Module 6: Chemical Equilibrium (CHM 1200)

Introduction

Many chemical reactions do not proceed in only one direction. Instead, the products that form during a reaction can also react to produce the original reactants.

Such reactions are called reversible reactions.

Over time, a reversible reaction may reach a condition where the forward and reverse reactions occur at the same rate. When this happens, the system is said to be in chemical equilibrium.

Understanding equilibrium is essential in many areas of chemistry, including:

• acid–base chemistry
• biochemical reactions
• industrial chemical processes

Although the term equilibrium may suggest that nothing is happening, equilibrium is actually a dynamic process in which reactions continue to occur in both directions.

Reversible Reactions

A reversible reaction is one that can proceed in both directions.

This type of reaction is represented using a double arrow:

$$A + B \rightleftharpoons C + D$$
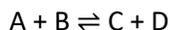
The arrow pointing to the right represents the forward reaction, where reactants form products.

The arrow pointing to the left represents the reverse reaction, where products form reactants.

Dynamic Equilibrium

At equilibrium:

• the forward reaction continues
• the reverse reaction continues

However, both reactions occur at the same rate.

As a result, the concentrations of reactants and products remain constant.

It is important to note that equilibrium does not mean that reactants and products have equal concentrations. It simply means their concentrations no longer change with time.

Example of Chemical Equilibrium

Consider the reaction:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$
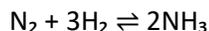
In this reaction:

Nitrogen gas reacts with hydrogen gas to form ammonia.

Initially, the reaction proceeds mainly in the forward direction.

As ammonia forms, some of the ammonia molecules begin reacting to reform nitrogen and hydrogen.

Eventually, the rates of the forward and reverse reactions become equal, and the system reaches equilibrium.

The Equilibrium Constant

The relative amounts of reactants and products present at equilibrium are described by the equilibrium constant, denoted by K.

For the reaction:

$$aA + bB \rightleftharpoons cC + dD$$
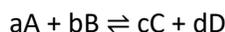
The equilibrium constant expression is:

$$K = ([C]^c [D]^d) / ([A]^a [B]^b)$$

where:

[A], [B], [C], [D] represent the concentrations of each substance.

Interpreting the Value of K

The magnitude of the equilibrium constant provides information about the reaction.

If K is large:

Products are favored at equilibrium.

If K is small:

Reactants are favored at equilibrium.

If K is approximately 1:

Reactants and products exist in comparable amounts.

ICE Tables

ICE tables are commonly used to organize equilibrium calculations.

ICE stands for:

Initial
Change
Equilibrium

This method allows students to systematically track how concentrations change during a reaction.

Structure of an ICE Table

Example reaction:

$$A \rightleftharpoons B$$

Stage	A	B
Initial	Initial concentration	Initial concentration
Change	-x	+x
Equilibrium	Initial - x	Initial + x

The variable **x** represents the change in concentration that occurs as the system moves toward equilibrium.

Worked Example

Consider the reaction:

$$A \rightleftharpoons B$$

Suppose the initial concentration of A is 1.0 M, and B is 0 M.

At equilibrium, some A has converted to B.

Construct an ICE table.

Stage	A	B
Initial	1.0	0
Change	-x	+x
Equilibrium	1.0 - x	x

This table helps express equilibrium concentrations in terms of the variable **x**.

Example With Equilibrium Constant

For the reaction:

$$A \rightleftharpoons B$$

Suppose the equilibrium constant is:

K = 4

Using the ICE table:

[A] = 1 - x
[B] = x

Substitute into equilibrium expression:

K = [B] / [A]

4 = x / (1 - x)

Now solve for x.

4(1 - x) = x

4 - 4x = x

4 = 5x

x = 0.8

Therefore:

[A] = 1 - 0.8 = 0.2 M

[B] = 0.8 M

Le Chatelier's Principle

Chemical equilibrium can be affected by changes in conditions such as:

• concentration
• temperature
• pressure

Le Chatelier's principle states:

When a system at equilibrium is disturbed, the system will adjust in a way that partially counteracts the disturbance.

Example: Concentration Change

Consider the reaction:

$$A + B \rightleftharpoons C$$

If additional reactant A is added to the system, the equilibrium shifts to the right, producing more product C.

Example: Temperature Change

Temperature changes can also affect equilibrium.

If heat is added to an endothermic reaction, the equilibrium shifts toward the products.

If heat is added to an exothermic reaction, the equilibrium shifts toward the reactants.

Practice Problems

1. What is meant by dynamic equilibrium?

2. Write the equilibrium constant expression for the reaction:

$$A + B \rightleftharpoons C$$

3. If K is very large, are reactants or products favored?

4. Construct an ICE table for the reaction:

$$X \rightleftharpoons Y$$

5. Explain Le Chatelier's principle.

Challenge Problems

1. A reaction has K = 0.01.
   Are reactants or products favored?

2. If additional product is added to a system at equilibrium, in which direction will the equilibrium shift?

3. Describe what happens to equilibrium when pressure increases in a gas reaction.