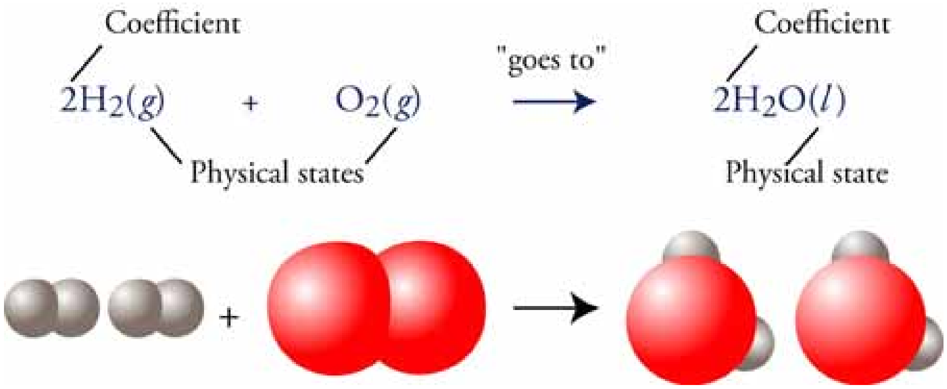
Chapter 5
An Introduction to Chemical Reactions



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 5.1 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 5.1: 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 5.2 Solubility of Ionic Compounds and Precipitation Reactions

Goals

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

This section begins by describing solutions in general, describing solutions of ionic compounds in particular, and most important, describing 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

The definition of the nature of solutions leads to the description of a simple chemical change that takes place when two solutions of ionic compounds are mixed, which leads 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.

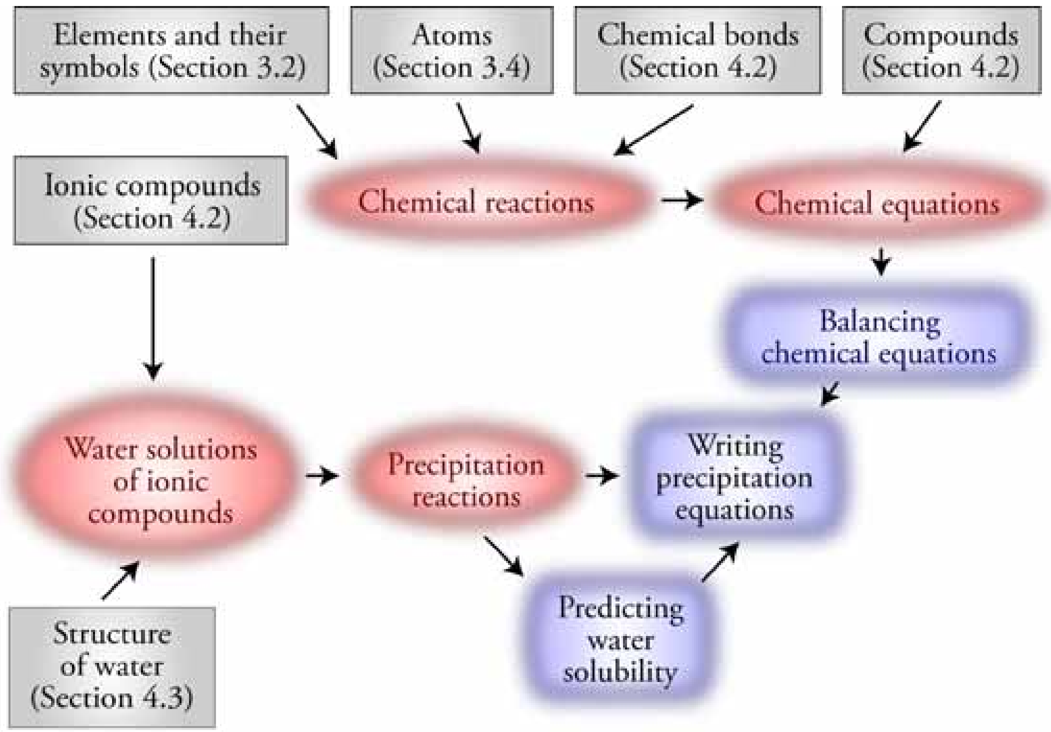
Internet: Precipitation Reactions

Internet: Predicting Water Solubility

Internet: Writing Net Ionic Equations for Precipitation Reactions

You might want to look closely at the *Having Trouble* section at the end of Chapter 5. It describes all of the skills from Chapters 3-5 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 5, but because they are still having trouble with skills from Chapters 3 and 4.

Chapter 5 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: 3, 4, and 10.)

☐ 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 5.1: Balancing Chemical Equations

Sample Study Sheet 5.2: 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: Dissolving NaCl
Internet: Precipitation Reaction
Internet: Predicting Water Solubility
Internet: Writing Complete and Net-Ionic Equations for Precipitation Reactions
Internet: Glossary Quiz

Exercises Key

✍ **Exercise 5.1 - Balancing Equations:** Balance the following chemical equations. *(Obj 4)*

a. $P_4(s)$ + **6**$Cl_2(g)$ → **4**$PCl_3(l)$

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

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

d. **3**$Mn(s)$ + **2**$CrCl_3(aq)$ → **3**$MnCl_2(aq)$ + **2**$Cr(s)$

e. $C_2H_2(g)$ + **5/2**$O_2(g)$ → **2**$CO_2(g)$ + $H_2O(l)$

or **2**$C_2H_2(g)$ + **5**$O_2(g)$ → **4**$CO_2(g)$ + **2**$H_2O(l)$

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

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

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

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

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

✍ **Exercise 5.2 - Predicting Water Solubility:** Predict whether each of the following is soluble or insoluble in water. *(Obj 9)*

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 5.3 - 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 10)*

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

b. **3**$KOH(aq)$ + $Fe(NO_3)_3(aq)$ → **3KNO_3(aq) + $Fe(OH)_3$(s)**

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

d. $K_2SO_4(aq)$ + $Pb(NO_3)_2(aq)$ → **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. 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**

b. O and H **covalent**

c. Fe and O **ionic**

d. N and Cl **covalent**

3. Describe the structure of liquid water, including a description of water molecules and the attractions between them.

   Water is composed of H_2O molecules that are attracted to each other due to the attraction between partially positive hydrogen atoms and the partially negative oxygen atoms of other molecules. See Figure 4.13.

   Each water molecule is moving constantly, breaking the attractions to some molecules, and making new attractions to other molecules. See Figure 4.14.

4. 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**
5. 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**
6. Write formulas that correspond to the following names.
   a. lithium fluoride **LiF**
   b. lead(II) hydroxide **$Pb(OH)_2$**
   c. potassium oxide **K_2O**
   d. sodium carbonate **Na_2CO_3**
   e. chromium(III) chloride **$CrCl_3$**
   f. sodium hydrogen phosphate **Na_2HPO_4**

Key Ideas Answers

7. 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.
9. A chemical equation is a **shorthand description** of a chemical reaction.
11. 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.
13. When balancing chemical equations, we do not change the **subscripts** in the formulas.
15. Every part of a water solution of an ionic compound has the **same proportions** of water molecules and ions as every other part.
17. In solutions of solids dissolved in liquids, we call the solid the **solute** and the liquid the **solvent**.
19. In solutions of two liquids, we call the **minor** component the solute and the **major** component the solvent.

21. Crystals are solid particles whose component atoms, ions, or molecules are arranged in an **organized, repeating** pattern.
23. Because spectator ions are not involved in the reaction, they are often **left out** of the chemical equation.

Problems Key

Section 5.1 Chemical Reactions and Chemical Equations

25. 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.

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

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

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

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

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

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

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

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

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

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

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

i. $\mathbf{3}P_2H_4(l) \rightarrow \mathbf{4}PH_3(g) + \frac{1}{2}P_4(s)$ or $\mathbf{6}P_2H_4(l) \rightarrow \mathbf{8}PH_3(g) + P_4(s)$

29. 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:

$CS_2 + \mathbf{3}Cl_2 \rightarrow S_2Cl_2 + CCl_4$

$\mathbf{4}CS_2 + \mathbf{8}S_2Cl_2 \rightarrow \mathbf{3}S_8 + \mathbf{4}CCl_4$

$S_8 + \mathbf{4}C \rightarrow \mathbf{4}CS_2$

31. Hydrochlorofluorocarbons (HCFCs), which contain hydrogen as well as carbon, fluorine, and chlorine, are less damaging to the ozone layer than the chlorofluorocarbons (CFCs) described in problem 30. HCFCs are therefore used instead of CFCs for many purposes. Balance the following equation that shows how the HCFC chlorodifluoromethane, $CHClF_2$, is made.

$\mathbf{2}HF + CHCl_3 \rightarrow CHClF_2 + \mathbf{2}HCl$

Section 5.2 Solubility of Ionic Compounds and Precipitation Reactions

33. 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 5)*

    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 vibrates 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 5.4 and 5.5 with Li^+ in the place of Na^+ and I^- in the place of Cl^-.)

35. 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 5)*

    Same answer as problem 33 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.

37. Solid camphor and liquid ethanol mix to form a solution. Which of these substances is the solute and which is the solvent? *(Obj 6)*

    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.

40. 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 8)*

    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 5.7 to 5.9 with silver ions in the place of calcium ions and bromide ions in the place of carbonate ions.

42. Predict whether each of the following substances is soluble or insoluble in water. *(Obj 9)*
    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**

44. Predict whether each of the following substances is soluble or insoluble in water. *(Obj 9)*
    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**

46. 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 10)*
    a. $Co(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow \mathbf{CoCO_3(s) + 2NaNO_3(aq)}$
    b. $\mathbf{2}KI(aq) + Pb(C_2H_3O_2)_2(aq) \rightarrow \mathbf{2KC_2H_3O_2(aq) + PbI_2(s)}$
    c. $CuSO_4(aq) + LiNO_3(aq)$ **no reaction**
    d. $\mathbf{3}Ni(NO_3)_2(aq) + \mathbf{2}Na_3PO_4(aq) \rightarrow \mathbf{Ni_3(PO_4)_2(s) + 6NaNO_3(aq)}$
    e. $K_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow \mathbf{2KNO_3(aq) + BaSO_4(s)}$

48. 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.

    $\mathbf{Al^{3+}(aq) + PO_4^{3-}(aq) \rightarrow AlPO_4(s)}$

50. 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.

    $\mathbf{Cd(C_2H_3O_2)_2(aq) + 2NaOH(aq) \rightarrow Cd(OH)_2(s) + 2NaC_2H_3O_2(aq)}$

Additional Problems

52. Balance the following chemical equations.

   a. $SiCl_4$ + **2**H_2O → SiO_2 + **4**HCl

   b. **2**H_3BO_3 → B_2O_3 + **3**H_2O

   c. I_2 + **3**Cl_2 → **2**ICl_3

   d. **2**Al_2O_3 + **3**C → **4**Al + **3**CO_2

54. Balance the following chemical equations.

   a. **4**NH_3 + Cl_2 → N_2H_4 + **2**NH_4Cl

   b. Cu + **2**$AgNO_3$ → $Cu(NO_3)_2$ + **2**Ag

   c. Sb_2S_3 + **6**HNO_3 → **2**$Sb(NO_3)_3$ + **3**H_2S

   d. Al_2O_3 + **3**Cl_2 + **3**C → **2**$AlCl_3$ + **3**CO

56. 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:

   2$Ca_3(PO_4)_2$ + **6**SiO_2 + **10**C → P_4 + **10**CO + **6**$CaSiO_3$

   P_4 + **5**O_2 + **6**H_2O → **4**H_3PO_4

58. Predict whether each of the following substances is soluble or insoluble in water.

   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**

60. 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 10)*

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

   b. $Ni(NO_3)_2(aq)$ + **2**$NaOH(aq)$ → **$Ni(OH)_2(s)$ + 2$NaNO_3(aq)$**

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

   d. $Zn(C_2H_3O_2)_2(aq)$ + $Na_2CO_3(aq)$ → **$ZnCO_3(s)$ + 2$NaC_2H_3O_2(aq)$**

Before working problems 62 through 78, you might want to review the procedures for writing chemical formulas that are described in Chapter 4. Remember that some elements are described with formulas containing subscripts (as in O_2).

62. 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.

   H_2 + Cl_2 → 2HCl

64. 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.

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

66. 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.

    $\mathbf{CaF_2 + H_2SO_4 \rightarrow 2HF + CaSO_4}$

68. 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.

    $\mathbf{Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3}$

71. All of the equations for the Solvay process described in problem 70 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.

    $\mathbf{CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2}$

73. All of the equations for the production of nitric acid described in problem 72 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.

    $\mathbf{NH_3 + 2O_2 \rightarrow HNO_3 + H_2O}$

75. 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.

    $\mathbf{C_3H_8(\mathit{g}) + 6H_2O(\mathit{g}) \rightarrow 3CO_2(\mathit{g}) + 10H_2(\mathit{g})}$

77. 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:

    a. Carbon combines with oxygen to form carbon monoxide.

        $\mathbf{C + ½O_2 \rightarrow CO}$

        or $\mathbf{2C + O_2 \rightarrow 2CO}$

    b. Iron(III) oxide combines with the carbon monoxide to form iron and carbon dioxide.

        $\mathbf{Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2}$

    c. Carbon monoxide changes into carbon (in the molten iron) and carbon dioxide.

        $\mathbf{2CO \rightarrow C + CO_2}$

79. 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 $Al_2(CO_3)_3$.

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

    $$\mathbf{FeCl_3(aq) + 3AgNO_3(aq) \rightarrow Fe(NO_3)_3(aq) + 3AgCl(\mathit{s})}$$

83. 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.

    $$\mathbf{2C_5H_{11}NSO_2(\mathit{s}) + 31/2O_2(\mathit{g}) \rightarrow 10CO_2(\mathit{g}) + 11H_2O(l) + 2SO_2(\mathit{g}) + N_2(\mathit{g})}$$

    or $$\mathbf{4C_{5H11}NSO_2(\mathit{s}) + 31O_2(\mathit{g}) \rightarrow 20CO_2(\mathit{g}) + 22H_2O(l) + 4SO_2(\mathit{g}) + 2N_2(\mathit{g})}$$