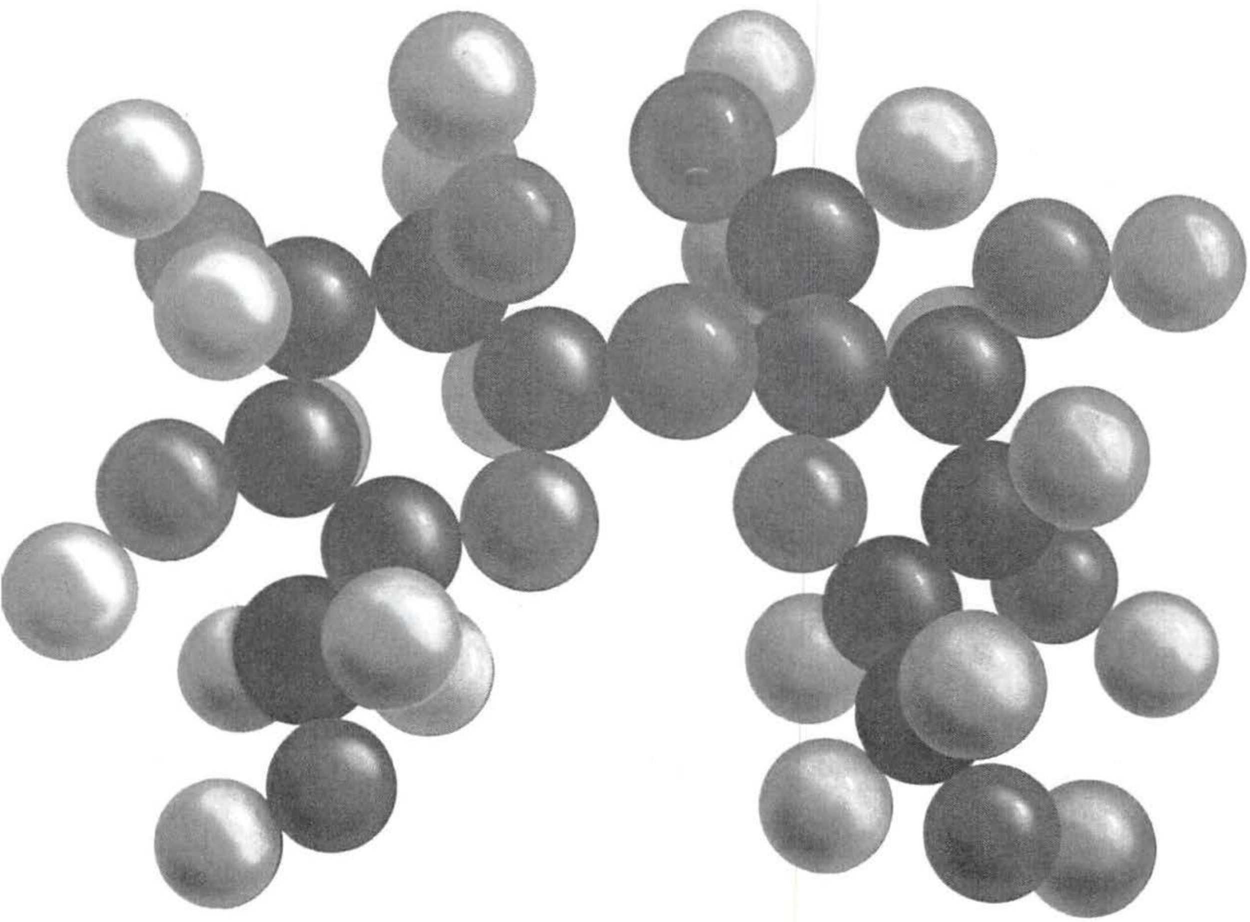
General,
Organic,
Biological

Introductory Chemistry



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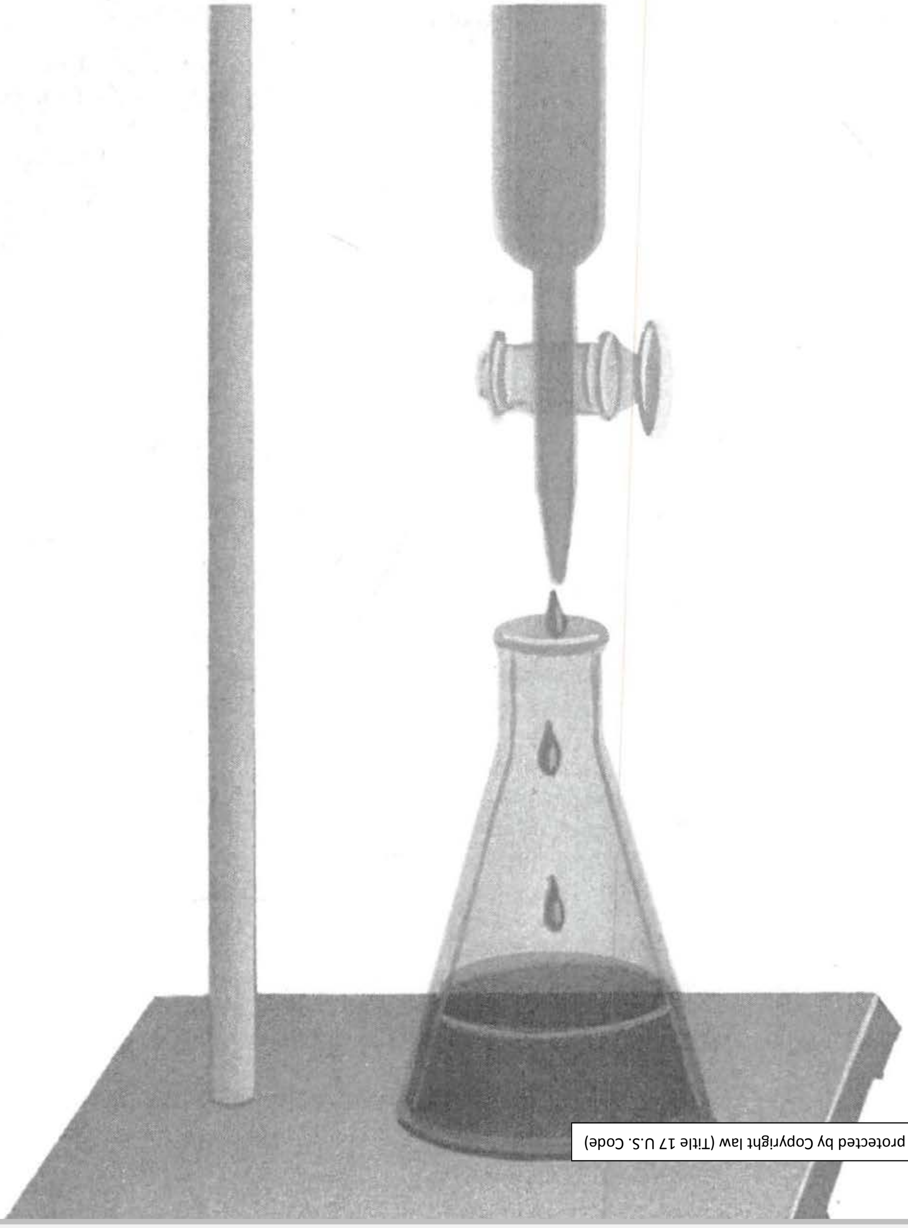
9 Acids, Bases, and Salts



OBJECTIVES

1. Show that you understand all key terms given in the margins and defined in the text.
2. Write equations that illustrate Brønsted acid and base behavior.
3. Write equations that illustrate the general characteristics of acids and bases.
4. Write equations that illustrate various ways to prepare salts.
5. Do calculations involving the pH and pOH concepts.
6. Write equations representing the stepwise dissociation of di- and triprotic acids.
7. Solve problems related to the analysis of acids and bases by titration.
8. Explain and write equations that illustrate the hydrolysis of salts.
9. Explain and write equations that illustrate the action of buffers.

Acids, bases, and salts are among the most common and important solutes found in solutions. Until late in the nineteenth century, these substances were characterized by such properties as taste or color changes induced in certain dyes. Acids taste sour; bases, bitter; and salts, salty. Litmus, a dye, is red in the presence of acids and blue in the presence of bases. These and other observations led to the correct conclusions that acids and bases are chemical opposites and that salts result when acids and bases react with each other.

Today we define acids and bases in more precise ways, which we will also use to study their characteristics.

9.1 THE ARRHENIUS THEORY

In 1887, Swedish chemist Svante Arrhenius proposed a theory dealing with electrolytic dissociation.

Arrhenius acid; Arrhenius base

Acids are substances that dissociate when dissolved in water and produce hydrogen ions, H^+. Similarly, bases are substances that dissociate and produce hydroxide ions, OH^-.

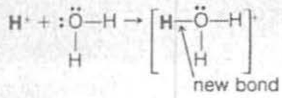
Hydrogen chloride, HCl, and sodium hydroxide, NaOH, are examples of an Arrhenius acid and base. They ionize in water as follows:

$$HCl \rightarrow H^+ + Cl^- \quad 9.1$$

$$NaOH \rightarrow Na^+ + OH^- \quad 9.2$$

Note that the hydrogen ion is a bare proton—the nucleus of a hydrogen atom.

9.2 THE BRØNSTED THEORY



9.3

Or more simply, $$H^+ + H_2O \rightarrow H_3O^+ \qquad 9.4$$

coordinate covalent (dative) bond

Covalent bonds in which both electrons are furnished by a single atom or molecule (by water in hydronium ions) are called coordinate covalent or dative bonds.

Johannes Brønsted in Denmark (and Thomas Lowry in England) proposed an acid-base theory in 1923 that took into account this behavior of hydrogen ions.

Brønsted acid; Brønsted base

An acid is any hydrogen containing substance that is capable of donating a proton (hydrogen ion) to another substance. A base is a substance capable of accepting a proton.

In conformity with this theory, the acidic behavior of HCl in water is written:

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^- \qquad 9.5$$

The HCl behaves as a Brønsted acid by donating a proton to a water molecule. The water molecule, by accepting the proton, behaves as a base.

The double arrow in Equation 9.5 indicates that the reaction is reversible, with the equilibrium lying far to the right. In actual water solutions approximately 92 percent of the dissolved HCl is in the ionic form at equilibrium. Remember from Section 8.6 that both the forward and reverse reactions are taking place in reactions at equilibrium. This means hydronium ions can donate protons to chloride ions and form HCl and H_2O molecules. Thus, H_3O^+ behaves as a Brønsted acid, and Cl^- as a Brønsted base.

Example 9.1. Identify all Brønsted acids and bases in the following reactions.

a) $HNO_3 + H_2O \rightleftharpoons H_3O^+ + NO_3^-$
b) $H_2SO_4 + 2H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$
c) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

Solution. a) The nitric acid, HNO_3, donates a proton to water in the forward reaction. Therefore, HNO_3 is a Brønsted acid and H_2O is a Brønsted base. In the reverse reaction, H_3O^+ donates a proton to the nitrate ion, NO_3^-. Therefore, H_3O^+ is a Brønsted acid and NO_3^- is a Brønsted base.
b) Similarly, H_2SO_4, sulfuric acid, is a Brønsted acid and H_2O is a Brønsted base (forward reaction). Also, H_3O^+ is a Brønsted acid, and the sulfate ion, SO_4^{2-}, is a Brønsted base (reverse reaction).
c) In this reaction the water now donates a proton instead of accepting one. Therefore, ammonia, NH_3, is a Brønsted base, while water is a Brønsted acid (forward reaction). The ammonium ion, NH_4^+, is an

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