Virden Collegiate Institute

30S Chemistry

Chemical Reactions: Stoichiometry

Student Study Guide

Stoichiometry

Before You Read

Review Vocabulary *Define the following terms.*

mole — the SI base unit used to measure the amount of atoms, particles, or formula units in a substance

molar mass — mass in grams of one mole of any pure substance

conversion factor — a ratio of equivalent values used to express the same quantity in different units

dimensional analysis — a method of problem-solving that focuses on the units used to describe matter

law of conservation of mass — states that mass is neither created nor destroyed during a chemical reaction, but is conserved

Chapter 10

Balance *the following equation.*

$$\boxed{3}\ Mg\ (s) + \boxed{3}\ AlCl_3\ (aq) \rightarrow \boxed{3}\ Al\ (s) + \boxed{3}\ MgCl_2\ (aq)$$

Chapter 11

Use *the periodic table in the back of your text to complete the chart.*

Pure Substance	Molar Mass
Carbon	12.011
Sodium	22.990
Oxygen	15.999
Sodium carbonate	**105.96**

Stoichiometry

Section 12.1 What is Stoichiometry?

Main Idea — **Details**

Skim *Section 1 of your text. Write three questions that come to mind from reading the headings and the illustration captions.*

1. Accept all reasonable responses.
2.
3.

New Vocabulary *Use your text to define each term.*

stoichiometry — the study of quantitative relationships between amounts of reactants used and products formed by a chemical reaction

mole ratio — a ratio between the numbers of moles of any two substances in a balanced chemical equation

Academic Vocabulary *Define the following term.*

qualitative — analysis which relates to the physical characteristics of a substance without considering the amount of material present

Mole-Mass Relationships in Chemical Reactions

Use with page 354.

Explain *the importance of the law of conservation of mass in chemical reactions.*

The law of conservation of mass states that matter is neither created nor destroyed in a chemical reaction. Chemical bonds in reactants break and new chemical bonds form to produce products, but the amount of matter present at the end of the reaction is the same as it was at the beginning of the reaction.

Main Idea

Interpreting Chemical Equations

Use with Example Problem 12-1, page 354.

Details

Summarize *Fill in the blanks to help you take notes while you read Example Problem 12-1.*

Problem

Interpret the equation in terms of **representative particles, moles**, and **mass**. Show that the law of conservation of mass is **observed**.

1. Analyze the Problem

Known: $C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g)$

Unknown: **The equation in terms of molecules =**

The equation in terms of moles =

The equation in terms of mass =

2. Solve for the Unknown

The coefficients indicate the number of **molecules**.

The coefficients indicate the number of **moles**.

Use the space below to calculate the mass of each reactant and each product. Multiply the number of moles by the conversion factor, molar mass.

$$\text{moles of reactant} \times \frac{\text{grams of reactant}}{1 \text{ mole of reactant}} = \text{grams of } \textbf{reactant}$$

$$\text{moles of product} \times \frac{\text{grams of reactant}}{1 \text{ mole of reactant}} = \text{grams of } \textbf{product}$$

Add the masses of the reactants.

44.09 g C_3H_8 + **160.0** g $5O_2$ = **204.1** g reactants

Add the masses of the products.

132.0 g CO_2 + **72.08** g H_2O = **204.1** g products

Determine if the **law of conservation of mass** is observed. Does the mass of the reactants equal the mass of the products? **Yes**.

3. Evaluate the Answer

Each product or reactant has **4** significant figures. Your answer must have **4** significant figures.

Main Idea — Details

Mole ratios

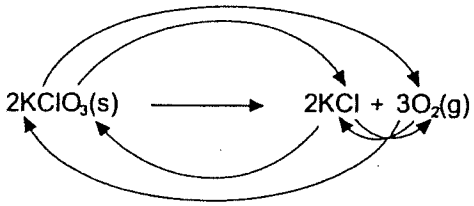
Use with page 356.

Examine *Relationships between coefficients can be used to write conversion factors called* mole ratios.

Example

Given the equation $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$

Each substance forms a **mole ratio** with the other substances in the reaction.



Write *the mole ratios that define the mole relationships in this equation. (Hint: Relate each reactant and each product to each of the other substances.)*

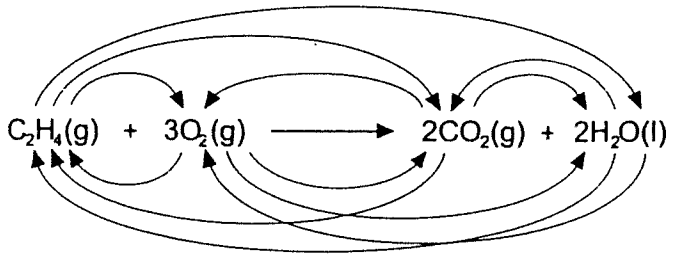
$$\frac{2 \text{ mol } KClO_3}{2 \text{ mol } KCl} \text{ and } \frac{2 \text{ mol } KClO_3}{3 \text{ mol } O_2}$$

$$\frac{2 \text{ mol } KCl}{2 \text{ mol } KClO_3} \text{ and } \frac{3 \text{ mol } O_2}{2 \text{ mol } KClO_3}$$

$$\frac{2 \text{ mol } KCl}{3 \text{ mol } O_2} \text{ and } \frac{3 \text{ mol } O_2}{2 \text{ mol } KCl}$$

You Try It

Draw *arrows with colored pencils that show the relationships of the substances in this equation.*



Write *the mole ratios for the above equation.*

$$\frac{1 \text{ mol } C_2H_4}{3 \text{ mol } O_2} \text{ and } \frac{1 \text{ mol } C_2H_4}{2 \text{ mol } CO_2} \text{ and } \frac{1 \text{ mol } C_2H_4}{2 \text{ mol } H_2O}$$

$$\frac{3 \text{ mol } O_2}{1 \text{ mol } C_2H_4} \text{ and } \frac{3 \text{ mol } O_2}{2 \text{ mol } CO_2} \text{ and } \frac{3 \text{ mol } O_2}{2 \text{ mol } H_2O}$$

$$\frac{2 \text{ mol } CO_2}{3 \text{ mol } O_2} \text{ and } \frac{2 \text{ mol } CO_2}{1 \text{ mol } C_2H_4} \text{ and } \frac{2 \text{ mol } CO_2}{2 \text{ mol } H_2O}$$

$$\frac{2 \text{ mol } H_2O}{3 \text{ mol } O_2} \text{ and } \frac{2 \text{ mol } H_2O}{2 \text{ mol } CO_2} \text{ and } \frac{2 \text{ mol } H_2O}{1 \text{ mol } C_2H_4}$$

Stoichiometry

Section 12.2 Stoichiometric Calculations

Main Idea

Details

Scan *Section 2, using the checklist below to preview your text.*

- Read all section titles.
- Read all boldfaced words.
- Read all tables and graphs.
- Look at all pictures and read the captions.
- Think about what you already know about this subject.

Write *three facts you discovered about stoichiometric calculations.*

1. Accept all reasonable responses.
2. _____
3. _____

Academic Vocabulary

Define the following terms.

convert — to change from one state, characteristic, or property to another

process — a series of events leading to a single result, or a series of events which can be repeated to achieve the identical result

significant — having, or likely to have, influence or effect

Using Stoichiometry

Use with page 358.

Identify *the tools needed for stoichiometric calculations.*

All stoichiometric calculations start with mole ratios based on a balanced chemical equation. Finally, mass-to-mole conversions are required.

Main Idea

Stoichiometric Mole-to-Mole Conversion

Use with Example Problem 12-2, page 359.

Details

Solve *Read Example Problem 12-2 in your text.*

You Try It

Problem

How many moles of aluminum oxide (Al_2O_3) are produced when 4.0 moles of aluminum (Al) are combined with oxygen gas (O_2)?

1. Analyze the Problem

Known: **moles of aluminum = 4.0 mol Al**

Unknown: **moles of oxygen = ? mol O_2**

Both the known and the unknown are in moles, therefore, you will do a mole-to-mole conversion.

2. Solve for the Unknown

Write the balanced chemical equation. Label the known and unknown.

$$\boxed{4}\ Al(s) + \boxed{3}\ O_2(g) = \boxed{2}\ Al_2O_3(s)$$

List the mole ratios for this equation. (Hint: *Draw arrows that show the relationships of the substances in this equation.*)

Circle the mole ratio that relates mol Al to mol of Al_2O_3.

$$\frac{\textbf{4 mol Al}}{\textbf{3 mol } O_2} \textbf{ and } \frac{\textbf{2 mol Al}}{\textbf{1 mol } Al_2O_3}$$

$$\frac{\textbf{3 mol } O_2}{\textbf{4 mol Al}} \textbf{ and } \frac{\textbf{3 mol } O_2}{\textbf{2 mol } Al_2O_3}$$

$$\frac{\textbf{2 mol } Al_2O_3}{\textbf{3 mol } O_2} \textbf{ and } \frac{\textbf{1 mol } Al_2O_3}{\textbf{2 mol Al}}$$

Multiply the known number of moles Al by the mole ratio to find the moles of unknown Al_2O_3.

$$\boxed{4.0}\ \text{moles of Al} \times \frac{\boxed{1.0}\ \text{moles of } Al_2O_3}{\boxed{2.0}\ \text{moles of Al}} = \boxed{2.0}\ \text{moles of } Al_2O_3$$

3. Evaluate the Answer

The given number of moles has $\boxed{2}$ significant figures. Therefore, the answer must have $\boxed{2}$ significant figures.

Main Idea

Stoichiometric Mole-to-Mass Conversion

Use with Example Problem 12-3, page 360.

Details

Solve *Read Example Problem 12-3 in your text.*

You Try It

Problem

How many grams of solid iron (III) chloride ($FeCl_3$) are produced when 2.00 moles of solid iron (Fe) are combined with chlorine gas(Cl_2)?

1. Analyze the Problem

Known: **moles of iron = 2.00 mol Fe**

Unknown: **grams of $FeCl_3$**

You are given the moles of the reactant, Fe, and must determine the mass of the product, $FeCl_3$, therefore, you will do a mole to mass conversion.

2. Solve for the Unknown

Write the balanced chemical equation. Identify the known and unknown substances.

$\boxed{2}\ Fe(s) + \boxed{3}\ Cl_2(g) = \boxed{2}\ FeCl_3(s)$

List the mole ratios for this equation. (Hint: *Draw arrows that show the relationships of the substances in this equation.*)

$$\frac{\text{1 mol Fe}}{\text{1 mol } FeCl_3} \text{ and } \frac{\text{2 mol Fe}}{\text{3 mol } Cl_2}$$

$$\frac{\text{1 mol } FeCl_3}{\text{1 mol Fe}} \text{ and } \frac{\text{2 mol } FeCl_3}{\text{3 mol } Cl_2}$$

$$\frac{\text{3 mol } Cl_2}{\text{2 mol } FeCl_3} \text{ and } \frac{\text{3 mol } Cl_2}{\text{2 mol Fe}}$$

Circle the mole ratio that relates moles of Fe to $FeCl_3$.

Multiply the number of moles of Fe by the mole ratio.

$$\boxed{2.00}\ \text{mol Fe} \times \frac{\boxed{1.00}\ \text{mol } FeCl_3}{\boxed{1.00}\ \text{mol Fe}} = \boxed{2.00}\ \text{mol } FeCl_3$$

Multiply the moles of $FeCl_3$ by the molar mass of $FeCl_3$.

$$\boxed{2.00}\ \text{mol } FeCl_3 \times \frac{\boxed{162}\ \text{g } FeCl_3}{1\ \text{mol } FeCl_3} = \boxed{324}\ \text{g } FeCl_3$$

3. Evaluate the Answer

The given number of moles has $\boxed{3}$ digits, so the mass of $FeCl_3$ must have $\boxed{3}$ digits.

Main Idea — **Details**

Stoichiometric Mass-to-Mass Conversion

Use with Example Problem 124, page 361.

Solve *Read Example Problem 12-4 in your text.*

You Try It

Problem

Determine the mass of ammonia (NH_3) produced when 3.75 g of nitrogen gas (N_2) react with hydrogen gas (H_2).

1. Analyze the Problem

Known: **mass of nitrogen gas = 3.75 g**

Unknown: **g NH_3**

You are given the mass of the reactant, N_2, and must determine the mass of the product NH_3. Do a mass-to-mass conversion.

2. Solve for the Unknown

Write the balanced chemical equation for the reaction.

$$\boxed{1}\ N_2(g) + \boxed{3}\ H_2(g) = \boxed{2}\ NH_3(g)$$

Convert grams of $N_2(g)$ to moles of $N_2(g)$ using the inverse of molar mass as the conversion factor.

$$\boxed{3.75}\ g\ N_2(g) \times \frac{1\ mol\ N_2}{\boxed{28.01}\ g\ N_2} = \boxed{0.13}\ mol\ N_2$$

List the mole ratios for this equation.

$$\frac{1\ mol\ N_2}{3\ mol\ H_2} \quad \frac{1\ mol\ N_2}{2\ mol\ NH_3} \quad \frac{3\ mol\ H_2}{1\ mol\ N_2}$$

$$\frac{3\ mol\ H_2}{2\ mol\ NH_3} \quad \frac{2\ mol\ NH_3}{3\ mol\ H_2} \quad \frac{2\ mol\ NH_3}{1\ mol\ N_2}$$

Multiply moles of N_2 by the mole ratio that relates N_2 to NH_3.

$$\boxed{0.13}\ mol\ N_2 \times \frac{\boxed{2}\ mol\ NH_3}{\boxed{1}\ mol\ N_2} = \boxed{0.26}\ mol\ NH_3$$

Multiply moles of NH_3 by the molar mass.

$$\boxed{0.26}\ mol\ NH_3 \times \frac{\boxed{17.03}\ g\ NH_3}{1\ mol\ NH_3} = \boxed{4.42}\ g\ NH_3$$

3. Evaluate the Answer

The given mass has $\boxed{3}$ significant figures, so the mass of NH_3 must have $\boxed{3}$ significant figures.

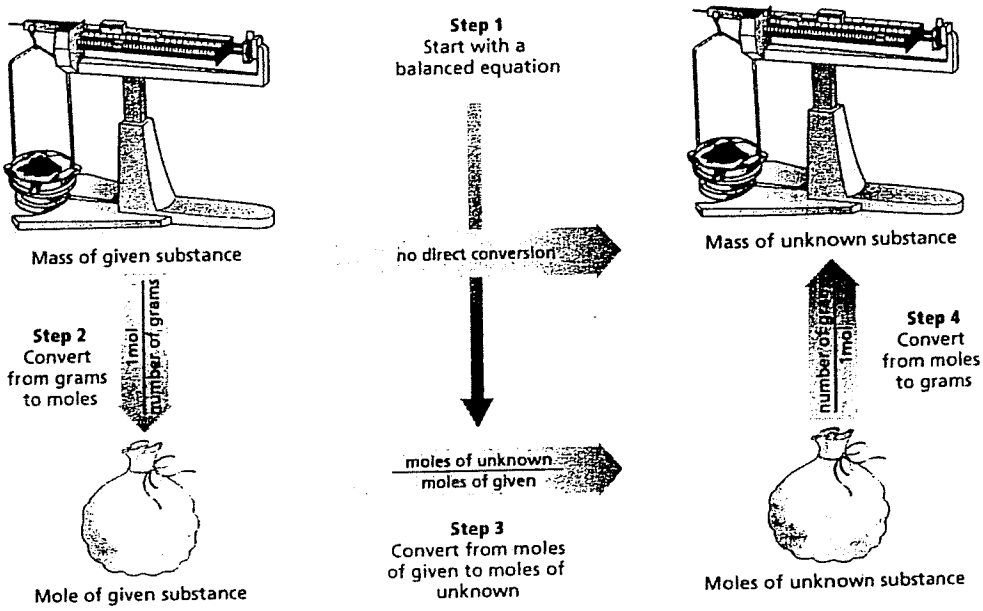
Main Idea

Steps in Stoichiometric Calculations

Use with page 363.

Details

Sequence *the steps needed to convert from the balanced equation to the mass of the unknown.*



Identify *the steps in stoichiometric calculations by completing the summary below.*

1. **Write a balanced chemical equation**. Interpret the equation in terms of **moles**.
2. **Determine the moles of the given substance using a mass-to-mole conversion**. Use the **appropriate mole ratio from the balanced chemical equation** as the conversion factor.
3. **Determine the moles of the unknown substance from the moles of the given substance.** Use the appropriate mole ratio from the **balanced chemical equation** as the conversion factor.
4. **From the moles of the unknown substance, determine the mass of the unknown substance using a mole-to-mass conversion.** Use **the molar mass** as the conversion factor.

Stoichiometry

Section 12.3 Limiting Reactants

Main Idea — **Details**

Scan *Section 3 of your text. Use the checklist below as a guide.*

- Read all section titles.
- Read all boldfaced words.
- Read all tables and graphs.
- Look at all pictures and read the captions.
- Think about what you already know about limiting reactants.

Write three facts you discovered about limiting reactants.

1. Accept all reasonable responses.
2. _____
3. _____

New Vocabulary *Use your text to define each term.*

limiting reactant — limits the extent of the chemical reaction and, thereby, determines the amount of product

excess reactant — leftover reactants in a chemical reaction

Academic Vocabulary *Define the following term.*

reassemble — to repair or restore to a previous condition; to rebuild

Main Idea

Details

Why do reactions stop?

Use with page 364.

What if *you have six slices of bread, three tomato slices, and two cheese slices. How many tomato-cheese sandwiches can you make? Which ingredient(s) limit the number of sandwiches you can make?*

You can make two sandwiches. Cheese is the limiting ingredient.

Calculating the Product When a Reactant is Limited

Organize *information about limiting reactants.*

I. When do reactants stop?

- A. Limiting reactant
  - 1. limits the extent of the reaction
  - 2. determines the amount of product
- B. All remaining reactants are excess reactants

II. Calculating the product when a reactant is limited

- A. Find the moles of each reactant
  - 1. convert the masses to moles
  - 2. multiply each mass by the inverse of the molar mass
- B. Determine the mole ratios for the equation
- C. Compare the available moles with the mole ratio to determine the limiting reactant
- D. Determine the amount of product that can be made with the moles of the limiting reactant.

Determining the Limiting Reactant

Use with Example Problem 12-5, page 364.

Solve *Read Example Problem 12-5 in your text.*

You Try It

Problem

If 100.0g of sulfur reacts with 50.0g of chlorine, what mass of disulfur dichloride is produced?

1. Analyze the Problem

Known: mass of sulfur = 100.0 g, mass of chlorine = 50.0 g

Unknown: g disulfur dichloride

2. Solve for the Unknown

Write the balanced chemical equation.

$S_8 + 4Cl_2 \longrightarrow 4S_2Cl_2$

Main Idea — Details

List the mole ratios for this equation.

$$\frac{1\ \text{mol } S_8}{4\ \text{mol } Cl_2} \quad \frac{1\ \text{mol } S_8}{4\ \text{mol } S_2Cl_2} \quad \frac{4\ \text{mol } Cl_2}{1\ \text{mol } S_8}$$

$$\frac{4\ \text{mol } Cl_2}{4\ \text{mol } S_2Cl_2} \quad \frac{4\ \text{mol } S_2Cl_2}{4\ \text{mol } Cl_2} \quad \frac{4\ \text{mol } S_2Cl_2}{1\ \text{mol } S_8}$$

Multiply each mass by the inverse of molar mass.

$$100\ \text{g } S_8 \times \frac{1\ \text{mol } S_8}{256.5\ \text{g } S_8} = 0.38\ \text{mol } S_8$$

$$50\ \text{g } Cl_2 \times \frac{1\ \text{mol } Cl_2}{70.91\ \text{g } Cl_2} = 0.70\ \text{mol } Cl_2$$

Calculate the actual ratio of available moles.

$$\frac{0.70\ \text{mol } Cl_2}{0.38\ \text{mol } S_8} = \frac{1.84\ \text{mol } Cl_2}{1\ \text{mol } S_8}$$

Determine the limiting reactant.

Because 1.84 moles of Cl_2 are available for every mol of S_8, but 4 moles of Cl_2 are required for the reaction, Cl_2 will be the limiting reactant.

Multiply the number of moles of the limiting reactant by the mole ratio of the product to the limiting reactant.

$$0.70\ \text{mol } Cl_2 \times \frac{4\ \text{mol } S_2Cl_2}{4\ \text{mol } Cl_2} = 0.70\ \text{mol } S_2Cl_2$$

Multiply moles of the product by the molar mass.

$$0.70\ \text{mol } S_2Cl_2 \times \frac{135.0\ \text{g } S_2Cl_2}{1\ \text{mol } S_2Cl_2} = 94.5\ \text{mol } S_2Cl_2$$

Multiply moles of the excess reactant by the molar mass.

$$0.70\ \text{mol } Cl_2 \times \frac{1\ \text{mol } S_8}{4\ \text{mol } Cl_2} = 0.18\ \text{mol } S_8$$

$$0.18\ \text{mol } S_8 \times \frac{256.5\ \text{g } S_8}{1\ \text{mol } S_8} = 46.1\ \text{g } S_8$$

Subtract the mass of the excess reactant needed from the mass available.

$$100\ \text{g } S_8 - 46.1\ \text{g } S_8 = 53.9\ \text{g } S_8$$

3. Evaluate the Answer

The given mass has [3] significant figures, so the mass of the unknown must have [3] significant figures.

Stoichiometry

Section 12.4 Percent Yield

Main Idea

Details

Skim *Section 4 of your text. Focus on the headings, subheadings, and boldfaced words. Summarize the main ideas of this section.*

Accept all reasonable responses.

New Vocabulary

In the left margin, write the terms defined below.

percent yield — *the ratio of actual yield to theoretical yield (from stoichiometric calculations) expressed as a percent*

theoretical yield — *in a chemical reaction, the maximum amount of product that can be produced from a given amount of reactant*

actual yield — *the amount of product actually produced when a chemical reaction is carried out in an experiment*

Academic Vocabulary

Define the following term.

maximize — to make the most of a possibility, to achieve the highest possible gain

How much product?

Use with page 370.

Write *the formula for percent yield.*

$$\frac{\text{actual yield (from an experiment)}}{\text{theoretical yield (from stoichiometric calculations)}} \times 100 = \text{percent yield}$$

Main Idea — Details

Calculating Percent Yield

Use with page 371.

Solve *Read Example Problem 12-6 in your text.*

You Try It

Problem

When 100.0 kg sand (SiO_2) are processed with carbon, CO and 51.4 kg SiC are recovered. What is the percent yield of SiC?

1. Analyze the Problem

Known: **mass of sand = 100 kg actual yield = 51.4 kg SiC**

Unknown: **theoretical yield = ? SiC percent yield = ? SiC**

2. Solve for the Unknown

Write the balanced chemical equation.

$SiO_2(s) + 3C(s) \longrightarrow SiC(s) + 2CO(g)$

Determine the mole ratio that relates **SiO_2** to **SiC**.

$$\longrightarrow \frac{\text{1 mol } SiO_2}{\text{1 mol SiC}}$$

Convert kg to g.

100 kg SiO_2 = **100 000** g, 51.4 kg SiC = **51 400** g

Convert mass to moles using the inverse of molar mass.

$$\text{100 000 g } SiO_2 \times \frac{\text{1 mole } SiO_2}{\text{60.09 g } SiO_2} = \text{1664 mol } SiO_2$$

Use the appropriate mole ratio to convert mol SiO_2 to mol SiC.

$$\text{1664 mol } SiO_2 \times \frac{\text{1 mol } SiO_2}{\text{1 mol SiC}} = \text{1664 mol SiC}$$

Calculate the theoretical yield. Multiply mol SiC by the molar mass.

$$\text{1664 mol SiC} = \frac{\text{40.1 g SiC}}{\text{1 mol SiC}} = \text{66 726.4 g SiC}$$

Divide the actual yield by the theoretical yield and multiply by 100.

$$\frac{\text{51.4 kg SiC}}{\text{66.7 kg SiC}} \times 100 = 77.0\%$$

3. Evaluate the Answer

The quantities have [3] significant figures, so the percent yield must have [3] significant figures.

Stoichiometry

Stoichiometry and the Stock Market

SYNTHESIZE

In the left margin, write the stoichiometry concepts that parallel the daily activities of a Wall Street professional.

theoretical yield

percent yield

excess of reactants

mass-to-mass conversion

limiting reactant

1. A stock analyst keeps a close eye on the earnings of corporations. She has determined how much each company should accomplish.
2. The same analyst tracks whether companies meet expectations or fall short.
3. A grain trader wants to be sure to have 100 000 bushels in reserve for the winter selling season. He places an order for 120 000 bushels because he knows spoilage may damage a percentage of the crop.
4. A livestock futures trader knows that one cattle car holds 10 steers averaging 1200 lbs. each. He wants to bid on an identical car full of sheep, which average about 200 lbs. each. He needs to know how many sheep are on the car.
5. A stockbroker learns that a medical supply company has acquired several tons of a rare silver compound that will allow it to make superior dental equipment. The question is whether the company will have enough of the product to meet the demands of the marketplace.

Stoichiometry Chapter Wrap-Up

Now that you have read the chapter, review what you have learned. Write the key equations and relationships.

Review

Use this checklist to help you study.

- ☐ Use this Science Notebook to study this chapter.
- ☐ Study the vocabulary words and scientific definitions.
- ☐ Review daily homework assignments.
- ☐ Reread the chapter, reviewing the tables, graphs, and illustrations.
- ☐ Review the Section Assessment questions at the end of each section.
- ☐ Look over the Study Guide at the end of the chapter.

Real-World Connection

Explain how stoichiometry is important to air bags and your safety.

The expansion of an air bag depends on a series of chemical reactions involving heat sodium azide, and potassium nitrate. If the chemical reactions are not precisely measured through stoichiometric calculations, the air bag may not inflate, or the inflated air bag may be so hard that it can cause harm.