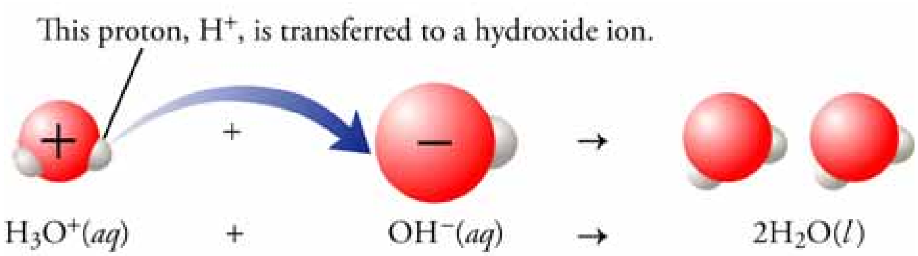
Chapter 6
Acids, Bases, and Acid-Base Reactions



Section Goals and Introductions

Section 6.1 Acids

Goals

- *To describe acids*
- *To make the distinction between strong and weak acids.*
- *To show the changes that take place on the particle level when acids dissolve in water.*
- *To show how you can recognize strong and weak acids.*

This section introduces one way to define acids, called the Arrhenius definition. The most important skills to develop in this section are (1) to be able to recognize acids from names or formulas and (2) to be able to describe the changes that take place at the particle level when strong and weak acids dissolve in water. Be sure to give special attention to Figures 6.1, 6.5, and 6.6. Visit our Web site to view an animation that illustrates the differences between strong and weak acids:

Internet: Acid Animation

Section 6.2 Acid Nomenclature

- *Goal: To describe how to convert between names and chemical formulas for acids.*

This section adds acids to the list of compounds for which you should be able to convert between names and formulas.

Section 6.3 Summary of Chemical Nomenclature

- *Goal: To review the process for converting between names and formulas for binary covalent compounds, binary ionic compounds, ionic compounds with polyatomic ions, binary acids, and oxyacids.*

Although chemical nomenclature may not be your favorite topic, it is an important one. The ability to convert among names and formulas for chemical compounds is crucial to communication between chemists and chemistry students. This section collects the nomenclature guidelines from Chapters 4 and 6 and gives you a chance to review them. Table 6.6 provides your most concise summary of these guidelines. Our Web site provides a tutorials that allows you to practice identifying types of substances and converting between names and formulas for chemical compounds:

Internet: Types of Substances

Internet: Chemical Nomenclature

Section 6.4 Strong and Weak Arrhenius Bases

Goals

- *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 does for bases what Section 6.1 does for acids: (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 6.8). *Sample Study Sheet 6.1* 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 6.5 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 6.10 contains the most important information.

Section 6.6 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 5.2 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 6.12, 6.13, and 6.15. Visit our Web site to see an animation showing an acid-base reaction.

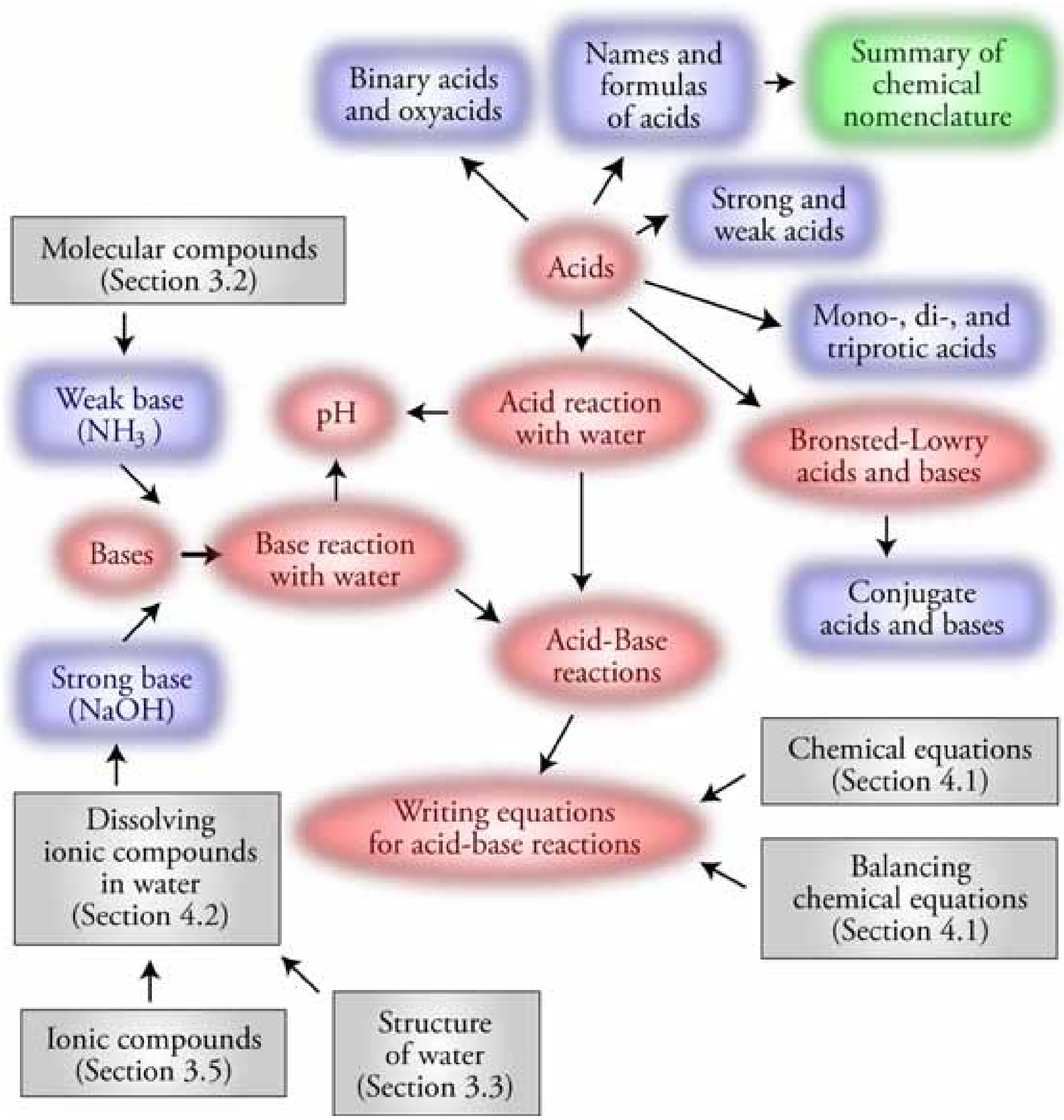
Internet: Acid-Base Reaction Animation

Section 6.7 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 6.1, 6.4, and 6.6 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 6 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: 13, 14, 18-21, and 24.)

☐ Reread *Sample Study Sheet 6.1: 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.

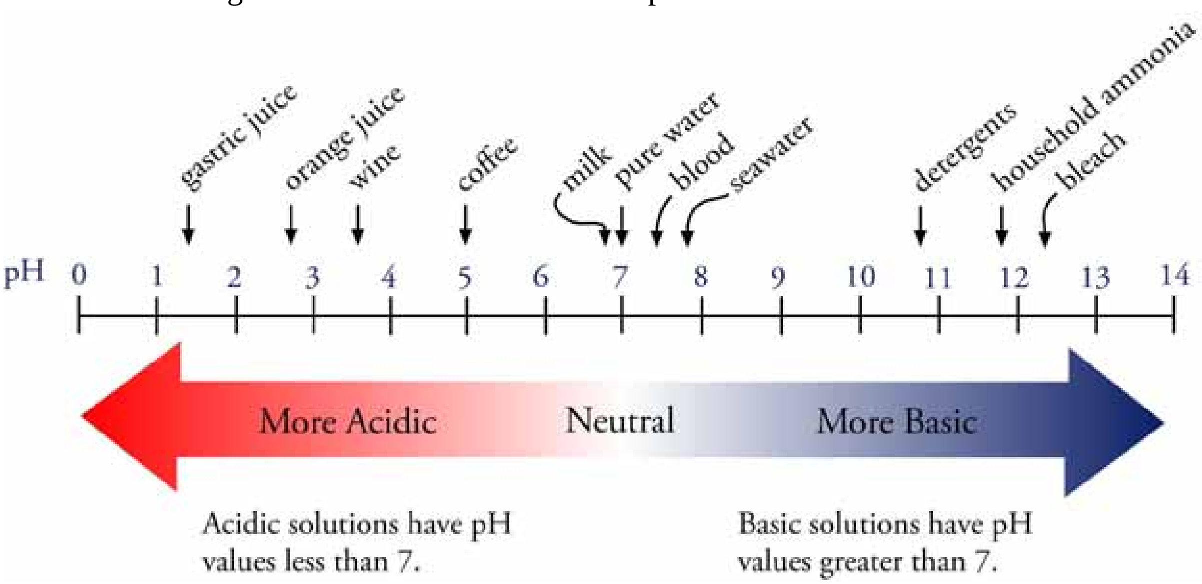
☐ Memorize the following. Be sure to check with your instructor to determine how much you are expected to know of the following.

- Guidelines for writing names and formulas for compounds

Type of compound	General formula	Examples	General name	Examples
Binary covalent Section 4.4	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic Section 4.5	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide or (name of metal)(Roman) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s) Section 4.5	M_aX_b or $(NH_4)_aX_b$ X = recognized formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) or (name of metal)(Roman) (name of polyatomic ion) or ammonium (root of nonmetal)ide or ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid Section 6.2	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid Section 6.2	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

Notes: M = symbol of metal
A and B = symbols of nonmetals
X = some element other than H or O
a, b, & c indicate subscripts

- 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: Acid Animation
Internet: Types of Substances
Internet: Chemical Nomenclature
Internet: Strong and Weak Bases
Internet: Identification of Strong and Weak Acids and Bases
Internet: Acid-Base Reaction
Internet: Glossary Quiz

Exercises Key

✍ **Exercise 6.1 - Formulas for Acids:** Write the chemical formulas that correspond to the names *(Obj 12)*

(a) hydrofluoric acid

This name has the form of a binary acid, hydro(root)ic acid, so its formula is **HF(aq)**.

(b) phosphoric acid

This name has the form of an oxyacid, (root)ic acid, so it contains hydrogen, phosphorus, and oxygen. Phosphate is PO_4^{3-}, so phosphoric acid is $\mathbf{H_3PO_4}$.

✍ **Exercise 6.2 - Naming Acids:** Write the names that correspond to the chemical formulas *(Obj 12)*

(a) HI(*aq*)

This is a binary acid, so its name has the form hydro(root)ic acid. HI(*aq*) is **hydriodic acid**. (The “o” in hydro- is usually left off.)

(b) $HC_2H_3O_2$.

The name of the oxyanion $C_2H_3O_2^-$ is acetate, so $HC_2H_3O_2$ is **acetic acid**. CH_3CO_2H and CH_3COOH are also commonly used as formulas for acetic acid.

✍ **Exercise 6.3 - Formulas to Names:** Write the names that correspond to the following chemical formulas. *(Obj 14)*

a. AlF_3 **aluminum fluoride**
b. PF_3 **phosphorus trifluoride**
c. H_3PO_4 **phosphoric acid**
d. $CaCO_3$ **calcium carbonate**
e. $Ca(HSO_4)_2$ **calcium hydrogen sulfate**
f. $CuCl_2$ **copper(II) chloride**
g. NH_4F **ammonium fluoride**
h. HCl(*aq*) **hydrochloric acid**
i. $(NH_4)_3PO_4$ **ammonium phosphate**

Exercise 6.4 - Names to Formulas: Write the chemical formulas that correspond to the following names. *(Obj 14)*

a. ammonium nitrate **NH_4NO_3**
b. acetic acid **$HC_2H_3O_2$**
c. sodium hydrogen sulfate **$NaHSO_4$**
d. potassium bromide **KBr**
e. magnesium hydrogen phosphate **$MgHPO_4$**
f. hydrofluoric acid **HF(aq)**
g. diphosphorus tetroxide **P_2O_4**
h. aluminum carbonate **$Al_2(CO_3)_3$**
i. sulfuric acid **H_2SO_4**

Exercise 6.5 - 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 18)*

a. HNO_3 **strong acid**
b. lithium hydroxide **strong base**
c. K_2CO_3 **weak base**
d. hydrofluoric acid **weak acid**

Exercise 6.6 - 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 24)*

a. $HCl(aq) + NaOH(aq) \rightarrow$ **$H_2O(l) + NaCl(aq)$**
b. $HF(aq) + LiOH(aq) \rightarrow$ **$H_2O(l) + LiF(aq)$**
c. $H_3PO_4(aq) +$ **3**$LiOH(aq) \rightarrow$ **$3H_2O(l) + Li_3PO_4(aq)$**
d. $Fe(OH)_3(s) +$ **3**$HNO_3(aq) \rightarrow$ **$Fe(NO_3)_3(aq) + 3H_2O(l)$**

Exercise 6.7 - 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 24)*

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

Exercise 6.8 - 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 27)*

a. **HNO_2** b. **H_2CO_3** c. **H_3O^+** d. **HPO_4^{2-}**

Exercise 6.9 - 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 28)*

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

✍ **Exercise 6.10 - Brønsted-Lowry Acids and Bases:** Identify the Brønsted-Lowry acid and base in each of the following equations. *(Obj 31)*

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

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

c. $H_2AsO_4^-(aq)$ + $2OH^-(aq)$ → $AsO_4^{3-}(aq)$ + $2H_2O(l)$
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 represents an ionic compound?
   a. $MgCl_2$ **ionic**
   b. PCl_3 **not ionic**
   c. $KHSO_4$ **ionic**
   d. Na_2SO_4 **ionic**
   e. H_2SO_4 **not ionic**
5. Write the names that correspond to the formulas KBr, $Cu(NO_3)_2$, and $(NH_4)_2HPO_4$.
   a. KBr **potassium bromide**
   b. $Cu(NO_3)_2$ **copper(II) nitrate**
   c. $(NH_4)_2HPO_4$ **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 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 5.4 and 5.5 with OH^- in the place of Cl^-.)
9. Write the complete equation for the precipitation reaction that takes place when water solutions of zinc chloride and sodium phosphate are mixed.

   $$\mathbf{3ZnCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Zn_3(PO_4)_2(s) + 6NaCl(aq)}$$

Key Ideas Answers

10. Any substance that has a **sour** taste is an acid.
12. On the basis of the Arrhenius definitions, an **acidic** solution is a solution with a significant concentration of H_3O^+.
14. Oxyacids (often called oxoacids) are molecular substances that have the general formula $\mathbf{H_aX_bO_c}$.
16. Strong acids form **nearly one** H_3O^+ ion in solution for each acid molecule dissolved in water, whereas weak acids yield **significantly less than one** H_3O^+ ion in solution for each acid molecule dissolved in water.
18. A **weak** acid is a substance that is incompletely ionized in water because of the reversibility of its reaction with water that forms hydronium ion, H_3O^+.
20. Binary acids are named by writing **hydro** followed by the root of the name of the halogen, then **–ic**, and finally **acid**.
22. 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.
24. Compounds that contain hydroxide ions are often called **hydroxides**.
26. A weak base is a base that produces **fewer** hydroxide ions in water solution than there are particles of base dissolved.
28. Basic solutions have pH values **greater than 7**, and the more basic the solution is, the **higher** its pH.
30. When an Arrhenius acid is combined with an Arrhenius base, we say that they **neutralize** each other.

32. Most Arrhenius neutralization reactions, such as the reaction between nitric acid and sodium hydroxide, are **double-displacement** reactions.
34. 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**.
36. The conjugate base of a molecule or ion is the molecule or ion that forms when one H^+ ion is **removed**.
38. 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 6.1 Acids

39. Describe how the strong monoprotic acid nitric acid, $HNO_3(aq)$ (used in the reprocessing of spent nuclear fuels) 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. ***(Obj 3)***

    When HNO_3 molecules dissolve in water, each HNO_3 molecule donates a proton, H^+, to water forming hydronium ion, H_3O^+, and nitrate ion, NO_3^-. This reaction goes to completion, and the solution of the HNO_3 contains essentially no uncharged acid molecules. Once the nitrate 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 nitrate ion. Figure 6.12 shows you how you can picture this solution.

41. Describe how the strong diprotic acid sulfuric acid, H_2SO_4 (used to make industrial explosives) 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. ***(Obj 10)***

    Each sulfuric acid molecule loses its first hydrogen ion completely.

    $$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

    The second hydrogen ion is not lost completely.

    $$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$$

    In a typical solution of sulfuric acid, for each 100 sulfuric acid molecules added to water, the solution contains about 101 hydronium ions, H_3O^+, 99 hydrogen sulfate ions, HSO_4^-, and 1 sulfate ion, SO_4^{2-}.

43. Explain why weak acids produce fewer H_3O^+ ions in water than strong acids, even when the same number of acid molecules are added to equal volumes of water. ***(Obj 7)***

    A weak acid is a substance that is incompletely ionized in water due to a reversible reaction with water that forms hydronium ion, H_3O^+. A strong acid is a substance that is completely ionized in water due to a completion reaction with water that forms hydronium ions, H_3O^+.

45. Identify each of the following as a strong or a weak acid. *(Obj 11)*
   a. sulfurous acid (for bleaching straw) **weak**
   b. H_2SO_4 (used to make plastics) **strong**
   c. oxalic acid (in car radiator cleaners) **weak**
47. Identify each of the following as a strong or a weak acid. *(Obj 11)*
   a. H_3PO_4 (added to animal feeds) **weak**
   b. hypophosphorous acid (in electroplating baths) **weak**
   c. HF(*aq*) (used to process uranium) **weak**
49. For each of the following, write the chemical equation for its reaction with water.
   a. The monoprotic weak acid nitrous acid, HNO_2

$$HNO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq)$$

   b. The monoprotic strong acid hydrobromic acid, HBr

$$HBr(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Br^-(aq)$$

Section 6.2 and 6.3 Acid Nomenclature and Summary of Chemical Nomenclature

51. Write the formulas and names of the acids that are derived from adding enough H^+ ions to the following ions to neutralize their charge.
   a. NO_3^- **HNO_3 nitric acid**
   b. CO_3^{2-} **H_2CO_3 carbonic acid**
   c. PO_4^{3-} **H_3PO_4 phosphoric acid**
53. Classify each of the following compounds as (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the chemical formula that corresponds to each name. *(Objs 12-14)*
   a. phosphoric acid **oxyacid H_3PO_4**
   b. ammonium bromide **ionic compound with polyatomic ion NH_4Br**
   c. diphosphorus tetriodide **binary covalent compound P_2I_4**
   d. lithium hydrogen sulfate **ionic compound with polyatomic ion $LiHSO_4$**
   e. hydrochloric acid **binary acid HCl(aq)**
   f. magnesium nitride **binary ionic compound Mg_3N_2**
   g. acetic acid **oxyacid $HC_2H_3O_2$**
   h. lead(II) hydrogen phosphate **ionic compound with polyatomic ion $PbHPO_4$**
55. Classify each of the following formulas as (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the name that corresponds to each formula. *(Objs 12-14)*
   a. HBr(*aq*) **binary acid hydrobromic acid**
   b. ClF_3 **binary covalent compound chlorine trifluoride**
   c. $CaBr_2$ **binary ionic compound calcium bromide**
   d. $Fe_2(SO_4)_3$ **ionic compound with polyatomic ion iron(III) sulfate**
   e. H_2CO_3 **oxyacid carbonic acid**
   f. $(NH_4)_2SO_4$ **ionic compound with polyatomic ion ammonium sulfate**
   g. $KHSO_4$ **ionic compound with polyatomic ion potassium hydrogen sulfate**

Section 6.4 Strong and Weak Arrhenius Bases

58. Classify each of the following substances as a weak acid, strong acid, weak base, or strong base in the Arrhenius acid-base sense. *(Obj 18)*

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

Section 6.5 pH and Acidic and Basic Solutions

60. Classify each of the following solutions as acidic, basic, or neutral. *(Obj 19)*

   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)**

62. Which is more acidic, carbonated water with a pH of 3.95 or milk with a pH of 6.3? *(Obj 20)*

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

64. Identify each of the following characteristics as associated with acids or bases. *(Objs 2 & 22)*

   a. tastes sour **acid**
   b. turns litmus red **acid**
   c. reacts with HNO_3 **base**

Section 6.6 Arrhenius Acid-Base Reactions

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. *(Obj 23)*

66. The strong acid hydrochloric acid, HCl(*aq*), and the strong base sodium hydroxide, NaOH(*aq*), form water and sodium chloride, NaCl(*aq*).

   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.

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$$

or $$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

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

68. 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.

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.

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

70. 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, $KCl(aq)$.

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.

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

or $$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

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.

72. 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 24)*

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**$HCl(aq) \rightarrow$ **$CdCl_2(aq) + 2H_2O(l)$**

74. Write the complete equation for the reaction between $HI(aq)$ and water-insoluble solid $CaCO_3$. *(Objs 24 & 25)*

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

76. 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 24)*

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

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

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

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

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

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

Section 6.7 Brønsted-Lowry Acids and Bases

81. Write the formula for the conjugate acid of each of the following. *(Obj 27)*

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

83. Write the formula for the conjugate base of each of the following. *(Obj 28)*

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

85. 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 29)*

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.

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

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

87. For each of the following equations, identify the Brønsted-Lowry acid and base for the forward reaction. *(Obj 31)*

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

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

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

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

89. 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 - $CH_3CH_2CH_2CO_2^-$

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

91. 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

93. 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.)

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**$HNO_3(aq) \rightarrow$ **$Al(NO_3)_3(aq) + 3H_2O(l)$**

95. Classify each of the following substances as acidic, basic, or neutral.

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)**

97. The pH of processed cheese is kept at about 5.7 to prevent it from spoiling. Is this acidic, basic, or neutral?

acidic

99. 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.

$CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$

100. 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.

$H_2SO_4(aq) + Mg(OH)_2(s) \rightarrow 2H_2O(l) + MgSO_4(aq)$

102. 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.)

$CH_3CH_2CO_2H(aq) + NaOH(aq) \rightarrow NaCH_3CH_2CO_2(aq) + H_2O(l)$

104. 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.)

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

$\rightarrow Na_2O_2CCH_2CH(OH)CO_2(aq) + 2H_2O(l)$

106. 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 $NaHSO_4^-/Na_2SO_4$**