Topic 7.1-7.2

Introduction to Equilibrium

Learning Objectives

- Define chemical equilibrium for a reversible reaction.
- Describe the state of dynamic equilibrium for reversible reactions.
- Determine the relative rates of the forward and reverse reactions based on the changes in reactant and product concentrations.

Topic Questions

- What is a reversible process?
- When does a system reach chemical equilibrium?
- What is dynamic equilibrium?
- What does an overall increase in reactants or products indicate about the reaction rates of the forward and reverse reactions?

7.1.01 Equilibrium Characteristics

[TRA-6.A.1 TRA-6.A.2]

As discussed in Sub-Topic 4.1.01, chemical substances can undergo either physical or chemical changes. A physical change occurs when a substance undergoes a change in state but its identity does not change. A chemical change occurs when electrons are gained or lost or when chemical bonds are broken and/or formed, resulting in the formation of a new molecule.

Many physical and chemical processes are *reversible* and are indicated by double arrows (⇄). **Reversible physical processes** include:

- Phase changes
- Compound dissolution and precipitation
- Gas absorption and desorption

Reversible chemical processes are reactions in which the reactants can be converted to products (forward reaction) but the products can also be converted back into the reactants (reverse reaction). Reversible chemical processes include:

- Proton (H^+) transfer in acid-base reactions
- Electron (e^-) transfers in redox reactions

Specific examples of both reversible physical and chemical processes are shown in Figure 7.1.

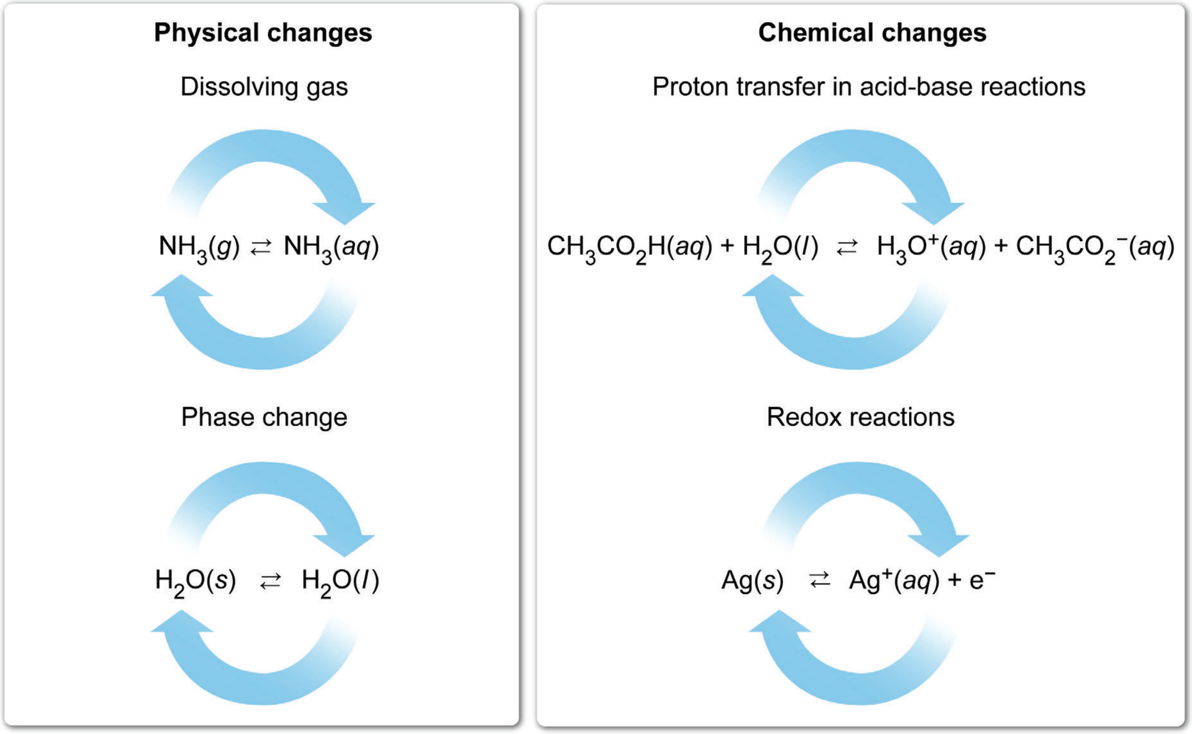

Figure 7.1 Reversible physical and chemical processes.

If a reversible reaction is performed in a container that initially has only reactants, only the *forward* reaction can take place. As the forward reaction progresses, products begin to form. These products can then react with one another and reform the reactants. During this time, the concentrations (or partial pressures) of reactants and products are changing because the rates of the forward and reverse reactions are different.

Over time, however, both the forward and the reverse reactions begin to take place at the same rate. When this happens, there is no detectable change in product or reactant concentrations over time (ie, the concentrations are constant) because any reactants consumed are replaced by the consumption of products, and vice versa. This state is called **chemical equilibrium**.

Note that equilibrium refers to equal rates, *not* equal concentrations. At equilibrium, the concentrations of the products and reactants can be very different, but the concentration of each remains *constant* because the forward and reverse rates are equal. For example, consider the reversible reaction:

$$A \rightleftarrows B$$

Figure 7.2 illustrates that, at equilibrium, the amount of product and reactant stays the same over time even though the amount of molecule A (ie, the reactant) is greater than that of molecule B (ie the product).

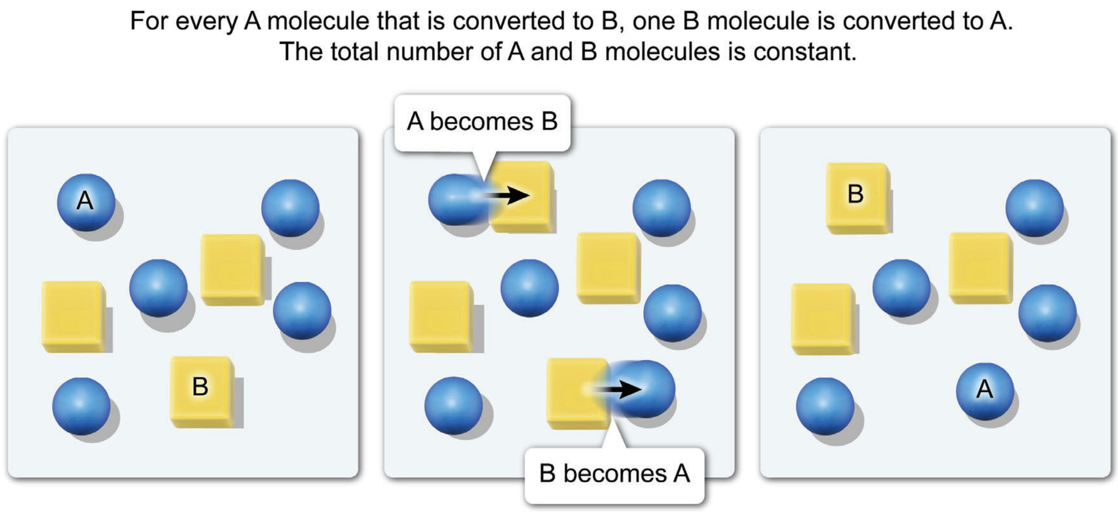

Figure 7.2 Concentrations of products and reactants are constant at equilibrium.

7.1.02 Dynamic Equilibrium

[TRA-6.A.3 TRA-6.A.4]

Reversible processes performed in a closed system (ie, no addition or removal of reactants or products) eventually reach the point where the forward and reverse reaction rates are equal (not zero), as shown by the graph of reaction rate versus time in Figure 7.3.

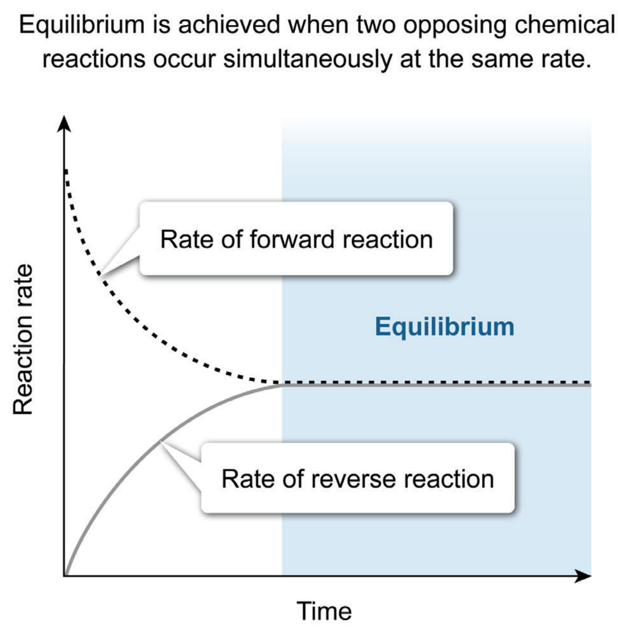

Figure 7.3 Equilibrium and reaction rates.

This means that both the forward and the reverse processes continue to take place at the same time, but their effects cancel each other. This results in no net change in the concentration of molecules, as shown by the graph in Figure 7.4. Because the reaction is continuously occurring (ie, does not stop), the system is said to be in a state of **dynamic** equilibrium.

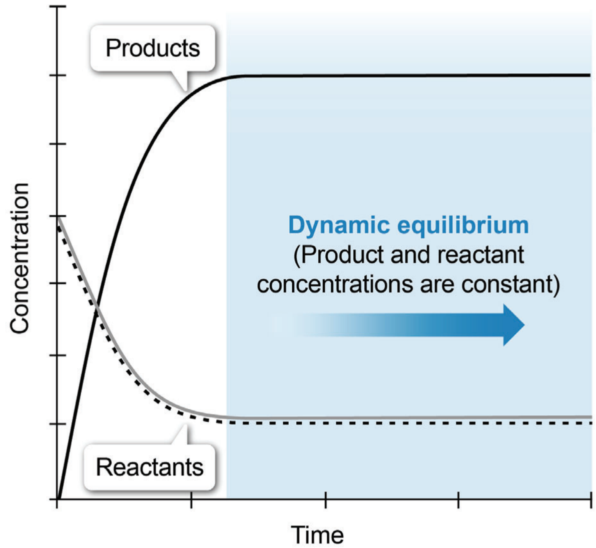

Figure 7.4 Reactant and product equilibrium concentrations.

7.2.01 Direction of Reversible Reactions

[TRA-6.B.1]

Consider the reversible reaction:

$$A \rightleftarrows B$$

When both products and reactants of a reversible reaction are present in the same container, both the forward reaction (ie, A → B) and the reverse reaction (ie, B → A) occur at the same time. However, the forward and reverse reaction rates depend on the concentrations of the reactants and products, respectively. By comparing the concentrations of reactants and products, the relative rates of the forward and reverse reactions can be evaluated.

For example, if the forward reaction occurs at a faster rate than the reverse reaction, there will be an overall increase in product concentration before reaching equilibrium (Figure 7.5).

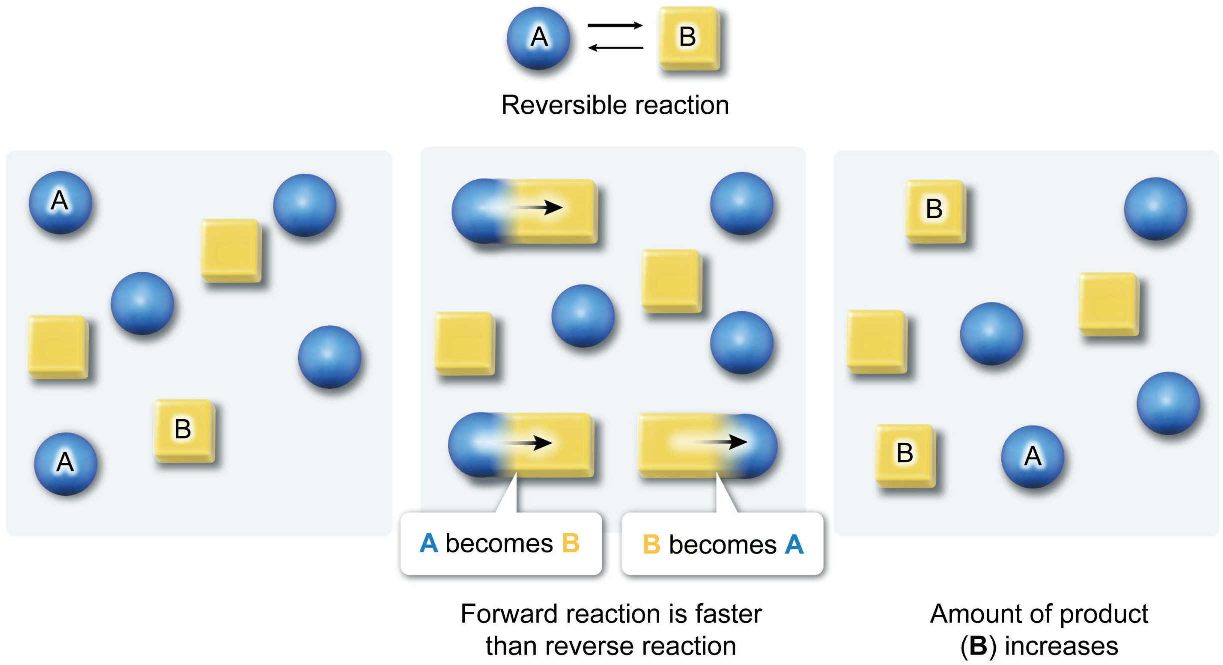

Figure 7.5 Increase in product formation.

On the other hand, if the reverse reaction occurs at a faster rate, there will be an overall increase in reactant concentration before reaching equilibrium (Figure 7.6).

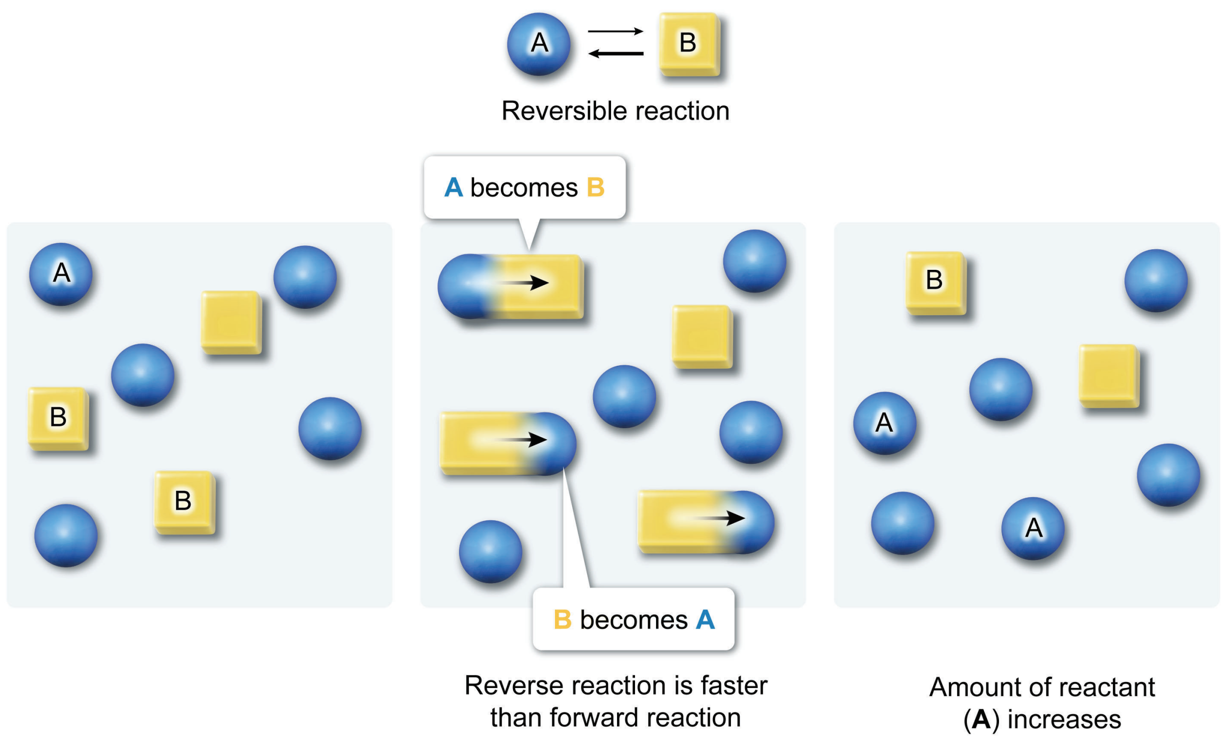

Figure 7.6 Increase in reactant formation.

If the forward and reverse reactions occur at the same rate, the system is in equilibrium, and product or reactant concentrations do not increase. The concentration of reactants and products in the reaction container remains constant over time.

Topic 7.1-7.2 Introduction to Equilibrium

Check for Understanding Quiz

1. A reversible chemical system is at equilibrium when:

   A. the forward and reverse reactions have stopped.

   B. the rates of the forward and reverse reactions are equal.

   C. the concentrations of products and reactants are equal.

   D. the number of product molecules is greater than reactant molecules.

2. If both reactants and products are present in a container, which of the following conditions will lead to the net formation of products in a reversible reaction?

   A. The forward reaction rate is faster than the reverse reaction rate.

   B. The reverse reaction rate is faster than the forward reaction rate.

   C. The forward and reverse reaction rates are equal.

   D. The rate of the forward reaction is zero.

Note: Answers to this quiz are in the back of the book (appendix).