The chemical equilibrium state describes concentrations of reactants and products in a reaction taking place in a closed system, which no longer change with time. In other words, the rate of the forward reaction equals the rate of the reverse reaction, such that the concentrations of reactants and products remain fairly stable, in a chemical reaction. Equilibrium is denoted in a chemical equation by the $\rightleftharpoons$ symbol.

## Introduction

1. Equilibrium may only be obtained in a closed system.

2. The rate of the forward reaction is equal to the rate of the reverse reaction.

3. Catalysts have no effect on the equilibrium point. However, changes in the concentrations of either the products or reactants, temperature, volume, or pressure can offset the equilibrium point. This point illustrated in Le Chatelier's Principle.

4. The consistency of observable or physical properties such as concentration, color, pressure, and density can indicate a reaction has reached equilibrium.
Conditions for Equilibrium

The equilibrium state can only be reached if the chemical reaction takes place in a closed system. Otherwise, some of the products may escape, leading to the absence of a reverse reaction. (Note that in the diagrams under "Characteristics of Chemical Equilibrium," all reactions are in closed systems.)

Meaning

When the concentrations of reactants and products have become constant, an equation is said to have reached a point of equilibrium. The consistency of measurable properties such as concentration, color, pressure and density can show a state of equilibrium. The equilibrium state is said to be dynamic, meaning that the reaction is continuously in motion. This consistency, however, does not mean that the reactions have stopped, but rather that the rates of the two opposing reactions have become equal. The amount of products and reactants produced are consistent, and there is no net change.

For example, in this equation, the product, methanol (CH$_3$OH), is being produced at the same rate as the reactants, CO and H$_2$, in the reverse (backwards) reaction.

$$\text{CO(g)} + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$$

A graphical representation of chemical equilibrium is shown in the graph below. Starting from the beginning of the reaction, represented by the y-axis (or when time = 0), the rate forward reaction rises sharply, while the rate of the reverse reaction decreases. This is due to the reaction consisting of pure reactants. In order to advance the reaction, reactants are converted to products, and it is only until a large enough concentration of products are available, that the reverse reaction becomes a factor. It is at this point that we reach equilibrium, where the forward and reverse rates converge at the same point, forming the equilibrium state.
Equilibrium Constant

Given a chemical reaction, \( aA + bB \rightarrow cC + dD \), the equilibrium constant equation is expressed by the formula:

\[
K = \frac{[\text{products}]}{[\text{reactants}]} = \frac{[C]^c[D]^d}{[A]^a[B]^b}
\]

Note that the coefficients of the products/reactants are expressed as powers of the concentration.

Although the concentrations of the products and reactants may vary, the ratio of concentrations of products to the concentrations of reactants will remain constant. Therefore the value of \( K \) in an equilibrium state remains constant. To predict the direction of a reaction, look to the value of \( K \), the equilibrium constant.

- When the \( K \) is large, \( (K >1) \), products are favored.
- When \( K =1 \), neither side is favored.
- When \( K \) is small, \( (K<1) \), reactants are favored.

Real Life use of Chemical Equilibrium

Hemoglobin is the protein in an individual's blood responsible for transporting oxygen to other cells. The following equation describes how the hemoglobin protein (Hb) binds to four oxygen atoms, which your body then uses.

\[ \text{Hb(aq)} + 4\text{O}_2(\text{g}) \rightarrow \text{Hb(O}_2)_4 \]

An illustrated example of oxygen interacting with hemoglobin

As long as oxygen is available, a healthy equilibrium is maintained. However, at significant altitudes where air pressure is lowered, such as the top of mountains, there is less oxygen. According to Le Châtelier's
principle, the equilibrium then shifts to the left, away from oxygenated hemoglobin. Therefore, someone lacking oxygen in their body’s cells and tissues tend to feel light-headed.

Problems

1. For the balanced chemical reaction below, write an equation for the equilibrium constant, $K$.

$$2H_2(g) + N_2 \rightleftharpoons N_2H_4(g)$$

2. When more products are added to the equation in Problem 1, in what direction will equilibrium shift?

3. True or False: A reaction is in a state of equilibrium when the equilibrium constant $K$ is equal to 0.

4. For the balanced chemical reaction below, write an equation to find the equilibrium constant, $K$.

$$N_2(g) + 2O_2(g) \rightleftharpoons 2NO_2(g)$$

5. Which of the following does not affect the equilibrium point of a reaction?

   a. Adding products
   b. Increasing the temperature
   c. Using a catalyst
   d. Decreasing volume

Answers:

1. $K = [N_2H_4]/[H_2]^2[N_2]$
2. Right- towards the products
3. False- when the equilibrium constant remains constant
4. $K = [NO_2]^2/[N_2][O_2]^2$
5. (c)

References

Outside Links

- [http://www.files.chem.vt.edu/RVGS/AC.../chem-eqm.html](http://www.files.chem.vt.edu/RVGS/AC.../chem-eqm.html)
- [http://www.pennmedicine.org/health_i...ages/19443.jpg](http://www.pennmedicine.org/health_i...ages/19443.jpg)

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