Chapter 9
Quantity Relationships In Chemical Reactions

Chapter 9–Assignment A: Mass Stoichiometry

The term stoichiometry refers to the quantitative relationships between the substances involved in a chemical reaction. Chemical quantities may be measured in several ways. In this assignment, you will consider only mass. Later in this chapter, you will learn to use thermochemical energy and possibly gas volume, temperature, and pressure as stoichiometric quantities. The method of stoichiometry is the same regardless of the quantities used; a single principle covers the entire area of reaction quantities. In this assignment, you are directed to the method of solving a stoichiometry problem, rather than to a specific problem.

New ideas that are introduced in this assignment are:

1) The coefficients in a chemical equation express the mole relationships between the different substances in the reaction. The coefficients may be used in a dimensional analysis conversion from moles of one substance to moles of another.

2) The “stoichiometry pattern” is a three-step method that can be used to solve almost all stoichiometry problems.

Learning Procedures

Study Sections 9.1–9.2. Focus on Goals 1–2 as you study.

Strategy Item 2 in the new ideas list above is extremely important. The stoichiometry pattern is not difficult to learn; once learned, it is easy to apply. Learn the pattern well in this assignment using mass as the only quantity measurement. Once you learn the pattern in this assignment, other stoichiometry problems become simple. And there will be many other stoichiometry problems in this course!

Answer Questions, Exercises, and Problems 1–15. Check your answers with those at the end of the chapter.

Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 1–15.
Chapter 9–Assignment B: Gas Stoichiometry at Standard Temperature and Pressure (STP) (Optional)

The new ideas in this section are:

1) **Molar volume** is the volume occupied by one mole of a gas.

2) The molar volume of all ideal gases at standard temperature and pressure (STP) is 22.4 L/mol.

Learning Procedures

**Study**  
Section 9.3. Focus on Goals 3–4 as you study.

**Strategy**  
22.4 liters per mole is a dimensional analysis conversion factor that can be used to convert between the volume of a gas at STP and the number of particles of that gas, counted in moles. 22.4 L/mol can be used only for ideal gases at STP.

**Answer**  

**Workbook**  
If your instructor recommends the *Active Learning Workbook*, do Questions, Exercises, and Problems 16–20.

Chapter 9–Assignment C: Gas Stoichiometry at Non–STP Conditions (Optional)

In this optional section, we build on Assignments A and B. We use the combined gas equation from Chapter 4 along with the molar volume of a gas at STP from Assignment B and the stoichiometry pattern from Assignment A. There are no new concepts here; this assignment just introduces a new combination of old concepts.

The ideas to review are:

1) The combined gas law equation is

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

If you know the volume of a gas at a certain temperature and pressure, the volume at a new temperature and pressure is given by algebraically rearranging the combined gas laws equation to

$$V_2 = \frac{P_1V_1T_2}{P_2T_1}$$

2) The coefficients in a chemical equation express the mole relationships between the different substances in the reaction. The coefficients may be used in a dimensional analysis conversion from moles of one substance to moles of another.
3) The molar volume of all ideal gases at standard temperature and pressure (STP) is 22.4 L/mol.

Learning Procedures

Study Section 9.4. Focus on Goal 5 as you study.

Strategy This assignment combines the three ideas listed above. Review them, if necessary, before starting this assignment. You may find a brief review of Section 4.6 particularly helpful if it has been some time since you studied Chapter 4.

Answer Questions, Exercises, and Problems 21–24. Check your answers with those at the end of the chapter.

Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 21–24.

Chapter 9–Assignment D: Percent Yield and Limiting Reactant Questions

In Assignment A, you learned the fundamental theory that underlies all quantitative reaction chemistry. The mass of any individual product actually obtained in a reaction is not always the same as the mass calculated by a standard stoichiometry calculation. Only rarely, and only under carefully controlled conditions are two or more reactants brought together in just the right quantities so that all reactants are totally consumed. Usually, there is more than enough of one substance (usually the least expensive) to react with all of another. The reaction proceeds until all of the second substance is used up. In this assignment, you add the ideas of percent yield and limiting reactant to stoichiometric calculations.

Look for these critical ideas:

1) The efficiency of a reaction is stated in percent yield, in which the actual yield is expressed as a percent of the theoretical yield calculated by stoichiometry.

2) The limiting reactant determines the maximum amount of product that can be obtained in a chemical reaction.

Learning Procedures

Study Sections 9.5–9.6 plus either Section 9.7 or Section 9.8, as directed by your instructor. Focus on Goals 6–7 as you study.

Strategy Remember that yield applies to products only. This will help you decide which conversion factors to use. Your strategy for limiting reactants depends on which section you use.

Answer Questions, Exercises, and Problems 25–32. Check your answers with those at the end of the chapter.
Workbook  If your instructor recommends the *Active Learning Workbook*, do Questions, Exercises, and Problems 25–32.

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**Chapter 9–Assignment E: Energy and Thermochemical Stoichiometry**

In Assignment A, we promised that if you learned how to use the stoichiometry pattern in solving problems involving mass, you would also know how to solve problems with other quantity units. Here’s where you cash in on your previous knowledge. In this assignment, you’ll learn to apply the stoichiometry pattern to problems involving heat energy.

The major ideas in this assignment are:

1) The SI unit of energy is the **joule**, a force of one newton applied for a distance of one meter.

2) Another energy unit used by chemists is the **calorie**, which is equal to 4.184 joules.

3) The joule (J) and the calorie (cal) are small energy units, so units 1000 times larger, the **kilojoule, kJ**, and the **kilocalorie, kcal**, are often used.

4) The amount of heat given off or absorbed in a chemical reaction is called the **change of enthalpy**, symbolized by $\Delta H$.

5) The $\Delta H$ of a reaction may be included in the chemical equation as a reactant or a product, or it may be written next to the equation. The equation is then called a **thermochemical equation**.

6) For an endothermic reaction, $\Delta H$ is positive; heat is a reactant in the thermochemical equation. For an exothermic reaction, $\Delta H$ is negative; heat is a product in the thermochemical equation.

7) Using the $\Delta H$ of a thermochemical equation and the coefficient of any substance in that equation, you can convert in either direction from moles of that substance to amount of heat absorbed or produced.

8) In thermochemical equations the value of $\Delta H$ may be given in either kJ or kJ/mole.

**Learning Procedures**

**Study**  Sections 9.9–9.11. Focus on Goals 8–10 as you study.

**Strategy**  Learn the relationships among joules, calories, and their corresponding kilo-units. Learn the two types of thermochemical equations. You then apply the stoichiometry pattern from Assignment A. Notice how all stoichiometry problems follow the same pattern.

**Answer**  Questions, Exercises, and Problems 33–41. Check your answers with those at the end of the chapter.
Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 33–41.

Chapter 9–Assignment F: Summary and Review

When the philosopher George Santayana (1863–1952) wrote, “They who cannot remember the past are condemned to repeat it,” he was referring to the many forgotten lessons of history.

He could also be referring to the lessons of chemistry. Formula writing from Chapter 6, formula calculations from Chapter 7, and equation writing from Chapter 8 all come together in solving stoichiometry problems. If you know these three basic skills well, and can follow the method by which all stoichiometry questions are solved, this chapter will present no difficulty. If you are weak in the basic skills needed to do stoichiometry problems, heal the weakness before you go on. You are building a pyramid of skills, with each new skill resting on the foundation of previous skills. The foundation must be firm, or collapse and panic will soon follow. Set the foundation firmly, so you build for the ages.

You were introduced to the units of heat energy, the joule and the calorie. Lots of people wonder at this point how a joule, a force through displacement, can represent heat. Try this experiment: Place the palms of your hands firmly together, so it would take a force to rub one palm against the other (this rubbing motion is the displacement). Now rub your palms. What do you feel? Right. Heat, a force through a displacement.

A word of caution. The sign of $\Delta H$ can cause problems. If $\Delta H$ is greater than zero, the reaction is endothermic; heat is a reactant, and a heat term can appear on the left side of the thermochemical equation. If $\Delta H$ is less than zero, the reaction is exothermic; heat is a reaction product, and a heat term can appear on the right side of the thermochemical equation.

Both mass and thermochemical types of stoichiometry questions are easily solved using the stoichiometry pattern given in the text. Never mind the details by which problems differ. Apply the pattern consistently and the details become similar, and also much clearer.

Learning Procedures

Review your lecture and textbook notes.

the Chapter in Review and the Key Terms and Concepts, and read the Study Hints and Pitfalls to Avoid.

Answer Problem Classification Exercises 1–10. Check your answers with those at the end of the chapter.

Questions, Exercises, and Problems 42–46. Include Questions 47–54 if assigned by your instructor. Check your answers with those at the end of the chapter.
Workbook  If your instructor recommends the *Active Learning Workbook*, do Questions, Exercises, and Problems 42–44. Include Questions 45–51 if assigned by your instructor.

Take  the chapter summary test that follows. Check your answers with those at the end of this assignment.

Chapter 9 Sample Test

*Instructions:* You may use a “clean” periodic table.

Questions 1–4 refer to the equation: 2 C₅H₁₀ + 15 O₂ → 10 CO₂ + 10 H₂O

1) How many moles of carbon dioxide result from the reaction of 3 moles of C₅H₁₀?

2) What mass of oxygen must react to form 12.0 moles of carbon dioxide?

3) If the reaction consumes 4.12 grams of oxygen, how many grams of water are also produced?
4) The reaction of 6.81 grams of C\textsubscript{5}H\textsubscript{10} yields 19.2 grams of carbon dioxide. Find the percentage yield.

5) Calculate the grams of iron(III) oxide produced if 15.2 grams of iron and 7.41 grams of oxygen react to form the compound until one of them is completely consumed.

6) Identify the substance that is in excess in Question 5, and calculate the mass of that substance that remains unreacted.

7) Express 127 joules as kilocalories.
8) Write in two different forms the thermochemical equation showing the decomposition of one mole of steam into hydrogen gas and oxygen gas if ∆H for this reaction is +286 kJ.

9) ∆H for the reaction in Questions 1–4 is –6.08 kJ. How many grams of C₅H₁₀ must be consumed to release 2.22 kJ?

Answers to Chapter 9 Sample Test

1) 

\[ \text{GIVEN:} \ 3 \text{ mol C}_5\text{H}_{10} \quad \text{WANTED:} \ \text{mol CO}_2 \]

\[ \text{PER/PATH:} \quad \text{mol C}_5\text{H}_{10} \quad \frac{10 \text{ mol CO}_2}{2 \text{ mol C}_5\text{H}_{10}} \quad \text{mol CO}_2 \]

\[ 3 \text{ mol C}_5\text{H}_{10} \div \frac{10 \text{ mol CO}_2}{2 \text{ mol C}_5\text{H}_{10}} = 15 \text{ mol CO}_2 \]

2) 

\[ \text{GIVEN:} \ 12.0 \text{ mol CO}_2 \quad \text{WANTED:} \ \text{mass O}_2 \text{ (assume g)} \]

\[ \text{PER/PATH:} \quad \text{mol CO}_2 \quad \frac{15 \text{ mol O}_2}{10 \text{ mol CO}_2} \quad \text{mol O}_2 \quad \frac{32.00 \text{ g O}_2}{\text{mol O}_2} \quad \text{g O}_2 \]

\[ 12.0 \text{ mol CO}_2 \div \frac{15 \text{ mol O}_2}{10 \text{ mol CO}_2} \div \frac{32.00 \text{ g O}_2}{\text{mol O}_2} = 576 \text{ g O}_2 \]
3) \textit{GIVEN:} 4.12 \text{g O}_2 \quad \textit{WANTED:} \text{g H}_2\text{O}

\textit{PER/PATH:} \begin{align*}
g \text{O}_2 & \quad \frac{32.00 \text{g O}_2}{\text{mol O}_2} \quad \text{mol} \text{O}_2 \quad \frac{10 \text{mol H}_2\text{O}}{15 \text{mol O}_2} \quad \frac{18.02 \text{g H}_2\text{O}}{\text{mol H}_2\text{O}} \quad \text{g H}_2\text{O} \\
4.12 \text{g O}_2 & \quad \frac{1 \text{mol O}_2}{32.00 \text{g O}_2} \quad \frac{10 \text{mol H}_2\text{O}}{15 \text{mol O}_2} \quad \frac{18.02 \text{g H}_2\text{O}}{\text{mol H}_2\text{O}} = 1.55 \text{g H}_2\text{O}
\end{align*}

4) \textit{GIVEN:} 6.81 \text{g C}_5\text{H}_{10}, 19.2 \text{g CO}_2 \text{act} \quad \textit{WANTED:} \% \text{yield; g CO}_2 \text{theo}

\textit{PER/PATH:} \begin{align*}
g \text{C}_5\text{H}_{10} & \quad \frac{70.13 \text{g C}_5\text{H}_{10}}{\text{mol C}_5\text{H}_{10}} \quad \text{mol C}_5\text{H}_{10} \quad \frac{10 \text{mol CO}_2}{2 \text{mol C}_5\text{H}_{10}} \quad \frac{44.01 \text{g CO}_2}{\text{mol CO}_2} \quad \text{g CO}_2 \\
6.81 \text{g C}_5\text{H}_{10} & \quad \frac{1 \text{mol C}_5\text{H}_{10}}{70.13 \text{g C}_5\text{H}_{10}} \quad \frac{10 \text{mol CO}_2}{2 \text{mol C}_5\text{H}_{10}} \quad \frac{44.01 \text{g CO}_2}{\text{mol CO}_2} = 21.4 \text{g CO}_2 \text{theo}
\end{align*}

\% \text{yield} = \frac{\text{g act}}{\text{g theo}} \times 100 = \frac{19.2 \text{g CO}_2}{21.4 \text{g CO}_2} \times 100 = 89.7\% \text{ yield}

5 & 6) \textbf{Comparison of Moles Method}

\begin{align*}
& 4 \text{Fe} + 3 \text{O}_2 \quad \rightarrow \quad 2 \text{Fe}_2\text{O}_3 \\
\text{Grams at start} & \quad 15.2 \quad 7.41 \\
\text{Molar mass, g/mol} & \quad 55.85 \quad 32.00 \quad 159.70 \\
\text{Moles at start} & \quad 0.272 \quad 0.232 \quad 0 \\
\text{Moles used (–), produced (+)} & \quad -0.272 \quad -0.204 \quad +0.136 \\
\text{Moles at end} & \quad 0 \quad 0.028 \quad 0.136 \\
\text{Grams at end} & \quad 0 \quad 0.90 \quad 21.7
\end{align*}

5 & 6) \textbf{Smaller Amount Method}

5) \textit{4 Fe + 3 O}_2 \rightarrow \text{2 Fe}_2\text{O}_3

\textit{GIVEN:} 15.2 \text{g Fe} \quad \textit{WANTED:} \text{g Fe}_2\text{O}_3

\textit{PER/PATH:} \begin{align*}
g \text{Fe} & \quad \frac{55.85 \text{g Fe}}{\text{mol Fe}} \quad \text{mol Fe} \quad \frac{2 \text{mol Fe}_2\text{O}_3}{4 \text{mol Fe}} \quad \frac{159.70 \text{g Fe}_2\text{O}_3}{\text{mol Fe}_2\text{O}_3} \quad \text{g Fe}_2\text{O}_3 \\
15.2 \text{g Fe} & \quad \frac{1 \text{mol Fe}}{55.85 \text{g Fe}} \quad \frac{2 \text{mol Fe}_2\text{O}_3}{4 \text{mol Fe}} \quad \frac{159.70 \text{g Fe}_2\text{O}_3}{\text{mol Fe}_2\text{O}_3} = 21.7 \text{g Fe}_2\text{O}_3
\end{align*}
Given: 7.41 g O₂

Wanted: g Fe₂O₃

Per/Path: g O₂ \[ \frac{32.00 \text{ g O}_2/\text{mol O}_2}{159.70 \text{ g Fe}_2\text{O}_3/\text{mol Fe}_2\text{O}_3} \] mol O₂ \[ \frac{2 \text{ mol Fe}_2\text{O}_3/3 \text{ mol O}_2}{159.70 \text{ g Fe}_2\text{O}_3/\text{mol Fe}_2\text{O}_3} \] g Fe₂O₃

21.7 g Fe₂O₃ is produced; Fe is the limiting reactant.

6) Given: 15.2 g Fe

Wanted: g O₂

Per/Path: g Fe \[ \frac{55.85 \text{ g Fe/mol Fe}}{3 \text{ mol O}_2/4 \text{ mol Fe}} \] mol Fe \[ \frac{3 \text{ mol O}_2/4 \text{ mol Fe}}{32.00 \text{ g O}_2/\text{mol O}_2} \] g O₂

7.41 g O₂ start – 6.53 g O₂ used = 0.88 g O₂ unreacted

7) Given: 127 J

Wanted: kcal

Per/Path: J \[ \frac{4.184 \text{ J/cal}}{1000 \text{ cal/kcal}} \] cal \[ \frac{1 \text{ kcal}}{1 \text{ cal}} \] kcal

8) \[ \text{H}_2\text{O}(g) \rightarrow \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \quad \Delta H = +286 \text{ kJ} \]

286 kJ + \[ \text{H}_2\text{O}(g) \rightarrow \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \]

9) Given: 2.22 kJ

Wanted: g C₃H₁₀

Per/Path: kJ \[ \frac{2 \text{ mol C}_3\text{H}_{10}/6.08 \text{ kJ}}{70.13 \text{ g C}_3\text{H}_{10}/\text{mol C}_3\text{H}_{10}} \] g C₃H₁₀

51.2 g C₃H₁₀