Chapter 7
An Introduction to Chemical Reactions

Section Goals and Introductions

Now that you know about atoms, elements, chemical bonds, and chemical compounds, you are ready to be introduced to chemical changes and the ways that we describe them.

Section 7.1 Chemical Reactions and Chemical Equations

Goals

- *To describe the nature of chemical reactions.*
- *To show how chemical reactions can be described with chemical equations.*
- *To show how to balance chemical equations.*

This section starts with a brief description of chemical reactions. The introduction to chemical reactions is followed by a description of how chemical changes are described with chemical equations. You will see many chemical equations in this text, so it is very important that you be able to interpret them. *Sample Study Sheet 7.1: Balancing Chemical Equations* describes the important skill of balancing equations so that they reflect the fact that the number of atoms of each element for the products of chemical changes always equals the number of atoms of each element in the initial reactants. Our Web site provides a tutorial that will allow you to practice balancing chemical equations.

> *Internet: Balancing Equations Tutorial*

Section 7.2 Liquid Water and Water Solutions

Goals

- *To describe the structure of liquid water.*
- *To describe the process by which ionic compounds dissolve in water.*

Many chemical reactions take place between reactants that are dissolved in water, so to visualize the processes for these reactions, it is important that you have a clear mental image of the particle nature of water. This section and an animation on our Web site will help you develop this image.

> *Internet: Structure of Water*

This section also describes solutions in general and solutions of ionic compounds in particular, and most important, describes the process by which ionic compounds dissolve in water. If you develop the ability to *see* this process in your mind's eye, it will help you understand the process of chemical changes between substances in solution. An animation on our Web site will help you to visualize the process of dissolving sodium chloride in water.

> *Internet: Dissolving NaCl*

Section 7.3 Solubility of Ionic Compounds and Precipitation Reactions

Goals

- *To describe the changes that take place on the molecular level during precipitation reactions.*

- *To provide guidelines for predicting water solubility of ionic compounds.*

- *To describe the process for predicting precipitation reactions and writing chemical equations for them.*

The description of the nature of solutions in Section 7.2 leads to the description of a simple chemical change that takes place when two solutions of ionic compounds are mixed, leading to the formation of an ionic compound that is insoluble in water and therefore comes out of solution as a solid. You will learn how to visualize the changes that take place in this type of reaction (called a precipitation reaction), how to predict whether mixtures of two solutions of ionic compounds will lead to a precipitation reaction, and how to write chemical equations for those reactions that do take place. Our Web site provides (1) an animation that will help you to visualize precipitation reactions, (2) a tutorial that will allow you to practice predicting whether ionic compounds are soluble in water or not, and (3) a description of the process for writing complete ionic and net ionic equations.

> *Internet: Precipitation Reactions*
> *Internet: Predicting Water Solubility*
> *Internet: Writing Precipitation Equations*

You might want to look closely at the Having Trouble section at the end of this section. It describes all of the skills from previous chapters that are necessary for writing chemical equations for precipitation reactions. Students often have trouble with writing these equations, not because of the new components to the process found in Chapter 7, but because they are still having trouble with skills from earlier chapters.

Section 7.4 Chemical Changes and Energy

Goals

- *To describe the relationship between energy and chemical reactions.*

- *To explain why some chemical changes release energy as they proceed and why others need to absorb energy to take place.*

This section explains why some chemical reactions absorb heat energy from their surroundings and why others release heat energy to their surroundings.

Chapter 7 Map
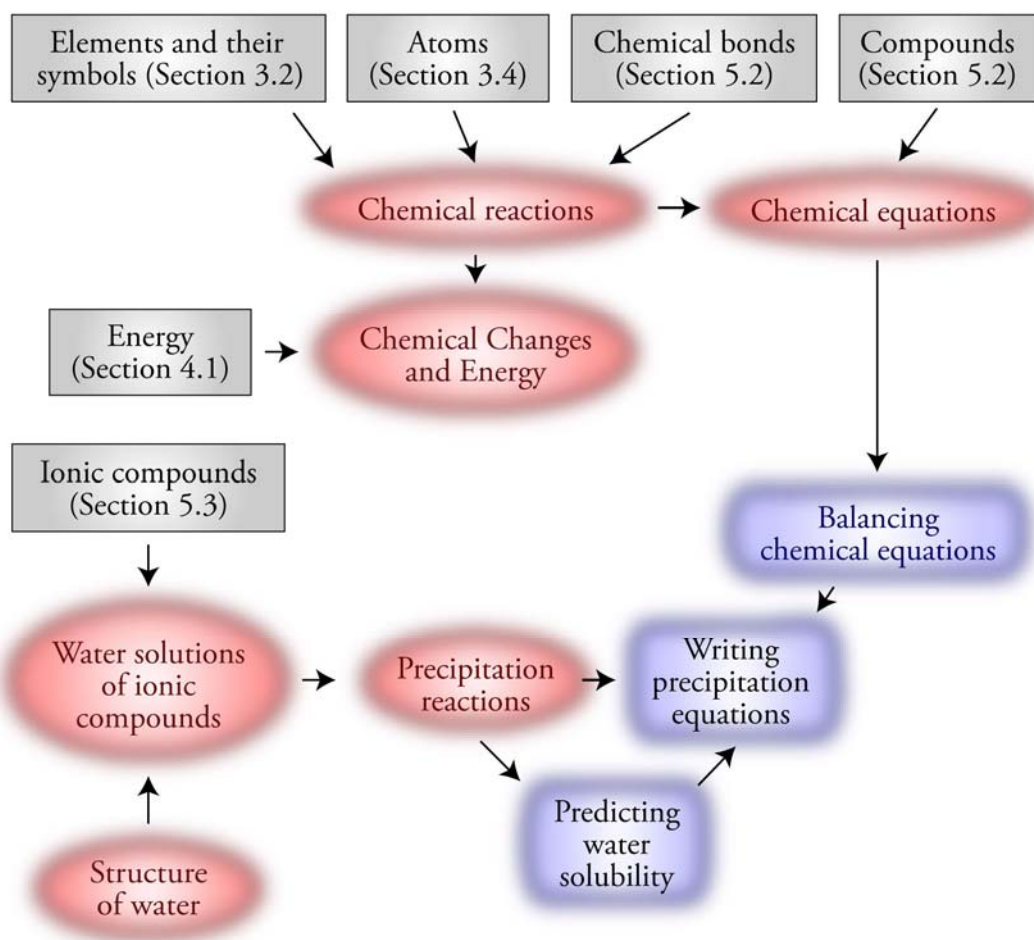
Chapter Checklist

- ☐ 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 at 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, 7, 12, 13, and 14.)

☐ 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 7.1: Balancing Chemical Equations

Sample Study Sheet 7.2: Predicting Precipitation Reactions and Writing Precipitation Equations

☐ Memorize the following solubility guidelines. Be sure to check with your instructor to determine how much you are expected to know of the following guidelines.

Category	Ions	Except with these ions	Examples
Soluble cations	Group 1 metallic ions and ammonium, NH_4^+	No exceptions	Na_2CO_3, LiOH, and $(NH_4)_2S$ are soluble.
Soluble anions	NO_3^- and $C_2H_3O_2^-$	No exceptions	$Bi(NO_3)_3$, and $Co(C_2H_3O_2)_2$ are soluble.
Usually soluble anions	Cl^-, Br^-, and I^-	Soluble with some exceptions, including with Ag^+ and Pb^{2+}	$CuCl_2$ is water soluble, but AgCl is insoluble.
	SO_4^{2-}	Soluble with some exceptions, including with Ba^{2+} and Pb^{2+}	$FeSO_4$ is water soluble, but $BaSO_4$ is insoluble.
usually insoluble anions	CO_3^{2-}, PO_4^{3-}, and OH^-	Insoluble with some exceptions, including with group 1 elements and NH_4^+	$CaCO_3$, $Ca_3(PO_4)_2$, and $Mn(OH)_2$ are insoluble in water, but $(NH_4)_2CO_3$, Li_3PO_4, and CsOH are soluble.

☐ 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: Balancing Equations
Internet: Structure of Water
Internet: Dissolving NaCl
Internet: Precipitation Reaction
Internet: Predicting Water Solubility
Internet: Writing Precipitation Equations
Internet: Glossary Quiz

Exercises Key

Exercise 7.1 - Balancing Equations: Balance the following chemical equations. *(Obj 4)*

    a. $P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(l)$

    b. $3PbO(s) + 2NH_3(g) \rightarrow 3Pb(s) + N_2(g) + 3H_2O(l)$

    c. $P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$

    d. $3Mn(s) + 2CrCl_3(aq) \rightarrow 3MnCl_2(aq) + 2Cr(s)$

    e. $C_2H_2(g) + 5/2O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$

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

    f. $3Co(NO_3)_2(aq) + 2Na_3PO_4(aq) \rightarrow Co_3(PO_4)_2(s) + 6NaNO_3(aq)$

    g. $2CH_3NH_2(g) + 9/2O_2(g) \rightarrow 2CO_2(g) + 5H_2O(l) + N_2(g)$

         or $4CH_3NH_2(g) + 9O_2(g) \rightarrow 4CO_2(g) + 10H_2O(l) + 2N_2(g)$

    h. $2FeS(s) + 9/2O_2(g) + 2H_2O(l) \rightarrow Fe_2O_3(s) + 2H_2SO_4(aq)$

         or $4FeS(s) + 9O_2(g) + 4H_2O(l) \rightarrow 2Fe_2O_3(s) + 4H_2SO_4(aq)$

Exercise 7.2 - Predicting Water Solubility: Predict whether each of the following is soluble or insoluble in water. *(Obj 11)*

    a. $Hg(NO_3)_2$ (used to manufacture felt)   **soluble**

    b. $BaCO_3$ (used to make radiation-resistant glass for color TV tubes)   **insoluble**

    c. K_3PO_4 (used to make liquid soaps)   **soluble**

    d. $PbCl_2$ (used to make other lead salts)   **insoluble**

    e. $Cd(OH)_2$ (storage battery electrodes)   **insoluble**

Exercise 7.3 - Precipitation Reactions: Predict whether a precipitate will form when each of the following pairs of water solutions is mixed. If there is a precipitation reaction, write the complete equation that describes the reaction. *(Obj 12)*

    a. $3CaCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$

    b. $3KOH(aq) + Fe(NO_3)_3(aq) \rightarrow 3KNO_3(aq) + Fe(OH)_3(s)$

    c. $NaC_2H_3O_2(aq) + CaSO_4(aq)$ **No Reaction**

    d. $K_2SO_4(aq) + Pb(NO_3)_2(aq) \rightarrow 2KNO_3(aq) + PbSO_4(s)$

Review Questions Key

1. Write the formulas for all of the diatomic elements. **H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2**

2. Write the definitions of energy, kinetic energy, and potential energy.

    Energy   *The capacity to do work.*

    Kinetic energy   *The capacity to do work due to the motion of an object.*

    Potential energy   *A retrievable, stored form of energy an object possesses by virtue of its position or state.*

3. Describe the relationship between stability, capacity to do work, and potential energy.

   Less stable means more likely to change. When things change they can do work. This greater capacity to do work is reflected in higher potential energy, so a less stable system has a greater capacity to do work and a higher potential energy.

4. Explain why energy must be absorbed to break a chemical bond.

   Separate atoms are less stable (more likely to change) and therefore higher potential energy than the same atoms in a chemical bond, so when chemical bonds are broken, energy must be added to supply the extra potential energy of the separate atoms.

5. Explain why energy is released when a chemical bond is formed.

   Atoms in a chemical bond are more stable (less likely to change) and therefore lower potential energy than the separate atoms, so when chemical bonds are made, the potential energy difference between separate atoms and the atoms in a bond is released.

6. Describe the changes that take place during heat transfer between objects at different temperatures.

   The particles in a higher-temperature object collide with other particles with greater average force than the particles of a lower-temperature object. Thus collisions between the particles of two objects at different temperatures cause the particles of the lower-temperature object to speed up, increasing the object's kinetic energy, and cause the particles of the higher-temperature object to slow down, decreasing this object's kinetic energy. In this way, energy is transferred from the higher-temperature object to the lower-temperature object. We call energy that is transferred in this way heat. The energy that is transferred through an object, as from the bottom of a cooking pan to its handle, is also called heat. Heat is the energy that is transferred from a region of higher temperature to a region of lower temperature as a consequence of the collisions of particles.

7. Predict whether atoms of each of the following pairs of elements would be expected to form ionic or covalent bonds.

   a. Mg and F   **ionic**   c. Fe and O   **ionic**

   b. O and H   **covalent**   d. N and Cl   **covalent**

8. Write formulas that correspond to the following names.

   a. ammonia NH_3

   b. methane CH_4

   c. propane C_3H_8

   d. water H_2O

9. Write formulas that correspond to the following names.

   a. nitrogen dioxide NO_2

   b. carbon tetrabromide CBr_4

   c. dibromine monoxide Br_2O

   d. nitrogen monoxide NO

10. Write formulas that correspond to the following names.
    a. lithium fluoride   **LiF**
    b. lead(II) hydroxide   **Pb(OH)$_2$**
    c. potassium oxide   **K$_2$O**
    d. sodium carbonate   **Na$_2$CO$_3$**
    e. chromium(III) chloride   **CrCl$_3$**
    f. sodium hydrogen phosphate   **Na$_2$HPO$_4$**

Key Ideas Answers

11. A chemical change or chemical reaction is a process in which one or more pure substances are **converted into** one or more different pure substances.

13. A chemical equation is a **shorthand description** of a chemical reaction.

15. To indicate that a chemical reaction requires the **continuous** addition of heat in order to proceed, we place an upper-case Greek **delta, Δ,** above the arrow in the reaction's chemical equation.

17. When balancing chemical equations, we do not change the **subscripts** in the formulas.

19. As in other liquids, the attractions between water molecules are strong enough to keep them the **same average distance apart** but weak enough to allow each molecule to be **constantly breaking** the attractions that momentarily connect it to some molecules and **forming new attractions** to other molecules.

21. Every part of a water solution of an ionic compound has the **same proportions** of water molecules and ions as every other part.

23. In solutions of solids dissolved in liquids, we call the solid the **solute** and the liquid the **solvent**.

25. In solutions of two liquids, we call the **minor** component the solute and the **major** component the solvent.

27. Crystals are solid particles whose component atoms, ions, or molecules are arranged in an **organized, repeating** pattern.

29. Because spectator ions are not involved in the reaction, they are often **left out** of the chemical equation.

31. If in a chemical reaction, more energy is released in the formation of new bonds than was necessary to break old bonds, energy is **released** overall, and the reaction is exergonic.

33. If less energy is released in the formation of the new bonds than is necessary to break the old bonds, energy must be **absorbed** from the surroundings for the reaction to proceed.
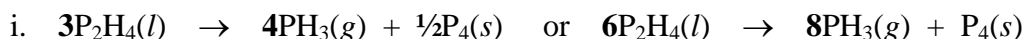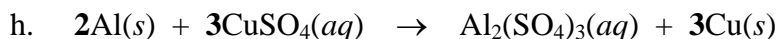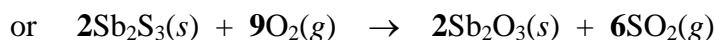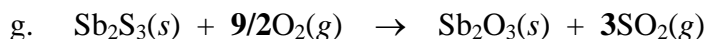
Problems Key

Section 7.1 Chemical Reactions and Chemical Equations

35. Describe the information given in the following chemical equation. *(Objs 2 & 3)*

$$2CuHCO_3(s) \xrightarrow{\Delta} Cu_2CO_3(s) + H_2O(l) + CO_2(g)$$
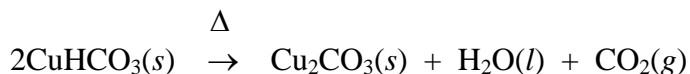
For each two particles of solid copper(I) hydrogen carbonate that are heated strongly, one particle of solid copper(I) carbonate, one molecule of liquid water, and one molecule of gaseous carbon dioxide are formed.

37. Balance the following equations. *(Obj 4)*

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

b. $4Cl_2(g) + 2CH_4(g) + O_2(g) \rightarrow 8HCl(g) + 2CO(g)$

c. $B_2O_3(s) + 6NaOH(aq) \rightarrow 2Na_3BO_3(aq) + 3H_2O(l)$

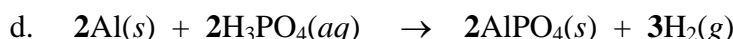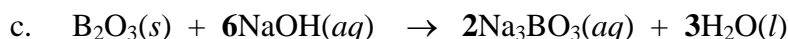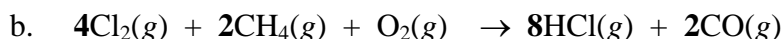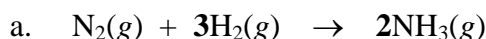d. $2Al(s) + 2H_3PO_4(aq) \rightarrow 2AlPO_4(s) + 3H_2(g)$

e. $CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ or $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

f. $C_6H_{14}(l) + 19/2 O_2(g) \rightarrow 6CO_2(g) + 7H_2O(l)$

　　　or $2C_6H_{14}(l) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$

g. $Sb_2S_3(s) + 9/2 O_2(g) \rightarrow Sb_2O_3(s) + 3SO_2(g)$

　　　or $2Sb_2S_3(s) + 9O_2(g) \rightarrow 2Sb_2O_3(s) + 6SO_2(g)$

h. $2Al(s) + 3CuSO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3Cu(s)$

i. $3P_2H_4(l) \rightarrow 4PH_3(g) + \frac{1}{2}P_4(s)$ or $6P_2H_4(l) \rightarrow 8PH_3(g) + P_4(s)$
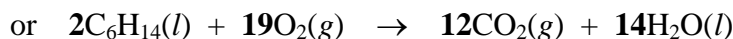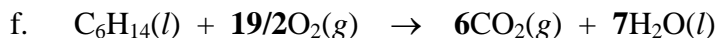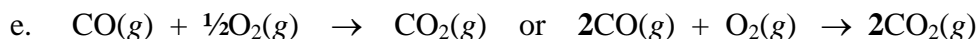
39. Because of its toxicity, carbon tetrachloride is prohibited in products intended for home use, but it is used industrially for a variety of purposes, including the production of chlorofluorocarbons (CFCs). It is made in a three-step process. Balance their equations: *(Obj 4)*

$$CS_2 + 3Cl_2 \rightarrow S_2Cl_2 + CCl_4$$
$$4CS_2 + 8S_2Cl_2 \rightarrow 3S_8 + 4CCl_4$$
$$S_8 + 4C \rightarrow 4CS_2$$
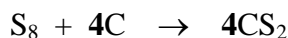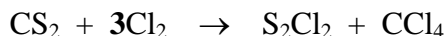
41. Hydrochlorofluorocarbons (HCFCs), which contain hydrogen as well as carbon, fluorine, and chlorine, are less damaging to the ozone layer than chlorofluorocarbons (CFCs). HCFCs are therefore used instead of CFCs for many purposes. Balance the following equation that shows how the HCFC chlorodifluoromethane, $CHClF_2$, is made. *(Obj 4)*

$$2HF + CHCl_3 \rightarrow CHClF_2 + 2HCl$$
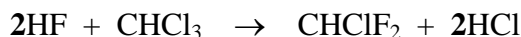
Section 7.2 Liquid Water and Water Solutions

43. What are the particles that form the basic structure of water? Describe the attraction that holds these particles together. Draw a rough sketch that shows the attraction between two water molecules. *(Obj 5)*

Water is composed of H_2O molecules. Pairs of these molecules are attracted to each other by the attraction between the partially positive hydrogen atom of one molecule and the partially negative oxygen atom of the other molecule. See Figure 7.4. Each water molecule is moving constantly, breaking the attractions to some molecules, and making new attractions to other molecules. Figure 7.5 shows the model we will use to visualize liquid water.

45. Describe the process for dissolving the ionic compound lithium iodide, LiI, in water, including the nature of the particles in solution and the attractions between the particles in the solution. *(Obj 7)*

When solid lithium iodide is added to water, all of the ions at the surface of the solid can be viewed as shifting back and forth between moving out into the water and returning to the solid surface. Sometimes when an ion moves out into the water, a water molecule collides with it, helping to break the ionic bond, and pushing it out into the solution. Water molecules move into the gap between the ion in solution and the solid and shield the ion from the attraction to the solid.

The ions are kept stable and held in solution by attractions between them and the polar water molecules. The negatively charged oxygen ends of water molecules surround the lithium ions, and the positively charged hydrogen ends of water molecules surround the iodide ions. (See Figures 7.7 and 7.8 with Li^+ in the place of Na^+ and I^- in the place of Cl^-.)

47. Describe the process for dissolving the ionic compound sodium sulfate, Na_2SO_4, in water. Include the nature of the particles in solution and the attractions between the particles in the solution. *(Obj 7)*

Same answer as problem 45 but with sodium ions, Na^+, instead of lithium ions and sulfate ions, SO_4^{2-}, in the place of iodide ions. The final solution will have two times as many sodium ions as sulfate ions.

49. Solid camphor and liquid ethanol mix to form a solution. Which of these substances is the solute and which is the solvent? *(Obj 8)*

In a solution of a solid in a liquid, the solid is generally considered the solute, and the liquid is the solvent. Therefore, camphor is the solute in this solution, and ethanol is the solvent.

Section 7.3 Precipitation Reactions

52. Black-and-white photographic film has a thin layer of silver bromide deposited on it. Wherever light strikes the film, silver ions are converted to uncharged silver atoms, creating a dark image on the film. Describe the precipitation reaction that takes place between water solutions of silver nitrate, $AgNO_3(aq)$, and sodium bromide, $NaBr(aq)$, to form solid silver bromide, $AgBr(s)$, and aqueous sodium nitrate, $NaNO_3(aq)$. Include the nature of the particles in the system before and after the reaction, a description of the cause of the reaction, and a description of the attractions between the particles before and after the reaction. *(Obj 10)*

> *At the instant that the solution of silver nitrate is added to the aqueous sodium bromide, there are four different ions in solution surrounded by water molecules, Ag^+, NO_3^-, Na^+, and Br^-. The oxygen ends of the water molecules surround the silver and sodium cations, and the hydrogen ends of water molecules surround the nitrate and bromide anions.*
>
> *When silver ions and bromide ions collide, they stay together long enough for other silver ions and bromide ions to collide with them, forming clusters of ions that precipitate from the solution.*
>
> *The sodium and nitrate ions are unchanged in the reaction. They were separate and surrounded by water molecules at the beginning of the reaction, and they are still separate and surrounded by water molecules at the end of the reaction. See Figures 7.10 to 7.12 with silver ions in the place of calcium ions and bromide ions in the place of carbonate ions.*

54. Predict whether each of the following substances is soluble or insoluble in water. *(Obj 11)*

    a. Na_2SO_3 (water treatment)   **soluble**

    b. iron(III) acetate   (wood preservative)   **soluble**

    c. $CoCO_3$ (red pigment)   **insoluble**

    d. lead(II) chloride   (preparation of lead salts)   **insoluble**

56. Predict whether each of the following substances is soluble or insoluble in water. *(Obj 11)*

    a. zinc phosphate   (dental cements)   **insoluble**

    b. $Mn(C_2H_3O_2)_2$ (cloth dyeing)   **soluble**

    c. nickel(II) sulfate   (nickel plating)   **soluble**

    d. $AgCl$ (silver plating)   **insoluble**

58. For each of the following pairs of formulas, predict whether the substances they represent would react in a precipitation reaction. The products formed in the reactions that take place are used in ceramics, cloud seeding, photography, electroplating, and paper coatings. If there is no reaction, write, "No Reaction". If there is a reaction, write the complete equation for the reaction. *(Obj 12)*

    a. $Co(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow$ **$CoCO_3(s) + 2NaNO_3(aq)$**

    b. **2**$KI(aq) + Pb(C_2H_3O_2)_2(aq) \rightarrow$ **$2KC_2H_3O_2(aq) + PbI_2(s)$**

    c. $CuSO_4(aq) + LiNO_3(aq)$ **no reaction**

    d. **3**$Ni(NO_3)_2(aq) + $**$2$**$Na_3PO_4(aq) \rightarrow$ **$Ni_3(PO_4)_2(s) + 6NaNO_3(aq)$**

    e. $K_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow$ **$2KNO_3(aq) + BaSO_4(s)$**

60. Phosphate ions find their way into our water system from the fertilizers dissolved in the runoff from agricultural fields and from detergents that we send down our drains. Some of these phosphate ions can be removed by adding aluminum sulfate to the water and precipitating the phosphate ions as aluminum phosphate. Write the net ionic equation for the reaction that forms the aluminum phosphate.

$$Al^{3+}(aq) + PO_4^{3-}(aq) \rightarrow AlPO_4(s)$$
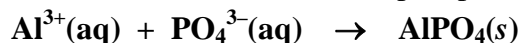
62. Cadmium hydroxide is used in storage batteries. It is made from the precipitation reaction of cadmium acetate and sodium hydroxide. Write the complete equation for this reaction.

$$Cd(C_2H_3O_2)_2(aq) + 2NaOH(aq) \rightarrow Cd(OH)_2(s) + 2NaC_2H_3O_2(aq)$$
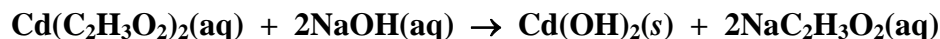
Section 7.4 Chemical Changes and Energy

64. Consider the following endergonic reaction. In general terms, explain why energy is absorbed in the process of this reaction. *(Obj 13)*
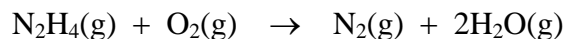
$$N_2(g) + O_2(g) \rightarrow 2NO(g)$$
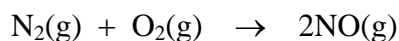
The bonds in the products must be less stable and therefore higher potential energy than the bonds in the reactants. Energy is absorbed in the reaction to supply the energy necessary to increase the potential energy of the products compared to reactants.

more stable bonds + energy → less stable bonds

lower PE + energy → higher PE

66. Hydrazine, N_2H_4, is used as rocket fuel. Consider a system in which a sample of hydrazine is burned in a closed container, followed by heat transfer from the container to the surroundings.

$$N_2H_4(g) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

a. In general terms, explain why energy is released in the reaction.

The bonds in the products must be more stable and therefore lower potential energy than the bonds in the reactants. The potential energy difference between reactants and products is released.

b. Describe the average internal kinetic energy of the product particles, compared to the reactant particles, before heat energy is transferred to the surroundings. If the average internal kinetic energy for the product(s) is greater than that for the reactants, from where did this energy come? If the average internal kinetic energy for the product(s) is lower than that for the reactants, where did this energy go? *(Obj 14)*

Some of the potential energy of the reactants is converted into kinetic energy of the products, making the average kinetic energy of the products higher than the average kinetic energy of the reactants.

c. Describe the changes in particle motion that occur as heat is transferred from the products to the surroundings.
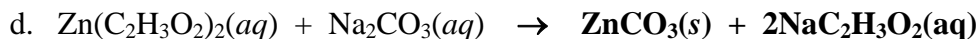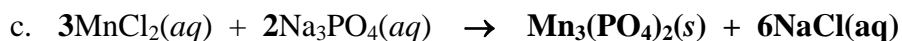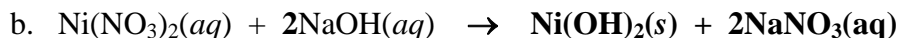
The particles of the higher-temperature products collide with the particles of the lower-temperature container with greater average force than the particles of the container. Therefore, collisions between the particles of the products and the container speed up the particles of the container, increasing its internal kinetic energy, while slowing the particles of the products, decreasing their kinetic energy. In this way, kinetic energy is transferred from the products to the container. Likewise, the container, which is now at a higher temperature, transfers energy to the lower-temperature surroundings. Heat has been transferred from the products to the container to the surroundings.

69. Classify each of the following changes as exothermic or endothermic.
    a. Leaves decaying in a compost heap   **exothermic**
    b. Dry ice (solid carbon dioxide) changing to carbon dioxide gas   **endothermic**
    c. Dew forming on a lawn at night   **exothermic**

71. Explain why all chemical reactions either absorb or evolve energy.   *(Obj 12)*

See Figure 7.15.

Additional Problems

72. Balance the following chemical equations.   *(Obj 4)*

    a. $SiCl_4$ + **2**H_2O $\rightarrow$ SiO_2 + **4**HCl
    b. **2**H_3BO_3 $\rightarrow$ B_2O_3 + **3**H_2O
    c. I_2 + **3**Cl_2 $\rightarrow$ **2**ICl_3
    d. **2**Al_2O_3 + **3**C $\rightarrow$ **4**Al + **3**CO_2

74. Balance the following chemical equations.   *(Obj 4)*

    a. **4**NH_3 + Cl_2 $\rightarrow$ N_2H_4 + **2**NH_4Cl
    b. Cu + **2**$AgNO_3$ $\rightarrow$ $Cu(NO_3)_2$ + **2**Ag
    c. Sb_2S_3 + **6**HNO_3 $\rightarrow$ **2**$Sb(NO_3)_3$ + **3**H_2S
    d. Al_2O_3 + **3**Cl_2 + **3**C $\rightarrow$ **2**$AlCl_3$ + **3**CO

76. Phosphoric acid, H_3PO_4, is an important chemical used to make fertilizers, detergents, pharmaceuticals, and many other substances. High purity phosphoric acid is made in a two-step process called the furnace process. Balance its two equations: *(Obj 4)*

    2$Ca_3(PO_4)_2$ + **6**SiO_2 + **10**C $\rightarrow$ P_4 + **10**CO + **6**$CaSiO_3$
    P_4 + **5**O_2 + **6**H_2O $\rightarrow$ **4**H_3PO_4

78. Predict whether each of the following substances is soluble or insoluble in water.   *(Obj 11)*

    a. manganese(II) chloride (used as a dietary supplement   **soluble**
    b. $CdSO_4$ (used in pigments)   **soluble**
    c. copper(II) carbonate (used in fireworks)   **insoluble**
    d. $Co(OH)_3$ (used as a catalyst)   **insoluble**

80. For each of the following pairs of formulas, predict whether the substances they represent would react to yield a precipitate. (The products formed in the reactions that take place are used to coat steel, as a fire-proofing filler for plastics, in cosmetics, and as a topical antiseptic.) If there is no reaction, write, "No Reaction." If there is a reaction, write the complete equation for the reaction. *(Obj 12)*

    a. $NaCl(aq) + Al(NO_3)_3(aq)$ **no reaction**

    b. $Ni(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Ni(OH)_2(s) + 2NaNO_3(aq)$

    c. $3MnCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Mn_3(PO_4)_2(s) + 6NaCl(aq)$

    d. $Zn(C_2H_3O_2)_2(aq) + Na_2CO_3(aq) \rightarrow ZnCO_3(s) + 2NaC_2H_3O_2(aq)$

82. Hydrochloric acid is used in the cleaning of metals (called pickling). Hydrogen chloride, used to make hydrochloric acid, is made industrially by combining hydrogen and chlorine. Write a balanced equation, without including states, for this reaction. *(Obj 4)*

    $H_2 + Cl_2 \rightarrow 2HCl$

84. Aluminum sulfate, commonly called alum, is used to coat paper made from wood pulp. (It fills in tiny holes in the paper and thus keeps the ink from running.) Alum is made in the reaction of aluminum oxide with sulfuric acid, H_2SO_4, which produces aluminum sulfate and water. Write a balanced equation, without including states, for this reaction. *(Obj 4)*

    $Al_2O_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2O$
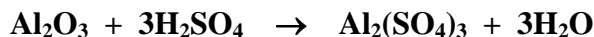
86. Hydrogen fluoride is used to make chlorofluorocarbons (CFCs) and in uranium processing. Calcium fluoride reacts with sulfuric acid, H_2SO_4, to form hydrogen fluoride and calcium sulfate. Write a balanced equation, without including states, for this reaction. *(Obj 4)*

 $CaF_2 + H_2SO_4 \rightarrow 2HF + CaSO_4$
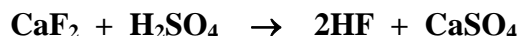
88. Sodium hydroxide, which is often called caustic soda, is used to make paper, soaps, and detergents. For many years, it was made from the reaction of sodium carbonate with calcium hydroxide (also called slaked lime). The products are sodium hydroxide and calcium carbonate. Write a balanced equation, without including states, for this reaction. *(Obj 4)*

 $Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3$
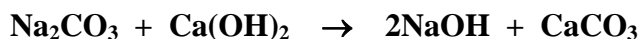
91. All of the equations for the Solvay process described in problem 90 can be summarized by a single equation, called a net equation, that describes the overall change for the process. This equation shows calcium carbonate reacting with sodium chloride to form sodium carbonate and calcium chloride. Write a balanced equation, without including states, for this net reaction. *(Obj 4)*

    $CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$
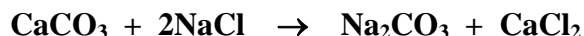
93. All of the equations for the production of nitric acid described in problem 92 can be summarized in a single equation, called a net equation, that describes the overall change for the complete process. This equation shows ammonia combining with oxygen to yield nitric acid and water. Write a balanced equation, without including states, for this net reaction. *(Obj 4)*

 $NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$
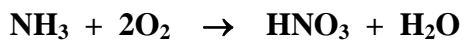
95. Hydrogen gas has many practical uses, including the conversion of vegetable oils into margarine. One way the gas is produced by the chemical industry is by reacting propane gas with gaseous water to form carbon dioxide gas and hydrogen gas. Write a balanced equation for this reaction, showing the states of reactants and products. *(Obj 4)*

$$C_3H_8(g) + 6H_2O(g) \rightarrow 3CO_2(g) + 10H_2(g)$$
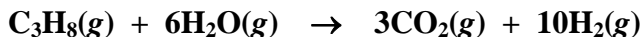
97. Pig iron is iron with about 4.3% carbon in it. The carbon lowers the metal's melting point and makes it easier to shape. To produce pig iron, iron(III) oxide is combined with carbon and oxygen at high temperature. Three changes then take place to form molten iron with carbon dispersed in it. Write a balanced equation, without including states, for each of these changes: *(Obj 4)*

    a. Carbon combines with oxygen to form carbon monoxide.

$$C + \tfrac{1}{2}O_2 \rightarrow CO$$
$$\text{or} \quad 2C + O_2 \rightarrow 2CO$$
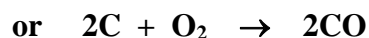
    b. Iron(III) oxide combines with the carbon monoxide to form iron and carbon dioxide.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$
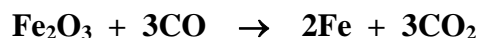
    c. Carbon monoxide changes into carbon (in the molten iron) and carbon dioxide.
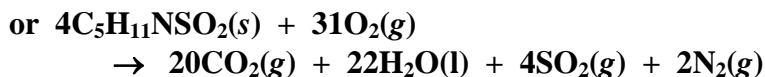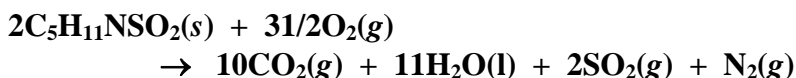
$$2CO \rightarrow C + CO_2$$

99. Assume you are given a water solution that contains either sodium ions or aluminum ions. Describe how you could determine which of these is in solution.

Add a water solution of an ionic compound that forms an insoluble substance with aluminum ions and a soluble substance with sodium ions. For example, a potassium carbonate solution would precipitate the aluminum ions as $Al_2(CO_3)_3$.

101. Write a complete, balanced chemical equation for the reaction between water solutions of iron(III) chloride and silver nitrate. *(Obj 4)*

$$FeCl_3(aq) + 3AgNO_3(aq) \rightarrow Fe(NO_3)_3(aq) + 3AgCl(s)$$
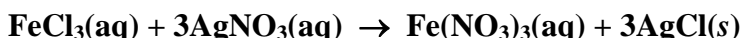
103. When the solid amino acid methionine, $C_5H_{11}NSO_2$, reacts with oxygen gas, the products are carbon dioxide gas, liquid water, sulfur dioxide gas, and nitrogen gas. Write a complete, balanced equation for this reaction. *(Obj 4)*

$$2C_5H_{11}NSO_2(s) + 31/2O_2(g)$$
$$\rightarrow 10CO_2(g) + 11H_2O(l) + 2SO_2(g) + N_2(g)$$
$$\text{or } 4C_5H_{11}NSO_2(s) + 31O_2(g)$$
$$\rightarrow 20CO_2(g) + 22H_2O(l) + 4SO_2(g) + 2N_2(g)$$

105. Classify each of the following changes as exothermic or endothermic.

    a. The burning fuel in a camp stove **exothermic**

    b. The melting of ice in a camp stove to provide water on a snow-camping trip **endothermic**