 22.4\ L = 67.2\ L$
volume $N_2O_3 = 2 \times 22.4\ L = 44.8\ L$
$2\ mol\ N_2 = 56\ g$
$3\ mol\ O_2 = \underline{96\ g}$
mass reactants = 152 g
$2\ mol\ N_2O_3 = 152\ g$
mass product = 152 g

20. $14\ \cancel{mol\ FeCl_3} \times \frac{3\ mol\ Cl_2}{2\ \cancel{mol\ FeCl_3}} = 21\ mol\ Cl_2$

Section Review 9.2

Part A Completion

1. representative particles
2. volumes
3. coefficients
4. mole ratios
5. product/reactant
6. reactant/product
7. moles

Part B True-False

8. AT
9. NT
10. AT
11. ST
12. NT
13. NT
14. AT

Part C Matching

15. c
16. b
17. d
18. e
19. a

Part D Questions and Problems

20. $4.8\ \cancel{g\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{32.0\ \cancel{g\ O_2}} \times \frac{2\ \cancel{mol\ CO}}{1\ \cancel{mol\ O_2}} \times \frac{22.4\ L\ CO}{1\ \cancel{mol\ CO}} = 6.7\ L\ CO$

21. $2.1 \times 10^{24}\ \cancel{molecules\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{6.02 \times 10^{23}\ \cancel{molecules\ O_2}} \times \frac{4\ \cancel{mol\ NH_3}}{7\ \cancel{mol\ O_2}} \times \frac{17.0\ g\ NH_3}{1\ \cancel{mol\ NH_3}} = 33.9\ g\ NH_3$

Section 9.3

Part A Completion

1. limiting reagent
2. used up
3. product
4. theoretical yield
5. maximum
6. actual yield

Part B True-False

7. AT
8. NT
9. NT
10. ST
11. AT
12. AT

Part C Matching

13. b
14. c
15. e
16. a
17. d

Part D Questions and Problems

18. a. $3.1\ \cancel{mol\ SO_2} \times \frac{1\ mol\ O_2}{2\ \cancel{mol\ SO_2}}$
$= 1.6\ mol\ O_2$ needed
SO_2 is the limiting reagent.

b. $3.1\ \cancel{mol\ SO_2} \times \frac{2\ mol\ SO_3}{2\ \cancel{mol\ SO_2}}$
$= 3.1\ mol\ SO_3$ can be formed
$2.7\ mol\ O_2 - 1.6\ mol\ O_2$
$= 1.1\ mol\ O_2$ in excess

Practice Problems 9

Section 9.1

1. $10A + 2C + Ci \rightarrow A_{10}C_2Ci$

$$25\ A_{10}C_2Ci \times \frac{10A}{A_{10}C_2Ci} = 250 \text{ apples}$$

2. $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$

$$12 \text{ mol } KClO_3 \times \frac{3 \text{ mol } O_2}{2 \text{ mol } KClO_3} = 18 \text{ mol } O_2$$

3. $$14 \text{ mol } KClO_3 \times \frac{3 \text{ mol } O_2}{2 \text{ mol } KClO_3} = 21 \text{ mol } O_2$$

4. $2H_2(s) + O_2(g) \rightarrow 2H_2O(g)$

$$2.0 \times 10^{23} \text{ molecules } O_2 \times \frac{2 \text{ molecules } H_2O}{1 \text{ molecule } O_2}$$

$$= 4.0 \times 10^{23} \text{ molecules } H_2O$$

$$22.5 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} = 45.0 \text{ mol } H_2O$$

Section 9.2

1. $$10 \text{ mol } H_2 \times \frac{2 \text{ mol HCl}}{1 \text{ mol } H_2} = 20 \text{ mol HCl}$$

2. $$14 \text{ mol } FeCl_3 \times \frac{3 \text{ mol } Cl_2}{2 \text{ mol } FeCl_3} = 21 \text{ mol } Cl_2$$

3. $$4 \text{ mol NO} \times \frac{2 \text{ mol } NO_2}{2 \text{ mol NO}} \times \frac{46 \text{ g } NO_2}{1 \text{ mol } NO_2}$$

$$= 184 \text{ g } NO_2$$

4. $$75.0 \text{ g } KClO_3 \times \frac{1 \text{ mol } KClO_3}{122.6 \text{ g } KClO_3}$$

$$\times \frac{3 \text{ mol } O_2}{2 \text{ mol } KClO_3} \times \frac{32.0 \text{ g } O_2}{1 \text{ mol } O_2} = 29.4 \text{ g } O_2$$

5. $2Ag(s) + Cl(g) \rightarrow 2AgCl(s)$

$$84 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{43.5 \text{ g AgCl}} \times \frac{2 \text{ mol Ag}}{2 \text{ mol AgCl}}$$

$$\times \frac{108 \text{ g Ag}}{1 \text{ mol Ag}} = 63 \text{ g Ag}$$

6. $$4.80 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.0 \text{ g } O_2} \times \frac{2 \text{ mol CO}}{1 \text{ mol } O_2}$$

$$\times \frac{22.4 \text{ L CO}}{1 \text{ mol CO}} = 6.72 \text{ L CO}$$

7. $$15.0 \text{ L } N_2O_3 \times \frac{3 \text{ L } O_2}{2 \text{ L } N_2O_3} = 22.5 \text{ L } O_2$$

8. $Zn(s) + 2HNO_3 \rightarrow H_2(g) + Zn(NO_3)_2$

$$7.5 \text{ L } H_2 \times \frac{1 \text{ mol } H_2}{22.4 \text{ L } H_2} \times \frac{1 \text{ mol Zn}}{1 \text{ mol } H_2}$$

$$\times \frac{65.4 \text{ g Zn}}{1 \text{ mol Zn}} = 22 \text{ g Zn}$$

Section 9.3

1. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

$$4 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2}{1 \text{ mol } O_2} = 8 \text{ mol } H_2$$

$$16 \text{ mol } H_2 \times \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2} = 8 \text{ mol } O_2$$

Oxygen is the limiting reagent.

$$4 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} = 8 \text{ mol } H_2O \text{ formed}$$

2. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

$$160.0 \text{ g } O_2 \times \frac{1 \text{ mol } O_2}{32.0 \text{ g } O_2} \times \frac{2 \text{ mol } H_2}{1 \text{ mol } O_2}$$

$$= 10.0 \text{ mol } H_2 \text{ needed}$$

Oxygen is the limiting reagent.

$$5.00 \text{ mol } O_2 \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} \times \frac{18.0 \text{ g } H_2O}{1 \text{ mol } H_2O}$$

$$= 180 \text{ g } H_2O$$

3. $C(s) + O_2(g) \rightarrow CO_2(g)$

$$18.0 \text{ g C} \times \frac{1 \text{ mol C}}{12.0 \text{ g C}} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol C}}$$

$$\times \frac{44.0 \text{ g } CO_2}{1 \text{ mol } CO_2} = 66.0 \text{ g } CO_2$$

$$\text{percent yield} = \frac{55.0 \text{ g } CO_2}{66.0 \text{ g } CO_2} \times 100\% = 83.3\%$$

4. $2HCl(g) \rightarrow H_2(g) + Cl_2(g)$

$$25.8 \text{ g HCl} \times \frac{1 \text{ mol HCl}}{36.5 \text{ g HCl}} \times \frac{1 \text{ mol } Cl_2}{2 \text{ mol HCl}}$$

$$\times \frac{71.0 \text{ g } Cl_2}{1 \text{ mol } Cl_2} = 25.1 \text{ g } Cl_2$$

$$\text{percent yield} = \frac{13.6 \text{ g } Cl_2}{25.1 \text{ g } Cl_2} \times 100\% = 54.2\%$$

5. $$100.0 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{143.5 \text{ g AgCl}} \times \frac{2 \text{ mol Ag}}{2 \text{ mol AgCl}}$$

$$\times \frac{108 \text{ g Ag}}{1 \text{ mol Ag}} = 75.3 \text{ g Ag}$$

mass of $Ag(s)$ reclaimed $= 0.946 \times 75.3$ g Ag $= 71.2$ g Ag

6. $$42.8 \text{ g Mg} \times \frac{1 \text{ mol Mg}}{24.3 \text{ g Mg}} \times \frac{2 \text{ mol MgO}}{2 \text{ mol Mg}}$$

$$\times \frac{40.3 \text{ g MgO}}{1 \text{ mol MgO}} = 71.0 \text{ g MgO}$$

actual yield $= 71.0$ g MgO $\times 0.817$ $= 58.0$ g MgO

Interpreting Graphics 9

1. a. 102.1 g/mol c. 180.1 g/mol
   b. 138.1 g/mol
2. Student 1: 0.0155 moles SA
   Student 2: 0.0147 moles SA
3. Student 1: 5.25 g acetic anhydride
   0.0514 moles
   Student 2: 5.25g acetic anhydride
   0.0514 moles
4. salicylic acid
5. Student 1: 2.79 g
   Student 2: 2.65 g
6. Student 1: 1.745 g
   Student 2: 2.509 g
7. Student 1: 62.5%
   Student 2: 94.7%
8. Student 2 exhibited much better lab technique, which is reflected by a higher percent yield than that obtained by Student 1. Student 2 should receive the higher grade.

Vocabulary Review 9

1. d	5. g	8. i
2. h	6. j	9. e
3. f	7. b	10. c
4. a		

Quiz for Chapter 9

1. coefficients	6. NT
2. reactant	7. NT
3. moles	8. NT
4. atoms	9. NT
5. 44.8	10. ST

Chapter 9 Test A

A. Matching

1. b	3. e	5. a
2. c	4. f	6. d

B. Multiple Choice

7. b	11. b	15. c
8. c	12. c	16. a
9. b	13. b	17. c
10. d	14. a	18. c

C. Problems

19. There is no limiting reagent, because the mole ratio of the reactants is 1 mol N_2 to 3 mol H_2.

20. $558\ \cancel{g\ Fe} \times \frac{1\ \cancel{mol\ Fe}}{55.8\ \cancel{g\ Fe}} \times \frac{3\ \cancel{mol\ CO}}{2\ \cancel{mol\ Fe}} \times \frac{28.0\ g\ CO}{1\ \cancel{mol\ CO}} = 4.20 \times 10^2\ g\ CO$

21. $15.0\ g\ CO_2 \times \frac{1\ mol\ CO_2}{44\ g\ CO_2} \times \frac{2\ mol\ C_4H_{10}}{8\ mol\ CO_2} \times \frac{58\ g\ C_4H_{10}}{1\ mol\ C_4H_{10}} = 4.94\ g\ C_4H_{10}$

22. a. Theoretical yield:

$4.0\ \cancel{g\ H_2} \times \frac{1\ \cancel{mol\ H_2}}{2.0\ \cancel{g\ H_2}} \times \frac{1\ \cancel{mol\ CH_3OH}}{2\ \cancel{mol\ H_2}} \times \frac{32.0\ g\ CH_3OH}{1\ \cancel{mol\ CH_3OH}} = 32.0\ g\ CH_3OH$

b. Percent yield: $\frac{28.0\ g}{32.0\ g} \times 100\% = 87.5\%$

D. Essay

23. The coefficients of a balanced chemical equation describe the relative number of moles of reactants and products. From this information, the amounts of reactants and products can be calculated. The number of moles may be converted to mass, volume, or number of representative particles.

E. Additional Problems

24. a. $5.00 \times 10^2\ \cancel{g\ Al_2(SO_4)_3} \times \frac{1\ \cancel{mol\ Al_2(SO_4)_3}}{342\ \cancel{g\ Al_2(SO_4)_3}} \times \frac{3\ \cancel{mol\ CaSO_4}}{1\ \cancel{mol\ Al_2(SO_4)_3}} \times \frac{136\ g\ CaSO_4}{1\ \cancel{mol\ CaSO_4}} = 596\ g\ CaSO_4$

$5.00 \times 10^2\ \cancel{g\ Al_2(SO_4)_3} \times \frac{1\ \cancel{mol\ Al_2(SO_4)_3}}{342\ \cancel{g\ Al_2(SO_4)_3}} \times \frac{3\ \cancel{mol\ Ca(OH)_2}}{1\ \cancel{mol\ Al_2(SO_4)_3}} \times \frac{74.1\ g\ Ca(OH)_2}{1\ \cancel{mol\ Ca(OH)_2}} = 325\ g\ Ca(OH)_2$

$Al_2(SO_4)_3$ is the limiting reagent.

b. $450\ g - 325\ g = 125\ g$ excess $Ca(OH)_2$

$125\ \cancel{g\ Ca(OH)_2} \times \frac{1\ mol\ Ca(OH)_2}{74.1\ \cancel{g\ Ca(OH)_2}} = 1.69\ mol\ Ca(OH)_2$ remaining

25. $10.0\ L\ H_2S \times \frac{3\ \cancel{mol\ O_2}}{2\ \cancel{mol\ H_2S}} = 15.0\ L\ O_2$

26. $5.00\ \cancel{L\ O_2} \times \frac{1\ \cancel{mol\ O_2}}{22.4\ \cancel{L\ O_2}} \times \frac{2\ \cancel{mol\ KClO_3}}{3\ \cancel{mol\ O_2}}$

$\times \frac{122.6\ g\ KClO_3}{1\ \cancel{mol\ KClO_3}} = 18.2\ g\ KClO_3$

27. $\frac{4.80\ L}{5.00\ L} \times 100\% = 96.0\%$

Chapter 9 Test B

A. Matching

1. b	3. d	5. f
2. e	4. a	6. c

B. Multiple Choice

7. d	12. b	17. c
8. d	13. c	18. d
9. b	14. b	19. a
10. d	15. a	20. b
11. d	16. c	21. c

C. Problems

22. $\frac{2\ mol\ NH_3}{3\ \cancel{mol\ H_2}} \times 12.0\ \cancel{mol\ H_2} = 8.00\ mol\ NH_3$

23. $\frac{1\ \cancel{mol\ SnF_2}}{2\ \cancel{mol\ HF}} \times \frac{1\ \cancel{mol\ HF}}{20.0\ \cancel{g\ HF}} \times 45.0\ \cancel{g\ HF}$

$\times \frac{156.7\ g\ SnF_2}{1\ \cancel{mol\ SnF_2}} = 176\ g\ SnF_2$

24. $\frac{1\ \cancel{mol\ CH_4}}{1\ \cancel{mol\ CO_2}} \times 150\ \cancel{mol\ CO_2} \times \frac{16.0\ g\ CH_4}{1\ \cancel{mol\ CH_4}}$

$= 2.4 \times 10^3\ g\ CH_4$

25. $\frac{2\ \cancel{mol\ Al_2O_3}}{3\ \cancel{mol\ O_2}} \times \frac{1\ \cancel{mol\ O_2}}{22.4\ \cancel{L\ O_2}} \times \frac{1\ \cancel{L}}{1000\ \cancel{mL}}$

$\times 625\ \cancel{mL}\ O_2 \times \frac{102\ g\ Al_2O_3}{1\ \cancel{mol\ Al_2O_3}}$

$= 1.90\ g\ Al_2O_3$

26. $50.8\ \cancel{g\ CaCO_3} \times \frac{1\ \cancel{mol\ CaCO_3}}{100.1\ \cancel{g\ CaCO_3}}$

$\times \frac{1\ \cancel{mol\ CaO}}{1\ \cancel{mol\ CaCO_3}} \times \frac{56.1\ g\ CaO}{1\ \cancel{mol\ CaO}}$

$= 28.5\ g\ CaO$

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

$= \frac{26.4\ g\ CaO}{28.5\ g\ CaO} \times 100\%$

$= 92.6\%\ yield$

D. Essay

27. Based on the 2:3 molar ratio between A and B, the 1.0 mol of A requires only 1.5 mol of B in order to react completely. The maximum amount of A_2B_3 that can be produced (0.50 mol) is thus limited by the amount of A that is available, with 0.50 mol of B remaining in excess.

E. Additional Problems

28. $6CO_2 + 6H_2O \xrightarrow{energy} C_6H_{12}O_6 + 6O_2$

$\frac{1\ \cancel{mol\ C_6H_{12}O_6}}{6\ \cancel{mol\ H_2O}} \times 4.50\ \cancel{mol\ H_2O}$

$\times \frac{180\ g\ C_6H_{12}O_6}{1\ \cancel{mol\ C_6H_{12}O_6}} = 135\ g\ C_6H_{12}O_6$

29. $\frac{4\ \cancel{mol\ CO_2}}{2\ \cancel{mol\ C_2H_2}} \times 5.00 \times 10^4\ \cancel{g\ C_2H_2}$

$\times \frac{1\ \cancel{mol\ C_2H_2}}{26.0\ \cancel{g\ C_2H_2}} \times \frac{44.0\ g\ CO_2}{1\ \cancel{mol\ CO_2}}$

$= 1.69 \times 10^5\ g\ CO_2$

29. $\frac{2\ \cancel{mol\ H_3PO_4}}{3\ \cancel{mol\ H_2SO_4}} \times 1.25 \times 10^5\ \cancel{kg\ H_2SO_4}$

$\times \frac{1\ \cancel{mol\ H_2SO_4}}{98.1\ \cancel{g\ H_2SO_4}} \times \frac{1000\ \cancel{g}}{1\ \cancel{kg}} \times \frac{98.0\ \cancel{g}\ H_3PO_4}{1\ \cancel{mol\ H_3PO_4}}$

$\times \frac{1\ kg}{1000\ \cancel{g}} = 8.32 \times 10^4\ kg\ H_3PO_4$

31. a. $\frac{3\ mol\ CuO}{2\ \cancel{mol\ NH_3}} \times \frac{1\ \cancel{mol\ NH_3}}{17.0\ \cancel{g\ NH_3}} \times 57.0\ \cancel{g\ NH_3}$

$= 5.03\ mol\ CuO$ needed

$290.0\ \cancel{g\ CuO} \times \frac{1\ mol\ CuO}{79.5\ \cancel{g\ CuO}}$

$= 3.65\ mol\ CuO$ present

Thus, CuO is the limiting reagent.

b. $\frac{2\ mol\ NH_3}{3\ \cancel{mol\ CuO}} \times 3.65\ \cancel{mol\ CuO}$

$= 2.43\ mol\ NH_3$ react

Since $57.0\ \cancel{g\ NH_3} \times \frac{1\ mol\ NH_3}{17.0\ \cancel{g\ NH_3}}$

$= 3.35\ mol\ NH_3$ present

NH_3 excess $= 3.35\ mol - 2.43\ mol$

$= 0.92\ mol$

c. $\frac{1\ \cancel{mol\ N_2}}{3\ \cancel{mol\ CuO}} \times 3.65\ \cancel{mol\ CuO} \times \frac{28.0\ g\ N_2}{1\ \cancel{mol\ N_2}}$

$= 34.1\ g\ N_2$

32. $\frac{4 \text{ mol NO}}{4 \text{ mol } NH_3} \times 10.0 \text{ kg } NH_3 \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol } NH_3}{17.0 \text{ g } NH_3} \times \frac{30.0 \text{ g NO}}{1 \text{ mol NO}} \times \frac{1 \text{ kg}}{1000 \text{ g}} \times 0.80 = 14.1 \text{ kg NO}$

Section Review 10.1

Part A Completion

1. motion
2. empty space
3. far apart
4. independently
5. random
6. collisions
7. kinetic energy
8. atmospheric
9. 0 °C
10. 101.3 kPa or 1 atm

Part B True-False

11. ST
12. AT
13. NT
14. AT
15. NT
16. AT

Part C Matching

17. b
18. c
19. d
20. e
21. a

Part D Questions and Problems

22. $4.30 \text{ atm} \times \frac{101.3 \text{ kPa}}{1 \text{ atm}} = 436 \text{ kPa}$

$4.30 \text{ atm} \times \frac{760 \text{ mm Hg}}{1 \text{ atm}} = 3.27 \times 10^3 \text{ mm Hg}$

23. According to the kinetic theory, the particles in a gas move rapidly in constant random motion. Because gas particles are far apart, no attractive or repulsive forces exist between the particles. They travel in straight lines and move independently of each other. The particles change direction when they rebound from collisions with one another or with other objects.
24. Odors travel long distances from their sources.

Section 10.2

Part A Completion

1. condensed
2. denser
3. vaporization
4. liquid
5. cooling
6. vaporize
7. vapor pressure
8. manometer
9. vapor pressure
10. 1 atm

Part B True-False

11. ST
12. ST
13. NT
14. AT
15. ST
16. ST

Part C Matching

17. a
18. e
19. c
20. d
21. b

Part D Questions and Problems

22. At the boiling point, the kinetic energy of some of the particles is strong enough to overcome the intermolecular forces that hold together the particles in the liquid state.
23. Liquid B would evaporate faster because it has a higher vapor pressure. The evaporation rate of a liquid is directly proportional to its vapor pressure.
24. Evaporation leads to cooling of a liquid because the gaseous particles require heat to evaporate; as they evaporate, they remove heat energy from the liquid and the temperature drops.

Section 10.3

Part A Completion

1. incompressible
2. fixed
3. melts
4. melting point
5. freezing points
6. high
7. crystalline
8. lattice
9. unit cell
10. amorphous

Part B True-False

11. AT
12. ST
13. NT
14. ST
15. AT

Part C Matching

16. f
17. d
18. g
19. a
20. b
21. h
22. c
23. e

Part D Questions and Problems

24. When a solid is heated, its particles vibrate more rapidly as their kinetic energy increases. When heat is sufficient, the disruptive vibrations of the particles are strong enough to overcome the interactions that hold them in fixed positions. The organization of the particles within the solid breaks down and the solid becomes liquid.

Section 10.4

Part A Completion

1. melt
2. condense
3. phase diagram
4. equilibrium
5. triple point
6. 0.016 °C
7. 0.61 kPa (0.0060 atm)
8. Sublimation
9. vapor pressure
10. Napthalene

Part B True-False

11. NT
12. AT
13. NT
14. AT
15. NT
16. NT

Part C Matching

17. b
18. c
19. d
20. e
21. a
22. f

Part D Questions and Problems

23. Some solids have such a high vapor pressure that they pass directly from the solid state to the gaseous state and back. This process is called sublimation.
24. The temperature of the system remains constant while the change of state is occurring.

Practice Problems 10

Section 10.1

1. According to kinetic theory, the pressure of a gas results from the collisions of gas particles with the walls of a container. The force of the collisions depends on the average speed at which the gas particles are traveling. Because the average speed of a collection of gas particles is directly proportional to the Kelvin temperature, an increase in temperature will increase the pressure inside the tire. If the tire is cooled, the pressure inside the tire will decrease.
2. Setting aside fluctuations due to changes in the weather, you would notice that the pressure reading on the barometer would decrease as you climbed in altitude.
3. $754.3\ \text{mm Hg} \times \dfrac{1\ \text{atm}}{760\ \text{mm Hg}} = 0.9925\ \text{atm}$

   $754.3\ \text{mm Hg} \times \dfrac{101.3\ \text{kPa}}{760\ \text{mm Hg}} = 100.5\ \text{kPa}$

4. The average kinetic energy of the particles of a substance is directly proportional to the Kelvin Temperature.

   $-100.0\ °\text{C} + 273 = 173\ \text{K}$

   $73\ °\text{C} + 273 = 346\ \text{K}$

   Thus, because the Kelvin temperature increases by a factor of two, the average kinetic energy increases by a factor of two.

Section 10.2

1. In general, the intermolecular forces between particles in a gas are weaker than the forces between particles of a liquid.
2. If the beaker is sealed, the vapor pressure will increase until a dynamic equilibrium has been established. At equilibrium, the rate at which liquid molecules are vaporizing equals the rate at which vapor molecules are condensing.
3. The fastest runner corresponds to the molecules in a liquid with the greatest kinetic energy. If these molecules have sufficient kinetic energy, they will vaporize, leaving behind slower molecules (runners), that is, molecules with a lower average kinetic energy.
4. The boiling point is the temperature at which the vapor pressure of water just equals the external atmospheric pressure. Under normal atmospheric pressure, the boiling point for water is 100 °C. Once the water begins to boil its temperature remains constant no matter how much extra heat is added. As the external pressure is increased, the temperature required to produce the corresponding vapor pressure also increases as does the temperature of the water at boiling. Thus, by increasing the external pressure, pressure cookers make it possible to heat foods to higher temperatures, which reduces the cooking time.

Section 10.3

1. The carbon atoms of graphite are packed in sheets. In diamond, each carbon atom is strongly bonded to four other carbon atoms in a regular three-dimensional array.
2. Allotropes are two or more different molecular forms of the same element in the same physical state. Diamond and graphite are both composed of carbon and are both solids under standard conditions. However, the arrangement of the carbon atoms in

Chemical Stoichiometry

Introduction

Chemical stoichiometry refers to the relationships between the amounts of reactants and products in a chemical reaction.

An Example

How many grams of H_2 would be needed to react completely with 20 grams of O_2 in the following reaction?

$$H_2 + O_2 \rightarrow H_2O$$

The technique we will use to solve problems such as this will be essentially the same. Namely, we will go through the following four steps;

{a} BALANCE THE EQUATION
{b} CONVERT TO MOLES
{c} EXAMINE MOLE RATIOS
{d} CONVERT UNITS

One Step At A Time

At this point the above example may not make complete sense to you. That's OK. We will use it as a reference point and come back to it later.

Right now you should be able to convert from grams to moles and vice versa. As a reminder, the following relationship may come in handy later;

$$\text{Moles} = \frac{\text{Grams of X}}{\text{Molar Mass of X}}$$

Later we will practice doing some mole/gram conversions in case you are a little rusty.

Balancing Chemical Equations

What does it mean when we say that a chemical equation is "balanced" ?

Let's look at our previous chemical equation;

$$H_2 + O_2 \rightarrow H_2O$$

For an equation to be balanced, it must have exactly the same number of each type of atom on each side of the equation. Our above example is obviously not balanced...

$$H_2 + O_2 \rightarrow H_2O$$

Reactants	Products
2 hydrogen atoms 2 oxygen atoms	2 hydrogen atoms 1 oxygen atom

As you can see there is an equal number of hydrogen atoms on each side of the equation. However, on the reactant side, (the left) we have 2 oxygens and on the product side, (which is the right) we have only one oxygen.

To remedy this situation we will try to add an oxygen atom to the right side.. We will do this by adding a coefficient.

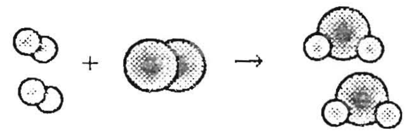
NEVER TRY TO BALANCE AN EQUATION BY CHANGING THE SUBSCRIPTS OF ANY OF THE CHEMICALS!

Let's see how we can add an oxygen atom by using a coefficient.

$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

Reactants	Products
4 hydrogen atoms 2 oxygen atoms	4 hydrogen atoms 2 oxygen atoms

Perhaps it is easier to see what is happening schematically.



As you can see we started with ;

2 molecules of H_2
this is 4 atoms of hydrogen.
and,
1 molecule of O_2
this is 2 atoms of oxygen.

And we also finished on the right side with;

2 molecules of H_2O
this is 4 atoms of hydrogen
& 2 atoms of oxygen.

Other Examples of Properly Balanced Chemical Equations...

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

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

$$2\,NO + O_2 \rightarrow 2\,NO_2$$

$$P_4 + 5\,O_2 \rightarrow 2\,P_2O_5$$

$$Mg + 2\,HCl \rightarrow MgCl_2 + H_2$$

Practice Balancing Equations

Fill in the number in the missing blank that will make each of the following reactions balanced.

[a] $FeS + \underline{2}HCl \rightarrow FeCl_2 + H_2S$

[b] $Xe + \underline{3}F_2 \rightarrow XeF_6$

[c] $\underline{2}HI \rightarrow H_2 + I_2$

[d] $Al_2O_3 + \underline{6}HCl \rightarrow 2\,AlCl_3 + 3H_2O$

[e] $2\,Au_2O_3 \rightarrow 4\,Au + \underline{3}O_2$

[f] $2\,Zn + O_2 \rightarrow \underline{2}ZnO$

[g] $2\,H_2S + \underline{3}O_2 \rightarrow 2\,H_2O + 2SO_2$

[h] $\underline{2}C + O_2 \rightarrow 2\,CO$

[i] $N_2 + \underline{3}H_2 \rightarrow 2\,NH_3$

[j] $2\,Na + \underline{1}Cl_2 \rightarrow 2\,NaCl$

Now check your answers on your teachers answer key. Remember never change any of the subscripts... only the coefficients. Changing the subscripts changes the composition of the compound in question.

Coefficient is 2

$2\,CuSO_4$

Subscript is 4

In the next section you will try to balance some equations on your own. Remember, you may have to add more than one coefficient to make an equation balance. In fact you may have to go back and forth a number of times to make things work out properly.

On Your Own...

In each of the following equations supply whatever coefficients are needed to make the equations balance.

[1] $2Sb + 3Br_2 \longrightarrow 2SbBr_3$

[2] $2Mg + O_2 \longrightarrow 2MgO$

[3] $NH_4NO_3 \longrightarrow N_2O + 2H_2O$

[4] $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$

[5] $Cu + 2HgNO_3 \rightarrow Cu(NO_3)_2 + 2Hg$

[6] $BaO + H_2O \longrightarrow Ba(OH)_2$

[7] $NH_3 + O_2 \longrightarrow NO + H_2O$

[8] $Al + F_2 \longrightarrow AlF_3$

[9] $Cu + S \longrightarrow Cu_2S$

[10] $Fe + O_2 \longrightarrow Fe_2O_3$

[11] $H_2 + O_2 \longrightarrow H_2O$

[12] $HgO \longrightarrow Hg + O_2$

[13] $Fe_3O_4 + H_2 \longrightarrow Fe + H_2O$

[14] $Mg + N_2 \longrightarrow Mg_3N_2$

[15] $O_2 \longrightarrow O_3$

[16] $Fe + S \rightarrow Fe_2S_3$

[17] $NH_4Cl + Ca(OH)_2 \longrightarrow CaCl_2 + NH_3 + H_2O$

[18] $HBr + O_2 \longrightarrow Br_2 + H_2O$

[19] $C + O_2 \longrightarrow CO_2$

[20] $H_2SO_4 + Li \rightarrow Li_2SO_4 + H_2$

[21] $HCl + NaOH \rightarrow NaCl + H_2O$

[22]* $NH_3 + O_2 \rightarrow NO + H_2O$

[23]* $I_2 + HNO_3 \longrightarrow HIO_3 + NO_2 + H_2O$

The last two problems may be somewhat more challenging.

Starting Stoichiometry

Stoichiometry sounds like such a strange word. Actually it comes from two simple Greek roots; stoic, meaning equal, and metry meaning to measure. Stoichiometry then means "equal measure". The word itself is pronounced s-toy-KEY-ahm-etry.

As we said on the first page, stoichiometry refers to the relative amounts of chemicals either consumed or produced in a chemical reaction.

Frequently a chemist might be interested in how much of one chemical would be needed to react with a given amount of another.

Example 1

Suppose that 50 grams of Magnesium is combined with oxygen according to the following reaction;

$$Mg + O_2 \rightarrow MgO$$

We wish to know what mass of MgO could be produced. We can begin by using the four steps that we used on page 1.

1. Balance the equation
2. Convert to moles
3. Examine the mole ratios
4. Convert to desired units

To begin with we will balance our equation. We can do this easily as follows; **(step 1)**

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

Count the atoms on each side to convince yourself that it's balanced.

Next we need to convert all amounts into moles. We can do this as follows; (step 2)

$$\text{Moles} = \frac{\text{Mass of X}}{\text{Molar Mass X}}$$

$$\text{Moles} = \frac{50 \text{ g Mg}}{24.3 \text{ grams/mole Mg}}$$

(24.3 is the atomic weight of Mg from the periodic table.)

$$= 2.06 \text{ moles of Mg}$$

Our third step will be to set up a ratio between the two chemicals involved in our problem. The two chemicals mentioned here are Mg and MgO. **(this is step 3)**

We look at the coefficients of our two chemicals. Since they are both 2 we have a 2:2 or essentially a 1:1 ratio. This means that for every mole of Mg that reacts... we will have 1 mole of MgO produced.

However we had 2.06 moles of Mg react (see step 2) so this means that we will have 2.06 moles of MgO produced.

Our 4th step is simply to convert from 2.06 moles of MgO into whatever units are asked for. In this case they want grams so...

Simply convert 2.06 moles of MgO into grams. **(step 4)**

(2.06 g MgO)(40.6 grams/mole)

= <u>83.6 grams of MgO produced</u>

This is our final answer!

But What If...

I know what you are thinking... What if the mole ratio isn't a simple 1:1 ratio? Let's look and see.

Example 2

Let's suppose that 100 grams of aluminum reacts with sulfur as shown below;

$$Al + S \rightarrow Al_2S_3$$

How many grams of sulfur would be needed to react with our aluminum ?

Step 1 Balance Reaction

$$2\,Al + 3\,S \rightarrow Al_2S_3$$

Step 2 Convert to Moles

$$\frac{100 \text{ g Al}}{27.0 \text{ g/mole Al}} = 3.7 \text{ moles Al}$$

Step 3 Set Up Mole Ratios

Look at the ratios between the chemicals mentioned in the problem. (Al and S)

$$2\,\underline{Al} + 3\,\underline{S} \rightarrow Al_2S_3$$

The ratio is 2:3 so we set up a ratio;

$$\frac{2}{3.7 \text{ moles Al}} = \frac{3}{X \text{ moles of S}}$$

$$X = 5.55 \text{ moles of S}$$

Note: The 2 & 3 in the above equation came from the coefficients of the chemicals involved. The 3.7 moles of Al came from step 2. And X is our number of moles of Sulfur.

Step 4 Convert Final Units

Notice that the units on our answer are currently moles. To convert this into grams we will simply multiply the number of moles of sulfur by its molar mass.

(5.55 moles S)(32 grams/mole)

= 177.6 grams of S

Now it's your turn...

OK now you get to try a few on your own. Remember to use the 4 steps that we went over. When you set up your mole ratio in step 3 simply use the coefficients in the balanced equation for your numerators and the number of moles from step 2 for one of your denominators. The other denominator will be X.

There is a periodic table on the next page.

1. 2 $KNO_3 \rightarrow$ 2 $KNO_2 + O_2$

How many grams of O_2 could be produced from 200 grams of KNO_3 ?

200g / 101.09/mole = 1.980 mole KNO_3 (39.01, 14.01, 48.00, 101.09/mole)

1.980 mole KNO_3 / 2 = 0.9899 mole O_2

31.7g O_2

2. $NH_3 + HCl \rightarrow NH_4Cl$

How many grams of HCl would be needed to react completely with 50g of NH_3 ?

50g / 17.03 = 2.935 mole NH_3

2.935 mole HCl

107g HCl (36.46g/mole HCl)

3. 2 Fe + 3 $Cl_2 \rightarrow$ 2 $FeCl_3$

How many grams of FeCl3 could be produced starting out from 250 grams of Fe ?

250g / 55.85 = 4.476 mole Fe

162.2g/mole $FeCl_3$

726g $FeCl_3$

4. 2 $KClO_3 \rightarrow$ 2 KCl + 3 O_2

If 40 grams of KCl were produced in the above reaction, then how many grams of O2 must have also been produced ?

40g / 74.55g/m = 0.5365 mole KCl

2 KCl / 3 O_2 = 0.5365 KCl / x O_2

0.8048 mole O_2

25.8g O_2

5. Ammonia is produced by the Haber process which combines elemental hydrogen and nitrogen gas as shown below;

N_2 + 3 $H_2 \rightarrow$ 2 NH_3

a. How many grams of H_2 would be needed to react completely with 50 grams of N_2 ?

50g / 28.00 = 1.784 mole

1 N_2 / 3 H_2 = 1.784 N_2 / X

5.34 mole H_2

10.8g H_2

b. How many grams of NH_3 could be produced from 50 g of N_2 ?

1.784 mole N_2 / X NH_3 = 2/2

1.784 mole NH_3 ⟹ 60.8g NH_3

c. What is the relationship ~~between~~ among 50 grams of N_2, your answer in part A, and your answer in part B ?

NOTE: THE SUBSCRIBERS COPY OF THIS ISSUE CONSTAINS AN INSERT WITH SOLUTIONS TO ALL PROBLEMS!

Chemical Stoichiometry

Introduction

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An Example

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One Step At A Time

At this point the above example may not make complete sense to you. That's OK. We will use it as a reference point and come back to it later.

Right now you should be able to convert from grams to moles and vice versa. As a reminder, the following relationship may come in handy later;

$$\text{Moles} = \frac{\text{Grams of X}}{\text{Molar Mass of X}}$$

Later we will practice doing some mole/gram conversions in case you are a little rusty.

Balancing Chemical Equations

What does it mean when we say that a chemical equation is "balanced" ?

Let's look at our previous chemical equation;

$$H_2 + O_2 \rightarrow H_2O$$

For an equation to be balanced, it must have exactly the same number of each type of atom on each side of the equation. Our above example is obviously not balanced...

$$H_2 + O_2 \rightarrow H_2O$$

Reactants	Products
2 hydrogen atoms 2 oxygen atoms	2 hydrogen atoms 1 oxygen atom

As you can see there is an equal number of hydrogen atoms on each side of the equation. However, on the reactant side, (the left) we have 2 oxygens and on the product side, (which is the right) we have only one oxygen.

To remedy this situation we will try to add an oxygen atom to the right side. We will do this by adding a coefficient.

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Let's see how we can add an oxygen atom by using a coefficient.

$$2\,H_2 + O_2 \rightarrow 2\,H_2O$$

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4 hydrogen atoms 2 oxygen atoms	4 hydrogen atoms 2 oxygen atoms

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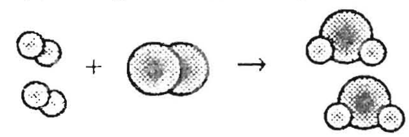

As you can see we started with ;

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this is 4 atoms of hydrogen.
and,
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$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

$$2\,NO + O_2 \rightarrow 2\,NO_2$$

$$P_4 + 5\,O_2 \rightarrow 2\,P_2O_5$$

$$Mg + 2\,HCl \rightarrow MgCl_2 + H_2$$

Practice Balancing Equations

Fill in the number in the missing blank that will make each of the following reactions balanced.

[a] FeS + __$HCl \rightarrow$ $FeCl_2$ + H_2S

[b] Xe + __$F_2 \rightarrow$ XeF_6

[c] __$HI \rightarrow$ H_2 + I_2

[d] Al_2O_3 + __$HCl \rightarrow$ 2 $AlCl_3$ + 3H_2O

[e] 2 $Au_2O_3 \rightarrow$ 4 Au + __O_2

[f] 2 Zn + $O_2 \rightarrow$ __ZnO

[g] 2 H_2S + __$O_2 \rightarrow$ 2 H_2O + SO_2

[h] __C + $O_2 \rightarrow$ 2 CO

[i] N_2 + __$H_2 \rightarrow$ 2 NH_3

[j] 2 Na + __$Cl_2 \rightarrow$ 2 $NaCl$

Now check your answers on your teachers answer key. Remember never change any of the subscripts... only the coefficients. Changing the subscripts changes the composition of the compound in question.

Coefficient is 2
2 $CuSO_4$
Subscript is 4

In the next section you will try to balance some equations on your own. Remember, you may have to add more than one coefficient to make an equation balance. In fact you may have to go back and forth a number of times to make things work out properly.

On Your Own...

In each of the following equations supply whatever coefficients are needed to make the equations balance.

[1] Sb + $Br_2 \longrightarrow$ $SbBr_3$

[2] Mg + $O_2 \longrightarrow$ MgO

[3] $NH_4NO_3 \longrightarrow$ N_2O + H_2O

[4] Ca + $H_2O \rightarrow$ $Ca(OH)_2$ + H_2

[5] Cu + $HgNO_3 \rightarrow$ $Cu(NO_3)_2$ + Hg

[6] BaO + $H_2O \longrightarrow$ $Ba(OH)_2$

[7] NH_3 + $O_2 \longrightarrow$ NO + H_2O

[8] Al + $F_2 \longrightarrow$ AlF_3

[9] Cu + $S \longrightarrow$ Cu_2S

[10] Fe + $O_2 \longrightarrow$ Fe_2O_3

[11] H_2 + $O_2 \longrightarrow$ H_2O

[12] $HgO \longrightarrow$ Hg + O_2

[13] Fe_3O_4 + $H_2 \longrightarrow$ Fe + H_2O

[14] Mg + $N_2 \longrightarrow$ Mg_3N_2

[15] $O_2 \longrightarrow$ O_3

[16] Fe + $S \rightarrow$ Fe_2S_3

[17] NH_4Cl + $Ca(OH)_2 \longrightarrow$ $CaCl_2$ + NH_3 + H_2O

[18] HBr + $O_2 \longrightarrow$ Br_2 + H_2O

[19] C + $O_2 \longrightarrow$ CO_2

[20] H_2SO_4 + $Li \rightarrow$ Li_2SO_4 + H_2

[21] HCl + $NaOH \rightarrow$ $NaCl$ + H_2O

[22]* NH_3 + $O_2 \rightarrow$ NO + H_2O

[23]* I_2 + $HNO_3 \longrightarrow$ HIO_3 + NO_2 + H_2O

The last two problems may be somewhat more challenging.

Practice Balancing Equations

Fill in the number in the missing blank that will make each of the following reactions balanced.

[a] $FeS + \_HCl \rightarrow FeCl_2 + H_2S$

[b] $Xe + \_F_2 \rightarrow XeF_6$

[c] $\_HI \rightarrow H_2 + I_2$

[d] $Al_2O_3 + \_HCl \rightarrow 2\,AlCl_3 + 3H_2O$

[e] $2\,Au_2O_3 \rightarrow 4\,Au + \_O_2$

[f] $2\,Zn + O_2 \rightarrow \_ZnO$

[g] $2\,H_2S + \_O_2 \rightarrow 2\,H_2O + SO_2$

[h] $\_C + O_2 \rightarrow 2\,CO$

[i] $N_2 + \_H_2 \rightarrow 2\,NH_3$

[j] $2\,Na + \_Cl_2 \rightarrow 2\,NaCl$

Now check your answers on your teachers answer key. Remember never change any of the subscripts... only the coefficients. Changing the subscripts changes the composition of the compound in question.

Coefficient is 2

$2CuSO_4$

Subscript is 4

In the next section you will try to balance some equations on your own. Remember, you may have to add more than one coefficient to make an equation balance. In fact you may have to go back and forth a number of times to make things work out properly.

On Your Own...

In each of the following equations supply whatever coefficients are needed to make the equations balance.

[1] $Sb + Br_2 \longrightarrow SbBr_3$

[2] $Mg + O_2 \longrightarrow MgO$

[3] $NH_4NO_3 \longrightarrow N_2O + H_2O$

[4] $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$

[5] $Cu + HgNO_3 \rightarrow Cu(NO_3)_2 + Hg$

[6] $BaO + H_2O \longrightarrow Ba(OH)_2$

[7] $NH_3 + O_2 \longrightarrow NO + H_2O$

[8] $Al + F_2 \longrightarrow AlF_3$

[9] $Cu + S \longrightarrow Cu_2S$

[10] $Fe + O_2 \longrightarrow Fe_2O_3$

[11] $H_2 + O_2 \longrightarrow H_2O$

[12] $HgO \longrightarrow Hg + O_2$

[13] $Fe_3O_4 + H_2 \longrightarrow Fe + H_2O$

[14] $Mg + N_2 \longrightarrow Mg_3N_2$

[15] $O_2 \longrightarrow O_3$

[16] $Fe + S \rightarrow Fe_2S_3$

[17] $NH_4Cl + Ca(OH)_2 \longrightarrow CaCl_2 + NH_3 + H_2O$

[18] $HBr + O_2 \longrightarrow Br_2 + H_2O$

[19] $C + O_2 \longrightarrow CO_2$

[20] $H_2SO_4 + Li \rightarrow Li_2SO_4 + H_2$

[21] $HCl + NaOH \rightarrow NaCl + H_2O$

[22]* $NH_3 + O_2 \rightarrow NO + H_2O$

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The last two problems may be somewhat more challenging.

Starting Stoichiometry

Stoichiometry sounds like such a strange word. Actually it comes from two simple Greek roots; stoic, meaning equal, and metry meaning to measure. Stoichiometry then means "equal measure". The word itself is pronounced s-toy-KEY-ahm-etry.

As we said on the first page, stoichiometry refers to the relative amounts of chemicals either consumed or produced in a chemical reaction.

Frequently a chemist might be interested in how much of one chemical would be needed to react with a given amount of another.

Example 1

Suppose that 50 grams of Magnesium is combined with oxygen according to the following reaction;

$$Mg + O_2 \rightarrow MgO$$

We wish to know what mass of MgO could be produced. We can begin by using the four steps that we used on page 1.

1. Balance the equation
2. Convert to moles
3. Examine the mole ratios
4. Convert to desired units

To begin with we will balance our equation. We can do this easily as follows; **(step 1)**

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

Count the atoms on each side to convince yourself that it's balanced.

Next we need to convert all amounts into moles. We can do this as follows; **(step 2)**

$$\text{Moles} = \frac{\text{Mass of X}}{\text{Molar Mass X}}$$

$$\text{Moles} = \frac{50 \text{ g Mg}}{24.3 \text{ grams/mole Mg}}$$

(24.3 is the atomic weight of Mg from the periodic table.)

$$= 2.06 \text{ moles of Mg}$$

Our third step will be to set up a ratio between the two chemicals involved in our problem. The two chemicals mentioned here are Mg and MgO. **(this is step 3)**

We look at the coefficients of our two chemicals. Since they are both 2 we have a 2:2 or essentially a 1:1 ratio. This means that for every mole of Mg that reacts... we will have 1 mole of MgO produced.

However we had 2.06 moles of Mg react (see step 2) so this means that we will have 2.06 moles of MgO produced.

Our 4th step is simply to convert from 2.06 moles of MgO into whatever units are asked for. In this case they want grams so...

Simply convert 2.06 moles of MgO into grams. **(step 4)**

(2.06 g MgO)(40.6 grams/mole)

= <u>83.6 grams of MgO produced</u>

This is our final answer!

But What If...

I know what you are thinking... What if the mole ratio isn't a simple 1:1 ratio? Let's look and see.

Example 2

Let's suppose that 100 grams of aluminum reacts with sulfur as shown below;

$$Al + S \rightarrow Al_2S_3$$

How many grams of sulfur would be needed to react with our aluminum ?

Step 1 Balance Reaction

$$2\,Al + 3\,S \rightarrow Al_2S_3$$

Step 2 Convert to Moles

$$\frac{100 \text{ g Al}}{27.0 \text{ g/mole Al}} = 3.7 \text{ moles Al}$$

Step 3 Set Up Mole Ratios

Look at the ratios between the chemicals mentioned in the problem. (Al and S)

$$2\,\underline{\underline{Al}} + 3\,\underline{\underline{S}} \rightarrow Al_2S_3$$

The ratio is 2:3 so we set up a ratio;

$$\frac{2}{3.7 \text{ moles Al}} = \frac{3}{X \text{ moles of S}}$$

$$X = 5.55 \text{ moles of S}$$

Note: The 2 & 3 in the above equation came from the coefficients of the chemicals involved. The 3.7 moles of Al came from step 2. And X is our number of moles of Sulfur.

Step 4 Convert Final Units

Notice that the units on our answer are currently moles. To convert this into grams we will simply multiply the number of moles of sulfur by its molar mass.

(5.55 moles S)(32 grams/mole)

= 177.6 grams of S

Now it's your turn...

OK now you get to try a few on your own. Remember to use the 4 steps that we went over. When you set up your mole ratio in step 3 simply use the coefficients in the balanced equation for your numerators and the number of moles from step 2 for one of your denominators. The other denominator will be X.

There is a periodic table on the next page.

1. $KNO_3 \rightarrow KNO_2 + O_2$

   How many grams of O_2 could be produced from 200 grams of KNO_3 ?

2. $NH_3 + HCl \rightarrow NH_4Cl$

   How many grams of HCl would be needed to react completely with 50g of NH_3 ?

3. $Fe + Cl_2 \rightarrow FeCl_3$

   How many grams of FeCl3 could be produced starting out from 250 grams of Fe ?

4. $KClO_3 \rightarrow KCl + O_2$

   If 40 grams of KCl were produced in the above reaction, then how many grams of O2 must have also been produced ?

5. Ammonia is produced by the Haber process which combines elemental hydrogen and nitrogen gas as shown below;

   $N_2 + H_2 \rightarrow NH_3$

   a. How many grams of H_2 would be needed to react completely with 50 grams of N_2 ?

   b. How many grams of NH_3 could be produced from 50 g of N_2 ?

   c. What is the relationship between 50 grams of N_2, your answer in part A, and your answer in part B ?

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