Chapter 10
Chemical Calculations and Chemical Equations

$$? \text{ mL } AgNO_3 \text{ soln} = 25.00 \cancel{\text{mL } Na_3PO_4 \text{ soln}} \left(\frac{1 \cancel{\text{L}}}{10^3 \cancel{\text{mL}}}\right)\left(\frac{0.500 \cancel{\text{mol } Na_3PO_4}}{1 \cancel{\text{L } Na_3PO_4 \text{ soln}}}\right)\left(\frac{3 \cancel{\text{mol } AgNO_3}}{1 \cancel{\text{mol } Na_3PO_4}}\right)\left(\frac{1 \cancel{\text{L}} \text{ } AgNO_3 \text{ soln}}{1.00 \cancel{\text{mol } AgNO_3}}\right)\left(\frac{10^3 \text{ mL}}{1 \cancel{\text{L}}}\right)$$

$$= 37.5 \text{ mL } AgNO_3 \text{ soln}$$

Converts given unit into liters.

Coefficients from balanced equation convert moles of one substance into moles of another substance.

Converts liters into desired unit.

Molarity as a conversion factor converts liters into moles.

Molarity as a conversion factor converts moles into liters.

- ♦ Review Skills

10.1 Equation Stoichiometry

Internet: Equation Stoichiometry Problems with Mixtures

10.2 Real-World Applications of Equation Stoichiometry

- Limiting Reactants
- Percent Yield

Special Topic 10.1: Big Problems Require Bold Solutions - Global Warming and Limiting Reactants

10.3 Molarity and Equation Stoichiometry

- Reactions in Solution and Molarity
- Equation Stoichiometry and Reactions in Solution

Internet: Acid-Base Titrations

- ♦ Chapter Glossary

Internet: Glossary Quiz

- ♦ Chapter Objectives

Review Questions

Key Ideas

Chapter Problems

Section Goals and Introductions

Section 10.1 Equation Stoichiometry

Goal: To show how the coefficients in a balanced chemical equation can be used to convert from mass of one substance in a given chemical reaction to the corresponding mass of another substance participating in the same reaction.

It's common that chemists and chemistry students are asked to convert from an amount of one substance in a given chemical reaction to the corresponding amount of another substance participating in the same reaction. This type of calculation, which uses the coefficients in a balanced equation to convert from moles of one substance to moles of another, is called equation stoichiometry. This section shows how to do equation stoichiometry problems for which you are asked to convert from *mass* of one substance in a given chemical reaction to the corresponding *mass* of another substance participating in the same reaction. For a related section, see *Equation Stoichiometry Problems with Mixtures* on our Web site.

Internet: Equation Stoichiometry Problems with Mixtures

Section 10.2 Real-World Applications of Equation Stoichiometry

Goals

- *To explain why chemists sometimes deliberately use a limited amount of one reactant (called the limiting reactant) and excessive amounts of others.*
- *To show how to determine which reactant in a chemical reaction is the limiting reactant.*
- *To show how to calculate the maximum amount of product that they can form from given amounts of two or more reactants in a chemical reaction.*
- *To explain why the actual yield in a reaction might be less than the maximum possible yield (called the theoretical yield).*
- *To explain what percent yield is and to show how to calculate the percent yield given the actual yield and enough information to determine the theoretical yield.*

Chemistry in the real world is sometimes more complicated than we make it seem in introductory chemistry texts. You will see in this section that reactions run in real laboratories never have exactly the right amounts of reactants for each to react completely, and even if they did, it is unlikely that all of the reactants would form the desired products. This section shows you why this is true and shows you how to do calculations that reflect these realities.

Section 10.3 Molarity and Equation Stoichiometry

Goals

- *To show how the concentration of solute in solution can be described with molarity, which is moles of solute per liter of solution.*
- *To show how to calculate molarity.*
- *To show how the molarity of a solution can be translated into a conversion factor that converts between moles of solute and volume of solution.*

Section 10.1 shows the general equation stoichiometry steps as

measurable property 1 → moles 1 → moles 2 → measurable property 2

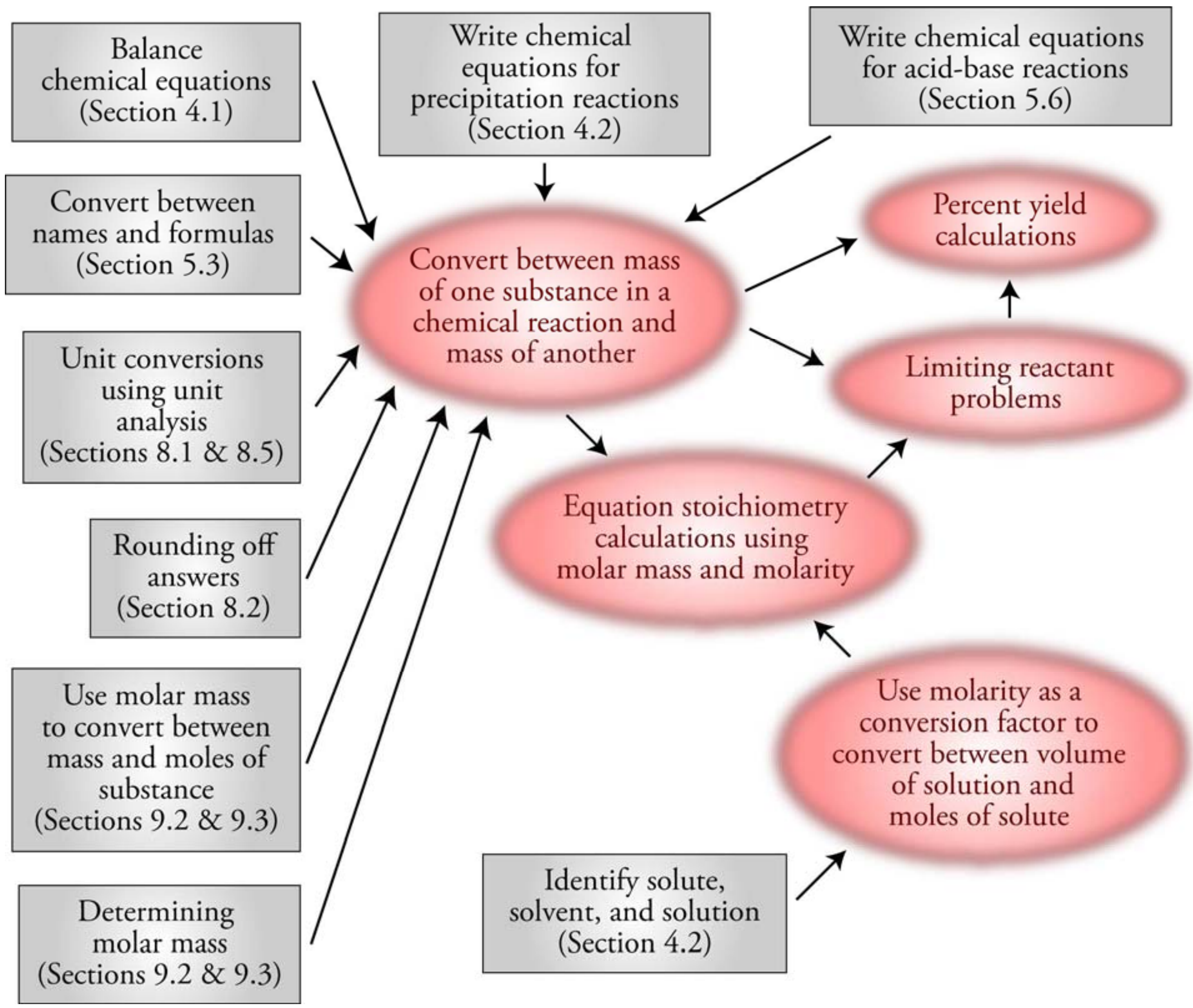
When the reactants and products of a reaction are pure solids and pure liquids, mass is the conveniently measurable property, but many chemical changes take place in either the gas phase or in solution. The masses of gases or of solutes in solution cannot be measured directly. For reactions run in solution, it's more convenient to measure the volume of the solution that contains the solute reactants and products. Therefore, to complete equation stoichiometry problems for reactions done in solution, we need a conversion factor that converts between volume of solution and moles of solute. This section defines that conversion factor, called molarity (moles of solute per liter of solution), shows you how it can be determined, and shows you how molarity can be translated into a conversion factor that allows you to convert between the measurable property of volume of solution and moles of solute.

The section ends with a summary of equation stoichiometry problems and shows how the skills developed in Section 10.1 can be mixed with the new skills developed in this section. Section 13.3 completes our process of describing equation stoichiometry problems by showing how to combine the information found in this chapter with calculations that convert between volume of gas and moles of gas.

See the two topics on our Web site that relate to this section: *Acid-Base Titrations* and *Making Solutions of a Certain Molarity*.

Internet: Acid-Base Titrations

Chapter 10 Map



Chapter Checklist

- ☐ Read the Review Skills section. If there is any skill mentioned that you have not yet mastered, review the material on that topic before reading this chapter.
- ☐ Read the chapter quickly before the lecture that describes it.
- ☐ Attend class meetings, take notes, and participate in class discussions.
- ☐ Work the Chapter Exercises, perhaps using the Chapter Examples as guides.
- ☐ Study the Chapter Glossary and test yourself on our Web site:

  Internet: Glossary Quiz

- ☐ Study all of the Chapter Objectives. You might want to write a description of how you will meet each objective. (Although it is best to master all of the objectives, the following objectives are especially important because they pertain to skills that you will need while studying other chapters of this text: 4, 9, 12, and 13.)
- ☐ Reread the Study Sheets in this chapter and decide whether you will use them or some variation on them to complete the tasks they describe.

  Sample Study Sheet 10.1: Basic Equation Stoichiometry - Converting Mass of One Compound in a Reaction to Mass of Another

  Sample Study Sheet 10.2: Limiting Reactant Problems

  Sample Study Sheet 10.3: Equation Stoichiometry Problems

- ☐ To get a review of the most important topics in the chapter, fill in the blanks in the Key Ideas section.
- ☐ Work all of the selected problems at the end of the chapter, and check your answers with the solutions provided in this chapter of the study guide.
- ☐ Ask for help if you need it.

Web Resources

Internet: Equation Stoichiometry Problems with Mixtures

Internet: Acid-Base Titrations

Internet: Glossary Quiz

Exercises Key

Exercise 10.1 - Equation Stoichiometry: Tetrachloroethene, C_2Cl_4, often called perchloroethylene (perc), is a colorless liquid used in dry cleaning. It can be formed in several steps from the reaction of dichloroethane, chlorine gas, and oxygen gas. The equation for the net reaction is

$$8C_2H_4Cl_2(l) + 6Cl_2(g) + 7O_2(g) \rightarrow 4C_2HCl_3(l) + 4C_2Cl_4(l) + 14H_2O(l)$$

a. Fifteen different conversion factors for relating moles of one reactant or product to moles of another reactant or product can be derived from this equation. Write five of them.

All fifteen possibilities are below.

$$\left(\frac{8\text{ mol }C_2H_4Cl_2}{6\text{ mol }Cl_2}\right) \text{ or } \left(\frac{8\text{ mol }C_2H_4Cl_2}{7\text{ mol }O_2}\right) \text{ or } \left(\frac{8\text{ mol }C_2H_4Cl_2}{4\text{ mol }C_2HCl_3}\right) \text{ or } \left(\frac{8\text{ mol }C_2H_4Cl_2}{4\text{ mol }C_2Cl_4}\right)$$

$$\text{or } \left(\frac{8\text{ mol }C_2H_4Cl_2}{14\text{ mol }H_2O}\right) \text{ or } \left(\frac{6\text{ mol }Cl_2}{7\text{ mol }O_2}\right) \text{ or } \left(\frac{6\text{ mol }Cl_2}{4\text{ mol }C_2HCl_3}\right) \text{ or } \left(\frac{6\text{ mol }Cl_2}{4\text{ mol }C_2Cl_4}\right)$$

$$\text{or } \left(\frac{6\text{ mol }Cl_2}{14\text{ mol }H_2O}\right) \text{ or } \left(\frac{7\text{ mol }O_2}{4\text{ mol }C_2HCl_3}\right) \text{ or } \left(\frac{7\text{ mol }O_2}{4\text{ mol }C_2Cl_4}\right) \text{ or } \left(\frac{7\text{ mol }O_2}{14\text{ mol }H_2O}\right)$$

$$\text{or } \left(\frac{4\text{ mol }C_2HCl_3}{4\text{ mol }C_2Cl_4}\right) \text{ or } \left(\frac{4\text{ mol }C_2HCl_3}{14\text{ mol }H_2O}\right) \text{ or } \left(\frac{4\text{ mol }C_2Cl_4}{14\text{ mol }H_2O}\right)$$

b. How many grams of water form when 362.47 grams of tetrachloroethene, C_2Cl_4, are made in the reaction above?

$$?\text{ g }H_2O = 362.47\text{ g }C_2Cl_4\left(\frac{1\text{ mol }C_2Cl_4}{165.833\text{ g }C_2Cl_4}\right)\left(\frac{14\text{ mol }H_2O}{4\text{ mol }C_2Cl_4}\right)\left(\frac{18.0153\text{ g }H_2O}{1\text{ mol }H_2O}\right)$$

$$\textit{or} \quad ?\text{ g }H_2O = 362.47\text{ g }C_2Cl_4\left(\frac{14\times 18.0153\text{ g }H_2O}{4\times 165.833\text{ g }C_2Cl_4}\right) = \mathbf{137.82\text{ g }H_2O}$$

c. What is the maximum mass of perchloroethylene, C_2Cl_4, that can be formed from 23.75 kilograms of dichloroethane, $C_2H_4Cl_2$?

$$?\text{ kg }C_2Cl_4 = 23.75\text{ kg }C_2H_4Cl_2\left(\frac{10^3\text{ g}}{1\text{ kg}}\right)\left(\frac{1\text{ mol }C_2H_4Cl_2}{98.959\text{ g }C_2H_4Cl_2}\right)\left(\frac{4\text{ mol }C_2Cl_4}{8\text{ mol }C_2H_4Cl_2}\right)\left(\frac{165.833\text{ g }C_2Cl_4}{1\text{ mol }C_2Cl_4}\right)\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)$$

$$\textit{or} \quad ?\text{ kg }C_2Cl_4 = 23.75\text{ kg }C_2H_4Cl_2\left(\frac{4\times 165.833\text{ kg }C_2Cl_4}{8\times 98.959\text{ kg }C_2H_4Cl_2}\right) = \mathbf{19.90\text{ kg }C_2Cl_4}$$

Exercise 10.2 - Limiting Reactant: The uranium(IV) oxide, UO_2, which is used as fuel in nuclear power plants, has a higher percentage of the fissionable isotope uranium-235 than is present in the UO_2 found in nature. To make fuel-grade UO_2, chemists first convert uranium oxides to uranium hexafluoride, UF_6, whose concentration of uranium-235 can be increased by a process called gas diffusion. The enriched UF_6 is then converted back to UO_2 in a series of reactions, beginning with

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

a. How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

$$? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6 \left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } UF_6}{352.019 \text{ g } UF_6}\right)\left(\frac{1 \text{ mol } UO_2F_2}{1 \text{ mol } UF_6}\right)\left(\frac{308.0245 \text{ g } UO_2F_2}{1 \text{ mol } UO_2F_2}\right)\left(\frac{1 \text{ Mg}}{10^6 \text{ g}}\right)$$

or $? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6 \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{1 \times 352.019 \text{ Mg } UF_6}\right)$ **= 21.476 Mg UO_2F_2**

$$? \text{ Mg } UO_2F_2 = 8.0 \text{ Mg } H_2O \left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } H_2O}{18.0153 \text{ g } H_2O}\right)\left(\frac{1 \text{ mol } UO_2F_2}{2 \text{ mol } H_2O}\right)\left(\frac{308.0245 \text{ g } UO_2F_2}{1 \text{ mol } UO_2F_2}\right)\left(\frac{1 \text{ Mg}}{10^6 \text{ g}}\right)$$

or $? \text{ Mg } UO_2F_2 = 8.0 \text{ Mg } H_2O \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{2 \times 18.0153 \text{ Mg } H_2O}\right)$ = *68 Mg UO_2F_2*

b. Why do you think the reactant in excess was chosen to be in excess?

Water is much less toxic and less expensive than the radioactive and rare uranium compound. Water in the form of either liquid or steam is also very easy to separate from the solid product mixture.

Exercise 10.3 - Percent yield: The raw material used as a source of chromium and chromium compounds is a chromium-iron ore called chromite. For example, sodium chromate, Na_2CrO_4, is made by roasting chromite with sodium carbonate, Na_2CO_3. (Roasting means heating in the presence of air or oxygen.) A simplified version of the net reaction is

$$4FeCr_2O_4 + 8Na_2CO_3 + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$$

What is the percent yield if 1.2 kg of Na_2CrO_4 is produced from ore that contains 1.0 kg of $FeCr_2O_4$?

$$? \text{ kg } Na_2CrO_4 = 1.0 \text{ kg } FeCr_2O_4 \left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol } FeCr_2O_4}{223.835 \text{ g } FeCr_2O_4}\right)\left(\frac{8 \text{ mol } Na_2CrO_4}{4 \text{ mol } FeCr_2O_4}\right)\left(\frac{161.9733 \text{ g } Na_2CrO_4}{1 \text{ mol } Na_2CrO_4}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

or $? \text{ kg } Na_2CrO_4 = 1.0 \text{ kg } FeCr_2O_4 \left(\frac{8 \times 161.9733 \text{ kg } Na_2CrO_4}{4 \times 223.835 \text{ kg } FeCr_2O_4}\right)$ = *1.4 kg Na_2CrO_4*

$$\text{Percent Yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{1.2 \text{ kg } Na_2CrO_4}{1.4 \text{ kg } Na_2CrO_4} \times 100$$ **= 86% yield**

Exercise 10.4 - Calculating a Solution's Molarity: A silver perchlorate solution was made by dissolving 29.993 g of pure $AgClO_4$ in water and then diluting the mixture with additional water to achieve a total volume of 50.00 mL. What is the solution's molarity?

$$\text{Molarity} = \frac{?\text{ mol AgClO}_4}{1\text{ L AgClO}_4\text{ soln}} = \frac{29.993\text{ g AgClO}_4}{50.0\text{ mL AgClO}_4\text{ soln}}\left(\frac{1\text{ mol AgClO}_4}{207.3185\text{ g AgClO}_4}\right)\left(\frac{10^3\text{ mL}}{1\text{ L}}\right)$$

$$= \frac{2.893\text{ mol AgClO}_4}{1\text{ L AgClO}_4\text{ soln}} = \mathbf{2.893\ M\ AgClO_4}$$

Exercise 10.5 - Molarity and Equation Stoichiometry: How many milliliters of 6.00 M HNO_3 are necessary to neutralize the carbonate in 75.0 mL of 0.250 M Na_2CO_3?

$$?\text{ mL HNO}_3\text{ soln} = 75.0\text{ mL Na}_2\text{CO}_3\left(\frac{0.250\text{ mol Na}_2\text{CO}_3}{10^3\text{ mL Na}_2\text{CO}_3}\right)\left(\frac{2\text{ mol HNO}_3}{1\text{ mol Na}_2\text{CO}_3}\right)\left(\frac{10^3\text{ mL HNO}_3\text{ soln}}{6.00\text{ mol HNO}_3}\right) = \mathbf{6.25\ mL\ HNO_3\ soln}$$

Exercise 10.6 - Molarity and Equation Stoichiometry: What is the maximum number of grams of silver chloride that will precipitate from a solution made by mixing 25.00 mL of 0.050 M $MgCl_2$ with an excess of $AgNO_3$ solution?

$$2AgNO_3(aq) + MgCl_2(aq) \rightarrow 2AgCl(s) + Mg(NO_3)_2(aq)$$

$$?\text{ g AgCl} = 25.00\text{ mL MgCl}_2\left(\frac{0.050\text{ mol MgCl}_2}{10^3\text{ mL MgCl}_2}\right)\left(\frac{2\text{ mol AgCl}}{1\text{ mol MgCl}_2}\right)\left(\frac{143.3209\text{ g AgCl}}{1\text{ mol AgCl}}\right)$$

$$= \mathbf{0.36\ g\ AgCl}$$

Review Questions Key

1. Write balanced equations for the following reactions. You do *not* need to include the substances' states.
   a. Hydrofluoric acid reacts with silicon dioxide to form silicon tetrafluoride and water.
      $\mathbf{4HF + SiO_2 \rightarrow SiF_4 + 2H_2O}$
   b. Ammonia reacts with oxygen gas to form nitrogen monoxide and water.
      $\mathbf{4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O}$
   c. Water solutions of nickel(II) acetate and sodium phosphate react to form solid nickel(II) phosphate and aqueous sodium acetate.
      $\mathbf{3Ni(C_2H_3O_2)_2 + 2Na_3PO_4 \rightarrow Ni_3(PO_4)_2 + 6NaC_2H_3O_2}$
   d. Phosphoric acid reacts with potassium hydroxide to form water and potassium phosphate.
      $\mathbf{H_3PO_4 + 3KOH \rightarrow 3H_2O + K_3PO_4}$
2. Write complete equations, including states, for the precipitation reaction that takes place between the reactants in Part (a) and the neutralization reaction that takes place in Part (b).
   a. $\mathbf{Ca(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaNO_3(aq)}$
   b. $\mathbf{3HNO_3(aq) + Al(OH)_3(s) \rightarrow 3H_2O(l) + Al(NO_3)_3(aq)}$

3. How many moles of phosphorous acid, H_3PO_3, are there in 68.785 g of phosphorous acid?

   Molecular mass of H_3PO_3 = 3 (1.00794) + 30.9738 + 3(15.9994) = 81.9958

   $$? \text{ mol } H_3PO_3 = 68.785 \text{ g } H_3PO_3 \left(\frac{1 \text{ mol } H_3PO_3}{81.9958 \text{ g } H_3PO_3}\right) = \mathbf{0.83888 \text{ mol } H_3PO_3}$$

4. What is the mass in kilograms of 0.8459 mole of sodium sulfate?

   Molecular mass of Na_2SO_4 = 2(22.9898) + 32.066 + 4(15.9994) = 142.043

   $$? \text{ mol } Na_2SO_4 = 0.8459 \text{ mol } Na_2SO_4 \left(\frac{142.043 \text{ g } Na_2SO_4}{1 \text{ mol } Na_2SO_4}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = \mathbf{0.1202 \text{ kg } Na_2SO_4}$$

Key Ideas Answers

5. If a calculation calls for you to convert from an amount of one substance in a given chemical reaction to the corresponding amount of another substance participating in the same reaction, it is an equation **stoichiometry** problem.
7. For some chemical reactions, chemists want to mix reactants in amounts that are as close as possible to the ratio that would lead to the complete reaction of each. This ratio is sometimes called the **stoichiometric** ratio.
9. Sometimes one product is more important than others are, and the amounts of reactants are chosen to **optimize** its production.
11. Because some of the reactant that was added in excess is likely to be mixed with the product, chemists would prefer that the substance in excess be a substance that is **easy to separate** from the primary product.
13. The tip-off for limiting reactant problems is that you are given **two or more amounts** of reactants in a chemical reaction, and you are asked to calculate the maximum **amount of product** that they can form.
15. There are many reasons why the actual yield in a reaction might be less than the theoretical yield. One key reason is that many chemical reactions are significantly **reversible**.
17. Another factor that affects the actual yield is a reaction's rate. Sometimes a reaction is so **slow** that it has not reached the maximum yield by the time the product is isolated.
19. When two solutions are mixed to start a reaction, it is more convenient to measure their **volumes** than their masses.
21. Conversion factors constructed from molarities can be used in stoichiometric calculations in very much the same way conversion factors from **molar mass** are used. When a substance is pure, its molar mass can be used to convert back and forth between the measurable property of **mass** and moles. When a substance is in solution, its molarity can be used to convert between the measurable property of **volume of solution** and moles of solute.

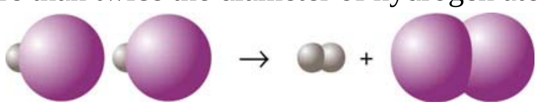
Problems Key

Section 10.1 Equation Stoichiometry and Section 10.2 Real-World Applications of Equation Stoichiometry

22. Because the bond between fluorine atoms in F_2 is relatively weak, and because the bonds between fluorine atoms and atoms of other elements are relatively strong, it is difficult to make diatomic fluorine, F_2. One way it can be made is to run an electric current through liquid hydrogen fluoride, HF. This reaction yields hydrogen gas, H_2, and fluorine gas, F_2.
    a. Write a complete balanced equation, including states, for this reaction.

    $$\mathbf{2HF(l) \xrightarrow{\text{electric current}} H_2(g) + F_2(g)}$$

    b. Redraw your equation, substituting rough drawings of space-filling models for the coefficients and formulas for the reactants and products. Fluorine atoms have a little more than twice the diameter of hydrogen atoms.

    c. Write a conversion factor that could be used to convert between moles of HF and moles of F_2.

    $$\left(\frac{\mathbf{1\,mol\,F_2}}{\mathbf{2\,mol\,HF}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{2\,mol\,HF}}{\mathbf{1\,mol\,F_2}}\right)$$

    d. How many moles of F_2 form when one mole of HF reacts completely?
    The number of moles of F_2 that form is one-half the number of moles of HF that react, so one mole of HF forms **one-half mole of F_2.**

    $$?\,\text{mol F}_2 = 1\,\text{mol HF}\left(\frac{1\,\text{mol F}_2}{2\,\text{mol HF}}\right) = \mathbf{0.5\,mol\,F_2}$$

    e. How many moles of HF react to yield 3.452 moles of H_2?

    $$?\,\text{mol HF} = 3.452\,\text{mol H}_2\left(\frac{2\,\text{mol HF}}{1\,\text{mol H}_2}\right) = \mathbf{6.904\,mol\,HF}$$

24. The bond between nitrogen atoms in N_2 molecules is very strong, making N_2 very unreactive. Because of this, magnesium is one of the few metals that react with nitrogen gas directly. This reaction yields solid magnesium nitride.
    a. Write a complete balanced equation, without including states, for the reaction between magnesium and nitrogen to form magnesium nitride.

    $$\mathbf{3Mg + N_2 \rightarrow Mg_3N_2}$$

    b. Write a conversion factor that could be used to convert between moles of magnesium and moles of magnesium nitride.

    $$\left(\frac{\mathbf{3\,mol\,Mg}}{\mathbf{1\,mol\,Mg_3N_2}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{1\,mol\,Mg_3N_2}}{\mathbf{3\,mol\,Mg}}\right)$$

c. How many moles of magnesium nitride form when 1.0 mole of magnesium reacts completely?

The number of moles of Mg_3N_2 that form is one-third the number of moles of Mg that react, so one mole of Mg forms **one-third mole of Mg_3N_2.**

$$? \text{ mol } Mg_3N_2 = 1 \text{ mol Mg}\left(\frac{1 \text{ mol } Mg_3N_2}{3 \text{ mol Mg}}\right) = \mathbf{0.33\ mol\ Mg_3N_2}$$

d. Write a conversion factor that could be used to convert between moles of nitrogen and moles of magnesium nitride.

$$\left(\frac{\mathbf{1\ mol\ N_2}}{\mathbf{1\ mol\ Mg_3N_2}}\right) \ \textbf{or} \ \left(\frac{\mathbf{1\ mol\ Mg_3N_2}}{\mathbf{1\ mol\ N_2}}\right)$$

e. How many moles of nitrogen react to yield 3.452 moles of magnesium nitride?

$$? \text{ mol } N_2 = 3.452 \text{ mol } Mg_3N_2\left(\frac{1 \text{ mol } N_2}{1 \text{ mol } Mg_3N_2}\right) = \mathbf{3.452\ mol\ N_2}$$

26. For many years, it was thought that the formation of sodium perbromate was impossible. But the production of xenon difluoride, XeF_2, which was also thought to be impossible to make, led to the discovery of the following reaction that yields the illusive sodium perbromate.

$$NaBrO_3 + XeF_2 + H_2O \rightarrow NaBrO_4 + 2HF + Xe$$

a. Write a conversion factor that could be used to convert between moles of xenon difluoride, XeF_2, and moles of hydrogen fluoride, HF.

$$\left(\frac{\mathbf{2\ mol\ HF}}{\mathbf{1\ mol\ XeF_2}}\right) \ \textbf{or} \ \left(\frac{\mathbf{1\ mol\ XeF_2}}{\mathbf{2\ mol\ HF}}\right)$$

b. How many moles of XeF_2 are necessary to form 16 moles of hydrogen fluoride?

The number of moles of HF that form is two times the number of moles of XeF_2 that react, so **8 moles of XeF_2** *form 16 moles of HF.*

$$? \text{ mol } XeF_2 = 16 \text{ mol HF}\left(\frac{1 \text{ mol } XeF_2}{2 \text{ mol HF}}\right) = \mathbf{8.0\ mol\ XeF_2}$$

c. What is the maximum number of moles of $NaBrO_4$ that could form in the combination of 2 moles of $NaBrO_3$ and 3 moles of XeF_2?

The two moles of $NaBrO_3$ form a maximum of two moles of $NaBrO_4$. It only takes two moles of XeF_2 to make two moles of $NaBrO_4$, so the XeF_2 is in excess. A maximum of **two moles of $NaBrO_4$** *can form.*

$$? \text{ mol } NaBrO_4 = 2 \text{ mol } NaBrO_3\left(\frac{1 \text{ mol } NaBrO_4}{1 \text{ mol } NaBrO_3}\right) = \mathbf{2\ mol\ NaBrO_4}$$

$$? \text{ mol } NaBrO_4 = 3 \text{ mol } XeF_2\left(\frac{1 \text{ mol } NaBrO_4}{1 \text{ mol } XeF_2}\right) = \mathit{3\ mol\ NaBrO_4}$$

The 2 moles of $NaBrO_3$ run out first, so it is the limiting reactant.

d. What is the maximum number of moles of $NaBrO_4$ that could form in the combination of 2 moles of $NaBrO_3$ and 3 million moles of XeF_2?

The XeF_2 is in excess, so no matter how much extra XeF_2 is added, the maximum yield is **2 moles of $NaBrO_4$**.

e. Write a conversion factor that could be used to convert between moles of sodium perbromate, $NaBrO_4$, and moles of hydrogen fluoride, HF.

$$\left(\frac{\textbf{2 mol HF}}{\textbf{1 mol NaBrO}_4}\right) \quad \textbf{or} \quad \left(\frac{\textbf{1 mol NaBrO}_4}{\textbf{2 mol HF}}\right)$$

f. How many moles of HF form along with 5.822 moles of sodium perbromate, $NaBrO_4$?

$$? \text{ mol HF} = 5.822 \text{ mol NaBrO}_4\left(\frac{2 \text{ mol HF}}{1 \text{ mol NaBrO}_4}\right) = \textbf{11.64 mol HF}$$

28. In Chapter 3, you were told that you can expect halogen atoms to form one covalent bond, but there are many compounds that contain halogen atoms with more than one bond. For example, bromine pentafluoride, which is used as an oxidizing agent in rocket propellants, has bromine atoms with five covalent bonds. Liquid bromine pentafluoride is the only product in the reaction of gaseous bromine monofluoride with fluorine gas.

a. Write a complete balanced equation, including states, for this reaction.

$$\textbf{BrF(g) + 2F}_2\textbf{(g)} \rightarrow \textbf{BrF}_5\textbf{(l)}$$

b. Write a conversion factor that could be used to convert between moles of fluorine and moles of bromine pentafluoride.

$$\left(\frac{\textbf{1 mol BrF}_5}{\textbf{2 mol F}_2}\right) \quad \textbf{or} \quad \left(\frac{\textbf{2 mol F}_2}{\textbf{1 mol BrF}_5}\right)$$

c. How many moles of bromine pentafluoride form when 6 moles of fluorine react completely?

The number of moles of BrF_5 that form is one-half the number of moles of F_2 that react, so **3 moles of BrF_5** *form from 6 moles of F_2.*

$$? \text{ mol BrF}_5 = 6 \text{ mol BrF}\left(\frac{1 \text{ mol BrF}_5}{1 \text{ mol BrF}}\right) = \textbf{3 mol BrF}_5$$

d. What is the maximum number of moles of bromine pentafluoride that could form in the combination of 8 moles of bromine monofluoride with 12 moles of fluorine?

The 8 moles of BrF form a maximum of 8 moles of BrF_5. The 12 moles of F_2 form a maximum of 6 moles of BrF_5. Therefore, the F_2 is limiting, and the BrF is in excess. A maximum of **6 moles of BrF_5** *can form.*

$$? \text{ mol BrF}_5 = 8 \text{ mol BrF}\left(\frac{1 \text{ mol BrF}_5}{1 \text{ mol BrF}}\right) = \textit{8 mol BrF}_5$$

$$? \text{ mol BrF}_5 = 12 \text{ mol F}_2\left(\frac{1 \text{ mol BrF}_5}{2 \text{ mol F}_2}\right) = \textbf{6 mol BrF}_5$$

The 12 moles of F_2 runs out first, so it is the limiting reactant.

e. Write a conversion factor that could be used to convert between moles of bromine monofluoride and moles of bromine pentafluoride.

$$\left(\frac{\mathbf{1\,mol\,BrF_5}}{\mathbf{1\,mol\,BrF}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{1\,mol\,BrF}}{\mathbf{1\,mol\,BrF_5}}\right)$$

f. How many moles of bromine monofluoride must react to yield 0.78 mole of bromine pentafluoride?

$$?\,\text{mol BrF} = 0.78\,\text{mol BrF}_5\left(\frac{1\,\text{mol BrF}}{1\,\text{mol BrF}_5}\right) = \mathbf{0.78\ mol\ BrF}$$

31. Aniline, C6H5NH2, is used to make many different chemicals, including dyes, photographic chemicals, antioxidants, explosives, and herbicides. It can be formed from nitrobenzene, C6H5NO2, in the following reaction with iron(II) chloride as a catalyst. (Objs 2-4, & 9)

$$4C_6H_5NO_2 + 9Fe + 4H_2O \xrightarrow{FeCl_2} 4C_6H_5NH_2 + 3Fe_3O_4$$

a. Write a conversion factor that could be used to convert between moles of iron and moles of nitrobenzene.

$$\left(\frac{\mathbf{9\,mol\,Fe}}{\mathbf{4\,mol\,C_6H_5NO_2}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{4\,mol\,C_6H_5NO_2}}{\mathbf{9\,mol\,Fe}}\right)$$

b. What is the minimum mass of iron that would be necessary to react completely with 810.5 g of nitrobenzene, $C_6H_5NO_2$?

$$?\,\text{g Fe} = 810.5\,\text{g C}_6\text{H}_5\text{NO}_2\left(\frac{1\,\text{mol C}_6\text{H}_5\text{NO}_2}{123.111\,\text{g C}_6\text{H}_5\text{NO}_2}\right)\left(\frac{9\,\text{mol Fe}}{4\,\text{mol C}_6\text{H}_5\text{NO}_2}\right)\left(\frac{55.845\,\text{g Fe}}{1\,\text{mol Fe}}\right)$$

$$\textit{or} \quad ?\,\text{g Fe} = 810.5\,\text{g C}_6\text{H}_5\text{NO}_2\left(\frac{9\times 55.845\,\text{g Fe}}{4\times 123.111\,\text{g C}_6\text{H}_5\text{NO}_2}\right) = \mathbf{827.2\ g\ Fe}$$

c. Write a conversion factor that could be used to convert between moles of aniline and moles of nitrobenzene.

$$\left(\frac{4\,\text{mol C}_6\text{H}_5\text{NH}_2}{4\,\text{mol C}_6\text{H}_5\text{NO}_2}\right) \text{or} \left(\frac{1\,\text{mol C}_6\text{H}_5\text{NH}_2}{1\,\text{mol C}_6\text{H}_5\text{NO}_2}\right) \text{or} \left(\frac{4\,\text{mol C}_6\text{H}_5\text{NO}_2}{4\,\text{mol C}_6\text{H}_5\text{NH}_2}\right) \text{or} \left(\frac{1\,\text{mol C}_6\text{H}_5\text{NO}_2}{1\,\text{mol C}_6\text{H}_5\text{NH}_2}\right)$$

d. What is the maximum mass of aniline, $C_6H_5NH_2$, that can be formed from 810.5 g of nitrobenzene, $C_6H_5NO_2$, with excess iron and water?

$$?\,\text{g C}_6\text{H}_5\text{NH}_2 = 810.5\,\text{g C}_6\text{H}_5\text{NO}_2\left(\frac{1\,\text{mol C}_6\text{H}_5\text{NO}_2}{123.111\,\text{g C}_6\text{H}_5\text{NO}_2}\right)\left(\frac{4\,\text{mol C}_6\text{H}_5\text{NH}_2}{4\,\text{mol C}_6\text{H}_5\text{NO}_2}\right)\left(\frac{93.128\,\text{g C}_6\text{H}_5\text{NH}_2}{1\,\text{mol C}_6\text{H}_5\text{NH}_2}\right)$$

$$\textit{or} \quad ?\,\text{g C}_6\text{H}_5\text{NH}_2 = 810.5\,\text{g C}_6\text{H}_5\text{NO}_2\left(\frac{4\times 93.128\,\text{g C}_6\text{H}_5\text{NH}_2}{4\times 123.111\,\text{g C}_6\text{H}_5\text{NO}_2}\right) = \mathbf{613.1\ g\ C_6H_5NH_2}$$

e. Write a conversion factor that could be used to convert between moles of Fe_3O_4 and moles of aniline.

$$\left(\frac{3\text{ mol }Fe_3O_4}{4\text{ mol }C_6H_5NH_2}\right) \quad \text{or} \quad \left(\frac{4\text{ mol }C_6H_5NH_2}{3\text{ mol }Fe_3O_4}\right)$$

f. What is the mass of Fe_3O_4 formed with the amount of aniline, $C_6H_5NH_2$, calculated in Part (d)?

$$?\text{ g }Fe_3O_4 = 613.1\text{ g }C_6H_5NH_2\left(\frac{1\text{ mol }C_6H_5NH_2}{93.128\text{ g }C_6H_5NH_2}\right)\left(\frac{3\text{ mol }Fe_3O_4}{4\text{ mol }C_6H_5NH_2}\right)\left(\frac{231.53\text{ g }Fe_3O_4}{1\text{ mol }Fe_3O_4}\right)$$

$$\textit{or}\ \ ?\text{ g }Fe_3O_4 = 613.1\text{ g }C_6H_5NH_2\left(\frac{3\times 231.53\text{ g }Fe_3O_4}{4\times 93.128\text{ g }C_6H_5NH_2}\right)$$

= 1143 g Fe_3O_4 or 1.143 kg Fe_3O_4

g. If 478.2 g of aniline, $C_6H_5NH_2$, are formed from the reaction of 810.5 g of nitrobenzene, $C_6H_5NO_2$, with excess iron and water, what is the percent yield?

$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}}\times 100 = \frac{478.2\text{ g }C_6H_5NH_2}{613.1\text{ g }C_6H_5NH_2}\times 100 \ \ \mathbf{= 78.00\%\ yield}$$

33. Because of its red-orange color, sodium dichromate, $Na_2Cr_2O_7$, has been used in the manufacture of pigments. It can be made by reacting sodium chromate, Na_2CrO_4, with sulfuric acid. The products other than sodium dichromate are sodium sulfate and water. *(Objs 2-4)*

a. Write a balanced equation for this reaction. (You do not need to write the states.)

$2Na_2CrO_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + Na_2SO_4 + H_2O$

b. How many kilograms of sodium chromate, Na_2CrO_4, are necessary to produce 84.72 kg of sodium dichromate, $Na_2Cr_2O_7$?

$$?\text{ kg }Na_2CrO_4 = 84.72\text{ kg }Na_2Cr_2O_7\left(\frac{10^3\text{ g}}{1\text{ kg}}\right)\left(\frac{1\text{ mol }Na_2Cr_2O_7}{261.968\text{ g }Na_2Cr_2O_7}\right)\left(\frac{2\text{ mol }Na_2CrO_4}{1\text{ mol }Na_2Cr_2O_7}\right)\left(\frac{161.9733\text{ g }Na_2CrO_4}{1\text{ mol }Na_2CrO_4}\right)\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)$$

$$\textit{or}\ \ ?\text{ kg }Na_2CrO_4 = 84.72\text{ kg }Na_2Cr_2O_7\left(\frac{2\times 161.9733\text{ kg }Na_2CrO_4}{1\times 261.968\text{ kg }Na_2Cr_2O_7}\right) \ \ \mathbf{= 104.8\ kg\ Na_2CrO_4}$$

c. How many kilograms of sodium sulfate are formed with 84.72 kg of $Na_2Cr_2O_7$?

$$?\text{ kg }Na_2SO_4 = 84.72\text{ kg }Na_2Cr_2O_7\left(\frac{10^3\text{ g}}{1\text{ kg}}\right)\left(\frac{1\text{ mol }Na_2Cr_2O_7}{261.968\text{ g }Na_2Cr_2O_7}\right)\left(\frac{1\text{ mol }Na_2SO_4}{1\text{ mol }Na_2Cr_2O_7}\right)\left(\frac{142.043\text{ g }Na_2SO_4}{1\text{ mol }Na_2SO_4}\right)\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)$$

$$\textit{or}\ \ ?\text{ kg }Na_2SO_4 = 84.72\text{ kg }Na_2Cr_2O_7\left(\frac{1\times 142.043\text{ kg }Na_2SO_4}{1\times 261.968\text{ kg }Na_2Cr_2O_7}\right) \ \ \mathbf{= 45.94\ kg\ Na_2SO_4}$$

35. The tanning agent, $Cr(OH)SO_4$, is formed in the reaction of sodium dichromate ($Na_2Cr_2O_7$), sulfur dioxide, and water. Tanning protects animal hides from bacterial attack, reduces swelling, and prevents the fibers from sticking together when the hides dry. This leads to a softer, more flexible leather. *(Objs 2-4)*

$$Na_2Cr_2O_7 + 3SO_2 + H_2O \rightarrow 2Cr(OH)SO_4 + Na_2SO_4$$

a. How many kilograms of sodium dichromate, $Na_2Cr_2O_7$, are necessary to produce 2.50 kg of $Cr(OH)SO_4$?

$$? \text{ kg } Na_2Cr_2O_7 = 2.50 \text{ kg } Cr(OH)SO_4\left(\frac{10^3\text{ g}}{1\text{ kg}}\right)\left(\frac{1\text{ mol } Cr(OH)SO_4}{165.067\text{ g } Cr(OH)SO_4}\right)\left(\frac{1\text{ mol } Na_2Cr_2O_7}{2\text{ mol } Cr(OH)SO_4}\right)\left(\frac{261.968\text{ g } Na_2Cr_2O_7}{1\text{ mol } Na_2Cr_2O_7}\right)\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)$$

or $$? \text{ kg } Na_2Cr_2O_7 = 2.50 \text{ kg } Cr(OH)SO_4\left(\frac{1\times 261.968\text{ kg } Na_2Cr_2O_7}{2\times 165.067\text{ kg } Cr(OH)SO_4}\right) = \mathbf{1.98\ kg\ Na_2Cr_2O_7}$$

b. How many megagrams of sodium sulfate are formed with 2.50 Mg of $Cr(OH)SO_4$?

$$? \text{ Mg } Na_2SO_4 = 2.50 \text{ Mg } Cr(OH)SO_4\left(\frac{10^6\text{ g}}{1\text{ Mg}}\right)\left(\frac{1\text{ mol } Cr(OH)SO_4}{165.067\text{ g } Cr(OH)SO_4}\right)\left(\frac{1\text{ mol } Na_2SO_4}{2\text{ mol } Cr(OH)SO_4}\right)\left(\frac{142.043\text{ g } Na_2SO_4}{1\text{ mol } Na_2SO_4}\right)\left(\frac{1\text{ Mg}}{10^6\text{ g}}\right)$$

or $$? \text{ Mg } Na_2SO_4 = 2.50 \text{ Mg } Cr(OH)SO_4\left(\frac{1\times 142.043\text{ Mg } Na_2SO_4}{2\times 165.067\text{ Mg } Cr(OH)SO_4}\right) = \mathbf{1.08\ Mg\ Na_2SO_4}$$

38. Chromium(III) oxide can be made from the reaction of sodium dichromate and ammonium chloride. What is the maximum mass, in grams, of chromium(III) oxide that can be produced from the complete reaction of 123.5 g of sodium dichromate, $Na_2Cr_2O_7$, with 59.5 g of ammonium chloride? The other products are sodium chloride, nitrogen gas, and water. *(Obj 6)*

$$Na_2Cr_2O_7 + 2NH_4Cl \rightarrow 2NaCl + Cr_2O_3 + 4H_2O + N_2$$

$$? \text{ g } Cr_2O_3 = 123.5\text{ g } Na_2Cr_2O_7\left(\frac{1\times 151.990\text{ g } Cr_2O_3}{1\times 261.968\text{ g } Na_2Cr_2O_7}\right) = \mathbf{71.65\ g\ Cr_2O_3}$$

$$? \text{ g } Cr_2O_3 = 59.5\text{ g } NH_4Cl\left(\frac{1\times 151.990\text{ g } Cr_2O_3}{2\times 53.4912\text{ g } NH_4Cl}\right) = \mathit{84.5\ g\ Cr_2O_3}$$

40. Tetraboron carbide, B_4C, which is used as a protective material in nuclear reactors, can be made from boric acid, H_3BO_3. *(Objs 6 & 7)*

$$4H_3BO_3 + 7C \xrightarrow{2400\ °C} B_4C + 6CO + 6H_2O$$

a. What is the maximum mass, in kilograms, of B_4C formed in the reaction of 30.0 kg of carbon with 54.785 kg of H_3BO_3?

$$?\ \text{kg } B_4C = 30.0\ \text{kg C}\left(\frac{1\times 55.255\ \text{kg } B_4C}{7\times 12.011\ \text{kg C}}\right) = \textit{19.7 kg } B_4C$$

$$?\ \text{kg } B_4C = 54.785\ \text{kg } H_3BO_3\left(\frac{1\times 55.255\ \text{kg } B_4C}{4\times 61.833\ \text{kg } H_3BO_3}\right) = \mathbf{12.239\ kg\ B_4C}$$

b. Explain why one of the substances in Part (a) is in excess and one is limiting.

There are two reasons why we are not surprised that the carbon is in excess. (1) We would expect carbon to be less expensive than the less common boric acid, and (2) the excess carbon can be separated easily from the solid B_4C by converting it to gaseous carbon dioxide or carbon monoxide.

42. Aniline, $C_6H_5NH_2$, which is used to make antioxidants, can be formed from nitrobenzene, $C_6H_5NO_2$, in the following reaction. *(Objs 6 & 7)*

$$4C_6H_5NO_2 + 9Fe + 4H_2O \xrightarrow{FeCl_2} 4C_6H_5NH_2 + 3Fe_3O_4$$

a. What is the maximum mass of aniline, $C_6H_5NH_2$, formed in the reaction of 810.5 g of nitrobenzene, $C_6H_5NO_2$, with 985.0 g of Fe and 250 g of H_2O?

$$?\ \text{g } C_6H_5NH_2 = 810.5\ \text{g } C_6H_5NO_2\left(\frac{4\times 93.128\ \text{g } C_6H_5NH_2}{4\times 123.111\ \text{g } C_6H_5NO_2}\right) = \mathbf{613.1\ g\ C_6H_5NH_2}$$

$$?\ \text{g } C_6H_5NH_2 = 985.0\ \text{g Fe}\left(\frac{4\times 93.128\ \text{g } C_6H_5NH_2}{9\times 55.845\ \text{g Fe}}\right) = 730.0\ \text{g } C_6H_5NH_2$$

$$?\ \text{g } C_6H_5NH_2 = 250\ \text{g } H_2O\left(\frac{4\times 93.128\ \text{g } C_6H_5NH_2}{4\times 18.0153\ \text{g } H_2O}\right) = 1.29\times 10^3\ \text{g } C_6H_5NH_2$$

b. Explain why two of these substances are in excess and one is limiting.

Both iron and water would be less expensive than nitrobenzene. They would also be expected to be less toxic than nitrobenzene.

44. Calcium carbide, CaC_2, is formed in the reaction between calcium oxide and carbon. The other product is carbon monoxide. *(Obj 6)*

a. Write a balanced equation for this reaction. (You do not need to write the states.)

$$\mathbf{CaO + 3C \rightarrow CaC_2 + CO}$$

b. If you were designing the procedure for producing calcium carbide from calcium oxide and carbon, which of the reactants would you have as the limiting reactant? Why?

The carbon is probably best to have in excess. We would expect carbon to be less expensive than the calcium oxide, and the excess carbon can be separated easily from the solid CaC_2 by converting it to gaseous carbon dioxide or carbon monoxide. Thus the CaO would be limiting.

c. Assuming 100% yield from the limiting reactant, what are the approximate amounts of CaO and carbon that you would combine to form 860.5 g of CaC_2?

$$? \text{ g CaO} = 860.5 \text{ g CaC}_2 \left(\frac{1 \times 56.077 \text{ g CaO}}{1 \times 64.100 \text{ g CaC}_2} \right) = \mathbf{752.8 \text{ g CaO}}$$

$$? \text{ g C} = 860.5 \text{ g CaC}_2 \left(\frac{3 \times 12.011 \text{ g C}}{1 \times 64.100 \text{ g CaC}_2} \right) = \mathbf{483.7 \text{ g C}}$$

We would add 752.8 g CaO and well over 483.7 g C.

46. Give four reasons why the actual yield in a chemical reaction is less than the theoretical yield. (Obj 8)

(1) Many chemical reactions are significantly reversible. Because there is a constant conversion of reactants to products and products to reactants, the reaction never proceeds completely to products. (2) It is common, especially in reactions involving organic compounds, to have side reactions. These reactions form products other than the desired product. (3) Sometimes a reaction is so slow that it has not reached the maximum yield by the time the product is isolated. (4) Even if 100% of the limiting reactant proceeds to products, the product still usually needs to be separated from the other components in the product mixture. (The other components include excess reactants, products of side reactions, and other impurities.) This separation generally involves some loss of product.

48. Does the reactant in excess affect the *actual* yield for a reaction? If it does, explain how.

Although the maximum (or theoretical) yield of a reaction is determined by the limiting reactant rather than reactants in excess, reactants that are in excess can affect the actual yield of an experiment. Sometimes the actual yield is less than the theoretical yield because the reaction is reversible. Adding a large excess of one of the reactants ensures that the limiting reactant reacts as completely as possible (by speeding up the forward rate in the reversible reaction and driving the reaction toward a greater actual yield of products).

Section 10.3 Molarity and Equation Stoichiometry

50. What is the molarity of a solution made by dissolving 37.452 g of aluminum sulfate, $Al_2(SO_4)_3$, in water and diluting with water to 250.0 mL total? (Obj 10)

$$\text{Molarity} = \frac{? \text{ mol Al}_2(\text{SO}_4)_3}{\text{L solution}} = \frac{37.452 \text{ g Al}_2(\text{SO}_4)_3}{250.0 \text{ mL soln}} \left(\frac{1 \text{ mol Al}_2(\text{SO}_4)_3}{342.154 \text{ g Al}_2(\text{SO}_4)_3} \right) \left(\frac{10^3 \text{ mL}}{1 \text{ L}} \right)$$

$$= \mathbf{0.4378 \text{ M Al}_2(\text{SO}_4)_3}$$

52. The following equation represents the first step in the conversion of UO_3, found in uranium ore, into the uranium compounds called “yellow cake.”

$$UO_3 + H_2SO_4 \rightarrow UO_2SO_4 + H_2O$$

a. How many milliliters of 18.0 M H_2SO_4 are necessary to react completely with 249.6 g of UO_3? *(Objs 11-13)*

$$? \text{ mL } H_2SO_4 \text{ soln} = 249.6 \text{ g } UO_3\left(\frac{1 \text{ mol } UO_3}{286.0271 \text{ g } UO_3}\right)\left(\frac{1 \text{ mol } H_2SO_4}{1 \text{ mol } UO_3}\right)\left(\frac{10^3 \text{ mL } H_2SO_4 \text{ soln}}{18.0 \text{ mol } H_2SO_4}\right)$$

= 48.5 mL H_2SO_4 soln

b. What is the maximum mass, in grams, of UO_2SO_4 that forms from the complete reaction of 125 mL of 18.0 M H_2SO_4? *(Objs 11-13)*

$$? \text{ g } UO_2SO_4 = 125 \text{ mL } H_2SO_4 \text{ soln}\left(\frac{18.0 \text{ mol } H_2SO_4}{10^3 \text{ mL } H_2SO_4 \text{ soln}}\right)\left(\frac{1 \text{ mol } UO_2SO_4}{1 \text{ mol } H_2SO_4}\right)\left(\frac{366.091 \text{ g } UO_2SO_4}{1 \text{ mol } UO_2SO_4}\right)$$

= 824 g UO_2SO_4

54. When a water solution of sodium sulfite, Na_2SO_3, is added to a water solution of iron(II) chloride, $FeCl_2$, iron(II) sulfite, $FeSO_3$, precipitates from the solution. *(Objs 11-13)*

a. Write a balanced equation for this reaction.

$$\mathbf{Na_2SO_3(\mathit{aq}) + FeCl_2(\mathit{aq}) \rightarrow 2NaCl(\mathit{aq}) + FeSO_3(\mathit{s})}$$

b. What is the maximum mass of iron(II) sulfite that will precipitate from a solution prepared by adding an excess of an Na_2SO_3 solution to 25.00 mL of 1.009 M $FeCl_2$?

$$? \text{ g } FeSO_3 = 25.00 \text{ mL } FeCl_2 \text{ soln}\left(\frac{1.009 \text{ mol } FeCl_2}{10^3 \text{ mL } FeCl_2 \text{ soln}}\right)\left(\frac{1 \text{ mol } FeSO_3}{1 \text{ mol } FeCl_2}\right)\left(\frac{135.909 \text{ g } FeSO_3}{1 \text{ mol } FeSO_3}\right)$$

= 3.428 g $FeSO_3$

56. Consider the neutralization reaction that takes place when nitric acid reacts with aqueous potassium hydroxide. *(Objs 11-13)*

a. Write a conversion factor that relates moles of HNO_3 to moles of KOH for this reaction.

$$\left(\frac{\mathbf{1 \text{ mol } HNO_3}}{\mathbf{1 \text{ mol } KOH}}\right)$$

b. What is the minimum volume of 1.50 M HNO_3 necessary to neutralize completely the hydroxide in 125.0 mL of 0.501 M KOH?

$$? \text{ mL } HNO_3 \text{ soln} = 125.0 \text{ mL KOH soln}\left(\frac{0.501 \text{ mol KOH}}{10^3 \text{ mL KOH soln}}\right)\left(\frac{1 \text{ mol } HNO_3}{1 \text{ mol KOH}}\right)\left(\frac{10^3 \text{ mL } HNO_3 \text{ soln}}{1.50 \text{ mol } HNO_3}\right)$$

= 41.8 mL HNO_3 soln

58. Consider the neutralization reaction that takes place when sulfuric acid reacts with aqueous sodium hydroxide. *(Objs 11-13)*

a. Write a conversion factor that relates moles of H_2SO_4 to moles of NaOH for this reaction.

$$\left(\frac{\mathbf{1 \text{ mol } H_2SO_4}}{\mathbf{2 \text{ mol } NaOH}}\right)$$

b. What is the minimum volume of 6.02 M H_2SO_4 necessary to neutralize completely the hydroxide in 47.5 mL of 2.5 M NaOH?

$$? \text{ mL } H_2SO_4 \text{ soln} = 47.5 \text{ mL NaOH soln}\left(\frac{2.5 \text{ mol NaOH}}{10^3 \text{ mL NaOH soln}}\right)\left(\frac{1 \text{ mol } H_2SO_4}{2 \text{ mol NaOH}}\right)\left(\frac{10^3 \text{ mL } H_2SO_4 \text{ soln}}{6.02 \text{ mol } H_2SO_4}\right) = \mathbf{9.9\ mL\ H_2SO_4 soln}$$

60. Consider the neutralization reaction that takes place when hydrochloric acid reacts with solid cobalt(II) hydroxide. (*Objs 11-13*)

a. Write a conversion factor that relates moles of HCl to moles of $Co(OH)_2$ for this reaction.

$$\left(\frac{\mathbf{2\ mol\ HCl}}{\mathbf{1\ mol\ Co(OH)_2}}\right)$$

b. What is the minimum volume of 6.14 M HCl necessary to react completely with 2.53 kg of solid cobalt(II) hydroxide, $Co(OH)_2$?

$$? \text{ L HCl soln} = 2.53 \text{ kg } Co(OH)_2\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol } Co(OH)_2}{92.9479 \text{ g } Co(OH)_2}\right)\left(\frac{2 \text{ mol HCl}}{1 \text{ mol } Co(OH)_2}\right)\left(\frac{1 \text{ L HCl soln}}{6.14 \text{ mol HCl}}\right) = \mathbf{8.87\ L\ HCl\ soln}$$

62. Consider the neutralization reaction that takes place when nitric acid reacts with solid chromium(III) hydroxide. (*Objs 19-21*)

a. Write a conversion factor that relates moles of HNO_3 to moles of $Cr(OH)_3$ for this reaction.

$$\left(\frac{\mathbf{3\ mol\ HNO_3}}{\mathbf{1\ mol\ Cr(OH)_3}}\right)$$

a. What is the minimum volume of 2.005 M HNO_3 necessary to react completely with 0.5187 kg of solid chromium(III) hydroxide, $Cr(OH)_3$?

$$? \text{ L } HNO_3 \text{ soln} = 0.5187 \text{ kg } Cr(OH)_3\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol } Cr(OH)_3}{103.0181 \text{ g } Cr(OH)_3}\right)\left(\frac{3 \text{ mol } HNO_3}{1 \text{ mol } Cr(OH)_3}\right)\left(\frac{1 \text{ L } HNO_3 \text{ soln}}{2.005 \text{ mol } HNO_3}\right) = \mathbf{7.534\ L\ HNO_3\ soln}$$

Additional Problems

64. Because nitrogen and phosphorus are both nonmetallic elements in group 15 on the periodic table, we expect them to react with other elements in similar ways. This is true, but there are also distinct differences between them. For example, nitrogen atoms form stable triple bonds to carbon atoms in substances such as hydrogen cyanide (often called hydrocyanic acid), HCN. Phosphorus atoms also form triple bonds to carbon atoms in substances such as HCP, but the substances that form are much less stable. The compound HCP can be formed in the following reaction.

$$CH_4 + PH_3 \xrightarrow{\text{electric arc}} HCP + 3H_2$$

a. Write a conversion factor that could be used to convert between moles of HCP and moles of H_2.

$$\left(\frac{\mathbf{3\ mol\ H_2}}{\mathbf{1\ mol\ HCP}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{1\ mol\ HCP}}{\mathbf{3\ mol\ H_2}}\right)$$

b. How many moles of HCP form along with 9 moles of H_2?

The number of moles of HCP that form is one-third the number of moles of H_2 that forms, so **3 moles of HCP** *form with 9 moles of H_2.*

$$?\ \text{mol HCP} = 9\ \text{mol}\ H_2 \left(\frac{1\ \text{mol HCP}}{3\ \text{mol}\ H_2}\right) = \mathbf{3\ mol\ HCP}$$

c. Write a conversion factor that could be used to convert between moles of methane, CH_4, and moles of hydrogen, H_2.

$$\left(\frac{\mathbf{3\ mol\ H_2}}{\mathbf{1\ mol\ CH_4}}\right) \quad \textbf{or} \quad \left(\frac{\mathbf{1\ mol\ CH_4}}{\mathbf{3\ mol\ H_2}}\right)$$

d. How many moles of hydrogen gas form when 1.8834 moles of CH_4 react with an excess of PH_3?

$$?\ \text{mol}\ H_2 = 1.8834\ \text{mol}\ CH_4 \left(\frac{3\ \text{mol}\ H_2}{1\ \text{mol}\ CH_4}\right) = \mathbf{5.6502\ mol\ H_2}$$

66. Iodine pentafluoride is an incendiary agent, which is a substance that ignites combustible materials. Iodine pentafluoride is usually made by passing fluorine gas over solid iodine, but it also forms when iodine monofluoride changes into the element iodine and iodine pentafluoride.

a. Write a balanced equation, without including states, for the conversion of iodine monofluoride into iodine and iodine pentafluoride.

$$\mathbf{5IF \rightarrow 2I_2 + IF_5}$$

b. How many moles of the element iodine form when 15 moles of iodine monofluoride react completely?

The number of moles of I_2 that form is two-fifths the number of moles of IF that react, so **6.0 moles of I_2** *form from 15 moles of IF.*

$$?\ \text{mol}\ I_2 = 15\ \text{mol IF} \left(\frac{2\ \text{mol}\ I_2}{5\ \text{mol IF}}\right) = \mathbf{6.0\ mol\ I_2}$$

c. How many moles of iodine pentafluoride form when 7.939 moles of iodine monofluoride react completely?

$$? \text{ mol IF}_5 = 7.939 \text{ mol IF}\left(\frac{1 \text{ mol IF}_5}{5 \text{ mol IF}}\right)$$ **= 1.588 mol IF_5**

68. Xenon hexafluoride is a better fluorinating agent than the xenon difluoride described in the previous problem, but it must be carefully isolated from any moisture. This is because xenon hexafluoride reacts with water to form the dangerously explosive xenon trioxide and hydrogen fluoride (hydrogen monofluoride).

a. Write a balanced equation, without including states, for the reaction of xenon hexafluoride and water to form xenon trioxide and hydrogen fluoride.

$XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$

b. How many moles of hydrogen fluoride form when 0.50 mole of xenon hexafluoride reacts completely?

The number of moles of HF that forms is 6 times the number of moles of XeF_6 that reacts, so **3.0 moles of HF** *form when 0.50 mole of XeF_6 react.*

$$? \text{ mol HF} = 0.50 \text{ mol XeF}_6\left(\frac{6 \text{ mol HF}}{1 \text{ mol XeF}_6}\right)$$ **= 3.0 mol HF**

c. What is the maximum number of moles of xenon trioxide that can form in the combination of 7 moles of xenon hexafluoride and 18 moles of water?

A maximum of 7 moles of XeO_3 forms from 7 moles of XeF_6. A maximum of 6 moles of XeO_3 forms from 18 moles of H_2O. Therefore, the H_2O is limiting, and the XeF_6 is in excess. A maximum of **6 moles of XeO_3** *can form.*

$$? \text{ mol XeO}_3 = 7 \text{ mol XeF}_6\left(\frac{1 \text{ mol XeO}_3}{1 \text{ mol XeF}_6}\right) = 7 \text{ mol XeO}_3$$

$$? \text{ mol XeO}_3 = 18 \text{ mol H}_2\text{O}\left(\frac{1 \text{ mol XeO}_3}{3 \text{ mol H}_2\text{O}}\right)$$ **= 6 mol XeO_3**

70. Hydriodic acid is produced industrially by the reaction of hydrazine, N_2H_4, with iodine, I_2. HI(*aq*) is used to make iodine salts such as AgI, which are used to seed clouds to promote rain. What is the minimum mass of iodine, I_2, necessary to react completely with 87.0 g of hydrazine, N_2H_4?

$N_2H_4 + 2I_2 \rightarrow 4HI + N_2$

$$? \text{ g I}_2 = 87.0 \text{ g N}_2\text{H}_4\left(\frac{1 \text{ mol N}_2\text{H}_4}{32.0452 \text{ g N}_2\text{H}_4}\right)\left(\frac{2 \text{ mol I}_2}{1 \text{ mol N}_2\text{H}_4}\right)\left(\frac{253.8090 \text{ g I}_2}{1 \text{ mol I}_2}\right)$$

or $$? \text{ g I}_2 = 87.0 \text{ g N}_2\text{H}_4\left(\frac{2 \times 253.8090 \text{ g I}_2}{1 \times 32.0452 \text{ g N}_2\text{H}_4}\right)$$ **= 1.38×10^3 g I_2** or **1.38 kg I_2**

72. Because plants need nitrogen compounds, potassium compounds, and phosphorus compounds to grow, these are often added to the soil as fertilizers. Potassium sulfate, which is used to make fertilizers, is made industrially by reacting potassium chloride with sulfur dioxide gas, oxygen gas, and water. Hydrochloric acid is formed with the potassium sulfate.

a. Write a balanced equation for this reaction. (You do not need to include states.)

$2KCl + SO_2 + \frac{1}{2}O_2 + H_2O \rightarrow K_2SO_4 + 2HCl$

or $4KCl + 2SO_2 + O_2 + 2H_2O \rightarrow 2K_2SO_4 + 4HCl$

b. What is the maximum mass, in kilograms, of potassium sulfate that can be formed from 2.76×10^5 kg of potassium chloride with excess sulfur dioxide, oxygen, and water?

$$? \text{ kg } K_2SO_4 = 2.76\times10^5 \text{ kg KCl}\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol KCl}}{74.5510 \text{ g KCl}}\right)\left(\frac{2 \text{ mol } K_2SO_4}{4 \text{ mol KCl}}\right)\left(\frac{174.260 \text{ g } K_2SO_4}{1 \text{ mol } K_2SO_4}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

or $$? \text{ kg } K_2SO_4 = 2.76\times10^5 \text{ kg KCl}\left(\frac{2\times174.260 \text{ kg } K_2SO_4}{4\times74.5510 \text{ kg KCl}}\right) = \mathbf{3.23 \times 10^5 \text{ kg } K_2SO_4}$$

c. If 2.94×10^5 kg of potassium sulfate is isolated from the reaction of 2.76×10^5 kg of potassium chloride, what is the percent yield?

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}}\times100 = \frac{2.94\times10^5 \text{ kg } K_2SO_4}{3.23\times10^5 \text{ kg } K_2SO_4}\times100 = \mathbf{91.0\% \text{ yield}}$$

74. The element phosphorus can be made by reacting carbon in the form of coke with calcium phosphate, $Ca_3(PO_4)_2$, which is found in phosphate rock.

$Ca_3(PO_4)_2 + 5C \rightarrow 3CaO + 5CO + 2P$

a. What is the minimum mass of carbon, C, necessary to react completely with 67.45 Mg of $Ca_3(PO_4)_2$?

$$? \text{ Mg C} = 67.45 \text{ Mg } Ca_3(PO_4)_2\left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } Ca_3(PO_4)_2}{310.18 \text{ g } Ca_3(PO_4)_2}\right)\left(\frac{5 \text{ mol C}}{1 \text{ mol } Ca_3(PO_4)_2}\right)\left(\frac{12.011 \text{ g C}}{1 \text{ mol C}}\right)\left(\frac{1 \text{ Mg}}{10^6 \text{ g}}\right)$$

or $$? \text{ Mg C} = 67.45 \text{ Mg } Ca_3(PO_4)_2\left(\frac{5\times12.011 \text{ Mg C}}{1\times310.18 \text{ Mg } Ca_3(PO_4)_2}\right) = \mathbf{13.06 \text{ Mg C}}$$

b. What is the maximum mass of phosphorus produced from the reaction of 67.45 Mg of $Ca_3(PO_4)_2$ with an excess of carbon?

$$? \text{ Mg P} = 67.45 \text{ Mg } Ca_3(PO_4)_2\left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } Ca_3(PO_4)_2}{310.18 \text{ g } Ca_3(PO_4)_2}\right)\left(\frac{2 \text{ mol P}}{1 \text{ mol } Ca_3(PO_4)_2}\right)\left(\frac{30.9738 \text{ g P}}{1 \text{ mol P}}\right)\left(\frac{1 \text{ Mg}}{10^6 \text{ g}}\right)$$

or $$? \text{ Mg P} = 67.45 \text{ Mg } Ca_3(PO_4)_2\left(\frac{2\times30.9738 \text{ Mg P}}{1\times310.18 \text{ Mg } Ca_3(PO_4)_2}\right) = \mathbf{13.47 \text{ Mg P}}$$

c. What mass of calcium oxide, CaO, is formed with the mass of phosphorus calculated in Part (b)?

$$? \text{ Mg CaO} = 13.47 \text{ Mg P}\left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right)\left(\frac{3 \text{ mol CaO}}{2 \text{ mol P}}\right)\left(\frac{56.077 \text{ g CaO}}{1 \text{ mol CaO}}\right)\left(\frac{1 \text{ Mg}}{10^6 \text{ g}}\right)$$

or $$? \text{ Mg CaO} = 13.47 \text{ Mg P}\left(\frac{3 \times 56.077 \text{ Mg CaO}}{2 \times 30.9738 \text{ Mg P}}\right) = \mathbf{36.58 \text{ Mg CaO}}$$

d. If 11.13 Mg of phosphorus is formed in the reaction of 67.45 Mg of $Ca_3(PO_4)_2$ with an excess of carbon, what is the percent yield?

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{11.13 \text{ Mg P}}{13.47 \text{ Mg P}} \times 100 = \mathbf{82.63\% \text{ yield}}$$

76. Thionyl chloride, $SOCl_2$, is a widely used source of chlorine in the formation of pesticides, pharmaceuticals, dyes, and pigments. It can be formed from disulfur dichloride in the following reaction.

$$2SO_2 + S_2Cl_2 + 3Cl_2 \rightarrow 4SOCl_2$$

If 1.140 kg of thionyl chloride is isolated from the reaction of 457.6 grams of disulfur dichloride, S_2Cl_2, with excess sulfur dioxide and chlorine gas, what is the percent yield?

$$? \text{ kg SOCl}_2 = 457.6 \text{ g S}_2\text{Cl}_2\left(\frac{1 \text{ mol S}_2\text{Cl}_2}{135.037 \text{ g S}_2\text{Cl}_2}\right)\left(\frac{4 \text{ mol SOCl}_2}{1 \text{ mol S}_2\text{Cl}_2}\right)\left(\frac{118.971 \text{ g SOCl}_2}{1 \text{ mol SOCl}_2}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

or $$? \text{ kg SOCl}_2 = 457.6 \text{ g S}_2\text{Cl}_2\left(\frac{4 \times 118.971 \text{ g SOCl}_2}{1 \times 135.037 \text{ g S}_2\text{Cl}_2}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = 1.613 \text{ kg SOCl}_2$$

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{1.140 \text{ kg SOCl}_2}{1.613 \text{ kg SOCl}_2} \times 100 = \mathbf{70.68\% \text{ yield}}$$

78. Sodium dichromate, $Na_2Cr_2O_7$, is converted to chromium(III) sulfate, which is used in the tanning of animal hides. Sodium dichromate can be made by reacting sodium chromate, Na_2CrO_4, with water and carbon dioxide.

$$2Na_2CrO_4 + H_2O + 2CO_2 \rightleftharpoons Na_2Cr_2O_7 + 2NaHCO_3$$

a. Show that the sodium chromate is the limiting reactant when 87.625 g of Na_2CrO_4 reacts with 10.008 g of water and excess carbon dioxide.

$$? \text{ g Na}_2\text{Cr}_2\text{O}_7 = 87.625 \text{ g Na}_2\text{CrO}_4\left(\frac{1 \text{ mol Na}_2\text{CrO}_4}{161.9733 \text{ g Na}_2\text{CrO}_4}\right)\left(\frac{1 \text{ mol Na}_2\text{Cr}_2\text{O}_7}{2 \text{ mol Na}_2\text{CrO}_4}\right)\left(\frac{261.968 \text{ g Na}_2\text{Cr}_2\text{O}_7}{1 \text{ mol Na}_2\text{Cr}_2\text{O}_7}\right)$$

or $$? \text{ g Na}_2\text{Cr}_2\text{O}_7 = 87.625 \text{ g Na}_2\text{CrO}_4\left(\frac{1 \times 261.968 \text{ g Na}_2\text{Cr}_2\text{O}_7}{2 \times 161.9733 \text{ g Na}_2\text{CrO}_4}\right) = 70.860 \text{ g Na}_2\text{Cr}_2\text{O}_7$$

$$? \text{ g Na}_2\text{Cr}_2\text{O}_7 = 10.008 \text{ g H}_2\text{O}\left(\frac{1 \text{ mol H}_2\text{O}}{18.0153 \text{ g H}_2\text{O}}\right)\left(\frac{1 \text{ mol Na}_2\text{Cr}_2\text{O}_7}{1 \text{ mol H}_2\text{O}}\right)\left(\frac{261.968 \text{ g Na}_2\text{Cr}_2\text{O}_7}{1 \text{ mol Na}_2\text{Cr}_2\text{O}_7}\right)$$

or $$? \text{ g Na}_2\text{Cr}_2\text{O}_7 = 10.008 \text{ g H}_2\text{O}\left(\frac{1 \times 261.968 \text{ g Na}_2\text{Cr}_2\text{O}_7}{1 \times 18.0153 \text{ g H}_2\text{O}}\right) = 145.53 \text{ g Na}_2\text{Cr}_2\text{O}_7$$

Since the Na_2CrO_4 forms the least product, it is the limiting reactant.

b. Explain why the carbon dioxide and water are in excess and sodium chromate is limiting.

Both water and carbon dioxide are very inexpensive and nontoxic. Since CO_2 is a gas and since water can be easily converted to steam, they are also very easily separated from solid products. Adding an excess of these substances drives the reversible reaction toward products and yields a more complete conversion of Na_2CrO_4 to $Na_2Cr_2O_7$.

80. What is the molarity of a solution made by dissolving 100.065 g of $SnBr_2$ in water and diluting with water to 1.00 L total?

$$\frac{?\text{ mol SnBr}_2}{1\text{ L soln}} = \frac{100.065\text{ g SnBr}_2}{1.00\text{ L soln}}\left(\frac{1\text{ mol SnBr}_2}{278.52\text{ g SnBr}_2}\right) = \mathbf{0.359\ M\ SnBr_2}$$

82. A precipitation reaction takes place when a water solution of sodium carbonate, Na_2CO_3, is added to a water solution of chromium(III) nitrate, $Cr(NO_3)_3$.

a. Write a balanced equation for this reaction.

$$\mathbf{3Na_2CO_3(\mathit{aq}) + 2Cr(NO_3)_3(\mathit{aq}) \rightarrow Cr_2(CO_3)_3(\mathit{s}) + 6NaNO_3(\mathit{aq})}$$

b. What is the maximum mass of chromium(III) carbonate that will precipitate from a solution prepared by adding an excess of an Na_2CO_3 solution to 10.00 mL of 0.100 M $Cr(NO_3)_3$?

$$?\text{ g Cr}_2(\text{CO}_3)_3 = 10.00\text{ mL Cr(NO}_3)_3\text{ soln}\left(\frac{0.100\text{ mol Cr(NO}_3)_3}{10^3\text{ mL Cr(NO}_3)_3\text{ soln}}\right)\left(\frac{1\text{ mol Cr}_2(\text{CO}_3)_3}{2\text{ mol Cr(NO}_3)_3}\right)\left(\frac{284.020\text{ g Cr}_2(\text{CO}_3)_3}{1\text{ mol Cr}_2(\text{CO}_3)_3}\right) = \mathbf{0.142\ g\ Cr_2(CO_3)_3}$$

84. Consider the neutralization reaction between nitric acid and aqueous barium hydroxide.

a. Write a conversion factor that shows the ratio of moles of nitric acid to moles of barium hydroxide.

$$\left(\frac{\mathbf{2\ mol\ HNO_3}}{\mathbf{1\ mol\ Ba(OH)_2}}\right)$$

b. What volume of 1.09 M nitric acid would be necessary to neutralize the hydroxide in 25.00 mL of 0.159 M barium hydroxide?

$$?\text{ mL HNO}_3\text{ soln} = 25.00\text{ mL Ba(OH)}_2\text{ soln}\left(\frac{0.159\text{ mol Ba(OH)}_2}{10^3\text{ mL Ba(OH)}_2}\right)\left(\frac{2\text{ mol HNO}_3}{1\text{ mol Ba(OH)}_2}\right)\left(\frac{10^3\text{ mL HNO}_3\text{ soln}}{1.09\text{ mol HNO}_3}\right) = \mathbf{7.29\ mL\ HNO_3\ soln}$$

86. Consider the neutralization reaction between hydrochloric acid and solid zinc carbonate.
    a. Write a conversion factor that shows the ratio of moles of hydrochloric acid to moles of zinc carbonate.

    $$\left(\frac{\mathbf{2\,mol\,HCl}}{\mathbf{1\,mol\,ZnCO_3}}\right)$$

    b. What volume of 0.500 M hydrochloric acid would be necessary to neutralize and dissolve 562 milligrams of solid zinc carbonate?

    $$?\text{ mL HCl soln} = 562\text{ mg ZnCO}_3\left(\frac{1\text{ g}}{10^3\text{ mg}}\right)\left(\frac{1\text{ mol ZnCO}_3}{125.40\text{ g ZnCO}_3}\right)\left(\frac{2\text{ mol HCl}}{1\text{ mol ZnCO}_3}\right)\left(\frac{10^3\text{ mL HCl soln}}{0.500\text{ mol HCl}}\right) = \mathbf{17.9\,mL\,HCl soln}$$

Challenge Problems

88. A solution is made by adding 22.609 g of a solid that is 96.3% NaOH to a beaker of water. What volume of 2.00 M H_2SO_4 is necessary to neutralize the NaOH in this solution?

    $$H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2H_2O(l) + Na_2SO_4(aq)$$

    $$?\text{ mL H}_2\text{SO}_4 = 22.609\text{ g solid}\left(\frac{96.3\text{ g NaOH}}{100\text{ g solid}}\right)\left(\frac{1\text{ mol NaOH}}{39.9971\text{ g NaOH}}\right)\left(\frac{1\text{ mol H}_2\text{SO}_4}{2\text{ mol NaOH}}\right)\left(\frac{10^3\text{ mL H}_2\text{SO}_4}{2.00\text{ mol H}_2\text{SO}_4}\right) = \mathbf{136\,mL\,H_2SO_4\,solution}$$

90. Aluminum sulfate, often called alum, is used in paper making to increase the paper's stiffness and smoothness and to help keep the ink from running. It is made from the reaction of sulfuric acid with the aluminum oxide found in bauxite ore. The products are aluminum sulfate and water. Bauxite ore is 30% to 75% aluminum oxide.
    a. Write a balanced equation for this reaction. (You do not need to write the states.)

    $$\mathbf{3H_2SO_4 + Al_2O_3 \rightarrow Al_2(SO_4)_3 + 3H_2O}$$

    b. What is the maximum mass, in kilograms, of aluminum sulfate that could be formed from 2.3×10^3 kilograms of bauxite ore that is 62% aluminum oxide?

    $$?\text{ kg Al}_2(\text{SO}_4)_3 = 2.3\times10^3\text{ kg ore}\left(\frac{62\text{ kg Al}_2\text{O}_3}{100\text{ kg ore}}\right)\left(\frac{1\times342.154\text{ kg Al}_2(\text{SO}_4)_3}{1\times101.9612\text{ kg Al}_2\text{O}_3}\right)$$

    $$\mathbf{= 4.8 \times 10^3\,kg\,Al_2(SO_4)_3}$$

92. Sodium tripolyphosphate (or STPP), $Na_5P_3O_{10}$, is used in detergents. It is made by combining phosphoric acid with sodium carbonate at 300 to 500 °C. What is the minimum mass, in kilograms, of sodium carbonate that would be necessary to react with excess phosphoric acid to make enough STPP to produce 1.025×10^5 kg of a detergent that is 32% $Na_5P_3O_{10}$?

    $$6H_3PO_4 + 5Na_2CO_3 \rightarrow 2Na_5P_3O_{10} + 9H_2O + 5CO_2$$

    $$?\text{ kg Na}_2\text{CO}_3 = 1.025\times10^5\text{ kg det.}\left(\frac{32\text{ kg Na}_5\text{P}_3\text{O}_{10}}{100\text{ kg det.}}\right)\left(\frac{5\times105.989\text{ kg Na}_2\text{CO}_3}{2\times367.864\text{ kg Na}_5\text{P}_3\text{O}_{10}}\right)$$

    $$\mathbf{= 2.4 \times 10^4\,kg\,Na_2CO_3}$$

94. Urea, NH_2CONH_2, is a common nitrogen source used in fertilizers. When urea is made industrially, its temperature must be carefully controlled because heat turns urea into biuret, $NH_2CONHCONH_2$, a compound that is harmful to plants. Consider a pure sample of urea that has a mass of 92.6 kg. If 0.5% of the urea in this sample decomposes to form biuret, what mass, in grams, of $NH_2CONHCONH_2$ will it contain?

$$2NH_2CONH_2 \rightarrow \underset{\text{biuret}}{NH_2CONHCONH_2} + NH_3$$

$$? \text{ kg } NH_2CONHCONH_2 = 92.6 \text{ kg } NH_2CONH_2 \text{ original}\left(\frac{0.5 \text{ kg } NH_2CONH_2 \text{ decomposed}}{100 \text{ kg } NH_2CONH_2 \text{ original}}\right)$$

$$\left(\frac{1\times 103.081 \text{ kg } NH_2CONHCONH_2}{2\times 60.056 \text{ kg } NH_2CONH_2}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right) = \mathbf{4\times 10^2 \text{ g } NH_2CONHCONH_2}$$

96. The white pigment titanium(IV) oxide (often called titanium dioxide), TiO_2, is made from rutile ore that is about 95% TiO_2. Before the TiO_2 can be used, it must be purified. The equation that follows represents the first step in this purification.

$$3TiO_2(s) + 4C(s) + 6Cl_2(g) \xrightarrow{900\ °C} 3TiCl_4(l) + 2CO(g) + 2CO_2(g)$$

a. How many pounds of $TiCl_4$ can be made from the reaction of 1.250×10^5 pounds of rutile ore that is 95% TiO_2 with 5.0×10^4 pounds of carbon?

$$? \text{ lb } TiCl_4 = 1.250\times 10^5 \text{ lb ore}\left(\frac{95 \text{ lb } TiO_2}{100 \text{ lb ore}}\right)\left(\frac{3\times 189.678 \text{ lb } TiCl_4}{3\times 79.866 \text{ lb } TiO_2}\right) = \mathbf{2.8\times 10^5 \text{ lb } TiCl_4}$$

$$? \text{ lb } TiCl_4 = 5.0\times 10^4 \text{ lb C}\left(\frac{3\times 189.678 \text{ lb } TiCl_4}{4\times 12.011 \text{ lb C}}\right) = 5.9 \times 10^5 \text{ lb } TiCl_4$$

b. Explain why two of these substances are in excess and one is limiting.

Carbon is inexpensive, nontoxic, and easy to convert to gaseous CO or CO_2, which are easy to separate from solid and liquid products. Although chlorine gas is a more dangerous substance, it is inexpensive and easy to separate from the product mixture. Because the ultimate goal is to convert the titanium in TiO_2 into $TiCl_4$, the TiO_2 is the more important reactant, so it is limiting.

98. What is the maximum mass of calcium hydrogen phosphate, $CaHPO_4$, that can form in the mixture of 12.50 kg of a solution that contains 84.0% H_3PO_4, 25.00 kg of $Ca(NO_3)_2$, 25.00 L of 14.8 M NH_3, and an excess of CO_2 and H_2O?

$$3H_3PO_4 + 5Ca(NO_3)_2 + 10NH_3 + 2CO_2 + 2H_2O \rightarrow 10NH_4NO_3 + 2CaCO_3 + 3CaHPO_4$$

$$? \text{ kg } CaHPO_4 = 12.50 \text{ kg } H_3PO_4 \text{ soln}\left(\frac{84.0 \text{ kg } H_3PO_4}{100 \text{ kg } H_3PO_4 \text{ soln}}\right)\left(\frac{3\times 136.057 \text{ kg } CaHPO_4}{3\times 97.9952 \text{ kg } H_3PO_4}\right)$$

$$= 14.6 \text{ kg } CaHPO_4$$

$$? \text{ kg } CaHPO_4 = 25.00 \text{ kg } Ca(NO_3)_2\left(\frac{3\times 136.057 \text{ kg } CaHPO_4}{5\times 164.088 \text{ kg } Ca(NO_3)_2}\right) = \mathbf{12.44 \text{ kg } CaHPO_4}$$

$$? \text{ kg } CaHPO_4 = 25.00 \text{ L } NH_3 \text{ soln}\left(\frac{14.8 \text{ mol } NH_3}{1 \text{ L } NH_3 \text{ soln}}\right)\left(\frac{3 \text{ mol } CaHPO_4}{10 \text{ mol } NH_3}\right)$$

$$\left(\frac{136.057 \text{ g } CaHPO_4}{1 \text{ mol } CaHPO_4}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = 15.1 \text{ kg } CaHPO_4$$