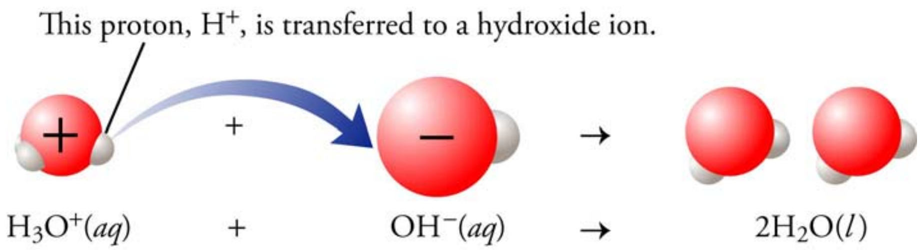
Chapter 8
Acids, Bases, and Acid-Base Reactions



Section Goals and Introductions

Section 8.1 Strong and Weak Acids and Bases

Goals

- *To review some of the information about acids described in Section 6.3.*
- *To describe bases and to make the distinction between strong and weak bases.*
- *To show how you can recognize strong and weak bases.*
- *To show the changes that take place on the particle level when bases dissolve in water.*

This section begins with a review of acids, followed by the following for bases: (1) it states the Arrhenius definition of base, (2) it provides you with the information necessary to identify strong and weak bases, and (3) it describes the changes that take place when one weak base (ammonia) dissolves in water (Figure 8.2). Sample Study Sheet 8.1 summarizes the steps for identification of strong and weak acids and bases. Visit our Web site for more information about strong and weak bases and the identification of strong and weak acids and bases.

Internet: Strong and Weak Bases

Internet: Identification of Strong and Weak Acids and Bases

Section 8.2 pH and Acidic and Basic Solutions

Goal: To explain the pH scale used to describe acidic and basic solutions.

This section provides an introduction to the pH scale used to describe acidic and basic solutions. Figure 8.4 contains the most important information.

Section 8.3 Arrhenius Acid-Base Reactions

Goals

- *To describe acid-base reactions, with an emphasis on developing the ability to visualize the changes that take place on the particle level.*
- *To show how you can predict whether two reactants will react in an acid-base reaction.*
- *To show how to write equations for acid-base reactions.*

This section does for acid-base reactions what Section 7.3 does for precipitation reactions. It might help to consider the similarities and differences between these two types of chemical changes. Be sure that you can visualize the changes that take place at the particle level for both types of chemical reactions. Pay special attention to Figures 8.5, 8.6, and 8.8. Visit our Web site to see an animation showing an acid-base reaction.

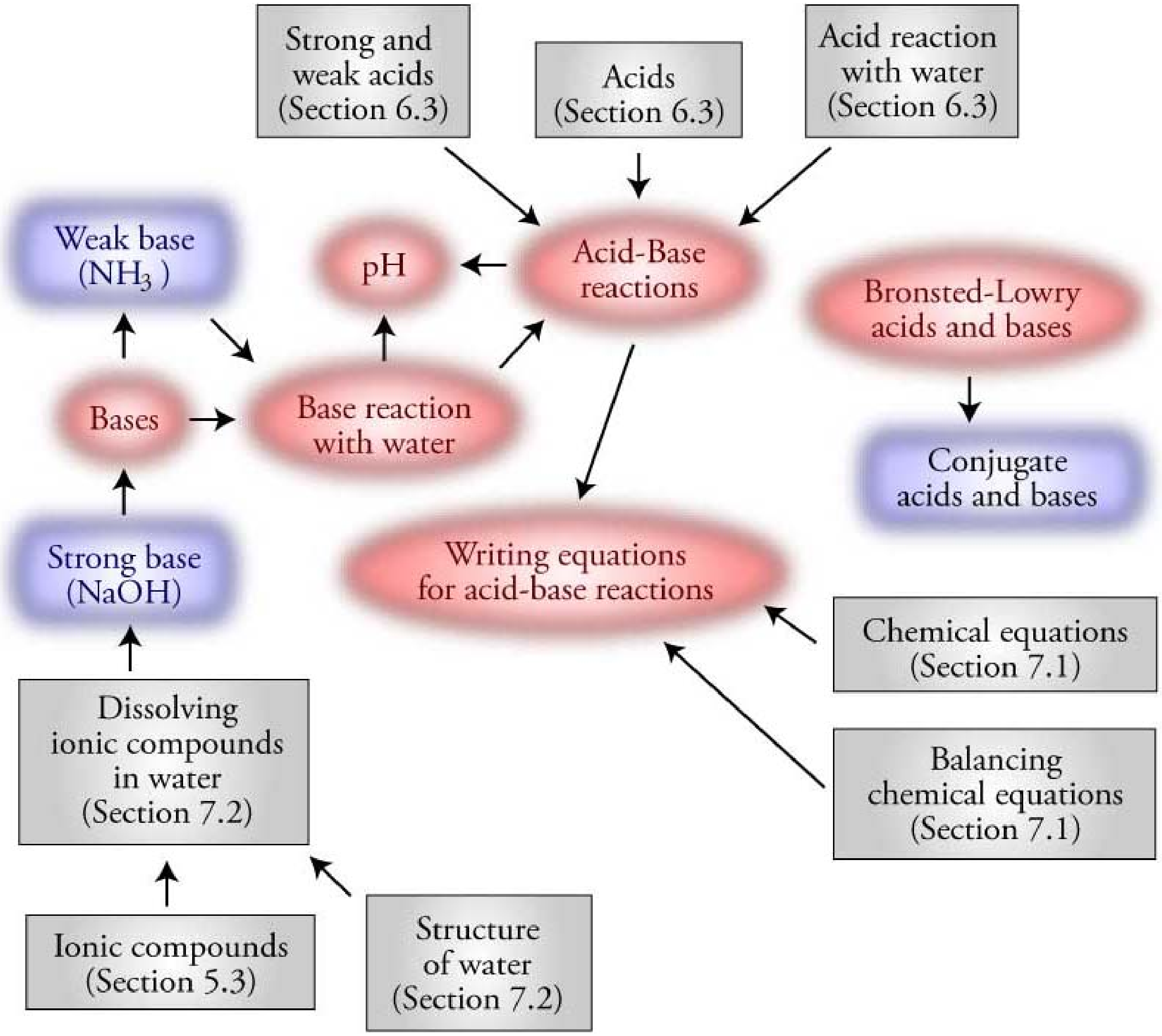
Internet: Acid-Base Reaction Animation

Section 8.4 Brønsted-Lowry Acids and Bases

Goal: To describe a second set of definitions for acid, base, and acid-base reactions, called the Brønsted-Lowry definitions.

Although the Arrhenius definitions of acid, base, and acid-base reactions provided in Sections 8.1 and 8.3 are very important, especially to the beginning chemistry student, chemists have found it useful to extend these definitions to include new substances as acids and bases that would not be classified as such according to the Arrhenius definitions. The new definitions, called the Brønsted-Lowry definitions, are described in this section.

Chapter 8 Map



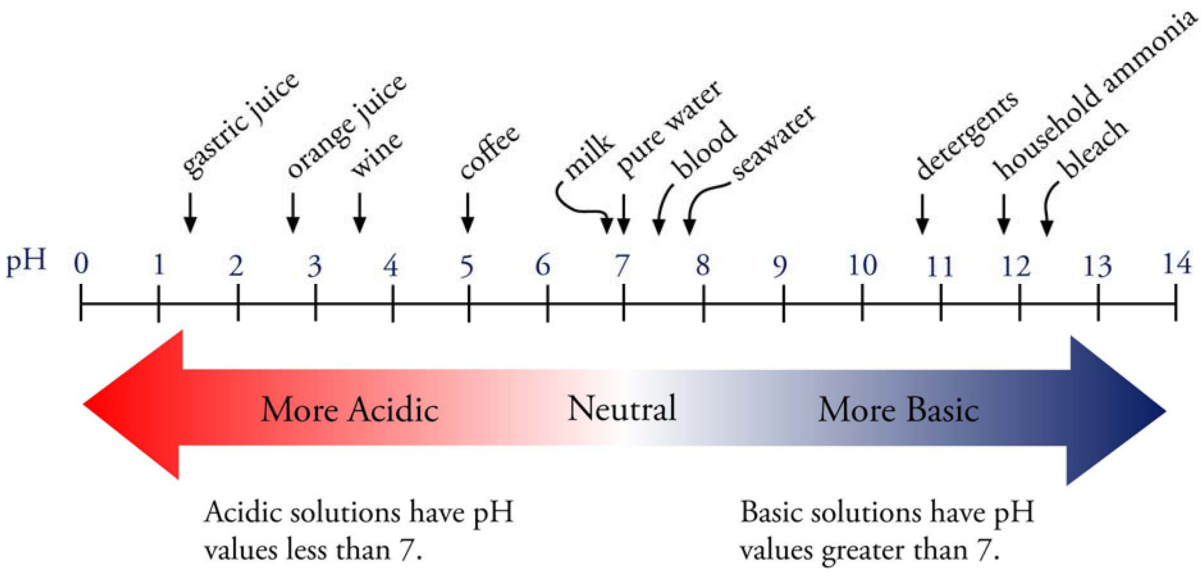
Chapter Checklist

- ☐ 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: 5, 6, 7, 8, 11, and 18.)

- ☐ Reread *Sample Study Sheet 8.1: Identification of Strong and Weak Acids and Bases* and decide whether you will use it or some variation on it to complete the task it describes.
- ☐ Memorize the following. Be sure to check with your instructor to determine how much you are expected to know of the following.
    - The significance of the numbers in the pH scale



- ☐ 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: Strong and Weak Bases
Internet: Identification of
Internet: Strong and Weak Acids and Bases
Internet: Acid-Base Reaction Animation
Internet: Glossary Quiz

Exercises Key

Exercise 8.1 - Identification of Acids and Bases: Identify each of the following as an Arrhenius strong acid, an Arrhenius weak acid, an Arrhenius strong base, or an Arrhenius weak base. *(Obj 5)*

a. HNO_3 **strong acid**

b. lithium hydroxide **strong base**

c. K_2CO_3 **weak base**

d. hydrofluoric acid **weak acid**

Exercise 8.2 - Neutralization Reactions: Write the complete equation for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.) *(Obj 11)*

a. $HCl(aq) + NaOH(aq) \rightarrow$ $\mathbf{H_2O(l) + NaCl(aq)}$

b. $HF(aq) + LiOH(aq) \rightarrow$ $\mathbf{H_2O(l) + LiF(aq)}$

c. $H_3PO_4(aq) + \mathbf{3}LiOH(aq) \rightarrow$ $\mathbf{3H_2O(l) + Li_3PO_4(aq)}$

d. $Fe(OH)_3(s) + \mathbf{3}HNO_3(aq) \rightarrow$ $\mathbf{Fe(NO_3)_3(aq) + 3H_2O(l)}$

Exercise 8.3 - Neutralization Reactions with Compounds Containing Carbonate: Write the complete equation for the neutralization reaction that takes place when water solutions of sodium carbonate, Na_2CO_3, and hydrobromic acid, HBr, are mixed. *(Obj 11)*

$\mathbf{Na_2CO_3(aq) + 2HBr(aq) \rightarrow 2NaBr(aq) + H_2O(l) + CO_2(g)}$

Exercise 8.4 - Conjugate Acids: Write the formula for the conjugate acid of (a) NO_2^-, (b) HCO_3^-, (c) H_2O, and (d) PO_4^{3-}. *(Obj 14)*

a. $\mathbf{HNO_2}$ b. $\mathbf{H_2CO_3}$ c. $\mathbf{H_3O^+}$ d. $\mathbf{HPO_4^{2-}}$

Exercise 8.5 - Conjugate Bases: Write the formula for the conjugate base of (a) $H_2C_2O_4$, (b) $HBrO_4$, (c) NH_3, and (d) $H_2PO_4^-$. *(Obj 15)*

a. $\mathbf{HC_2O_4^-}$ b. $\mathbf{BrO_4^-}$ c. $\mathbf{NH_2^-}$ d. $\mathbf{HPO_4^{2-}}$

Exercise 8.6 - Brønsted-Lowry Acids and Bases: Identify the Brønsted-Lowry acid and base in each of the following equations. *(Obj 18)*

a. $HNO_2(aq) + NaBrO(aq) \rightarrow HBrO(aq) + NaNO_2(aq)$
B/L acid **B/L base**

b. $H_2AsO_4^-(aq) + HNO_2(aq) \rightleftharpoons H_3AsO_4(aq) + NO_2^-(aq)$
B/L base **B/L acid**

c. $H_2AsO_4^-(aq) + 2OH^-(aq) \rightarrow AsO_4^{3-}(aq) + 2H_2O(l)$
B/L acid **B/L base**

Review Questions Key

1. Define the following terms.
   a. aqueous
      Water solutions are called aqueous solutions.
   b. spectator ion
      Ions that are important for delivering other ions into solution to react, but do not actively participate in the reaction themselves are called spectator ions.
   c. double-displacement reaction
      A chemical reaction that has the following form is called a double-displacement reaction.

$$AB + CD \rightarrow AD + CB$$

d. net ionic equation

A net ionic equation is a chemical equation for which the spectator ions have been eliminated, leaving only the substances actively involved in the reaction.

2. Write the name of the polyatomic ions represented by the formulas CO_3^{2-} and HCO_3^-.

a. CO_3^{2-} **carbonate**

b. HCO_3^- **hydrogen carbonate**

3. Write the formulas for the polyatomic ions dihydrogen phosphate ion and acetate ion.

a. dihydrogen phosphate ion $\mathbf{H_2PO_4^-}$

b. acetate ion $\mathbf{C_2H_3O_2^-}$

4. Which of the following formulas represent an ionic compound?

a. $MgCl_2$ **ionic**

b. PCl_3 **not ionic**

c. $KHSO_4$ **ionic**

d. Na_2SO_4 **ionic**

e. H_2SO_3 **not ionic**

5. Write the names that correspond to the formulas KBr, $Cu(NO_3)_2$, and $(NH_4)_2HPO_4$.

f. KBr **potassium bromide**

g. $Cu(NO_3)_2$ **copper(II) nitrate**

h. $(NH_4)_2HPO_4$ **ammonium hydrogen phosphate**

6. Write the formulas that correspond to the names nickel(II) hydroxide, ammonium chloride, and calcium hydrogen carbonate.

a. nickel(II) hydroxide $\mathbf{Ni(OH)_2}$

b. ammonium chloride $\mathbf{NH_4Cl}$

c. calcium hydrogen carbonate $\mathbf{Ca(HCO_3)_2}$

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

a. iron(III) hydroxide **insoluble**

b. barium sulfate **insoluble**

c. aluminum nitrate **soluble**

d. copper(II) chloride **soluble**

8. Describe how the strong monoprotic acid hydrochloric acid, HCl acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

When HCl molecules dissolve in water, each HCl molecule donates a proton, H^+, to water forming a hydronium ion, H_3O^+, and a chloride ion, Cl^-. This reaction goes to completion, and the solution of the HCl contains essentially no uncharged acid molecules. Once the chloride ion and the hydronium ion are formed, the negatively charged oxygen atoms of the water molecules surround the hydronium ion and the positively charged hydrogen atoms of the water molecules surround the chloride ion. Figure 6.2 shows you how you can picture this solution.

9. Describe how the weak monoprotic acid acetic acid, $HC_2H_3O_2$, acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

When an acetic acid molecule, $HC_2H_3O_2$, collides with an H_2O molecule, an H^+ can be transferred to the water to form a hydronium ion, H_3O^+, and an acetate ion, $C_2H_3O_2^-$. The $C_2H_3O_2^-$ ions formed in solution reverse the change by reacting with the hydronium ions and pulling H^+ ions back to reform $HC_2H_3O_2$ and H_2O. The forward and reverse reactions take place constantly, and soon after the addition of $HC_2H_3O_2$ to water, they proceed at an equal rate. There is no net change in the amounts of the $HC_2H_3O_2$, H_2O, $C_2H_3O_2^-$, or H_3O^+ in the solution. See Figure 6.6.

10. Describe the process by which the ionic compound sodium hydroxide dissolves in water.
When solid sodium hydroxide, NaOH, is added to water, all of the sodium ions, Na^+, and hydroxide ions, OH^-, 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 sodium ions, and the positively charged hydrogen ends of water molecules surround the hydroxide ions. (See Figures 7.7 and 7.8 with OH^- in the place of Cl^-.)

11. Write the complete equation for the precipitation reaction that takes place when water solutions of zinc chloride and sodium phosphate are mixed.
$$3ZnCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Zn_3(PO_4)_2(s) + 6NaCl(aq)$$

Key Ideas Answers

12. According to the modern version of the Arrhenius theory of acids and bases, a base is a substance that produces **hydroxide ions, OH^-,** when it is added to water.
14. Compounds that contain hydroxide ions are often called **hydroxides**.
16. A weak base is a base that produces **fewer** hydroxide ions in water solution than there are particles of base dissolved.
18. Basic solutions have pH values **greater than 7**, and the more basic the solution is, the **higher** its pH.
20. When an Arrhenius acid is combined with an Arrhenius base, we say that they **neutralize** each other.
22. Most Arrhenius neutralization reactions, such as the reaction between nitric acid and sodium hydroxide, are **double-displacement** reactions.
24. A Brønsted-Lowry acid is a proton (H^+) **donor**, a Brønsted-Lowry base is a proton **acceptor**, and a Brønsted-Lowry acid-base reaction is a proton **transfer**.
26. The conjugate base of a molecule or ion is the molecule or ion that forms when one H^+ ion is **removed**.
28. The **Brønsted-Lowry** system is often used to describe specific acid-base reactions, but the **Arrhenius** system is used to describe whether isolated substances are acids, bases, or neither.

Problems Key

Section 8.1 Strong and Weak Arrhenius Bases

30. Classify each of the following substances as a weak acid, strong acid, weak base, or strong base in the Arrhenius acid-base sense. (Obj 5)

a.	H_2CO_3	**weak acid**	e.	NH_3	**weak base**
b.	cesium hydroxide	**strong base**	f.	chlorous acid	**weak acid**
c.	HF(*aq*)	**weak acid**	g.	HCl(*aq*)	**strong acid**
d.	sodium carbonate	**weak base**	h.	benzoic acid	**weak acid**

Section 8.2 pH and Acidic and Basic Solutions

32. Classify each of the following solutions as acidic, basic, or neutral. *(Obj 6)*
    a. tomato juice with a pH of 4.53 — pH < 7, so **acidic**
    b. milk of magnesia with a pH of 10.4 — pH > 7, so **basic**
    c. urine with a pH of 6.8 — pH about 7, so **essentially neutral (or more specifically, very slightly acidic)**

34. Which is more acidic, carbonated water with a pH of 3.95 or milk with a pH of 6.3? *(Obj 7)*

    The lower the pH is, the more acidic the solution. **Carbonated water** *is more acidic than milk.*

36. Identify each of the following characteristics as associated with acids or bases.
    a. tastes sour **acid**
    b. turns litmus red **acid**
    c. reacts with HNO_3 **base**

Section 8.3 Arrhenius Acid-Base Reactions

38. Describe the process that takes place between the participants in each of the following neutralization reactions, mentioning the nature of the particles in the solution before and after the reaction. The strong acid hydrochloric acid, HCl(*aq*), and the strong base sodium hydroxide, NaOH(*aq*), form water and sodium chloride, NaCl(*aq*). *(Obj 10A)*

    Because hydrochloric acid, HCl(aq), is an acid, it reacts with water to form hydronium ions, H_3O^+, and chloride ions, Cl^-. Because it is a strong acid, the reaction is a completion reaction, leaving only H_3O^+ and Cl^- in solution with no HCl remaining.

    $$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$
    $$\text{or} \quad HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

    Because NaOH is a water-soluble ionic compound, it separates into sodium ions, Na^+, and hydroxide ions, OH^-, when it dissolves in water. Thus, at the instant that the two solutions are mixed, the solution contains water molecules, hydronium ions, H_3O^+, chloride ions, Cl^-, sodium ions, Na^+, and hydroxide ions, OH^-.

    When the hydronium ions collide with the hydroxide ions, they react to form water. If an equivalent amount of acid and base are added together, the H_3O^+ and the OH^- will be completely reacted.

    $$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$$
    $$\text{or} \quad H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

    The sodium ions and chloride ions remain in solution with the water molecules.

40. Describe the process that takes place between the participants in each of the following neutralization reactions, mentioning the nature of the particles in the solution before and after the reaction. The strong acid nitric acid, $HNO_3(aq)$, and water-insoluble nickel(II) hydroxide, $Ni(OH)_2(s)$, form nickel(II) nitrate, $Ni(NO_3)_2(aq)$, and water. *(Obj 10B)*

A solution with an insoluble ionic compound, such as $Ni(OH)_2$, at the bottom has a constant escape of ions from the solid into the solution balanced by the constant return of ions to the solid due to collisions of ions with the surface of the solid. Thus, even though $Ni(OH)_2$ has very low solubility in water, there are always a few Ni^{2+} and OH^- ions in solution.

If a nitric acid solution is added to water with solid $Ni(OH)_2$ at the bottom, a neutralization reaction takes place. Because the nitric acid is a strong acid, it is ionized in solution, so the nitric acid solution contains hydronium ions, H_3O^+, and nitrate ions, NO_3^-. The hydronium ions will react with the basic hydroxide ions in solution to form water molecules.

Because the hydronium ions remove the hydroxide anions from solution, the return of ions to the solid is stopped. The nickel(II) cations cannot return to the solid unless they are accompanied by anions to balance their charge. The escape of ions from the surface of the solid continues. When hydroxide ions escape, they react with the hydronium ions and do not return to the solid. Thus there is a steady movement of ions into solution, and the solid that contains the basic anion dissolves. The complete equation for this reaction is below.

$$Ni(OH)_2(s) + 2HNO_3(aq) \rightarrow Ni(NO_3)_2(aq) + 2H_2O(l)$$

42. Describe the process that takes place between the participants in each of the following neutralization reactions, mentioning the nature of the particles in the solution before and after the reaction. The strong acid hydrochloric acid, $HCl(aq)$, and the weak base potassium carbonate, $K_2CO_3(aq)$, form water, carbon dioxide, $CO_2(g)$, and potassium chloride, $KCl(aq)$. *(Obj 10C)*

Because hydrochloric acid, HCl(aq), is an acid, it reacts with water to form hydronium ions, H_3O^+, and chloride ions, Cl^-. Because it is a strong acid, the reaction is a completion reaction, leaving only H_3O^+ and Cl^- in an HCl(aq) solution with no HCl remaining.

$$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

$$\text{or} \quad HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

Because K_2CO_3 is a water-soluble ionic compound, it separates into potassium ions, K^+, and carbonate ions, CO_3^{2-}, when it dissolves in water. The carbonate ions are weakly basic, so they react with water in a reversible reaction to form hydrogen carbonate, HCO_3^- and hydroxide, OH^-.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + OH^-(aq)$$

Thus, at the instant that the two solutions are mixed, the solution contains water molecules, hydronium ions, H_3O^+, chloride ions, Cl^-, potassium ions, K^+, carbonate ions, CO_3^{2-}, hydrogen carbonate ions, HCO_3^-, and hydroxide ions, OH^-.

The hydronium ions react with hydroxide ions, carbonate ions, and hydrogen carbonate ions. When the hydronium ions collide with the hydroxide ions, they react to form water. When the hydronium ions collide with the carbonate ions or hydrogen carbonate ions, they react to form carbonic acid, H_2CO_3. The carbonate with its minus two charge *requires two H^+ ions to yield a neutral compound, and the hydrogen carbonate requires one H^+ to neutralize its minus one charge.*

$$2H_3O^+(aq) + CO_3^{2-}(aq) \rightarrow H_2CO_3(aq) + 2H_2O(l)$$

or $$2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2CO_3(aq)$$

$$H_3O^+(aq) + HCO_3^-(aq) \rightarrow H_2CO_3(aq) + H_2O(l)$$

or $$H^+(aq) + HCO_3^-(aq) \rightarrow H_2CO_3(aq)$$

The carbonic acid is unstable in water and decomposes to form carbon dioxide gas and water.

$$H_2CO_3(aq) \rightarrow CO_2(g) + H_2O(l)$$

If an equivalent amount of acid and base are added together, the H_3O^+, OH^-, CO_3^{2-}, and HCO_3^-, will be completely reacted.

The potassium ions and chloride ions remain in solution with the water molecules.

44. Write the complete equation for the neutralization reactions that take place when the following water solutions are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.) *(Obj 11)*

a. $HCl(aq) + LiOH(aq) \rightarrow$ **$H_2O(l) + LiCl(aq)$**

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

c. $KOH(aq) + HF(aq) \rightarrow$ **$KF(aq) + H_2O(l)$**

d. $Cd(OH)_2(s)$ + **2**$HCl(aq) \rightarrow$ **$CdCl_2(aq) + 2H_2O(l)$**

46. Write the complete equation for the reaction between $HI(aq)$ and water-insoluble solid $CaCO_3$. *(Objs 11 & 12)*

$2HI(aq) + CaCO_3(s) \rightarrow H_2O(l) + CO_2(g) + CaI_2(aq)$

48. Iron(III) sulfate is made in industry by the neutralization reaction between solid iron(III) hydroxide and aqueous sulfuric acid. The iron(III) sulfate is then added with sodium hydroxide to municipal water in water treatment plants. These compounds react to form a precipitate that settles to the bottom of the holding tank, taking impurities with it. Write the complete equations for both the neutralization reaction that forms iron(III) sulfate and the precipitation reaction between water solutions of iron(III) sulfate and sodium hydroxide. *(Obj 11)*

$2Fe(OH)_3(s) + 3H_2SO_4(aq) \rightarrow Fe_2(SO_4)_3(aq) + 6H_2O(l)$

$Fe_2(SO_4)_3(aq) + 6NaOH(aq) \rightarrow 2Fe(OH)_3(s) + 3Na_2SO_4(aq)$

50. Complete the following equations by writing the formulas for the acid and base that could form the given products.

a. **$HCl(aq)$** + **$NaOH(aq)$** $\rightarrow H_2O(l) + NaCl(aq)$

b. **$H_2SO_4(aq)$** + **$2LiOH(aq)$** $\rightarrow 2H_2O(l) + Li_2SO_4(aq)$

c. **$2HCl(aq)$** + **$K_2CO_3(aq)$** $\rightarrow H_2O(l) + CO_2(g) + 2KCl(aq)$

Section 8.4 Brønsted-Lowry Acids and Bases

53. Write the formula for the conjugate acid of each of the following. *(Obj 14)*

a. IO_3^- **HIO_3** b. HSO_3^- **H_2SO_3** c. PO_3^{3-} **HPO_3^{2-}** d. H^- **H_2**

55. Write the formula for the conjugate base of each of the following. *(Obj 15)*

a. $HClO_4$ **ClO_4^-** b. HSO_3^- **SO_3^{2-}** c. H_3O^+ **H_2O** d. H_3PO_2 **$H_2PO_2^-$**

57. Explain why a substance can be a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in a different reaction. Give an example to illustrate your explanation. *(Obj 16)*

The same substance can donate an H^+ in one reaction (and act as a Brønsted-Lowry acid) and accept an H^+ in another reaction (and act as a Brønsted-Lowry base). For example, consider the following net ionic equations for the reaction of dihydrogen phosphate ion.

$H_2PO_4^-(aq) + HCl(aq) \rightarrow H_3PO_4(aq) + Cl^-(aq)$
B/L base **B/L acid**

$H_2PO_4^-(aq) + 2\,OH^-(aq) \rightarrow PO_4^{3-}(aq) + 2H_2O(l)$
B/L acid **B/L base**

59. For each of the following equations, identify the Brønsted-Lowry acid and base for the forward reaction. *(Obj 18)*

a. $NaCN(aq) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + HCN(aq)$
B/L base **B/L acid**

b. $H_2PO_3^-(aq) + HF(aq) \rightleftharpoons H_3PO_3(aq) + F^-(aq)$
B/L base **B/L acid**

c. $H_2PO_3^-(aq) + 2OH^-(aq) \rightarrow PO_3^{3-}(aq) + 2H_2O(l)$
B/L acid **B/L base**

d. $3NaOH(aq) + H_3PO_3(aq) \rightarrow 3H_2O(g) + Na_3PO_3(aq)$
B/L base **B/L acid**

61. Butanoic acid, $CH_3CH_2CH_2CO_2H$, is a monoprotic weak acid that is responsible for the smell of rancid butter. Write the formula for the conjugate base of this acid. Write the equation for the reaction between this acid and water, and indicate the Brønsted-Lowry acid and base for the forward reaction. (The acidic hydrogen atom is on the right side of the formula.)

Conjugate base - $CH_3CH_2CH_2CO_2^-$

$CH_3CH_2CH_2CO_2H(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3CH_2CH_2CO_2^-(aq)$
B/L acid **B/L base**

63. Identify the amphoteric substance in each of the following equations.

$HCl(aq) + HS^-(aq) \rightarrow Cl^-(aq) + H_2S(aq)$

$HS^-(aq) + OH^-(aq) \rightarrow S^{2-}(aq) + H_2O(l)$

$HS^-(aq)$

Additional Problems

65. For each of the following pairs of compounds, write the complete equation for the neutralization reaction that takes place when the substances are mixed. (You can assume that there is enough base to remove all of the acidic hydrogen atoms, that there is enough acid to neutralize all of the basic hydroxide ions, and that each reaction goes to completion.) *(Objs 11 & 12)*
   a. $HBr(aq) + NaOH(aq) \rightarrow$ **$H_2O(l) + NaBr(aq)$**
   b. $H_2SO_3(aq)$ + **2**$LiOH(aq) \rightarrow$ **$2H_2O(l) + Li_2SO_3(aq)$**
   c. $KHCO_3(aq) + HF(aq) \rightarrow$ **$KF(aq) + H_2O(l) + CO_2(g)$**
   d. $Al(OH)_3(s)$ + **3**$HNO_3(aq) \rightarrow$ **$Al(NO_3)_3(aq) + 3H_2O(l)$**
67. Classify each of the following substances as acidic, basic, or neutral. *(Obj 6)*
   a. An apple with a pH of 2.9 **acidic**
   b. Milk of Magnesia with a pH of 10.4 **basic**
   c. Fresh egg white with a pH of 7.6 **very slightly basic (essentially neutral)**
69. The pH of processed cheese is kept at about 5.7 to prevent it from spoiling. Is this acidic, basic, or neutral? *(Obj 6)*

   acidic
71. The walls of limestone caverns are composed of solid calcium carbonate. The ground water that makes its way down from the surface into these caverns is often acidic. The calcium carbonate and the H^+ ions from the acidic water react to dissolve the limestone. If this happens to the ceiling of the cavern, the ceiling can collapse, leading to what is called a sinkhole. Write the net ionic equation for the reaction between the solid calcium carbonate and the aqueous H^+ ions.

   $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$
72. Magnesium sulfate, a substance used for fireproofing and paper sizing, is made in industry from the reaction of aqueous sulfuric acid and solid magnesium hydroxide. Write the complete equation for this reaction.

   $H_2SO_4(aq) + Mg(OH)_2(s) \rightarrow 2H_2O(l) + MgSO_4(aq)$
74. The smell of Swiss cheese is, in part, due to the monoprotic weak acid propanoic acid, $CH_3CH_2CO_2H$. Write the equation for the complete reaction between this acid and sodium hydroxide. (The acidic hydrogen atom is on the right.)

   $CH_3CH_2CO_2H(aq) + NaOH(aq) \rightarrow NaCH_3CH_2CO_2(aq) + H_2O(l)$
76. Malic acid, $HO_2CCH_2CH(OH)CO_2H$, is a diprotic weak acid found in apples and watermelon. Write the equation for the complete reaction between this acid and sodium hydroxide. (The acidic hydrogen atoms are on each end of the formula.)

   $HO_2CCH_2CH(OH)CO_2H(aq) + 2NaOH(aq)$

   $\rightarrow Na_2O_2CCH_2CH(OH)CO_2(aq) + 2H_2O(l)$
78. For the following equation, identify the Brønsted-Lowry acid and base for the forward reaction, and write the formulas for the conjugate acid-base pairs.

   $NaHS(aq) + NaHSO_4(aq) \rightarrow H_2S(g) + Na_2SO_4(aq)$

   B/L base B/L acid

   Conjugate acid-base pairs: **HS^-/H_2S and HSO_4^-/SO_4^{2-}**

   or **$NaHS/H_2S$ and $NaHSO_4/Na_2SO_4$**