

# CHAPTER 9

# CHEMICAL EQUILIBRIUM

**Q1. Define complete reaction?**

**Ans. Complete reaction:**

A complete reaction is one in which all reactants have been converted to products.

**Q2. Define reversible reaction. Give examples.**

**Ans.** A reaction in which the products can react together to reform the original reactant is called reversible reaction.

**OR**

A reaction which proceeds in the forward reaction as well as in the reverse direction under the same conditions is called a reversible reaction.

**Properties of reversible reaction:**

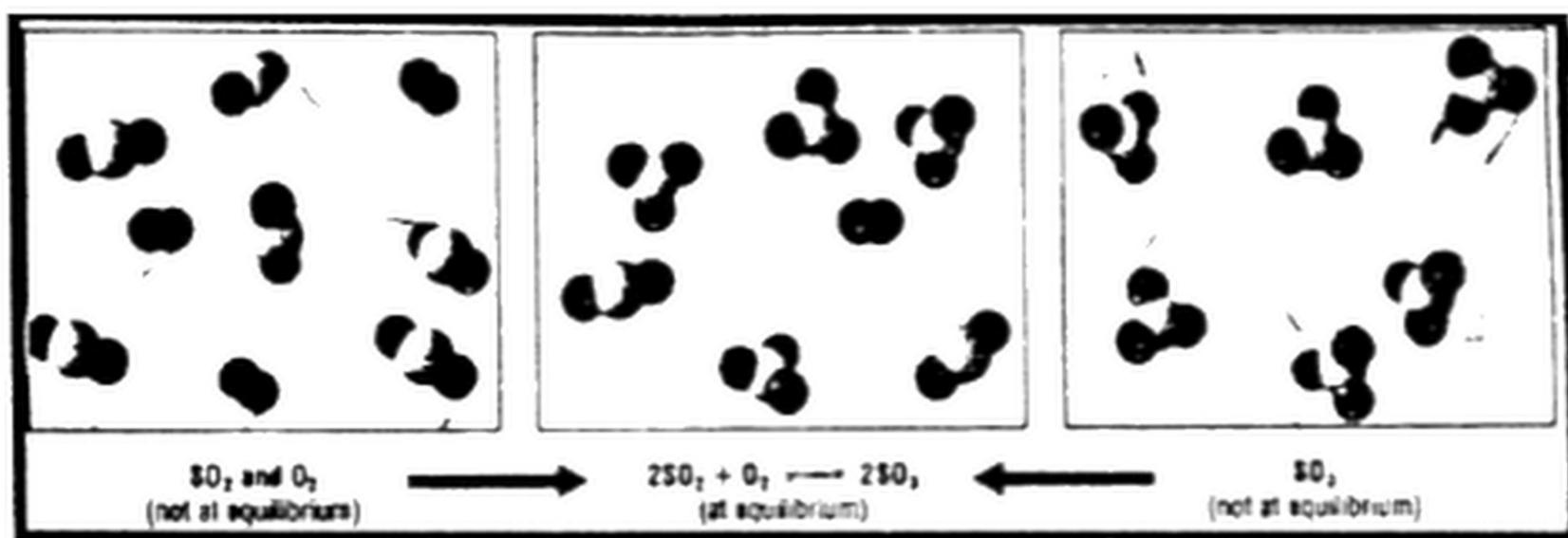
Reversible reactions never go to completion. All reversible changes (physical and chemical) occur simultaneously in both the directions.

The double arrow  $\rightleftharpoons$  in the chemical equation shows that the reaction is reversible.

**Examples:**





Reaction between SO<sub>2</sub> and O<sub>2</sub>

Molecules of SO<sub>2</sub> and O<sub>2</sub> react to give SO<sub>3</sub>. Molecules of SO<sub>3</sub> decompose to give SO<sub>2</sub> and O<sub>2</sub>.

#### Forward Reaction:

In the first reaction from left to right (from left to right) SO<sub>2</sub> and O<sub>2</sub> produce SO<sub>3</sub>.



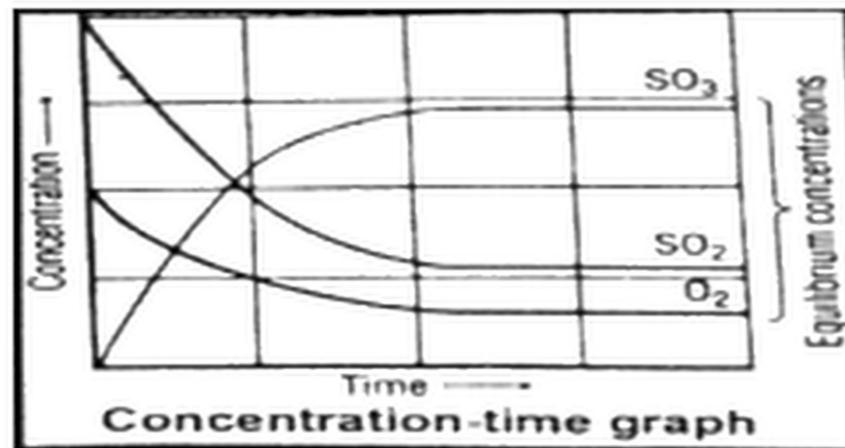
#### Reverse reaction:

In the second reaction (from right to left) SO<sub>3</sub> decompose into SO<sub>2</sub> and O<sub>2</sub>



#### Equilibrium state:

As the concentration of SO<sub>3</sub> becomes higher, the reverse reaction speeds up. Eventually, the two rates become equal. At this stage SO<sub>3</sub> decompose into SO<sub>2</sub> and O<sub>2</sub> as fast as SO<sub>2</sub> and O<sub>2</sub> produce SO<sub>3</sub>. At this stage



Concentration - Time graph

**Q5. Define chemical equilibrium?**

**Ans. Chemical equilibrium:**

A state of chemical reaction in which forward and reverse reaction takes place at the same rate is called chemical equilibrium.

**Q6. Why chemical equilibrium is a dynamic equilibrium?**

**Ans. Dynamic equilibrium:**

Chemical equilibrium is a dynamic equilibrium. This is because reactions do not stop when they come to equilibrium state. The individual's molecules keep on reacting continuously. But there is no change in actual amounts of reactants and products. This means concentration of reactants and products become constant at equilibrium stage.

**Q7. Example 9.1: Writing the forward and reverse reactions.**

Writing the forward and reverse reactions for the following reversible reaction:

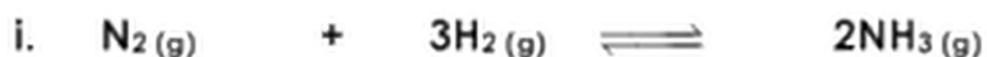


**Problem solving strategy:**

1. The reaction from left to right is the forward reaction.
2. The reaction from right to left is the reverse reaction.

**Solution: Forward reaction:****Reverse reaction:****Self-Assessment Exercise 9.1**

Write both forward and reverse reactions and describe macroscopic characteristics of each?

**Solution (i):****Forward reaction:****Reverse reaction:**

**Q8. Define law of mass action and derive expression for the equilibrium constant?**

Two chemists C.M Guldberg and P. Waage in 1864 proposed the law of mass action to describe the equilibrium state:

*"It states that the rate at which a substance reacts is directly proportional to its active mass and the rate at which a reaction proceeds is directly proportional to the product of the active masses of the reactants."*

### Active Mass:

The term "active mass" represents the concentration of reactants and products in moles.dm<sup>-3</sup> for a dilute solution, and is expressed in terms of square brackets [ ].

### Derivation for the expression for the equilibrium constant:

Consider a hypothetical reaction in which 'a' moles of reactant A and 'b' moles of reactant B react to give 'c' moles of product C and 'd' moles of product D at equilibrium.



According to the law of mass action;

Rate of forward reaction  $\propto [A]^a [B]^b$

Rate of forward reaction =  $k_f [A]^a [B]^b$

Rate of reverse reaction  $\propto [C]^c [D]^d$

Rate of reverse reaction =  $k_r [C]^c [D]^d$

Where  $k_f$  and  $k_r$  are the rate constants for forward and the reverse reactions respectively.

### At equilibrium stage:

Rate of forward reaction = Rate of reverse reaction. Thus

$$k_f [A]^a [B]^b = k_r [C]^c [D]^d$$

$$\underline{K_f} = \underline{\frac{[C]^c [D]^d}{[A]^a [B]^b}}$$

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

### Equilibrium constant:

Where  $K_c = \frac{K_f}{K_r}$  and is known as equilibrium constant, and the above equation is known as equilibrium constant expressions. The square brackets indicate the concentration of the chemical species at equilibrium in moles. $\text{dm}^{-3}$ .

### Q9. Define equilibrium constant?

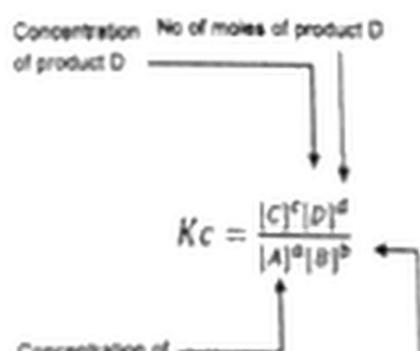
#### Ans. Equilibrium constant:

Equilibrium constant is defined as the ratio of the product of concentration of products to the product of concentration of reactants each raised to the power equal to the coefficient in the balanced chemical equation.



$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

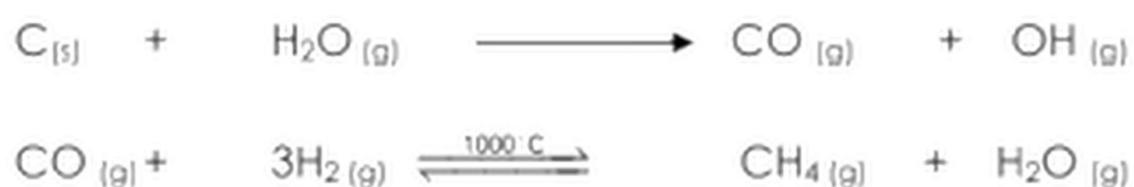
Q10. In the following flow diagram concentration of which species are taken in the numerator in  $K_c$  expression? Where the co-efficient of balanced chemical equation are shown in  $K_c$  expression?



**Ans.** Concentration of products is taken in numerator and concentration of reactants in denominator. Coefficient of balance chemical equation (a, b, c, d indicates number of moles of A, B, C, D) are shown in  $K_c$  as the raised to the power of concentration of products and reactant.

**Q11. Example 9.2: Writing Equilibrium Constant Expression.**

Coal can be converted to a gaseous fuel as methane. Coal reacts with hot steam to form CO and  $H_2$ . These gases can react further to give methane.  $1000^\circ\text{C}$ .



**Write equilibrium constant expression for this reaction.**

**Problem solving strategy:**

1. Write products in the numerator and reactants in the denominator in square brackets.
2. Raise each concentration to the power that corresponds to the coefficient of each species in the balanced chemical equation

**Solution:**

$$K_c = \frac{[\text{CH}_4][\text{H}_2\text{O}]}{[\text{CO}][\text{H}_2]^3}$$

**Self-Assessment Exercise 9.2**

**1. Following reaction can occur during lightning storms.**

Derive equilibrium constant expression for this reaction.

2. Write equilibrium constant expression for the following reactions.



Solution (1):



$$K_c = \frac{[\text{O}_3]^2}{[\text{O}_2]^3}$$

Solution (2):



$$K_c = \frac{[\text{H}_2\text{O}]^2[\text{Cl}_2]^2}{[\text{HCl}]^4[\text{O}_2]}$$



$$K_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]}$$

$$K_c = \frac{[H_2][F_2]}{[HF]^2}$$



$$K_c = \frac{[N_2O_4]}{[NO_2]^2}$$

(iv). State conditions for equilibrium.

**Ans. Conditions for equilibrium:**

- i. Concentration of none of the reactants or products of changed.
- ii. Temperature of the system is kept constant.
- iii. Pressure or volume of the system is kept constant.

**Q12. Example 9.3: determining units of equilibrium constants. Determine the units of equilibrium constants for following reactions.**



**Problem solving strategy:**

1. Write equilibrium constant expression.
2. Write units of concentration of each species i.e. mol dm<sup>-3</sup> within the square brackets.
3. Simplify the expressions.

**Solution:**

$$K_c = \frac{[\text{mole. dm}^{-3}]^2}{[\text{mole. dm}^{-3}][\text{mole. dm}^{-3}]}$$

$$K_c = \text{no units}$$

$K_c$  has no units when the total number of moles of reactants is equal to the total number of moles of products in a balanced chemical equation.

$$\text{ii. } K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2][\text{O}_2]}$$

$$K_c = \frac{[\text{mole. dm}^{-3}]^2}{[\text{mole. dm}^{-3}]}$$

$$K_c = \text{moles. dm}^{-3}$$

$$\text{iii. } K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]}$$

$$K_c = \frac{[\text{mole. dm}^{-3}]^2}{[\text{mole. dm}^{-3}]^2 [\text{mole. dm}^{-3}]}$$

$$K_c = \text{dm}^{-3} \cdot \text{mol}^{-1}$$

### DO YOU KNOW

#### Catalyst:

A catalyst is a substance which increases the rate of a chemical reaction. Catalysts reduce the time taken to reach equilibrium, but they have no effect on the position of equilibrium once this reached.

### Science Titbits

**Always add the acid to water when diluting it:**

For this reason, this must be avoided. Always add the acid to water when diluting it.

### Self-Assessment Exercise 9.3

Determine the units of equilibrium constants for the following reaction.



**Solution:**



$$K_c = \frac{[\text{NO}]^2}{[\text{N}_2][\text{O}_2]} = \frac{[\text{mole.dm}^{-3}]^2}{[\text{mole.dm}^{-3}][\text{mole.dm}^{-3}]} = \text{no units}$$

**Note:**  $K_c$  has no units when the total number of moles of reactants is equal to the total number of moles of products in a balanced chemical equation.

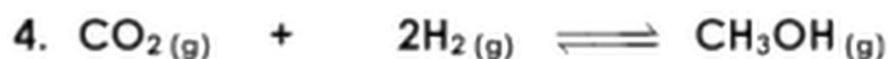


$$K_c = \frac{[\text{H}_2\text{O}][\text{CO}]}{[\text{H}_2][\text{CO}_2]} = \frac{[\text{mole.dm}^{-3}][\text{mole.dm}^{-3}]}{[\text{mole.dm}^{-3}][\text{mole.dm}^{-3}]} = \text{no units}$$

**Note:**  $K_c$  has no units when the total number of moles of reactants is equal to the total number of moles of products in a balanced chemical equation.



$$K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{[\text{mole.dm}^{-3}][\text{mole.dm}^{-3}]}{[\text{mole.dm}^{-3}]} = [\text{mol.dm}^{-3}]$$



$$K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}_2][\text{H}_2]^2} = \frac{[\text{mole.dm}^{-3}]}{[\text{mole.dm}^{-3}][\text{mole.dm}^{-3}]^2} = [\text{mol.dm}^{-3}]^2 = \text{mol}^2.\text{dm}^{-6}$$

### Q13. What is the importance of Haber process?

**Ans.** Ammonia is produced by the reaction of nitrogen with hydrogen at 450°C, 200 atm pressures and in the presence of catalyst.



This is known as Haber's process. This is a reversible process and produces only 33% NH<sub>3</sub> at equilibrium. The high pressure is used to favor the formation of ammonia. Then, cooling the equilibrium mixture gives 98% ammonia.

### Q14. What is the importance of contact process?

**Ans.** Sulphuric acid is produced on the large scale by contact process. In this process sulphur is converted into sulphur dioxide.



Sulphur dioxide is purified and further oxidized at 450°C and 200 atm pressures in the presence of Pt or V<sub>2</sub>O<sub>5</sub> as catalyst.



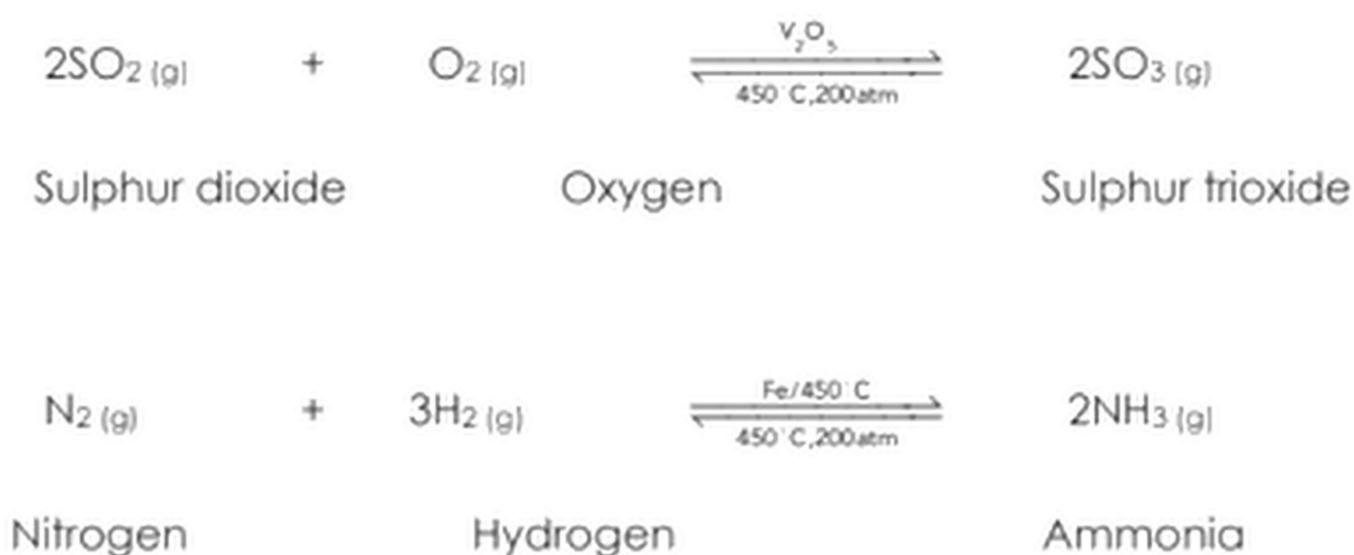
This reaction is reversible reaction. Here again by the application of principles of chemical equilibrium, maximum amount of  $\text{SO}_2$  is converted into  $\text{SO}_3$ . Sulphur trioxide is then converted into 100% pure sulphuric acid.

**Q15. Explain Le Chatellier's principle.**

**Ans. Le Chatellier's principle:**

*It says that if you impose a change in concentration, temperature or pressure on a chemical system at equilibrium, the system responds in a way that opposes the change.*

With the application of this principle, components of air i.e.  $\text{N}_2$  and  $\text{O}_2$  can be used successfully in producing important chemicals, ammonia and sulphuric acid in 98% yield. Both these processes involve reversible reaction, so inadequate (insufficient) number of products are formed under normal conditions.



As such these reactions are uneconomical, however, Le Chatellier's principle has made it possible to get maximum number of products.

