Section 7.5

1 FOCUS

Objectives

7.5.1 **Identify** and **describe** physical and chemical equilibria.

7.5.2 **Describe** the factors affecting chemical equilibrium.

Reading Focus

Build Vocabulary L2

Paraphrase To help students understand the vocabulary terms, paraphrase their definitions using words and phrases students are more familiar with. For example, explain that a system is in *equilibrium* when there is no overall change in amounts even though there is a great deal of movement back and forth. A *reversible reaction* is a chemical reaction that can go forward and backward at the same time.

Reading Strategy L2

1. Physical equilibrium **2.** Chemical equilibrium **B.** Factors affecting chemical equilibrium **3.** Concentration

2 INSTRUCT

Types of Equilibria

Build Science Skills L2

Using Models

ACTIVITY

Purpose Students model dynamic equilibrium using playing cards.

Materials playing cards, watch

Class Time 10 minutes

Procedure Have one student use a watch to count seconds out loud one through six every six seconds. Have a second student pull cards from a deck and place them down in rows of six, one card down each second. After three rows of cards have been placed, have a third student begin to remove pairs of cards and place them on the deck every two seconds. Students will observe that the number of rows of cards does not change, because the cards are added and removed at the same rate.
Kinesthetic, Group

7.5 Equilibrium

Reading Focus

Key Concepts

- Under what conditions do physical and chemical equilibria occur?
- How do equilibrium systems respond to change?

Vocabulary

- equilibrium
- reversible reaction

Reading Strategy

Outlining As you read, make an outline of the most important ideas in this section.

I. Equilibrium
  A. Types of Equilibria
    1. ____________
    2. ____________
  B. ____________
    1. Temperature
    2. Pressure
    3. ____________

Suppose you're waiting in line for a toll booth at a bridge, like some of the cars shown in Figure 24. You notice that every time a car passes by a toll booth in the direction you are traveling, another car passes through the toll plaza in the opposite direction. The rate of cars entering equals the rate of cars exiting. As a result, the number of cars on either side of the toll plaza remains constant, although cars are continually entering and exiting the bridge.

Types of Equilibria

The traffic at a toll bridge is similar to a system in equilibrium. **Equilibrium** (plural *equilibria*) is a state in which the forward and reverse paths of a change take place at the same rate.

Recall that changes to matter are either physical or chemical. When opposing physical changes take place at the same rate, a physical equilibrium is reached. When opposing chemical changes take place at the same rate, a chemical equilibrium is reached.

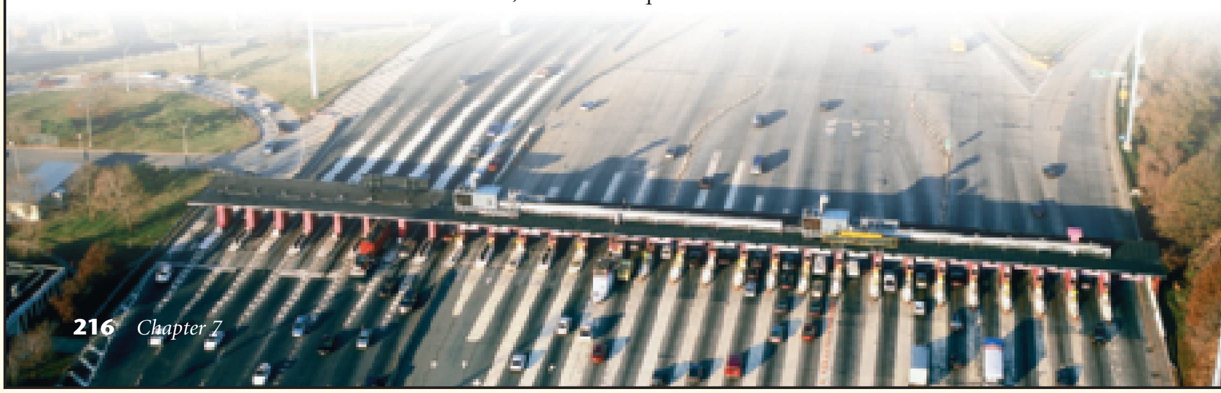


Figure 24 About 190,000 vehicles pass through the toll plaza of New York City's Verrazano-Narrows Bridge every day.

Section Resources

Print

- ***Reading and Study Workbook With Math Support,*** Section 7.5
- ***Transparencies,*** Section 7.5

Technology

- ***Interactive Textbook,*** Section 7.5
- ***Presentation Pro CD-ROM,*** Section 7.5
- ***Go Online,*** NSTA SciLinks, Factors affecting equilibrium

Physical Equilibrium What happens when you pour some water into a jar and then close the lid? You might think that nothing happens at all. But in fact, some of the water undergoes a physical change by evaporating. As more water evaporates, some of the water vapor condenses. Eventually, the rate of evaporation equals the rate of condensation, and the system reaches equilibrium as shown in Figure 25.

When liquid water is in equilibrium with water vapor, you can describe the system by writing this equation.

$$H_2O(l) \rightleftharpoons H_2O(g)$$

Here, *l* stands for liquid and *g* stands for gas. The pair of arrows in this equation indicates that the forward change (evaporation) and the reverse change (condensation) are happening simultaneously and at the same rate. Both the forward and reverse changes are physical changes, so this equation represents a physical equilibrium. **When a physical change does not go to completion, a physical equilibrium is established between the forward and reverse changes.**

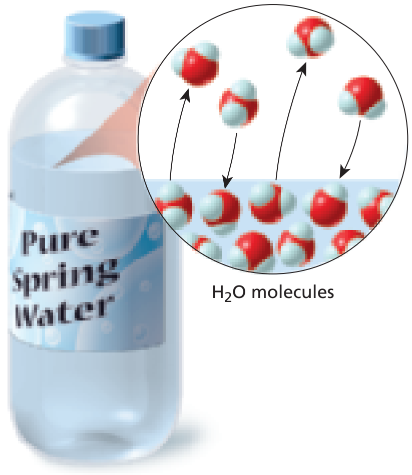


Figure 25 Liquid water left in a closed container eventually reaches equilibrium with its vapor. **Interpreting Diagrams** ***What do the arrows represent in the diagram above?***

Chemical Equilibrium All the chemical equations you have seen so far have been written with single arrows, which suggest that all reactions go to completion in one direction. In reality, however, most reactions are reversible to some extent. A **reversible reaction** is a reaction in which the conversion of reactants into products and the conversion of products into reactants can happen simultaneously.

In the previous section, you read about the synthesis of sulfur trioxide from sulfur dioxide and oxygen. This is actually a reversible reaction that can be expressed as

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

If sulfur dioxide and oxygen are mixed in a closed container, the forward reaction will start to produce sulfur trioxide. However, once molecules of sulfur trioxide form, some of them will change back into the reactants by the reverse reaction. Eventually, the rate of the forward reaction (synthesis) will equal the rate of the reverse reaction (decomposition), and the system will reach equilibrium. **When a chemical reaction does not go to completion, a chemical equilibrium is established between the forward and reverse reactions.** During chemical equilibrium, the reactants change into products just as fast as the products change back into reactants.

Reading Checkpoint ***What happens during chemical equilibrium?***

Go Online NSTA SCiLINKS

For: Links on factors affecting equilibrium
Visit: www.SciLinks.org
Web Code: ccn-1075

Use Visuals L1

Figure 25 Have students examine the molecular models of water in the bottle of spring water. Ask, **In which states does water exist inside the bottle?** *(Liquid and vapor)* **Are the molecules of water in the liquid state chemically different than the molecules of water in the vapor state?** *(No, both states of water have the same chemical properties.)* Tell the students that the two states of water are at equilibrium. Ask, **What do you know about the rates of the forward and reverse processes?** *(At equilibrium, the forward and reverse processes occur at the same rate.)* **How is this modeled in Figure 25?** *(The arrows show the same number of molecules leaving the liquid as there are molecules entering the liquid.)* **Visual**

Address Misconceptions L2

Many students incorrectly associate equilibrium only with having equal amounts of reactants and products. Challenge this misconception by discussing the following example. A beaker at 0°C contains 2 g of ice and 8 g of water. The rate of melting equals the rate of freezing. Is the system at equilibrium? *(Yes)*
Verbal, Logical

Go Online NSTA SCiLINKS

Download a worksheet on factors affecting equilibrium for students to complete, and find additional teacher support from NSTA SciLinks.

Customize for English Language Learners

Think-Pair-Share
Have students work in pairs to think of situations in which there is dynamic equilibrium. Examples include a doorman controlling the number of people who go in and out of an event, a clerk restocking the shelves at a grocery store, and a fountain consisting of a stream of water that pours into an overflowing vessel. Strengthen discussion skills by having students share their examples with the class. Encourage students to examine Figure 24 for an example of equilibrium in a real-world setting. Be sure that students understand that these examples are "open" systems, while dynamic equilibrium is a "closed" system.

Answer to . . .

Figure 25 *The arrows in the diagram shown represent opposing physical changes. The arrows pointing up represent evaporation, as liquid water changes into vapor. The arrows pointing down represent condensation, as the vapor changes into water.*

Reading Checkpoint *During chemical equilibrium, the reactants change into products at the same rate as the products change into reactants.*

Problem-Solving Activity

Recreating High Altitudes

L2

Defining the Problem The problem is how to design a training facility that can recreate a high-altitude environment. The design will depend on what property of the air you wish to manipulate.

Organizing Information The equation $Hb + O_2 \rightleftharpoons HbO_2$ describes the hemoglobin-oxygen-oxyhemoglobin system. At high altitudes, the concentration of oxygen decreases, which shifts the equilibrium to the left. In response to the reduced oxyhemoglobin levels, the body produces more hemoglobin.

Creating a Solution The desired shift in the equilibrium happens when you lower the concentration of oxygen. One way you can do this is by reducing the pressure of the air inside the training facility. Another way to lower oxygen concentration is to change the composition of the air within the facility. This can be done by piping in air with a reduced fraction of oxygen. In the second solution, the facility can be operated at normal air pressure.

Presenting Your Plan Students might point out certain structural characteristics of their designs in their proposals. For example, a normal-pressure/low-oxygen facility would require a customized ventilation system that pipes in air with reduced oxygen levels. **Logical**

For Extra Help

L1

Before they start, make sure students understand what the physical properties of air at a high altitude are. **Logical**

Factors Affecting Chemical Equilibrium

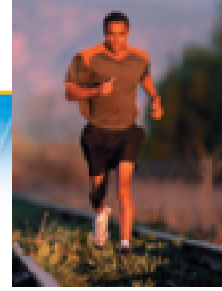
Build Reading Literacy

L1

Reciprocal Teaching Refer to page **628D** in **Chapter 21**, which provides the guidelines for reciprocal teaching.

Have students read the section with a partner. One partner reads a paragraph out loud. Then, the other partner summarizes the paragraph's contents and explains the main concepts. The partners continue to switch roles with each new paragraph until they have finished the section. **Intrapersonal**

Problem-Solving Activity



Recreating High Altitudes

An important chemical equilibrium in your blood involves the reaction of hemoglobin (Hb) with oxygen (O_2) to form oxyhemoglobin (HbO_2).

$$Hb + O_2 \rightleftharpoons HbO_2$$

This equilibrium changes with altitude. As you move from lower to higher elevations, the concentration of oxygen in the air decreases, and the equilibrium shifts in the direction that produces less oxyhemoglobin. Your body responds to the shift by producing more hemoglobin. Studies have shown that athletes can improve their performance at sea level by living or training at high altitudes. Some training facilities are designed to recreate high altitudes. Imagine that you are asked to build such a facility.

Defining the Problem In your own words, state the problem you face.

Organizing Information Use Le Châtelier's principle to determine how high altitudes affect this equilibrium system.

Creating a Solution The physical properties of the air inside the training facility include temperature, pressure, and composition. Figure out how to shift the equilibrium in the direction you want by changing one of these properties.

Presenting Your Plan Write a proposal to an athletic team that could benefit from using your training facility. Explain how your facility recreates a high-altitude environment.

Factors Affecting Chemical Equilibrium

Like reaction rates, chemical equilibria can change depending on the conditions of the reaction. While a reaction rate either increases or decreases in response to a change, an equilibrium shifts. That is, the equilibrium favors either the forward or the reverse reaction. **When a change is introduced to a system in equilibrium, the equilibrium shifts in the direction that relieves the change.** This rule was first observed by Henri Le Châtelier, shown in Figure 26. Today, the rule is known as Le Châtelier's principle.

Figure 26 French Chemist Henri-Louis Le Châtelier (1850–1936) published the first version of his principle of chemical equilibrium in 1884.

The making of ammonia is an example of a process in which chemists apply Le Châtelier's principle. Ammonia is an important industrial chemical used to make fertilizers, cleaning agents, dyes, and plastics. The following equation describes the synthesis of ammonia.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) + \text{Heat}$$

Suppose you have a system that contains nitrogen, hydrogen, and ammonia in equilibrium. By applying Le Châtelier's principle, you can predict how this system will be affected by changes in temperature, pressure, and concentration. In the ammonia plant shown in Figure 27, chemists must consider these same factors.

Temperature In the equation for the synthesis of ammonia, heat is written as a product. This tells you that the forward reaction is exothermic. In the reverse reaction, heat is a reactant. So the decomposition of ammonia is endothermic.

What would happen if you increased the temperature of a system that contained nitrogen, hydrogen, and ammonia? According to Le Châtelier's principle, if you added heat to the system, the equilibrium would shift in the direction that removes heat from the system. The system would favor the reverse reaction, which is endothermic. So by increasing the temperature, you would decrease the amount of ammonia.

Pressure Suppose you increased the pressure of the system. According to Le Châtelier's principle, if you increased the pressure, the equilibrium would shift in the direction that decreases the pressure of the system. In order to decrease pressure, the system would favor the reaction that produces fewer gas molecules. You can see that the left side of the equation has four gas molecules, while the right side has two. So by increasing the pressure, you would shift the equilibrium to the right, producing more ammonia.

Concentration A change in concentration of the reactants or products can also affect equilibrium. Suppose you removed ammonia from the nitrogen-hydrogen-ammonia system. Le Châtelier's principle tells you that the equilibrium would shift in the direction that produces ammonia. In order to produce ammonia, the system would favor the forward reaction.

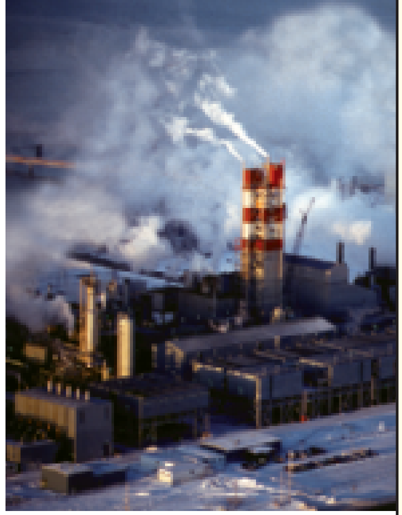


Figure 27 Operating an ammonia plant at relatively low temperature, high pressure, and low ammonia concentration maximizes the amount of ammonia produced.

Section 7.5 Assessment

Reviewing Concepts

1. What happens when a physical change does not go to completion? What happens when a reaction does not go to completion?
2. Once a chemical reaction has reached equilibrium, how does the system respond to change?
3. What does the double-ended arrow indicate in the following chemical equation?

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

4. For which of the following reactions are both reactants and products likely to be found when the reaction appears to be complete? Explain.

$$Mg + O_2 \longrightarrow 2MgO$$

$$HF + H_2O \rightleftharpoons H_3O^+ + F^-$$

Critical Thinking

5. **Inferring** Suppose the following reaction is allowed to come to equilibrium.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

How will increasing the pressure on this system affect the amount of N_2O_4 formed?

6. **Using Models** At 0°C, liquid water is in equilibrium with ice. Make a drawing of water molecules at this temperature, and describe what is happening.

Connecting Concepts

Phase Changes Write an equation for a system in which the sublimation and deposition of water have reached equilibrium. Use what you studied in Section 3.3 to explain what changes are happening.

Integrate Industry L2

The industrial synthesis of ammonia is called the Haber process and applies Le Châtelier's principle to maximize the efficiency of the production of ammonia according to the equation given in the text. Increasing the temperature increases the reaction rate, but shifts the equilibrium to the left. In order to shift the equilibrium back to the right, high pressure is applied. Ask, **What factors are used to shift equilibrium in the industrial synthesis of ammonia?** *(Temperature and pressure are used to shift equilibrium.)* **Logical**

3 ASSESS

Evaluate Understanding L2

Have students work in groups to perform a brief play that models a system in chemical or physical equilibrium.

Reteach L1

Compare the symbols used to show the movement of the water molecules with the double-arrow symbol used in a chemical equation that represents a reversible reaction. Ask students to discuss how these symbols are appropriate for describing equilibrium.

Connecting Concepts

$H_2O(s) \rightleftharpoons H_2O(g)$

In the forward change, ice is sublimating (changing into vapor). In the reverse change, water vapor is depositing (changing into ice). Because the system is in equilibrium, these opposite physical changes are taking place at the same rate.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 7.5.

Section 7.5 Assessment

1. A physical equilibrium is reached between the forward and reverse changes. A chemical equilibrium is reached between the forward and reverse reactions.
2. The system shifts in the direction that relieves the change.
3. The reaction is reversible, meaning that both the forward and reverse reactions are taking place at the same time.
4. The second reaction. The double-ended arrow indicates a reaction that reaches equilibrium. This means that both reactants and products are present when the reaction appears to be complete.
5. Increasing the pressure of the system will cause the equilibrium to shift to the right, so as to decrease the total number of gas molecules. As a result, the amount of N_2O_4 in the system will increase.
6. In their drawings, students should differentiate between solid and liquid phases of the system. They could do this by using different colors, or by showing an orderly arrangement for solid water and a disorderly arrangement for liquid water. Students can model the phase changes by drawing arrows (as in Figure 25 on p. 217). Because the system is in equilibrium, half of the arrows should show melting and the other half should show freezing.