Steven S. Zumdahl
Susan A. Zumdahl
Donald J. DeCoste

Chapter 8

Reactions in Aqueous Solutions

Gretchen M. Adams • University of Illinois at Urbana-Champaign

Objective

1. To learn about some of the factors that cause reactions to occur
2. To learn to identify the solid that forms in a precipitation reaction
3. To learn to write molecular, complete ionic, and net ionic equations

Understa

Understanding Reactio

A. Predicting Whether a Reaction Will Occur

- Four driving forces favor chemical change.
  - Formation of a solid
  - Formation of water
  - Transfer of electrons
  - Formation of a gas

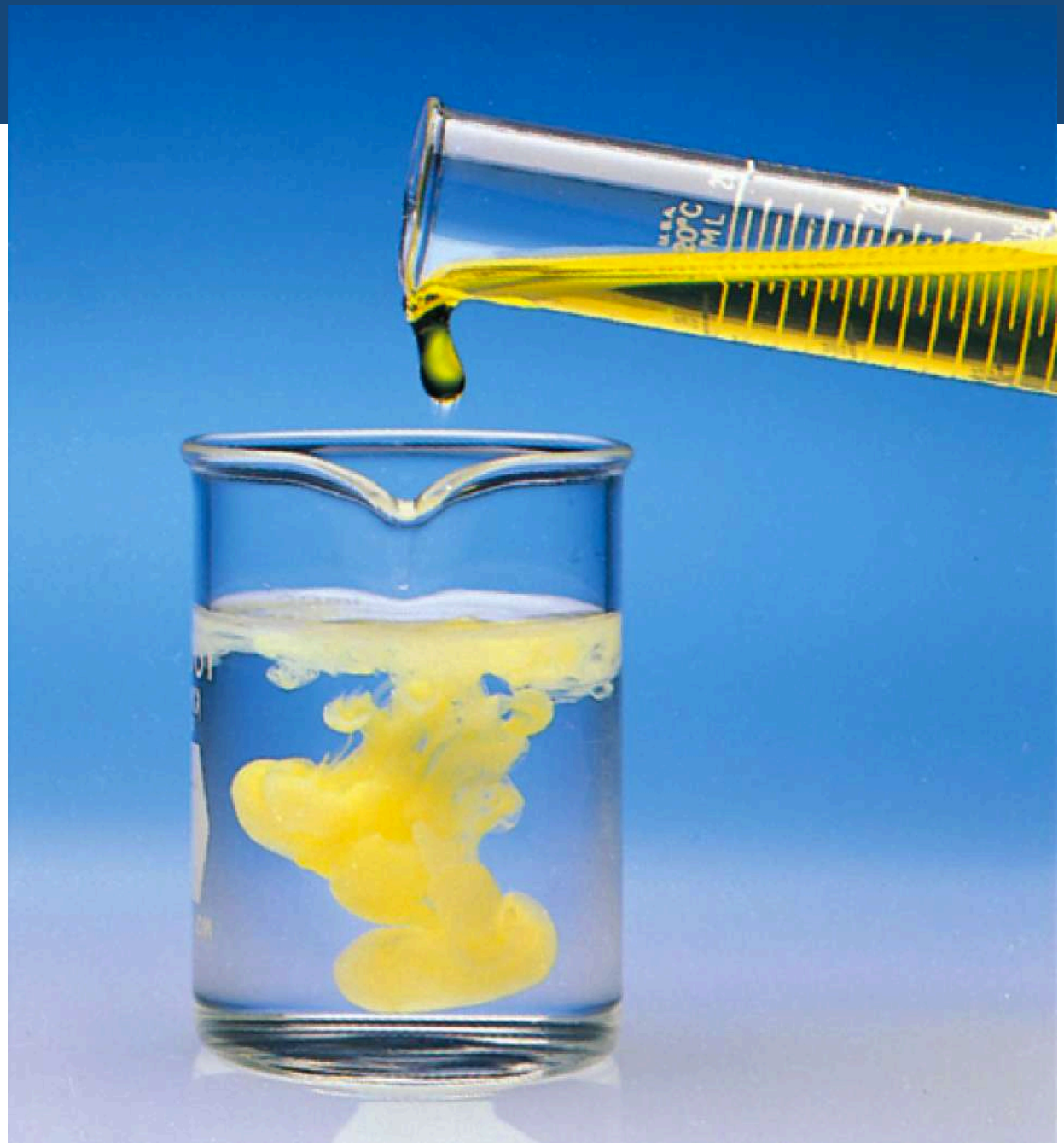


Figure 8-1 p256

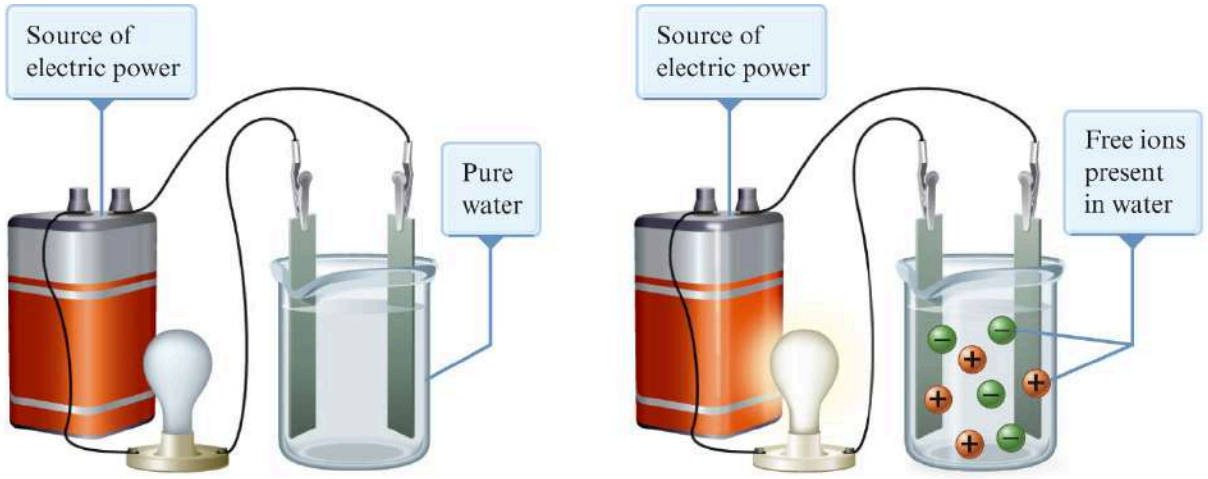
B. Reactions in Which a Solid Forms

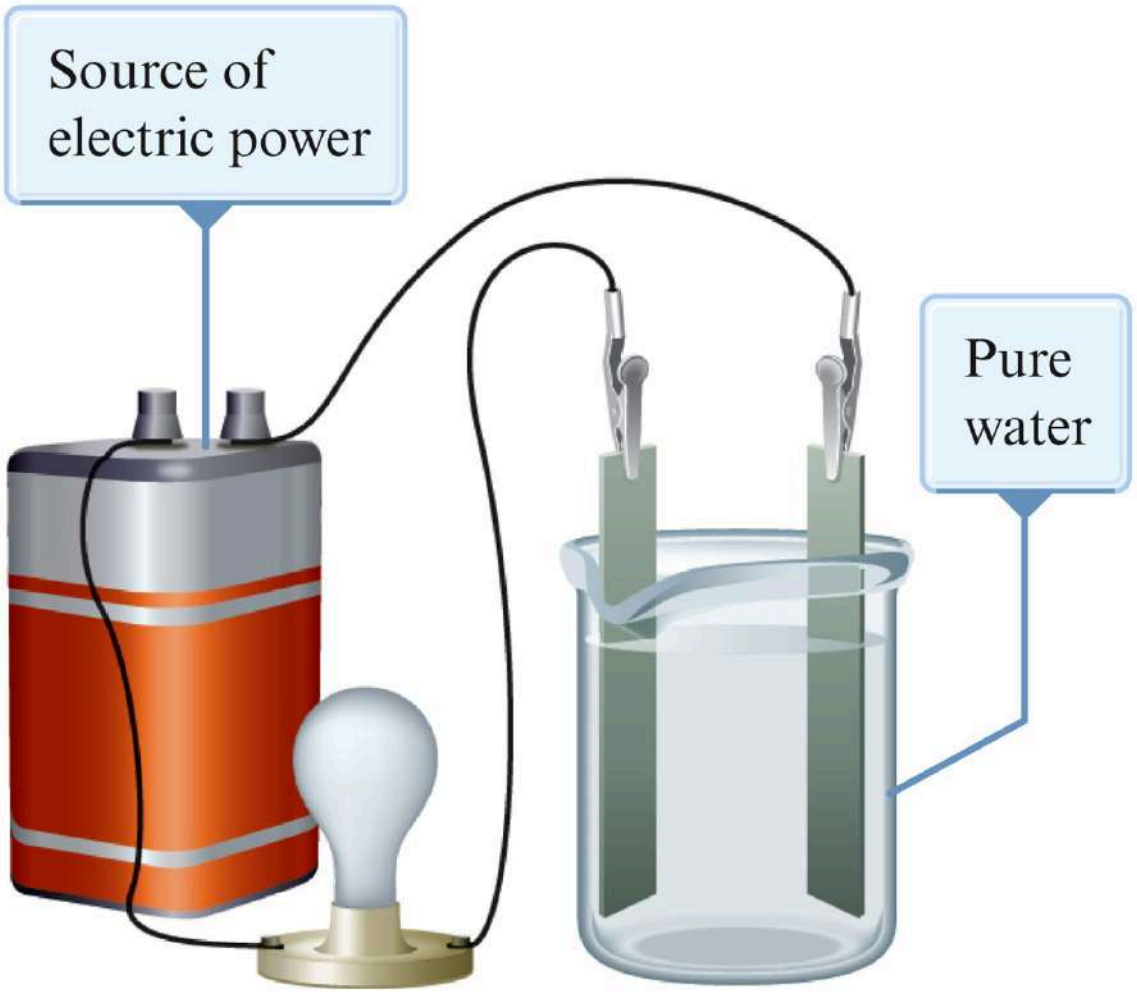
- A reaction in which a solid forms is called a precipitation reaction.
  - Solid = precipitate

B. Reactions in Which a Solid Forms

What Happens When an Ionic Compound Dissolves in Water?

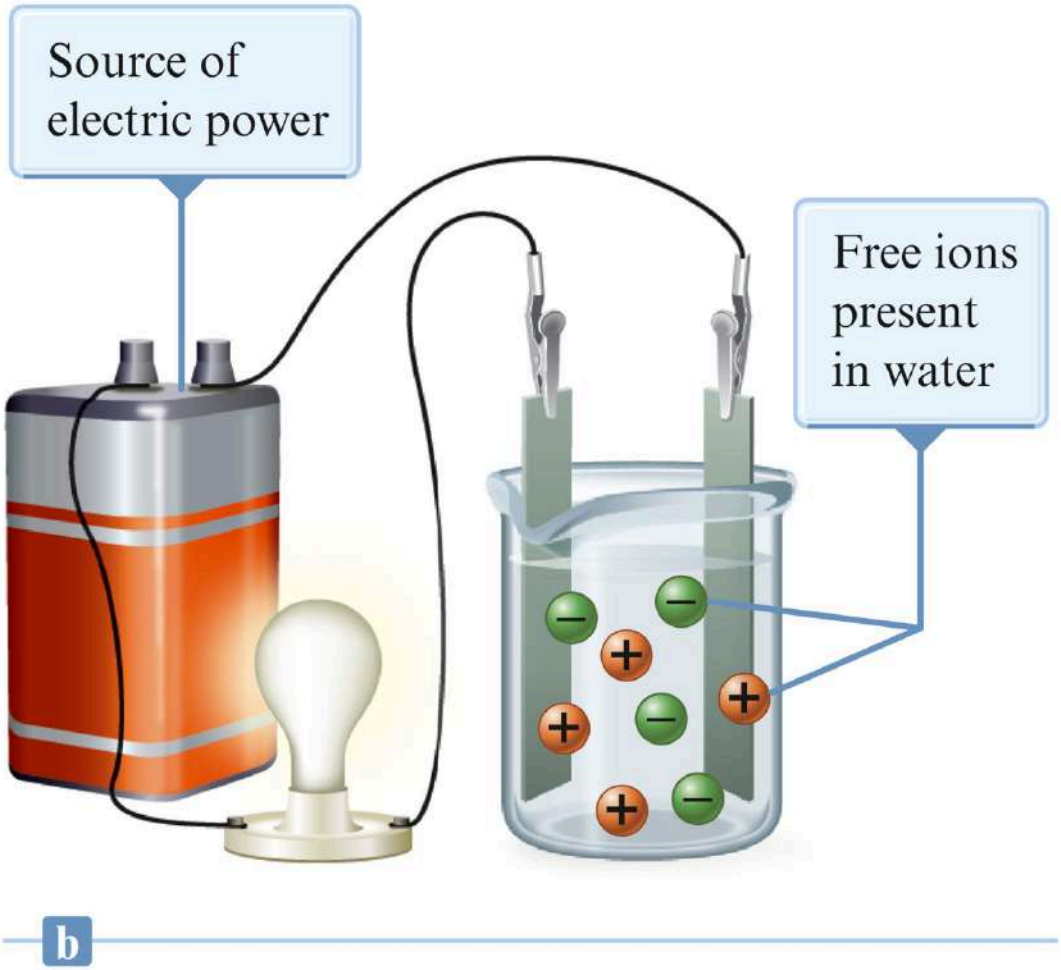
- The ions separate and move around independently.





Pure water does not conduct an electric current. The lamp does not light.

Figure 8-2a p257



When an ionic compound is dissolved in water, current flows and the lamp lights. The result of this experiment is strong evidence that ionic compounds dissolved in water exist in the form of separated ions.

Figure 8-2b p257

B. Reactions in Which a Solid Forms

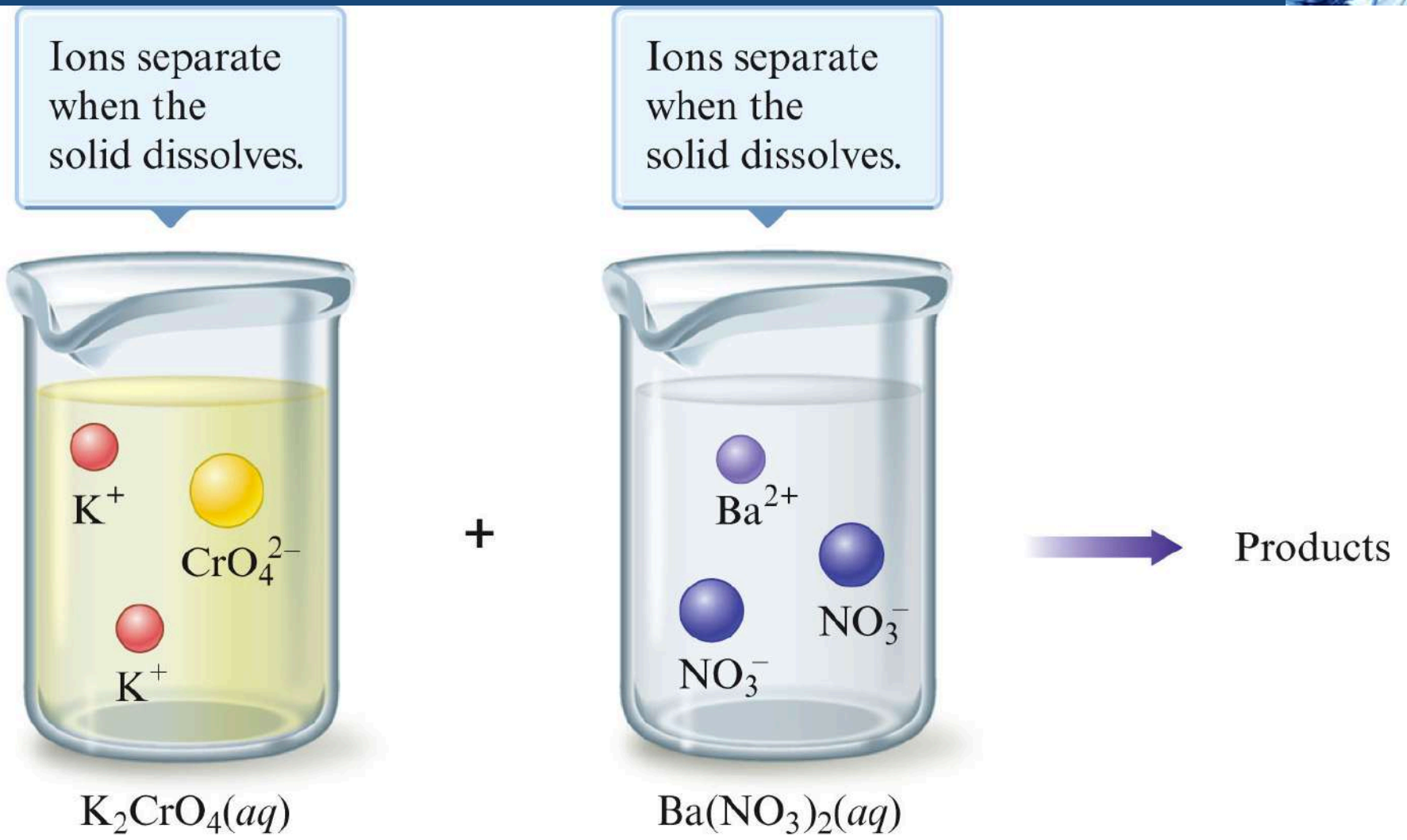
What Happens When an Ionic Compound Dissolves in Water?

- $K_2CrO_4(aq) + Ba(NO_3)_2(aq) \rightarrow$ Products

$$2K^+(aq) + CrO_4^{2-}(aq) + Ba^{2+}(aq) + 2NO_3^-(aq) \longrightarrow \text{Products}$$

The ions in $K_2CrO_4(aq)$ | The ions in $Ba(NO_3)_2(aq)$

Understanding Reactions in Aqueous Solutions



B. Reactions in Which a Solid Forms

How to Decide What Products Form

Determine the possible products from the ions in the reactants.
In our example

K2CrO4*(aq)* + Ba(NO3)2*(aq)* → Products

The possible ions combinations are

	NO_3^-	CrO_4^{2-}
K^+	KNO_3	K_2CrO_4
Ba^{2+}	$Ba(NO_3)_2$	$BaCrO_4$

B. Reactions in Which a Solid Forms

How to Decide What Products Form

Decide which is most likely to be the yellow solid formed in the reaction.

K2CrO4*(aq)* reactant
Ba(NO3)2*(aq)* reactant
The possible combinations are KNO3 and BaCrO4.

- KNO_3 white solid
- $BaCrO_4$ yellow solid

Understanding Reactions in Aqueous Solutions

$$\underbrace{2K^+(aq) + CrO_4^{2-}(aq)}_{\text{The ions in } K_2CrO_4(aq)} + \underbrace{Ba^{2+}(aq) + 2NO_3^-(aq)}_{\text{The ions in } Ba(NO_3)_2(aq)} \longrightarrow \text{Products}$$

Understanding Reactions in Aqueous Solutions

B. Reactions in Which a Solid Forms

Using Solubility Rules

Table 8.1 General Rules for Solubility of Ionic Compounds (Salts) in Water at 25°C

1. Most nitrate (NO_3^-) salts are soluble.
2. Most salts of Na^+, K^+, and NH_4^+ are soluble.
3. Most chloride salts are soluble. Notable exceptions are AgCl, $PbCl_2$, and Hg_2Cl_2.
4. Most sulfate salts are soluble. Notable exceptions are $BaSO_4$, $PbSO_4$, and $CaSO_4$.
5. Most hydroxide compounds are only slightly soluble.* The important exceptions are NaOH and KOH. $Ba(OH)_2$ and $Ca(OH)_2$ are moderately soluble.
6. Most sulfide (S^{2-}), carbonate (CO_3^{2-}), and phosphate (PO_4^{3-}) salts are only slightly soluble.*

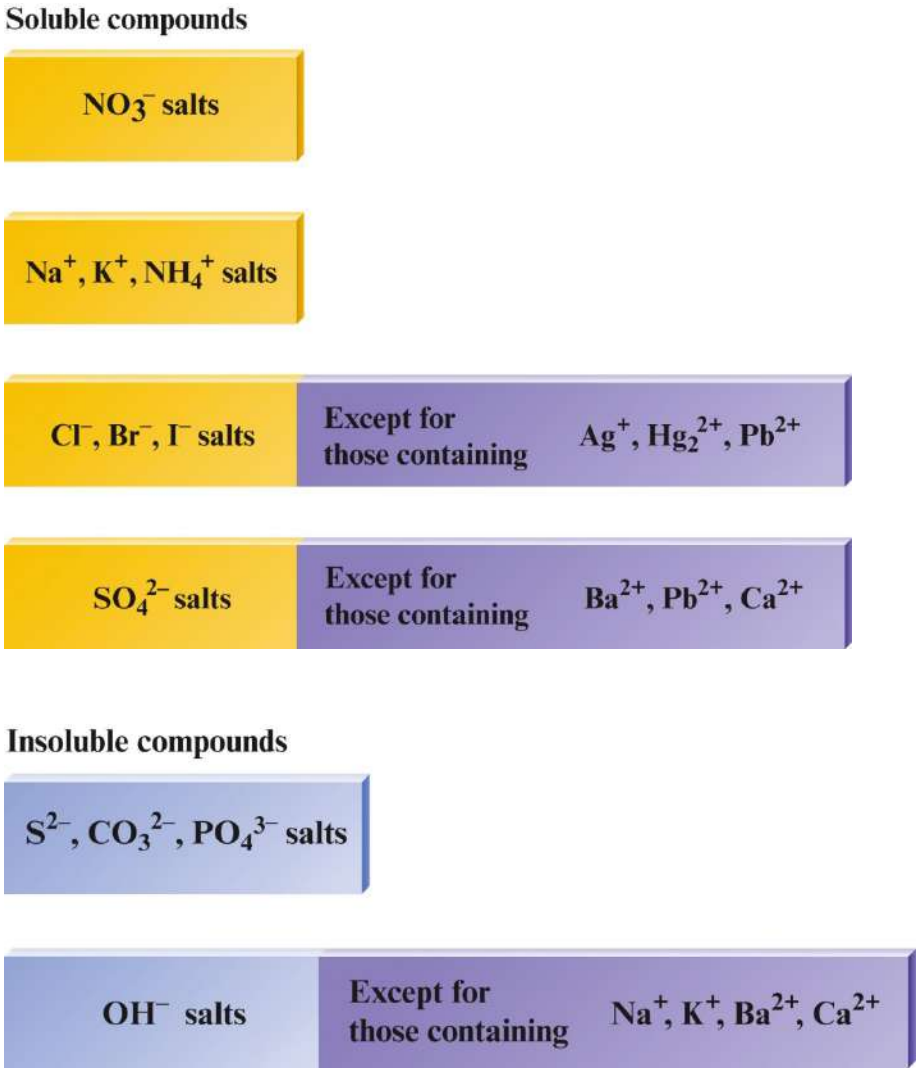
*The terms *insoluble* and *slightly soluble* really mean the same thing: such a tiny amount dissolves that it is not possible to detect it with the naked eye.

B. Reactions in Which a Solid Forms

Using Solubility Rules

Predicting Precipitates

- Soluble solid
- Insoluble solid
- Slightly soluble solid



B. Reactions in Which a Solid Forms

Let's Review

How to Predict Precipitates When Solutions of Two Ionic Compounds Are Mixed

Step 1 Write the reactants as they actually exist before any reaction occurs. Remember that when a salt dissolves, its ions separate.

Step 2 Consider the various solids that could form. To do this, simply *exchange the anions* of the added salts.

Step 3 Use the solubility rules (Table 8.1) to decide whether a solid forms and, if so, to predict the identity of the solid.

Concept Check

Which of the following ions form compounds with Pb^{2+} that are generally soluble in water?

a) S^{2-}

b) Cl^{-}

c) NO_3^{-}

d) SO_4^{2-}

e) Na^{+}

C. Describing Reactions in Aqueous Solutions

- Three types of equations:
  - Molecular (formula) equation $\Rightarrow$
    complete formulas of all reactants and products

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

C. Describing Reactions in Aqueous Solutions

- Three types of equations:
  - Complete ionic equation $\Rightarrow$
    all strong electrolytes are shown as ions

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow$$
$$AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

C. Describing Reactions in Aqueous Solutions

- Three types of equations:
  - Net ionic equation ⇒

    only those components of the solution that undergo a change

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

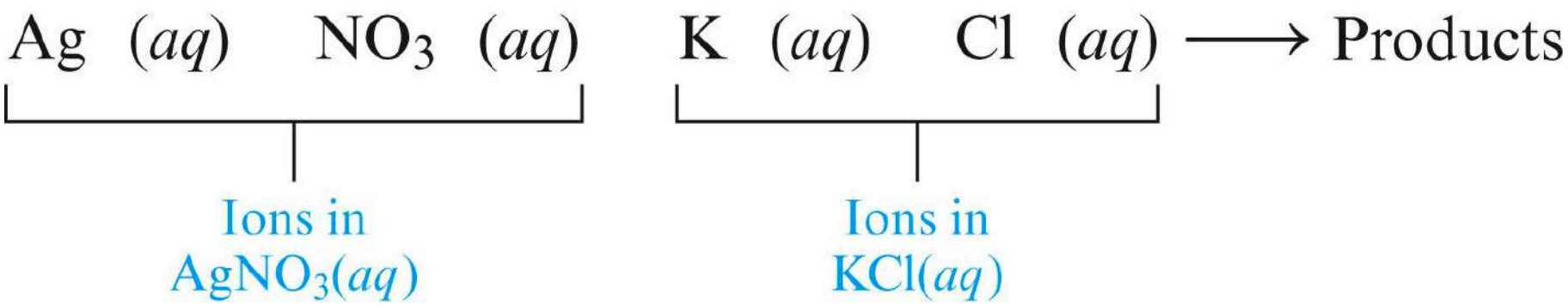
- Spectator ion (those that remain unchanged) ⇒

  not shown in the net ionic equation

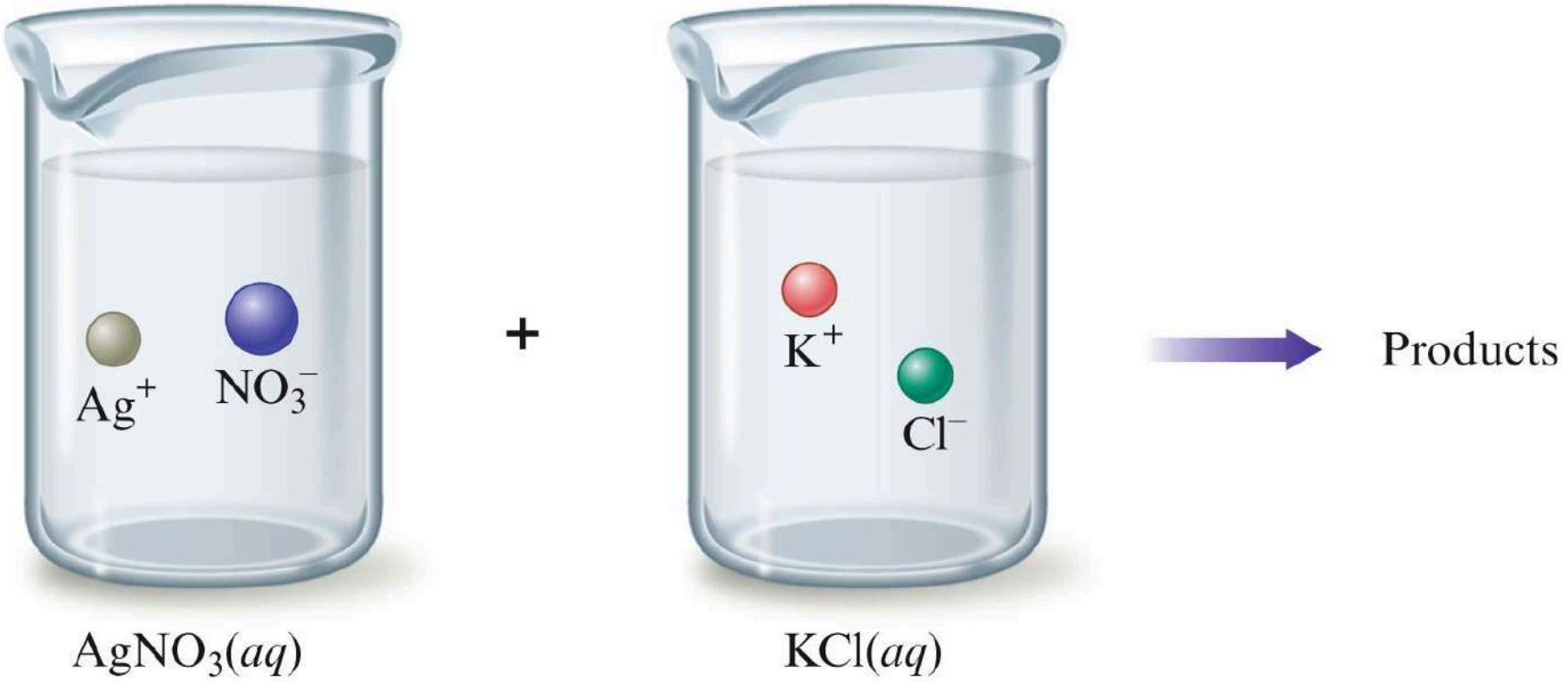
Na^+ and NO_3^- are spectator ions.

Figure 8-4 p264

Understanding Reactions in Aqueous Solutions



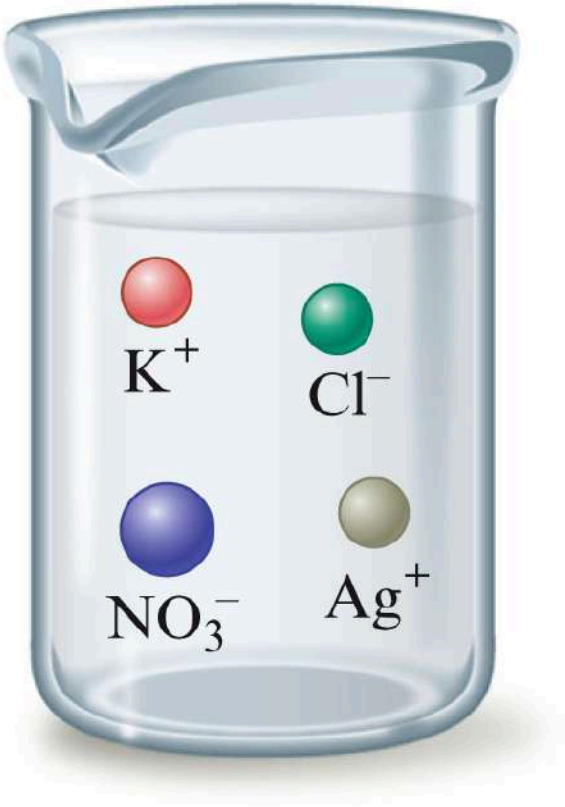
Understanding Reactions in Aqueous Solutions

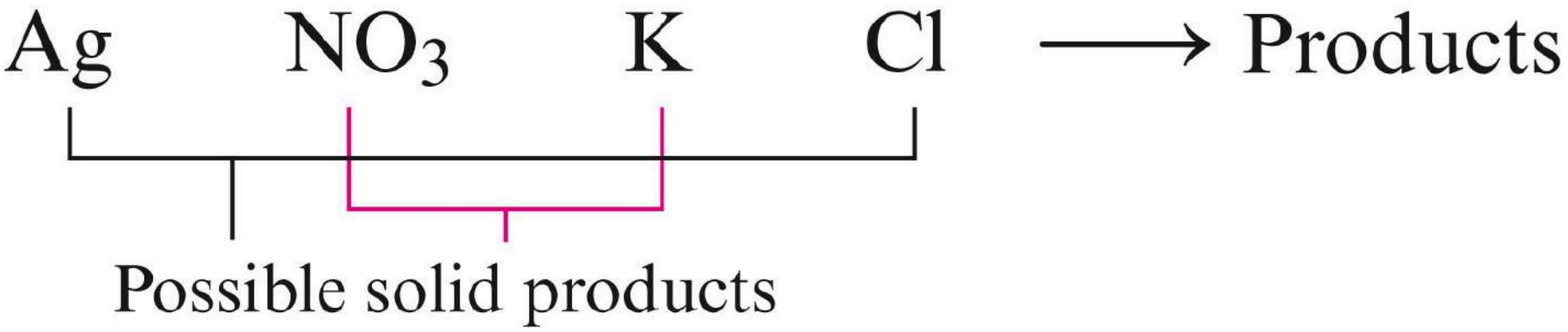


Understanding Reactions in Aqueous Solutions

$AgNO_3(aq) + KCl(aq)$

Solution contains




Ag
NO3
K
Cl
Products
Possible solid products

Understanding Reactions in Aqueous Solutions

$$Ag^+(aq) + NO_3^-(aq) + K^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$$

Understanding Reactions in Aqueous Solutions

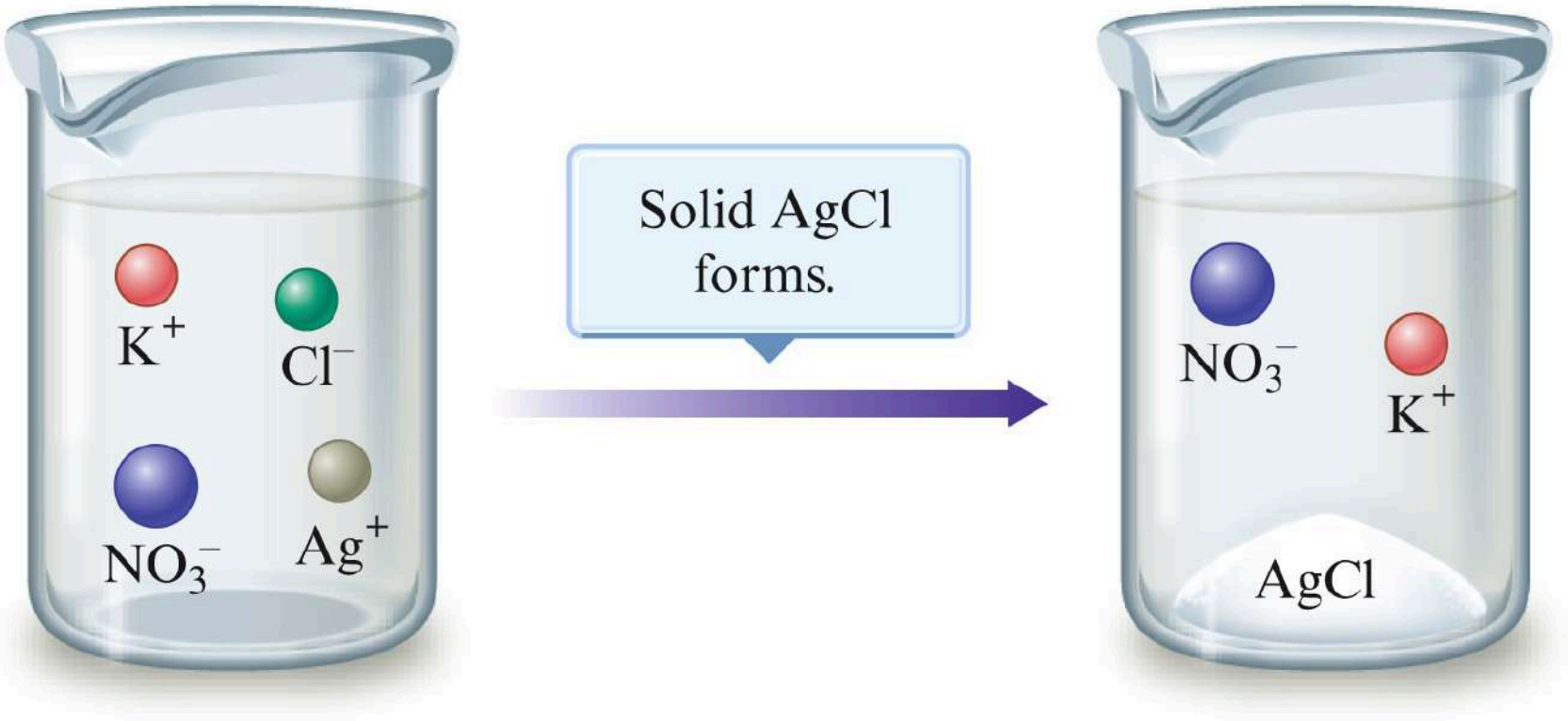
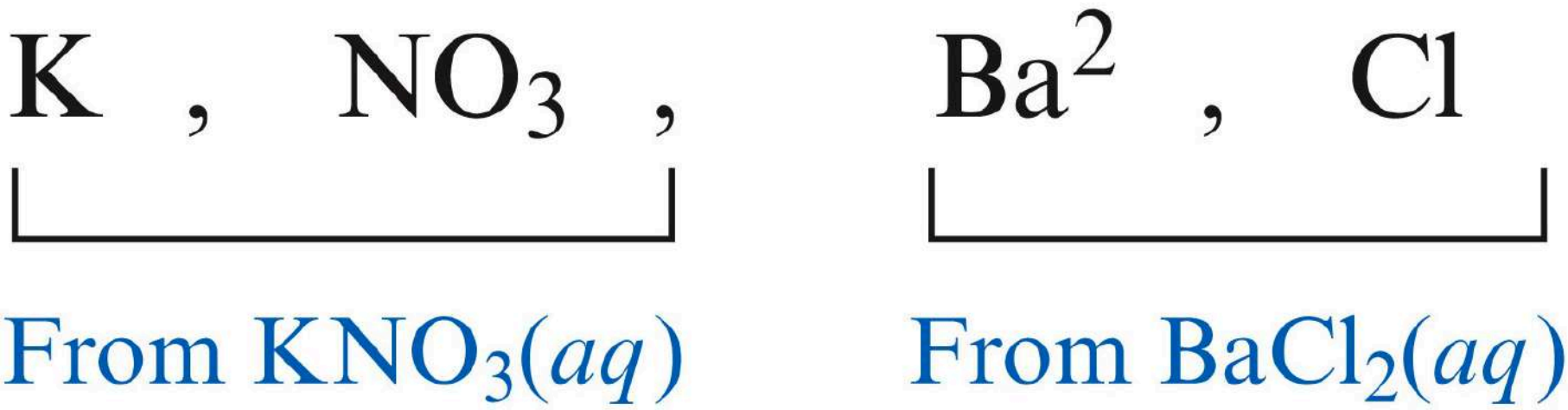
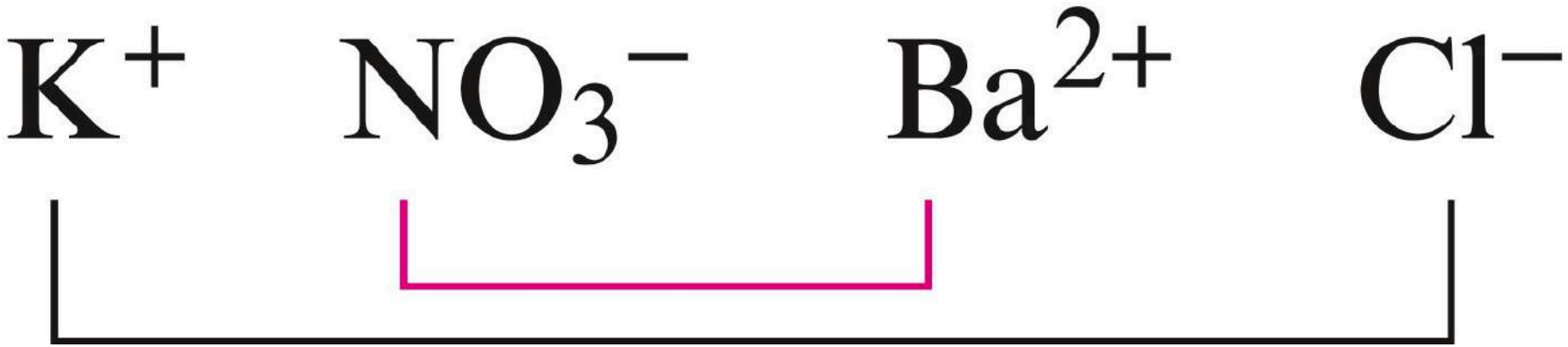
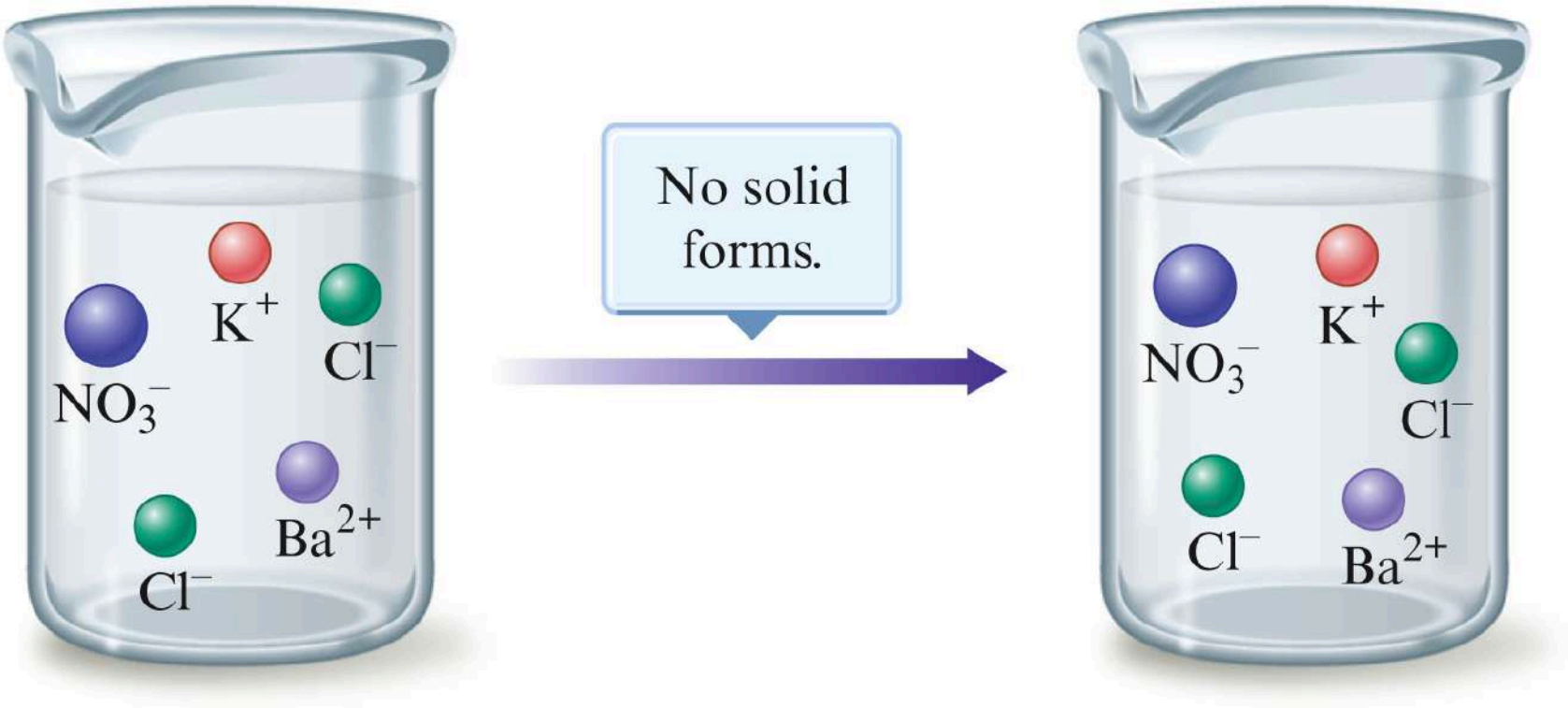


Figure 8-4 p264


K , NO3 ,
Ba2 , Cl
From KNO3(aq)
From BaCl2(aq)


K^+
NO_3^-
Ba^{2+}
Cl^-

Understanding Reactions in Aqueous Solutions



Na^+, SO_4^{2-}, Pb^{2+}, NO_3^-

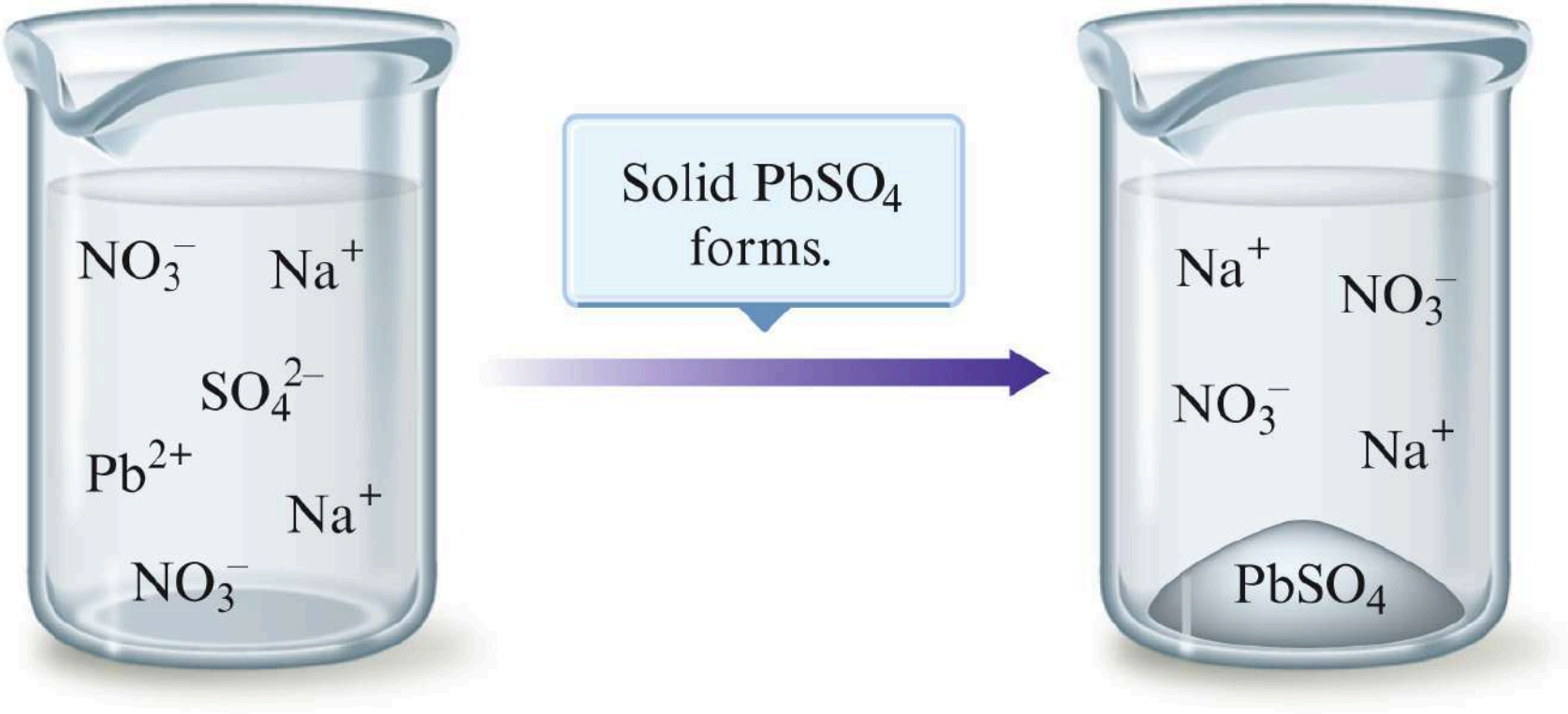
From $Na_2SO_4(aq)$

From $Pb(NO_3)_2(aq)$


Na^+
SO_4^{2-}
Pb^{2+}
NO_3^-

$$Na_2SO_4(aq) + Pb(NO_3)_2(aq) \longrightarrow PbSO_4(s) + \underbrace{2NaNO_3(aq)}_{\text{Remains dissolved}}$$

Understanding Reactions in Aqueous Solutions

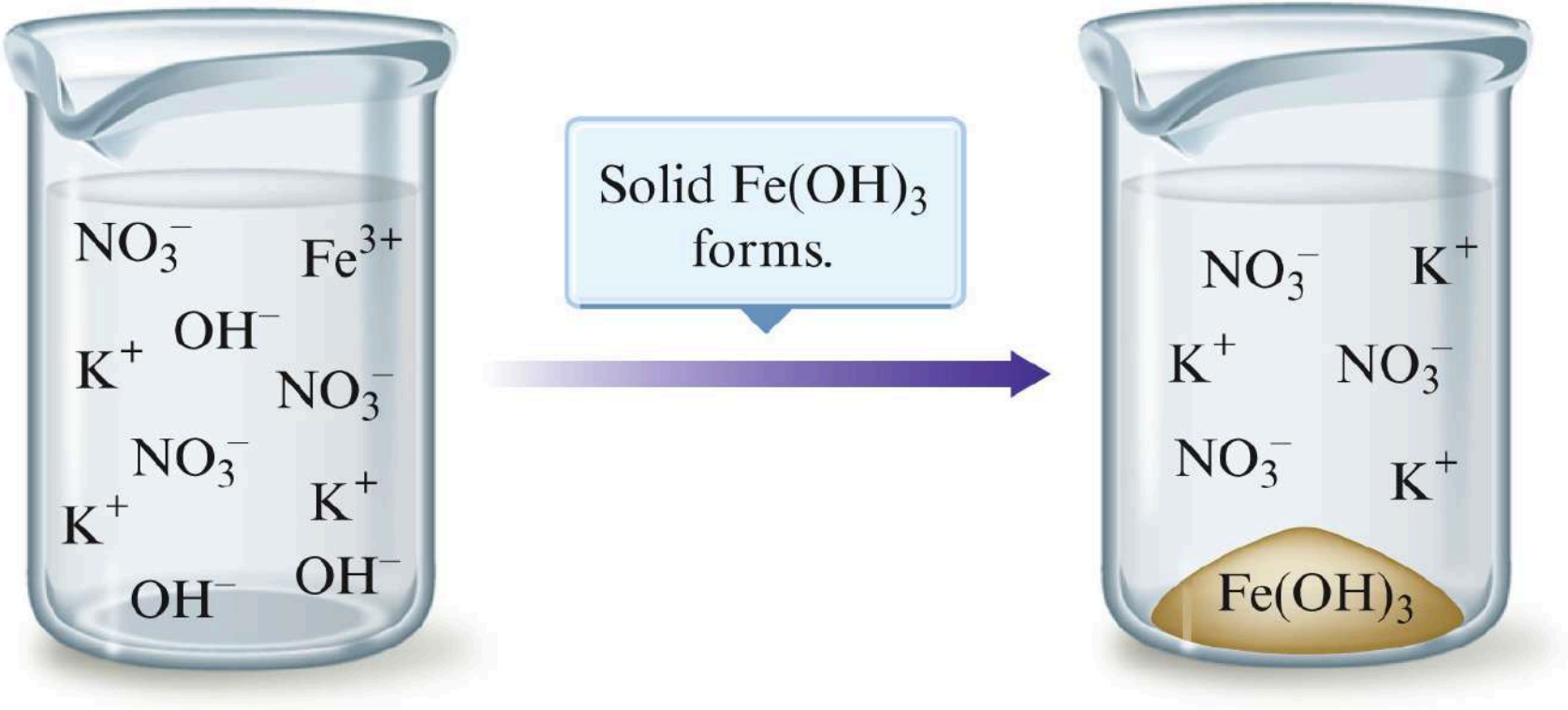


K^+, OH^-, Fe^{3+}, NO_3^-

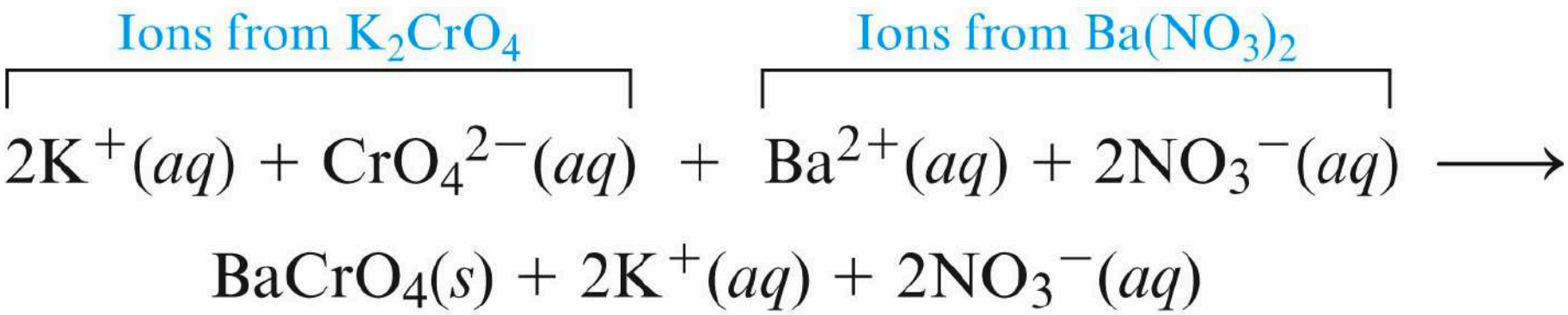
From $KOH(aq)$ From $Fe(NO_3)_3(aq)$


K+
OH−
Fe3+
NO3−

Understanding Reactions in Aqueous Solutions



Understanding Reactions in Aqueous Solutions



Concept Check

Write the correct molecular equation, complete ionic equation, and net ionic equation for the reaction between cobalt(II) chloride and sodium hydroxide.

Molecular Equation:

$CoCl_2(aq) + 2NaOH(aq) \rightarrow Co(OH)_2(s) + 2NaCl(aq)$

Complete Ionic Equation:

$Co^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + 2OH^-(aq) \rightarrow$

$Co(OH)_2(s) + 2Na^+(aq) + 2Cl^-(aq)$

Net Ionic Equation:

$Co^{2+}(aq) + 2OH^-(aq) \rightarrow Co(OH)_2(s)$

Objective

1. To learn about reactions between strong acids and strong bases
2. To learn about the reaction between a metal and a nonmetal
3. To understand how electron transfer produces a chemical reaction

A. Reactions that Form Water: Acids and Bases

Arrhenius Acids and Bases

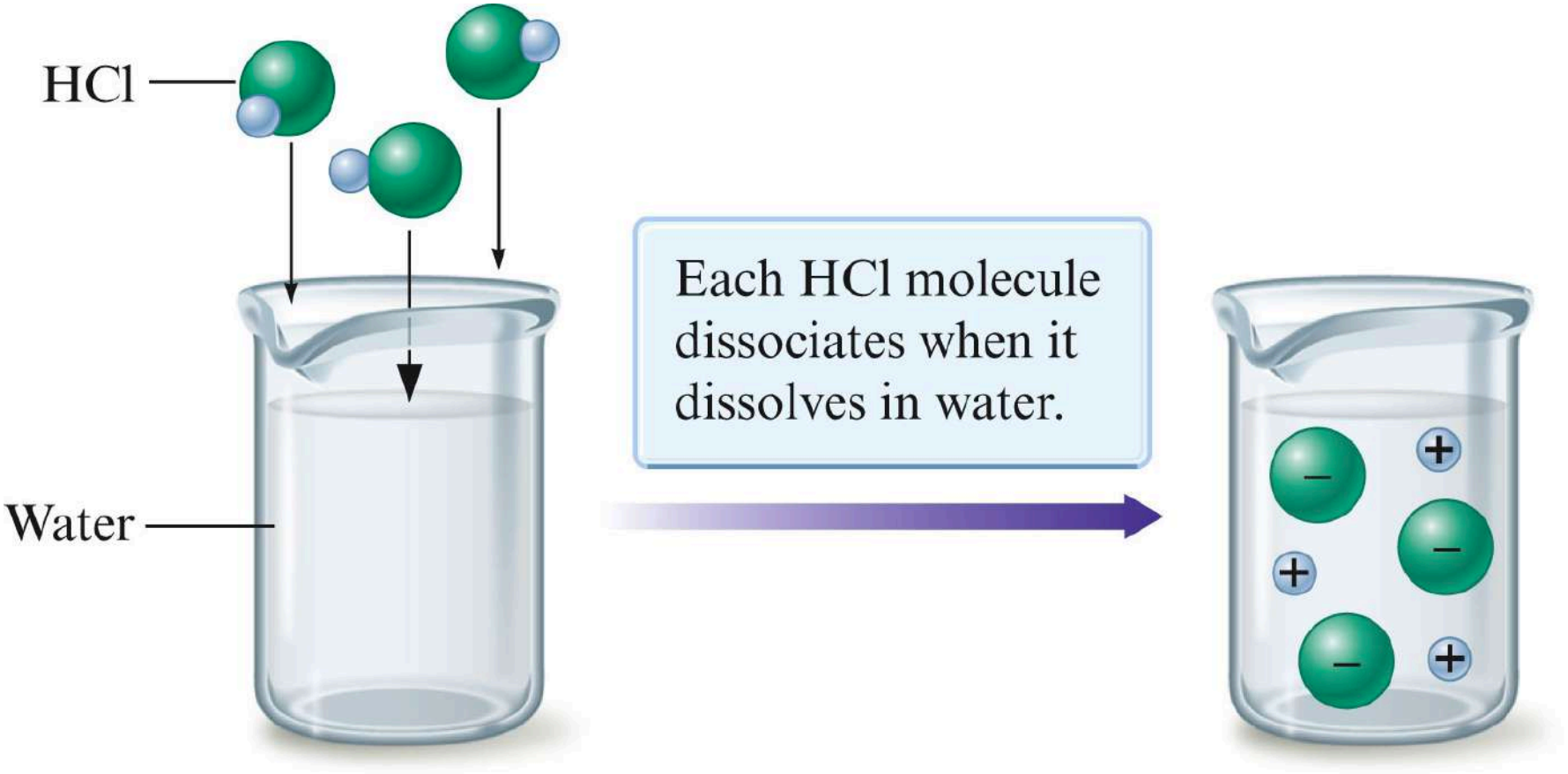
- A strong acid is one in which virtually every molecule dissociates (ionizes) in water to an H^+ ion and an anion.

$$HCl \xrightarrow{H_2O} H^+(aq) + Cl^-(aq)$$

$$HNO_3 \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$

$$H_2SO_4 \xrightarrow{H_2O} H^+(aq) + HSO_4^-(aq)$$

Other Reactions in Aqueous Solutions



A. Reactions that Form Water: Acids and Bases

Arrhenius Acids and Bases

- A strong base is a metal hydroxide that is completely soluble in water, giving separate OH^- ions and cations.
  - Most common ⇒ NaOH, KOH

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

Other Reactions in Aqueous Solutions

Other Reactions in Aqu

A. Reactions that Form Water: Acids and Bases

Arrhenius Acids and Bases

- The products of the reaction of a strong acid and a strong base are water and a salt.
  - Salt $\Rightarrow$ Ionic compound

Net ionic equation

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

Reaction of H+ and OH− is called an acid-base reaction.

  - $H^+ \Rightarrow$ acidic ion
  - $OH^- \Rightarrow$ basic ion

Other Reactions in Aqu

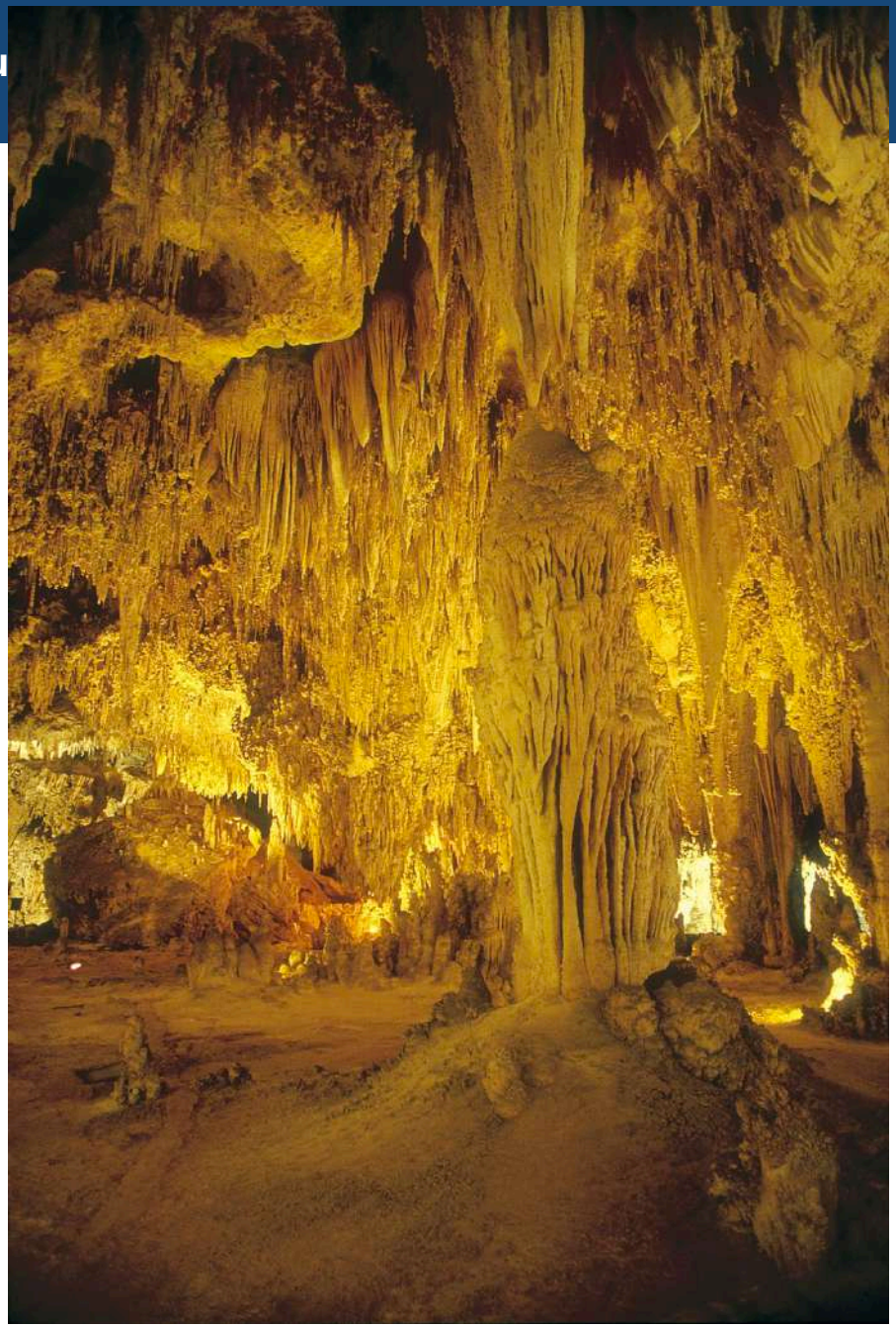
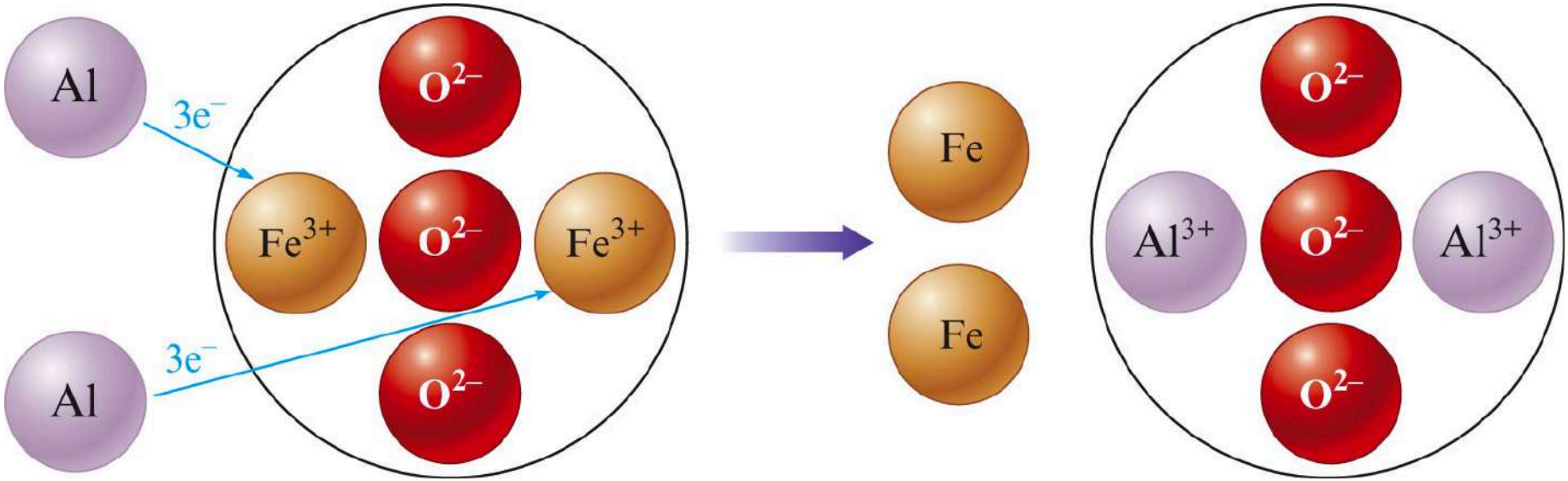


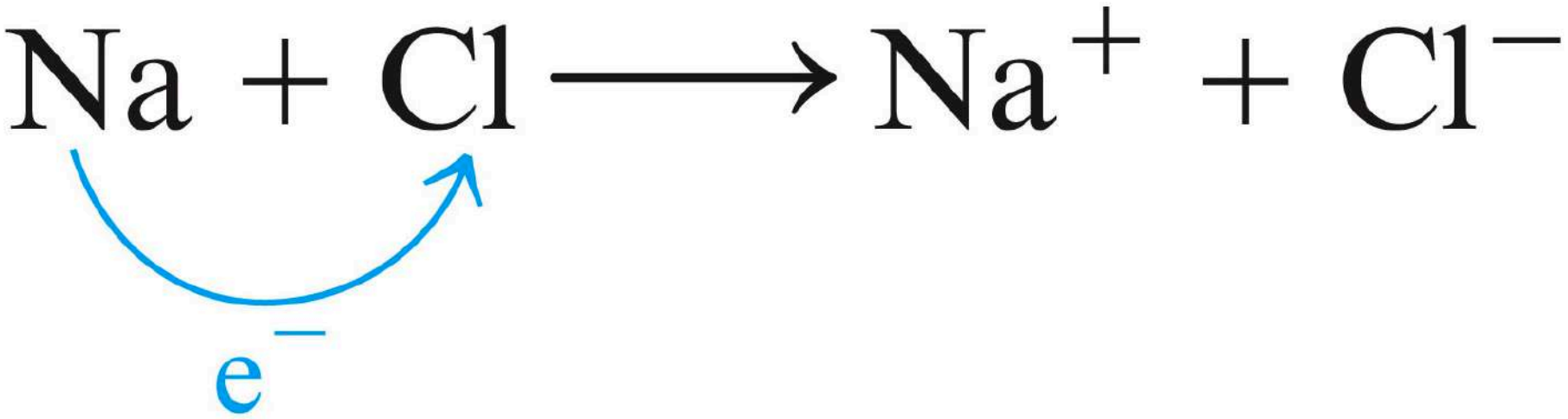
Figure 8-5 p276

B. Reactions of Metals with Nonmetals (Oxidation-Reduction)

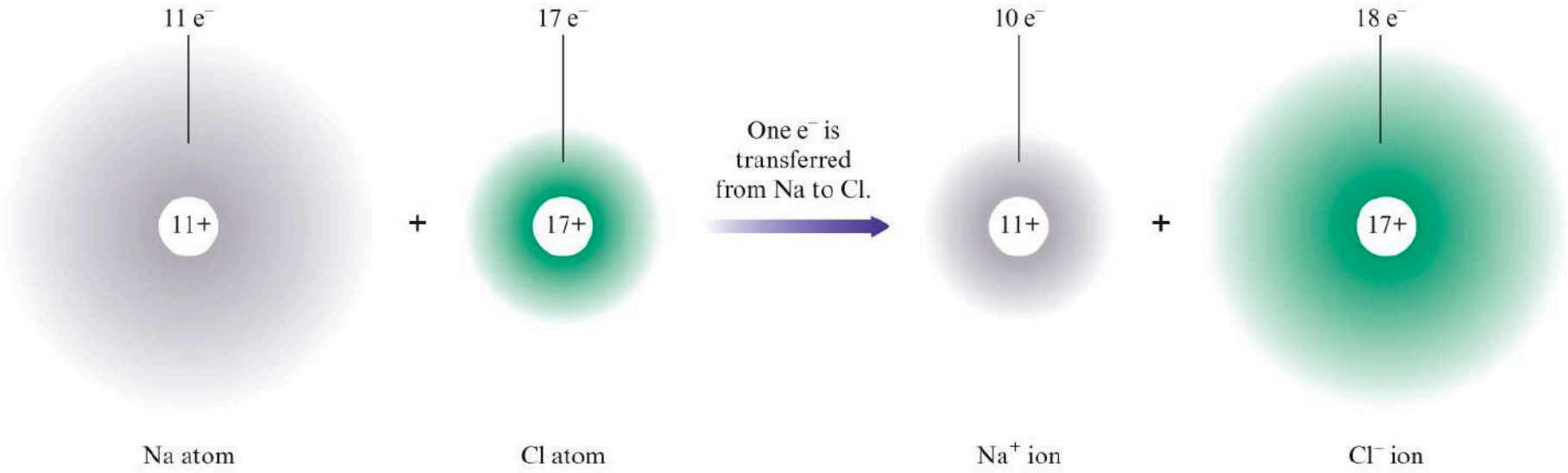
Reactions between metals and nonmetals involve a transfer of electrons from the metal to the nonmetal.

- oxidation – reduction reaction




Na + Cl ⟶ Na+ + Cl−
e−

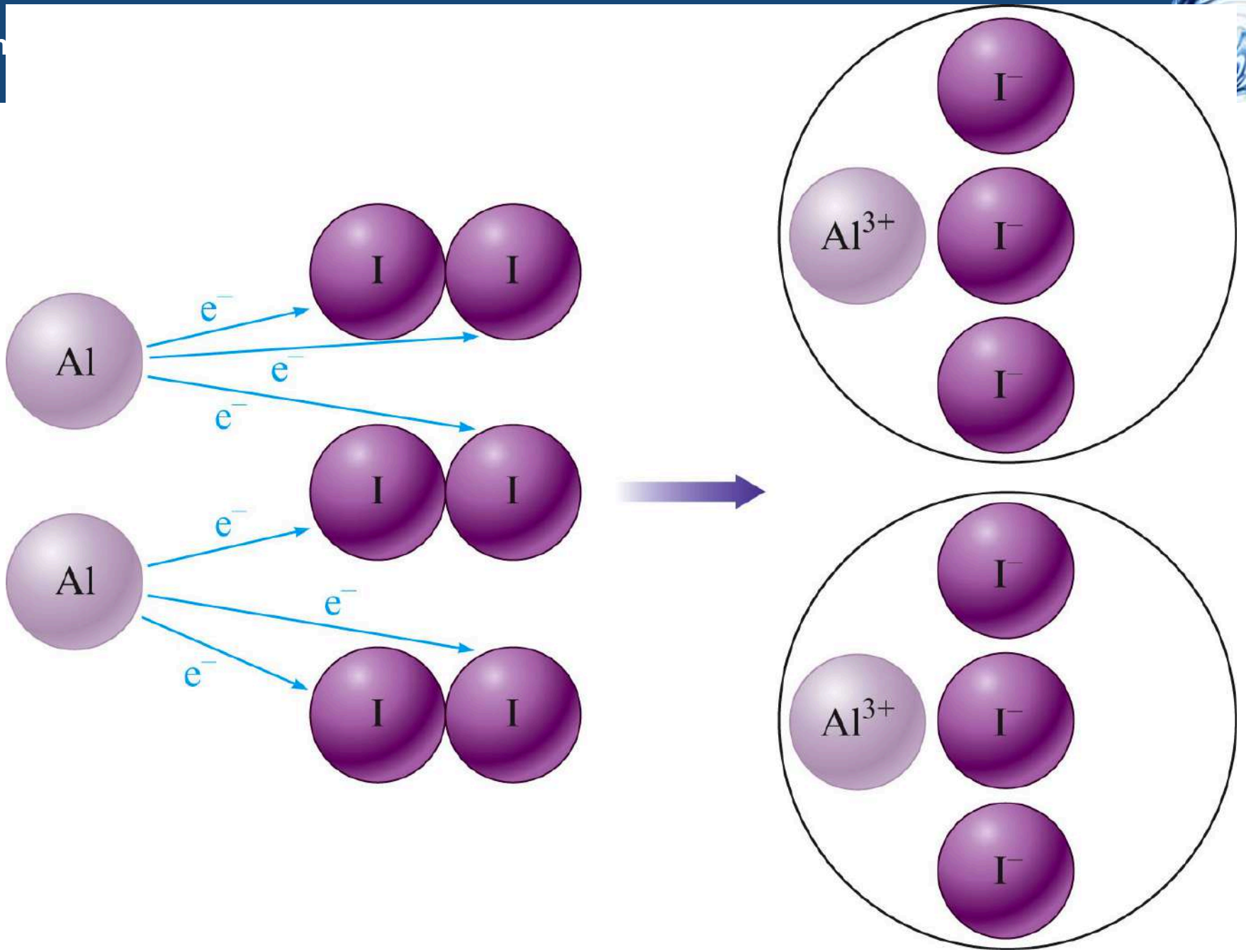
Other Reactions in Aqueous Solutions



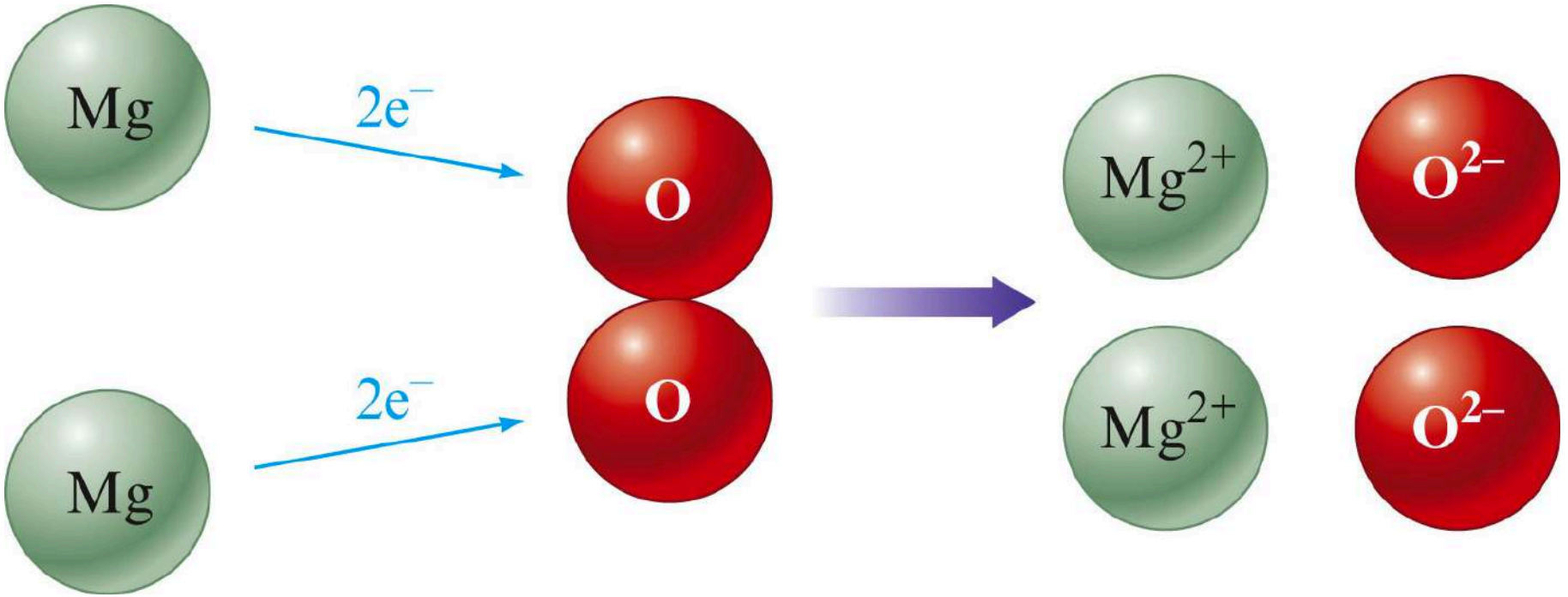
Other

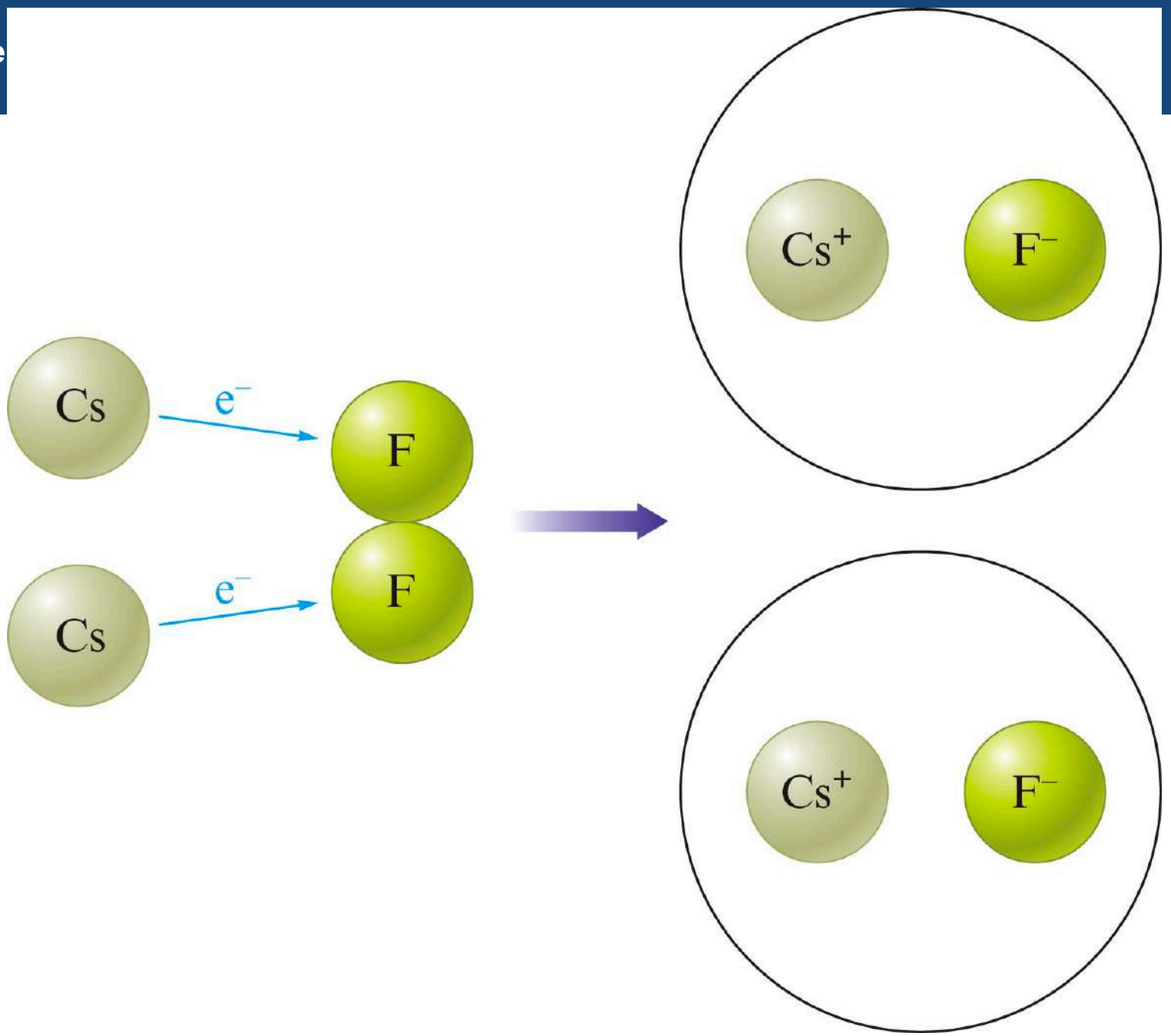
Figure 8-6 p277

Oth

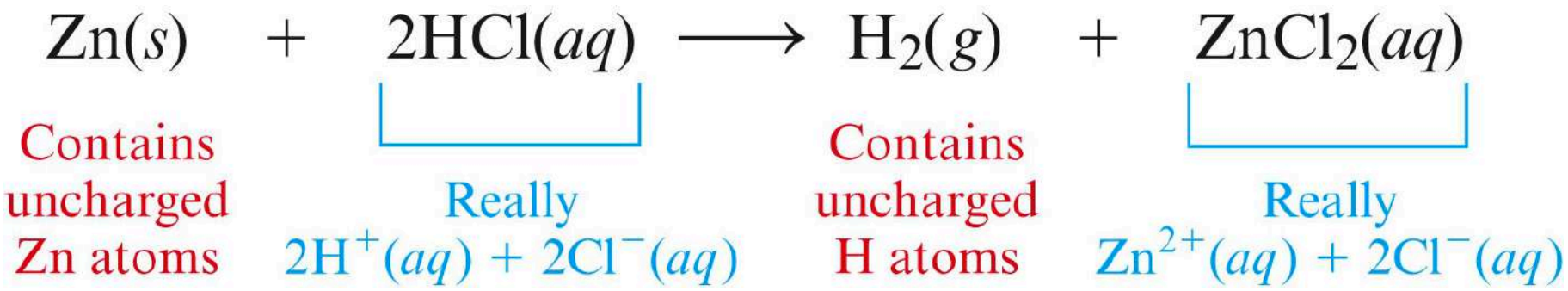


Other Reactions in Aqueous Solutions

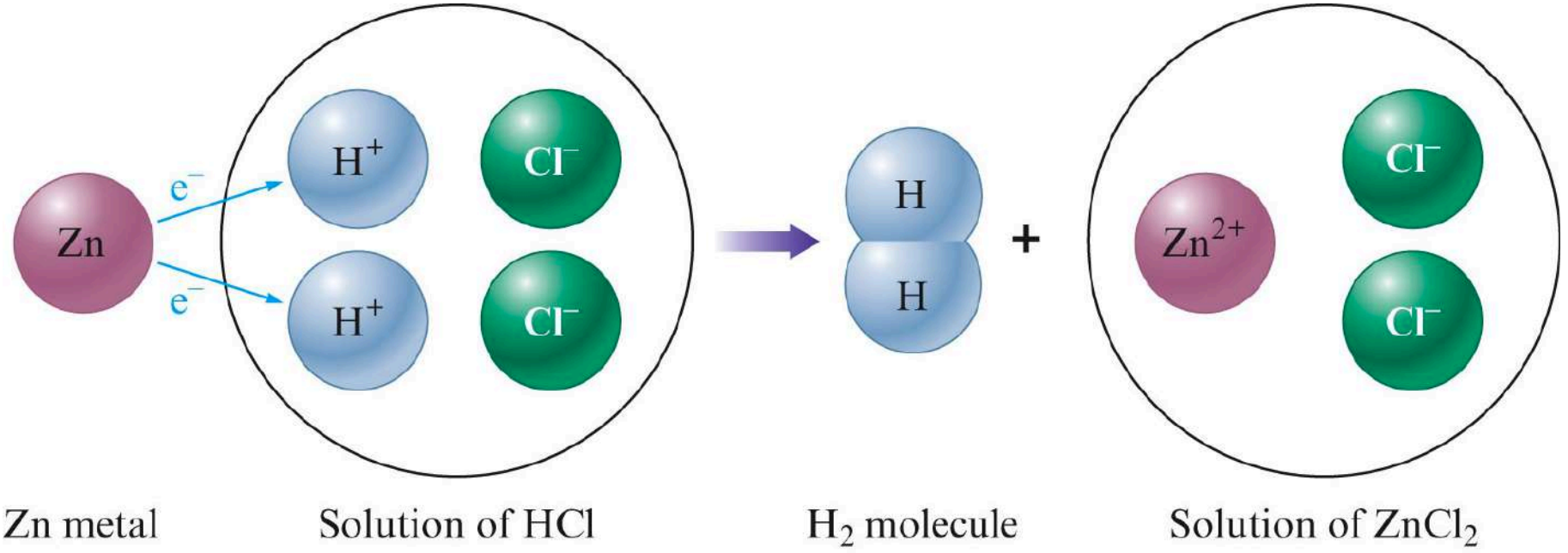



Cs
e⁻
F
Cs
e⁻
F
Cs⁺
F⁻
Cs⁺
F⁻

Other Reactions in Aqueous Solutions



Other Reactions in Aqueous Solutions



Classifying Reactions

Objective

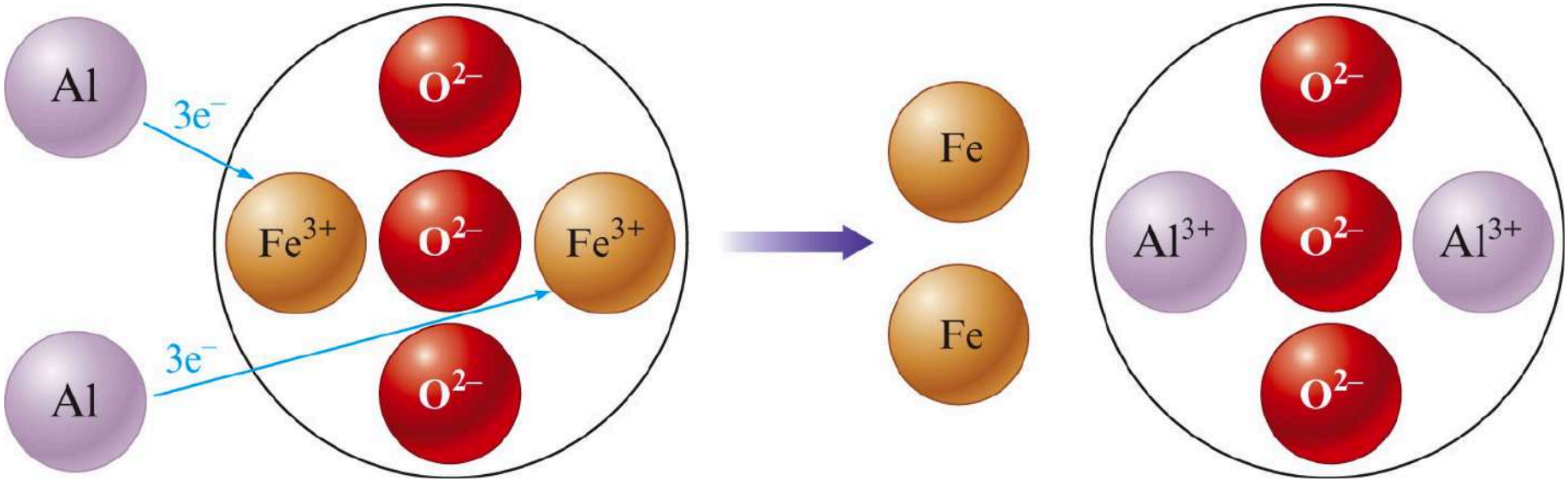
1. To learn various classification schemes for reactions

A. Ways to Classify Reactions

- Driving forces for a reaction:
  - Formation of a solid
    - AB + CD $\rightarrow$ AD + CB
    - Precipitation reaction
    - Double displacement reaction
  - Formation of water
    - $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
    - Acid-base reaction

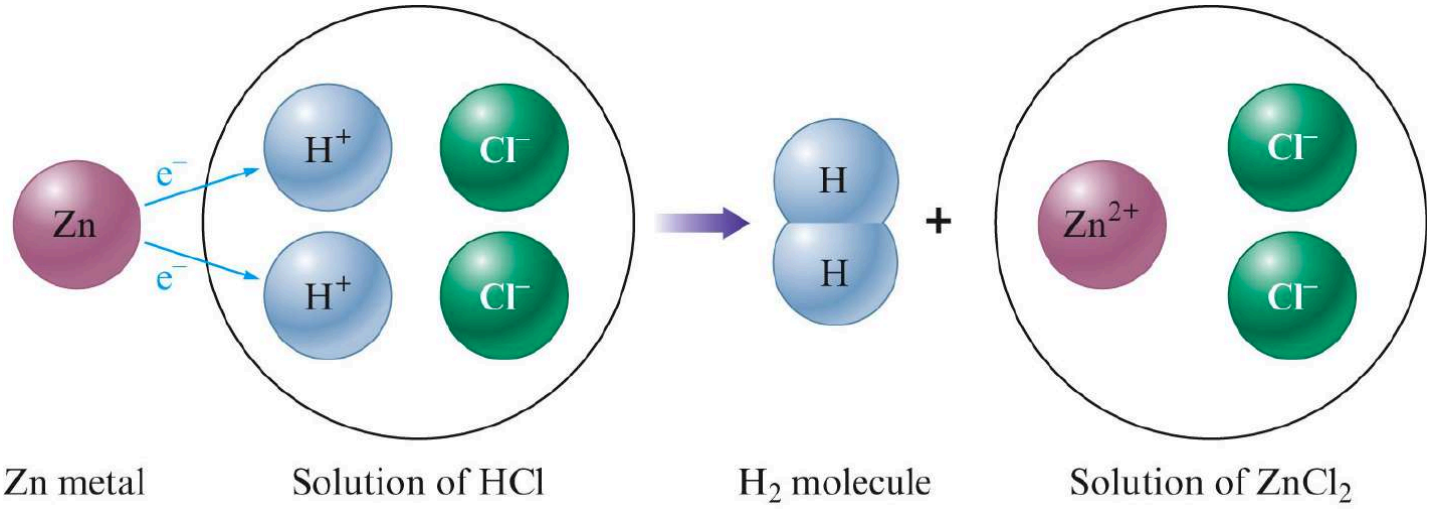
A. Ways to Classify Reactions

- Driving forces for a reaction:
  - Transfer of electrons



A. Ways to Classify Reactions

- Driving forces for a reaction:
  - Transfer of electrons
  - Formation of a Gas



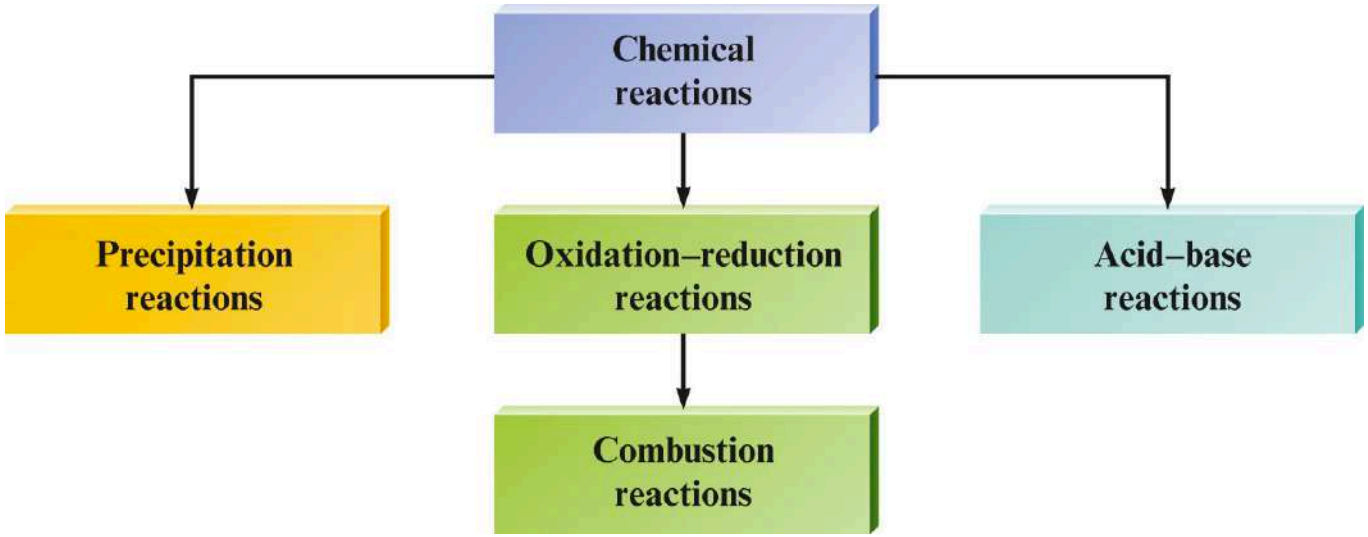
$$A + BC \rightarrow B + AC$$

Single replacement reaction

B. Other Ways to Classify Reactions

Combustion Reactions

- Involve oxygen and produce energy so rapidly that a flame results
  - $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
  - Special class of oxidation-reduction reactions



B. Other Ways to Classify Reactions

Synthesis (Combination) Reactions

- A synthesis reaction is one in which a compound forms from simpler materials.
  - $C(g) + O_2(g) \rightarrow CO_2(g)$
  - Special class of oxidation-reduction reactions

B. Other Ways to Classify Reactions

Decomposition Reactions

- A decomposition reaction occurs when a compound is broken down into simpler substances.

B. Other Ways to Classify Reactions

Summary