# Equilibrium

In football, each team can have only a certain number of players on the field for each play. Different players come and go, but the total number of players on the field remains the same. You can think of players leaving and entering the field as opposing processes that occur at the same rate. Such a condition is known as equilibrium.

**Equilibrium** is a condition that exists when two opposing processes occur at the same rate. There are numerous examples of equilibrium in science:

- genetic equilibrium
  - a theoretical state in which a population is not evolving

- homeostasis
  - an organism's ability to regulate its internal environment

- mechanical equilibrium
  - the state in which the sum of the forces acting on an object is zero

- thermal equilibrium
  - the state where an object and its surroundings stop exchanging heat (i.e. they are at the same temperature)

- vapor-liquid equilibrium
  - the state where the rates of evaporation and condensation are equal for a liquid in a sealed container

Each of the above situations describes physical processes that oppose each other. In order for two physical processes to be in equilibrium, two conditions must be met:

1. The system must be closed (no matter can enter or leave the system).

2. The temperature must be constant.

**Reversible Reactions**

In past courses, we have always assumed that chemical reactions proceeded until one of the reactants was entirely consumed. In other words, the reactions proceeded to **completion**. While this is true for many reactions, some chemical reactions stop short of completion.

The reason why some reactions stop short of completion is because some reactions are **reversible reactions**, in which the products take part in a separate reaction to reform the reactants.

In theory, all reactions are reversible. However, while some reactions are reversible on their own, others are only reversible under restricted conditions. Still other reactions cannot even be forced to reverse under any conditions using what we currently know.

Consider the conversion of nitrogen dioxide to dinitrogen tetroxide (both major contributors of smog).

$$\underbrace{2NO_2(g)}_{brown} \rightarrow \underbrace{N_2O_4(g)}_{colorless}$$

When nitrogen dioxide is placed in an evacuated, sealed glass container, the initial dark brown color decreases in intensity as it is converted to colorless dinitrogen tetroxide. You might expect that as the reaction proceeds, the brown gas will eventually be completely changed into the colorless gas, but this is not the case. Instead, the intensity of the brown color decreases but eventually becomes constant, indicating that the concentrations of the reactant and product are no longer changing.

This reaction is an example of a reversible reaction. This means that just as nitrogen dioxide forms dinitrogen tetroxide in one direction,

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

dinitrogen tetroxide forms nitrogen dioxide in the other direction.

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

Rather than using the single arrow with which we are familiar, the standard way to write a reversible reaction is to use a double arrow to show that the reaction can proceed in both directions.

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

The reaction in which nitrogen dioxide forms dinitrogen tetroxide is called the **forward reaction**. The reaction in which dinitrogen tetroxide forms nitrogen dioxide is called the **reverse reaction**.

**Chemical Equilibrium**

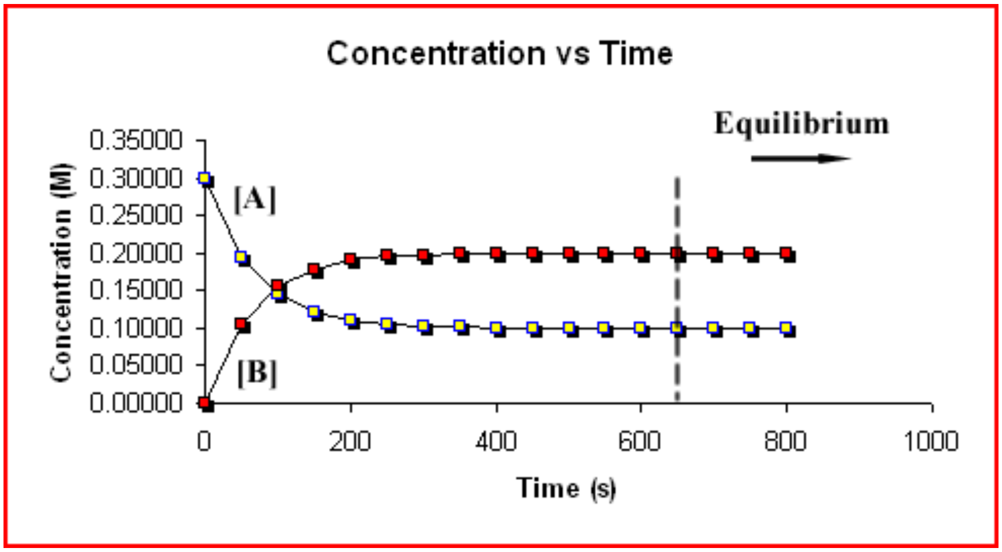
When substances enter into a reaction, the concentration of the reactants decreases as the reactants are converted into products. At the same time, the concentration of the products increases.

Since the concentration of each substance is changing, the rate of each reaction will be changing as well. The rate of the forward reaction will decrease from its original rate as the concentration of the reactants decreases. The rate of the reverse reaction will increase from zero (since there were no products at the start) as the concentration of the products increases.

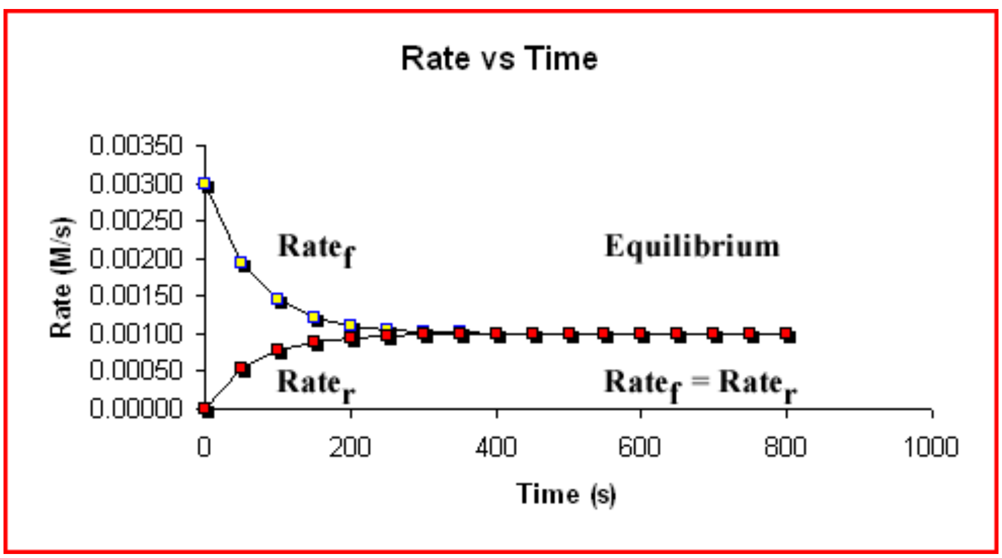
Eventually, the reaction reaches a stage known as **chemical equilibrium** at which the rate of the forward reaction and the rate of the reverse reaction are equal. In other words, reactants are being consumed in the forward reaction at exactly the same rate that they are being produced by the reverse reaction. Thus, the reactant concentration remains constant. The same is true for the products.

**Chemical equilibrium** is the state in which the concentrations of reactants and products remain constant because the rate at which they are formed in one reaction equals the rate at which they are consumed in the opposite reaction.

The graph below illustrates how the concentrations of the reactants [A] and products [B] change as the reaction progresses.




The graph below illustrates how the rates of the forward ($Rate_f$) and reverse ($Rate_r$) reactions change as the reaction progresses.



It is important to recognize that reaching equilibrium does not mean that the reaction has come to a stop. Chemical equilibrium is a dynamic process in which reactants are being converted into products and products is being converted into reactants, but both processes occur at the same rate. Thus, the net change in concentration is zero.

**Equilibrium Conditions**

In order for a chemical reaction to reach a state of equilibrium, the following conditions must be met:

1. There must be constant observable macroscopic properties (temperature, pressure, concentration).

2. The system must be closed (no matter can enter or leave).

3. Temperature must be constant.

4. The reaction must be reversible.

Name ______________________ Date ____________ Class ____________

# 16–1 Review and Reinforcement

## *The Concept of Equilibrium*

*On the line at the left, write the letter of the answer that best matches each description below.*

| | | |
|---|---|---|
| ______ | 1. the formation of products from reactants | a. reversible reaction |
| ______ | 2. a chemical reaction in which the products can generate the original reactants | b. chemical equilibrium |
| ______ | 3. the speed at which a reaction occurs | c. reverse reaction |
| ______ | 4. the regeneration of reactants from products | d. reaction rate |
| ______ | 5. the state in which the concentrations of reactants and products remain constant with time | e. forward reaction |

*Answer each of the following questions in the space provided.*

6. Explain how reaction rate and equilibrium are related. Give an example illustrating this relationship.

______________________________________________

______________________________________________

______________________________________________

7. In performing most calculations with chemical reactions, it is assumed that the reactants are entirely consumed. Is this assumption always appropriate? Explain.

______________________________________________

______________________________________________

______________________________________________

8. Can all reversible reactions be observed in the laboratory? Why or why not?

______________________________________________

______________________________________________

______________________________________________

______________________________________________

9. In the reaction below, which is the forward reaction and which is the reverse reaction?
$2SO_2 + O_2 \rightleftharpoons 2SO_3$

______________________________________________

______________________________________________

______________________________________________

Name ____________________ Date ____________ Class ____________

## *16–1 Review and Reinforcement (continued)*

**10.** What factors control the rate of a reaction?

**11.** How is the concentration of reactants related to the rate of a reaction?

**12.** When placed in a sealed container, $N_2$ and $H_2$ react according to the following equation: $N_2 + 3H_2 \rightleftharpoons 2NH_2$. How do the reaction rates and concentrations change as chemical equilibrium is attained?

**13.** Why will any chemical reaction reach equilibrium in a closed container?

**14.** Does a reaction stop once it has reached equilibrium? Explain.

**15.** Why is chemical equilibrium referred to as a dynamic equilibrium?