Chapter 1
Chemical Equilibrium

Time Allocation

Teaching periods	= 12
Assessment period	= 02
Weightage	= 12%

MAJOR CONCEPTS:

1.1 Reversible Reaction and Dynamic Equilibrium.
1.2 Law of Mass Action and Derivation of the expression for the Equilibrium Constant.
1.3 Equilibrium constant and Its Units.
1.4 Importance of Equilibrium Constant.

STUDENTS LEARNING OUT COMES (SLO'S)

Students will be able to:

- Define chemical equilibrium in terms of reversible reaction. (Understanding)
- Write both forward and reverse reaction and describe macroscopic characteristics of each reaction. (Applying)
- Define law of Mass action. (Understanding)
- Derive an expression for equilibrium constant and its unit. (Applying)
- State necessary conditions for equilibrium and the ways that equilibrium can be recognized. (Understanding)
- Describe equilibrium constant (Kc) equation for a reaction. (Remembering)

Introduction:

You know that many physical and chemical changes are occurring in our surrounding which may be due to chemical reaction. In these reactions reactants are converted into one or more products. The reactions may be reversible (condensation, evaporation, freezing, melting) or irreversible (Combustion, rusting). The reversible chemical reaction never goes to completion because product reacts and reproduce reactants again and take place in forward and reverse direction. This state in which forward reaction rate and reverse reaction rate are equal known as equilibrium. Which we will discuss in detail in this chapter.

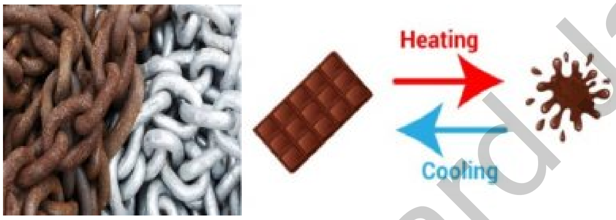


Figure 1.1 Irreversible and Reversible Changes

Do You Know?

Equilibrium in our Body

Equilibrium is present in our bodies. Hemoglobin is macromolecule that transports oxygen around our bodies. Without it we would not survive. The haemoglobin has to be able to take up oxygen, but also to release it and this is done through changes in the chemical equilibrium of this reaction in different places in our bodies.

1.1 Reversible reaction and Dynamic Equilibrium

As we know that a reaction which never complete and exist in forward and reverse direction such as conversion of ice into water by melting and conversion of water into ice by freezing is an example of reversible reaction. As shown in figure 1.2.

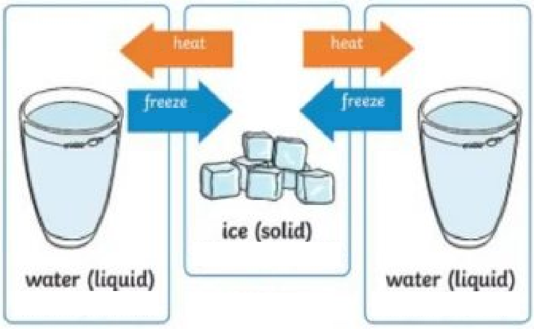


Figure 1.2 Changing of state by reversible reaction

A chemical reaction is a chemical change which involve reactants and products. For example, formation of water from hydrogen gas and oxygen gas, decomposition reaction of sodium bicarbonate into sodium carbonate , water, and carbon dioxide etc. A chemical reaction contains two quantities; reactant and product which are separated by an arrow.

$$\underset{\substack{\downarrow\\ \textbf{REACTANT}}}{2NaHCO_3} \longrightarrow \underset{\substack{\downarrow\\ \textbf{PRODUCT}}}{Na_2CO_3 + CO_2 + H_2O}$$

The direction of a reaction can be predicted by type of arrow; single headed arrow (→) used for irreversible reactions and a double half headed arrows (⇄)are used for reversible reaction, that never goes to completion. A reversible reaction containing two processes; forward and reverse. Hence, a reversible reaction can move in either direction depends upon conditions.

Figure 1.3
The original laboratory apparatus designed by Fritz Haber and Robert Le Rossignol in 1908 for synthesizing ammonia

Let us take an example of manufacturing of ammonia.When one mole of nitrogen gas reacts with three moles of hydrogen it produces two moles of ammonia gas.
This is known as 'Forward reaction'.

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

On contrast, two moles of ammonia gas may also be converted into one mole of nitrogen and three moles of hydrogen. This is known as ' Reverse reaction'.

$$N_{2(g)} + 3H_{2(g)} \leftarrow 2NH_{3(g)}$$

When both of these reactions are written together as a reversible reaction, they are represented as:

$$N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_{3(g)}$$

You know equilibrium means a 'balance'. Equilibrium exists in many ways in our surrounding.

The reaction rate depends on the concentration of the reactants. At the beginning the quantity of reactant is higher, and the rate of product formation is the higher. As the reactant amount decreases, the rate of reactant transformation also decreases, and the rate of product formation decreases. After a certain time, the concentrations of reactants and products become constant, and this state is called dynamic equilibrium.

Rate of forward reaction = Rate of reverse reaction

In a reversible reaction, dynamic equilibrium is established before the completion of reaction. The rate of both farward and reverse reaction becomes equal upon reaching the equilibrium point.The following graph which is of concentrations vs. time, shows that the concentrations of both reactants and product becomes constant at equilibrium.

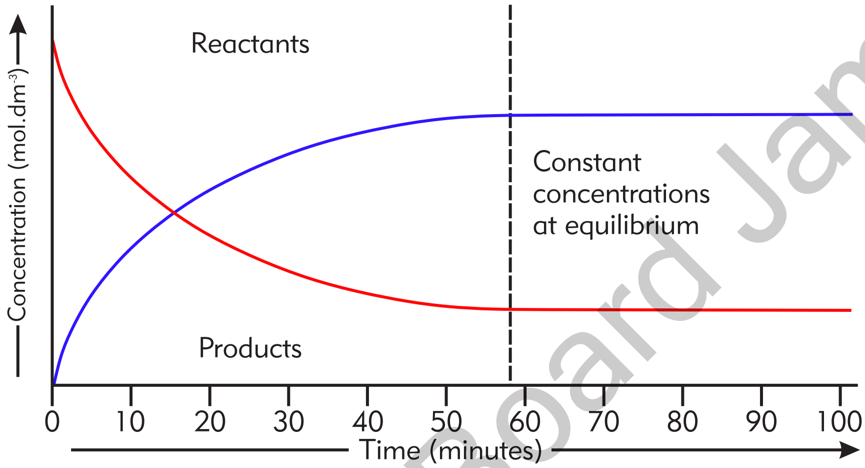


Figure 1.4 Dynamic equilibrium

An example of a reaction at equilibrium is a reaction of hydrogen and iodine in a closed container to produce hydrogen iodide. At the start of the reaction there is a high concentration of hydrogen and iodine and, after that the concentration decreases as hydrogen iodide is formed.

The concentration of hydrogen iodide increases as the forward reaction proceeds. As hydrogen iodide is formed, the reverse reaction is then able to occur.

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

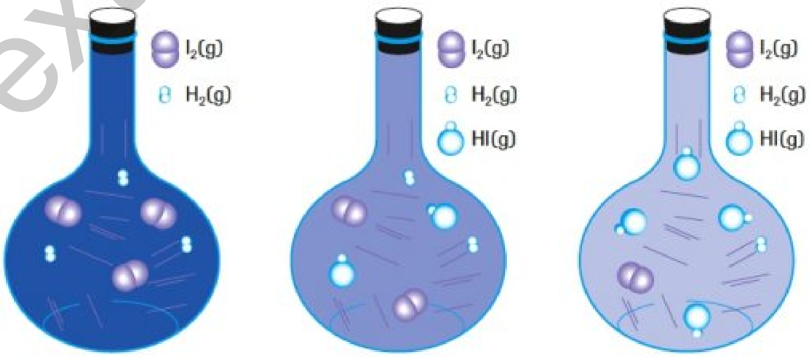


Figure 1.5 Hydrogen-iodine equilibrium system

So, there is no observable changes although both forward and reverse reactions are occurring. The reaction has not stopped but reached dynamic equilibrium.

Macroscopic characteristics of forward and reverse reaction

Forward reaction:

1. It is always directed from left to right in a chemical reaction
2. Reactants produce products(Reactants → Products)
3. Initially rate is fast but gradually slow down

Reverse reaction:

1. It is always directed from right to left in a chemical reaction
2. Product produce reactant (Reactants ← Products)
3. Initially rate is slow but gradually speed up

Macroscopic characteristics of forward and reverse reaction in dynamic equilibrium

1. A dynamic equilibrium can only exists in a closed system – neither reactants nor products can enter or leave the system
2. At equilibrium, the concentrations of reactants and products remain constant
3. At equilibrium, the forward and reverse reactions are taking place at equal and opposite rates.
4. Equilibrium can be approached from either side of the reaction equation
5. An equilibrium state can be disturbed and again achieved under the given condition of concentration, pressure, and temperature.

Test Yourself

1. Write down forward and reverse reactions for the following.

$$N_2\,(g) + O_2\,(g) \rightleftharpoons 2NO\,(g)$$

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

$$COCl_2\,(g) \rightleftharpoons CO\,(g) + Cl_2\,(g)$$

1.2 Law of Mass action and derivation of expression for equilibrium constant

The rate at which a substance reacts is directly proportional to its active mass and the rate of a reaction is directly proportional to the product of the active masses of the reacting substances.

The law of mass action also suggests that the ratio of the reactant concentration and the product concentration is constant at a state of chemical equilibrium.

Let us apply law of mass action on a hypothetical reversible reaction.

$$aA + bB \leftrightharpoons cC + dD$$

First let us discuss forward reaction, where A and B are reactants whereas 'a' and 'b' are number of moles needed to balance a chemical equation. The rate of forward reaction according to law of mass action is:

$$R_f \ \alpha \ [A]^a [B]^b$$

$$R_f = k_f [A]^a [B]^b$$

Where K_f is the rate constant for forward reaction.

Likewise, rate of reverse reaction is directly proportional to product of molar concentrations of C and D whereas 'c' and 'd' are number of moles needed to balance a chemical reaction.

$$R_r \ \alpha \ [C]^c [D]^d$$

$$R_r = k_r [C]^c [D]^d$$

Where K_r is the rate constant for reverse reaction. You know at equilibrium rate of forward and reverse reaction becomes equal. So,

$$R_f = R_r$$

Putting the values of R_f and R_r, we have

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

By taking constants on L.H.S and variables on R.H.S, we have

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

OR

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

OR

$$Kc = \frac{kf}{kr}$$

Do You Know?

What is Active Mass?

The concentration of reacting substance is called Active mass. The unit of active mass is mol dm^{-3} and its value is expressed in square brackets.

Hence,

$$Kc = \frac{[\text{Product}]}{[\text{Reactant}]}$$

Where Kc is called equilibrium constant.

Hence proven that law of mass action describe relation between active masses of reactants and products with rate of reaction. All the reversible reactions can be expressed in this form. Such as:

Example 1:

For the reaction of sulphur dioxide and oxygen to form sulphur trioxide, the balanced reversible reaction is:

$$2SO_{2(g)} + O_{2(g)} \leftrightharpoons 2SO_{3(g)}$$

According to law of mass action

Rate of forward reaction: $R_f = k_f [SO_2]^2 [O_2]$

Rate of reverse reaction: $R_r = k_r [SO_3]^2$

The expression for equilibrium constant Kc is:

$$Kc = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

Test Yourself

- Define the term active mass
- Figure out coefficients for given hypothetical reaction.
  $9X_{(g)}+Y_{3(g)} \rightleftharpoons 3X_3Y_{(g)}$
- Write down Kc equation for given reactions.
  - $S_{(s)}+O_{2(g)} \leftrightharpoons SO_{2(g)}$
  - $SO_{2(g)}+NO_{2(g)} \rightleftharpoons NO_{(g)}+SO_{3(g)}$
  - $NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(l)}$

1.3 Equilibrium constant and its units

Equilibrium constants are determined by observing the concentrations of each ingredient in a single reaction until it reaches equilibrium and then calculating its numerical value. You have to figure out the ratio of product to reactant concentrations. It is impossible to change a given reaction's equilibrium constant since concentrations are measured at equilibrium, and this is true regardless of initial concentrations. The temperature is the single factor affecting the equilibrium constant's value.

Important characteristics of equilibrium constant expression are as follows:

1. Kc only works in equilibrium.
2. It represents the equilibrium concentration of the reactant and product in mol.dm^{-3}.
3. Kc is independent of reactant and product concentrations.
4. Kc varies with temperature.
5. Kc is a balanced chemical equation coefficient. In a balanced chemical equation, each reactant and product has a concentration equal to its coefficient.
6. Kc represents equilibrium position. If Kc is larger than 1, the reaction is forward. If Kc is less than 1, the reaction is a reverse reaction.
7. Remember that equilibrium constant Kc is a ratio of reactant to product that is utilized to define chemical behavior.

At equilibrium :

Rate of the forward reaction = Rate of the backward reaction.

An equal number of moles on both sides of the equation has no unit in Kc. Because Kc expression uses concentration units that cancel. The unit of concentration is $mol.dm^{-3}$. Consider a reaction:

$$CO_{2(g)} + H_{2(g)} \leftrightharpoons CO_{(g)} + H_2O_{(l)}$$

$$Kc = \frac{[CO][H_2O]}{[CO_2][H_2]}$$

$$Kc = \frac{\cancel{[mol.dm^{-3}]}\cancel{[mol.dm^{-3}]}}{\cancel{[mol.dm^{-3}]}\cancel{[mol.dm^{-3}]}} = \text{no unit}$$

For reactions when the number of moles of reactants and product are not equal, Kc has a unit. Let us consider the following reaction:

$$N_{2(g)} + 3H_{2(g)} \leftrightharpoons 2NH_{3(g)}$$

$$Kc = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$Kc = \frac{[mol.dm^{-3}]^2}{[mol.dm^{-3}][mol.dm^{-3}]^3} = \frac{1}{[mol.dm^{-3}]^2} = mol^{-2}.dm^6$$

Numerical 01

Equilibrium occurs when nitrogen monoxide gas reacts with oxygen gas to form nitrogen dioxide gas.

$$2NO_{(g)} + O_{2(g)} \rightleftarrows 2NO_{2(g)}$$

At equilibrium at 230°C, the concentrations are measured to be : [NO] = 0.0542 $mol.dm^{-3}$, $[O_2]$ = 0.127 $mol.dm^{-3}$, and [NO 2] = 15.5 $mol.dm^{-3}$. Calculate the equilibrium constant at this temperature.

Solution

Given equilibrium concentrations of reactants and product are:

$[NO] = 0.0542\ mol.dm^{-3}$
$[O_2] = 0.127\ mol.dm^{-3}$
$[NO_2] = 15.5\ mol.dm^{-3}$

Write equilibrium expression as:

$$Kc = \frac{[NO_2]^2}{[NO]^2[O_2]}$$

Now put equilibrium concentration values in equilibrium constant expression

$$Kc = \frac{\left[15.5\text{mol}.dm^{-3}\right]^2}{\left[0.0542\text{mol}.dm^{-3}\right]^2\left[0.127\text{mol}.dm^{-3}\right]}$$

$$Kc = 6.44\times10^5\ \text{mol}^{-1}\cdot\text{dm}^3$$

Numerical 02

A reaction takes place between iron ion and chloride ion as:

$$Fe^{+3}_{(aq)} + 4Cl^-_{(aq)} \rightleftharpoons FeCl_4^-{}_{(aq)}$$

At equilibrium, the concentrations are measured to be (Fe^{+3}) is 0.2mol.dm^{-3}, Cl^- is 0.28mol.dm^{-3} and $FeCl_4^-$ is $0.95\times10^{-4}\ \text{mol.dm}^{-3}$. Calculate equilibrium constant Kc for given reaction.

Solution

Given equilibrium concentrations of reactants and product are:

$[Fe^{+3}] = 0.2\ \text{mol.dm}^{-3}$

$[Cl^-] = 0.28\ \text{mol.dm}^{-3}$

$[FeCl_4^-] = 0.95\times10^{-4}\ \text{mol.dm}^{-3}$

Write equilibrium expression as:

$$Kc = \frac{[FeCl_4^-\ ]}{[Fe^{+3}][Cl^-]^4}$$

Now put equilibrium concentration values in equilibrium constant expression

$$Kc = \frac{[\,0.95\times10^{-4}\ \ \text{mol .dm}^{-3}]}{[0.2\ \text{mol .dm}^{-3}][0.28\text{mol.dm}^{-3}]^4}$$

$$Kc = \frac{[0.95\text{x}10^{-4}\text{mol .dm}^{-3}]}{[0.2\ \text{mol .dm}^{-3}][0.28\text{mol.dm}^{-3}]^4}$$

$$Kc = 7.72\text{x}10^{-2}\text{mol}^{-4}\cdot\text{dm}^{12}$$

Numerical 03

Nitrogen oxides are air pollutants produced by the reaction of nitrogen and oxygen at high temperature. At 2000 °C, the value of the equilibrium constant for the given reaction is 4.1×10^{-4}

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$$

Find the concentration of NO in an equilibrium mixture at 1 atm pressure at 2000°C. In air, $[N_2] = 0.036$ mol/L and $[O_2] = 0.0089$ mol/L.

We are given all of the equilibrium concentrations except that of NO. Thus, we can solve for the missing equilibrium concentration by rearranging the equation for the equilibrium constant.

$$Kc = \frac{[NO]^2}{[N_2][O_2]}$$

$$[NO]^2 = Kc[N_2][O_2]$$

Taking square root on both the sides, we have

$$\sqrt{[NO]^2} = \sqrt{(4.1 \times 10^{-4}\,\text{mol/L})\,(0.036\,\text{mol/L})\,(0.0089\,\text{mol/L})}$$

$$[NO] = 3.6 \times 10^{-4}\ \text{mol/L}$$

1.4 Importance of equilibrium constant

The value of Kc varies depending on the response. Kc isn't only a calculating constant. It affects both the direction and the extent of a chemical reaction.

1. Direction of a chemical reaction

When dealing with reversible reactions, it is critical to determine the reaction's direction at any given time. For example, to produce ammonia efficiently from nitrogen and hydrogen, we must optimize the process. So it's critical to forecast the reaction's condition at any given time.The reaction quotient, Qc, can help make such predictions. It has the same mathematical structure as Kc, but Qc is a ratio of real concentrations computed at a given moment (not a ratio of equilibrium concentrations).

Comparing Kc and Qc values predicts response direction. We have three categories:

1. If Qc = Kc, the actual product and reactant concentrations are equal to the equilibrium concentrations, and the system is stable.
2. If Qc < Kc then there is increase in product concentration for equilibrium. So the forward reaction occurs, forming additional products.

3. If Qc > Kc, There is decrease in product concentration & to achieve equilibrium. As, the process reverses, forming more reactants.

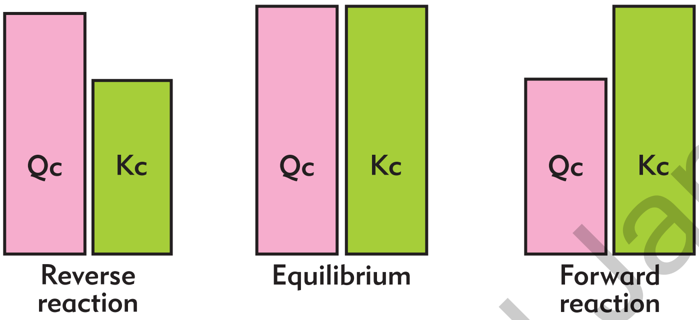


Figure 1.6 Directions of chemical reaction

2. Extent of chemical reaction

At a certain temperature, the extent of a reaction is measured. The magnitude of an equilibrium constant can predict the scope of a chemical reaction. As magnitude may be very high, very low, or moderate, so can be Extent of chemical reaction.

i. Kc is very small

Reactions with low Kc never finish. That is, maximum reactant concentration and minimum product concentration. These are called 'reverse or backward responses.

$$F_{2(g)} \rightleftharpoons 2F_{(g)} \qquad Kc= 7.4 \times 10^{-13} \text{ at } 227^{\circ}C$$

ii. Kc is very large

Reactions with high Kc values are virtually complete. That is, maximum product concentration and minimum reactant concentration. This type of reaction is known as 'Forward reaction'.

$$2H_{2(g)}+O_{2(g)} \rightleftharpoons 2H_2O_{(g)} \qquad Kc= 2.4 \times 10^{47} \text{ at } 227^{\circ}C$$

iii. Kc is neither very small nor very large

Reactions which have moderate value of Kc are considered to be at equilibrium. The concentration of reactants and products is almost same. For example:

$$N_2\,O_{4(g)} \rightleftharpoons 2NO_{2(g)} \qquad Kc= 0.36 \text{ at } 25^{\circ}C$$

Do You Know?

Equilibrium constants exist for certain groups of equilibria, such as for weak acids, weak bases, the autoionization of water, and slightly soluble salts.

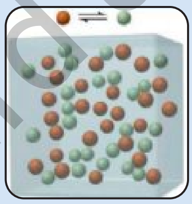
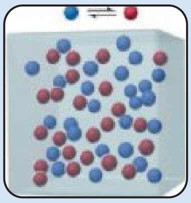
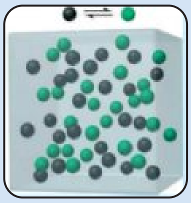
Test Yourself

- The value of K_C for the following reaction at 717 K is 48.

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

At a particular instant, the concentration of H_2, I_2 and HI are found to be 0.2 mol L^{-1}, 0.2 mol L^{-1} and 0.6 mol L^{-1} respectively. Calculate reaction quotient for given reaction. Also predict direction of reaction.

- **Match each of the following statement with appropriate diagram.**

A	Small Kc indicates that reaction mixture mostly contains reactants.	(i)	
B	Moderate Kc indicate that reaction mixture contains equal amount of reactant and product.	(ii)	
C	Large Kc indicates that reaction mixture mostly contain product.	(iii)	

Society, Technology and Science

The atmosphere is composed of nitrogen, oxygen, carbon dioxide, methane, nitrous oxide and ozone but the nitrogen and oxygen gases are the most important part of the atmosphere. They are 99% of the atmosphere and use to manufacture chemicals such as nitrogen is used for preparation of ammonia and ammonia is used to prepare nitrogenous fertilizers. Oxygen is used for preparation of sulphur dioxide and sulphur dioxide is used to prepare sulphuric acid.

Summary

- In our daily life we must have observed certain changes occurring, either physically or chemically. In chemical change a stage observed, in which rate of forward reaction becomes equal to the rate of reverse reaction indicating a state of equilibrium.
- Chemical equilibrium always observed in reversible reactions. In reversible reactions reactants and product interconvert into each other. These reactions will never reach to completion. Reversible reactions proceed in either direction i,e forward and backward.
- In dynamic equilibrium the rate of forward reaction is high, and rate of reverse reaction is slow in beginning. As equilibrium achieved both the rates become equal.
- Dynamic equilibrium can only be achieved in a closed container with fixed temperature.
- According to law of mass action:

  "At any instant, the rate of a chemical reaction at a given temperature is directly proportional to the product of the active masses of the reactants at that instant."

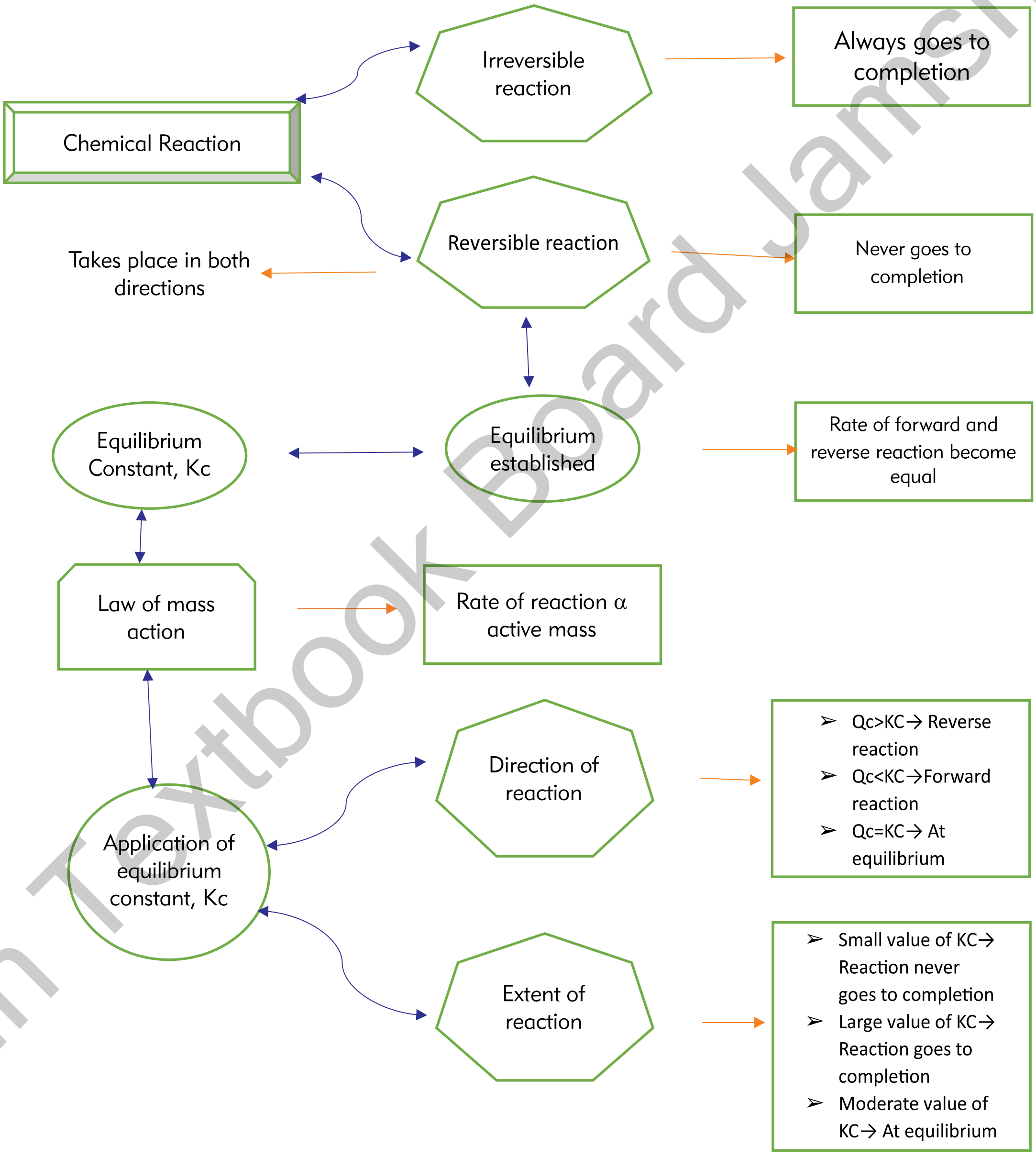
  $$aA + bB \leftrightharpoons cC + dD$$

  the equilibrium equation is given by:

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

  Where Kc is equilibrium constant.
- An equilibrium constant Kc is used to show relationship between molar concentration of product and molar concentration of reactant. As Kc is a ratio and usually has no unit. Kc is independent of initial concentration of reactant and product. Kc is temperature dependent.
- The value of equilibrium constant, Kc tells us the extent of a reaction, i.e., it indicates how far the reaction has proceeded towards product formation at a given temperature. It also gives direction of reaction.
- Under non-equilibrium conditions, reaction quotient 'Qc' is defined as the ratio of the product of active masses of reactant and products raised to the respective stoichiometric coefficients in the balanced chemical equation to that of the reactants.

CONCEPT DIAGRAM



Exercise

SECTION- A: MULTIPLE CHOICE QUESTIONS

Tick the correct answer from the following.

1. Which one of the following statements is false about dynamic equilibrium?
   - a. It takes place in a close container
   - b. Concentration of reactant and products are not changed
   - c. Rate of forward reaction is equal to rate of reverse reaction
   - d. Equilibrium cannot be disturbed by any external stress

2. Consider the following reaction and indicate which of the following best describe equilibrium constant expression Kc.

   $4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_20$

   - a. $Kc = \frac{[NO]^4\,[H_2O]^6}{[NH_3]^4\,[O_2]^5}$
   - b. $Kc = \frac{[NH_3]^4\,[O_2]^5}{[NO]^4[H_2O]^6}$
   - c. $Kc = \frac{[NH_3][O_2]}{[H_2O][NO]}$
   - d. $Kc = \frac{[4NO][6H_2O]}{[4NH_3][5S_2]}$

3. A reaction which is never goes to completion is known as reversible reaction. Reversible reaction is represented by:
   - a. Doted lines
   - b. Single arrow
   - c. Double arrow
   - d. Double straight line

4. When the magnitude of Kc is small, indicates
   - a. Reaction mixture contain most of the reactant
   - b. Reaction mixture contain most of the product
   - c. Reaction mixture contain almost equal amount of reactant and product
   - d. Reaction goes to completion

5. For which system does the equilibrium constant, Kc has units of concentration

a. $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

b. $N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$

c. $H_{2(g)} + I_{2(g)} \rightleftharpoons 2\ HI_{(g)}$

d. $CO_{2(g)} + H_{2(g)} \rightleftharpoons CO_{(g)} + H_2O_{(l)}$

6. The unit of Kc for reaction $N_2 + O_2 \rightleftharpoons 2NO$

a. mol dm^{-3}

b. $mol^{-2}\ dm^6$

c. $mol^{-1}\ dm^3$

d. no unit

7. The system is stable in equilibrium when:

a. $Q_c = K_c$

b $Q_c > K$

c $Q_c < K$

d None of these

8. Qc can be defined as:

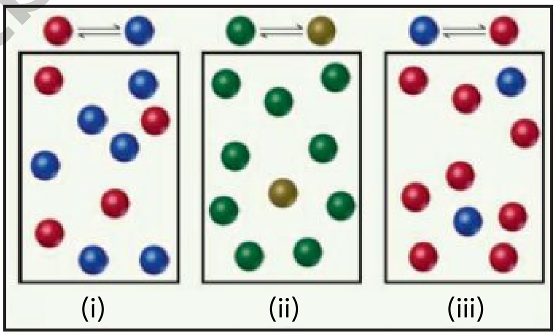
a. ratio of product and reactants

b. ratio of molar concentration of product and reactant at specific time

c. ratio of molar concentration of product and molar volume of reactant

d. ratio of molar concentration of product and reactant raised to the power of coefficient

9. Which of the following represent backward reaction?



a. (i) and (ii)

b. (ii) and

c. (ii) only

d. (iii) o nly

10. The value of Kc increases when:
   a. [Product] is less
   b. [Product] is more
   c. [Reactant] is more
   d. [Reactant = product]

SECTION- B: SHORT QUESTIONS:

1. Define chemical equilibrium with example.
2. Why chemical equilibrium is dynamic?
3. When writing an equation, how is a reversible reaction distinguished from irreversible reaction?
4. Write an equilibrium equation of monoatomic carbon and a molecule of oxygen as reactant and carbon monoxide as product.
5. Outline the characteristics of reversible reaction.
6. Distinguished between reversible and irreversible reaction.
7. State law of mass action. How is the active mass is represented?
8. Why equilibrium constant may or may not have unit? Justify with example.
9. How direction of a reaction can be predicted if Kc is known to you.
10. Write equilibrium constant expression for the following equations:
    i) $N_2 + 2O_2 \rightleftharpoons 2NO_2$
    ii) $N_2 + 3H_2 \rightleftharpoons 2NH_3$
    iii) $H_2 + Br_2 \rightleftharpoons 2HBr$

SECTION- C: DETAILED QUESTIONS:

1. Describe dynamic equilibrium with two examples.
2. State law of mass action. Derive an expression for equilibrium constant.
3. Describe the characteristics of equilibrium constant.
4. How can you predict the following stages of a reaction by comparing the values of Kc and Qc.
   i) Net reaction proceeds in forward direction.
   ii) Net reaction proceeds in reverse direction
5. Predict which system at equilibrium will contain maximum amount of product and which system will contain maximum amount of reactant?
   a) $2CO_{2(g)} \rightleftharpoons 2CO_{(g)} + O_{2(g)}$ $Kc(927^{\circ}C) = 3.1 \times 10^{-18}$ $mol.dm^{-3}$
   b) $2O_{3(g)} \rightleftharpoons 3O_{2(g)}$ $Kc(298K) = 5.9 \times 10^{55}$ $mol.dm^{-3}$

SECTION- D: Numerical

1. Dinitrogen tetra oxide N_2O_4 decomposed into nitrogen dioxide NO_2 in a reversible reaction. Derive equilibrium constant expression for the reaction of decomposition. Also interpret unit of Kc for balanced chemical reversible reaction.
2. PCl_5, PCl_3 and Cl_2 are at equilibrium at 500K in a closed container and their concentrations are 0.8×10^{-3} mol dm^{-3}, 1.2×10^{-3} mol dm^{-3} and 1.2×10^{-3} mol dm^{-3} respectively. Calculate the value of K_C for the reaction along with unit.
3. The value of Kc for the reaction is 1×10^{-4}

$$2HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)}$$

At a given temperature, the molar concentration of reaction mixture is $HI = 2 \times 10^{-5}$ mol dm^{-3}, $H_2 = 1 \times 10^{-5}$ mol dm^{-3} and $I_2 = 1 \times 10^{-5}$ mol dm^{-3}. Predict the direction of the reaction.