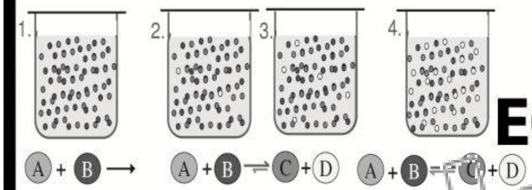
CHAPTER 9

CHEMICAL EQUILIBRIUM



INTRODUCTION

SHORT QUESTIONS

Q.1 What are chemical reactions? ***(Knowledge Base)***

Ans: **CHEMICAL REACTION**

Definition:

"The process in which chemical change occurs in nature and composition of substances is called chemical reaction".

Examples:

- Rusting of iron
- $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$

Q.2 Differentiate between reactants and products. ***(Understanding Base)*** **(MTN 2016 G-I, FSD 2016 G-II)**

Ans: **DIFFERENTIATION**

The differences between reactants and products are as follows:

Reactants	Products
Definition	
• In a chemical reaction the substances that combine are called reactants.	• The new substances formed during a chemical reaction are called products.
Example	
• In a reaction $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$ H_2 and O_2 are reactants.	• In a reaction $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$ H_2O is product.

Q.3 What is complete reaction? How it is represented? ***(Understanding Base)*** **(LHR 2018)**

Ans: A reaction in which **all** the **reactants** are **converted** into **products** is called complete reaction.

Representation: It is represented by single arrow " $\longrightarrow$ "

Example: $\mathbf{2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}}$

Q.4 Write down an example of equilibrium in nature. ***(Knowledge Base + Understanding Base)***

Ans: **EQUILIBRIUM IN NATURE**

Following examples describe the phenomenon of equilibrium in nature:

(i) Between O_2 and CO_2:

We owe our existence to equilibrium phenomenon taking place in atmosphere. We inhale oxygen and exhale carbon dioxide, while plants consume carbon dioxide and release oxygen. This natural process is responsible for the existence of life on the Earth.

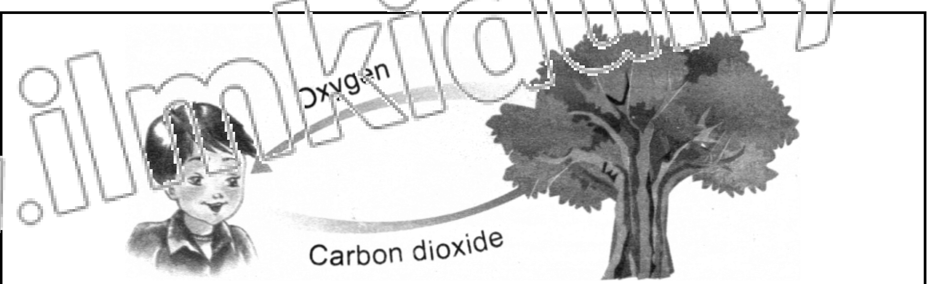


Figure: Showing Equilibrium Between O_2 and CO_2 in atmosphere

INTRODUCTION

MULTIPLE CHIOICE QUESTIONS

1. In chemical reactions the substances that combine are called: *(K.B)* **(FSD 2017 G-I)**
(A) Products (B) Reaction intermediates
(C) Reactants (D) Both A and C

2. Name the reactants in the equation, $2H_{2(g)} + O_{2(g)} \xrightarrow[\text{Heat}]{\text{Pt}} 2H_2O_{(l)}$ **: *(K.B)***
(A) Water (B) Hydrogen and oxygen
(C) Oxygen (D) None of these

3. The reactions in which all the reactants have been converted into products are known as: *(K.B)*
(A) Incomplete reactions (B) Complete reactions
(C) Continuous reactions (D) Reversible reactions

4. A complete reaction is one in which: *(U.B)* **(LHR 2016)**
(A) All the reactants convert into products
(B) All the reactants do not convert into products
(C) Half of the reactants convert into products
(D) Only 10% reactants convert into products

5. Plants consume carbon dioxide and release: *(K.B)*
(A) Oxygen (B) Water
(C) Carbon monoxide (D) Hydrogen

6. Human beings exhale: *(K.B)*
(A) Oxygen (B) Carbon monoxide
(C) Carbon dioxide (D) All of these

7. Name the products in the equation, $2H_{2(g)} + O_{2(g)} \xrightarrow[\text{Heat}]{\text{Pt}} 2H_2O_{(l)}$ **:*(K.B)***
(A) Water (B) Hydrogen and oxygen
(C) Oxygen (D) None of these

9.1 REVERSIBLE REACTION AND DYNAMIC EQUILIBRIUM

LONG QUESTIONS

Q.1 Explain in detail the reversible reaction with the help of suitable examples. *(Knowledge Base + Understanding Base)* **(Ex: Q.1)** **(SGD 2014)**

OR

Describe dynamic equilibrium with the help of examples. **(MTN 2017, RWP 2017)**

Ans: **REVERSIBLE REACTIONS**

Definition:
"*The reactions in which the **products** can **recombine** to **form reactants** are called reversible reactions*".

Example 1:
(Reaction between H_2 and I_2):
Let us discuss a reaction between hydrogen and iodine. Because one of the reactant, **iodine is purple,** while the product **hydrogen iodide** is colorless, proceedings of the reaction are easily observable.

Forward Reaction:

On heating, hydrogen and iodine vapours in a closed flask, hydrogen iodide is formed. As a result, purple color of iodine fades as it reacts to form colorless hydrogen iodide.

$$\underset{\text{Colorless}}{H_2} + \underset{\text{Purple}}{I_2} \xrightarrow{\Delta} \underset{\text{Colorless}}{2HI}$$

Reverse Reaction:

When only hydrogen iodide is heated in a flask, purple colour appears because of formation of iodine vapours. Such as:

$$\underset{\text{Colorless}}{2HI} \dashrightarrow \underset{\text{Colorless}}{H_2} + \underset{\text{Purple}}{I_2}$$

In this case, hydrogen iodide acts as reactant and produces hydrogen and iodine vapours. This reaction is reverse of the above. Therefore, it is called reverse reaction.

At Equilibrium State:

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

$$2HI \rightleftharpoons H_2 + I_2$$

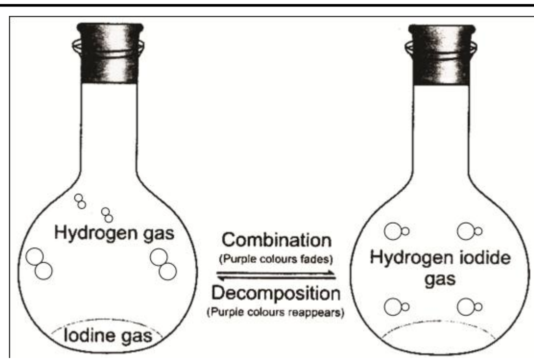


Figure: Showing Establishment of Reversible Reaction

Example 2:

(Reaction between Calcium Oxide and Carbon Dioxide):

(i) In Open Container:

When $CaCO_3$ is heated in an open flask, it decomposes to form calcium oxide and carbon dioxide. CO_2 escapes out and reaction goes to completion.

$$CaCO_3 \longrightarrow CaO + CO_2 \text{ (decomposition)}$$

In these two reactions, decomposition is reverse to combination or vice versa.

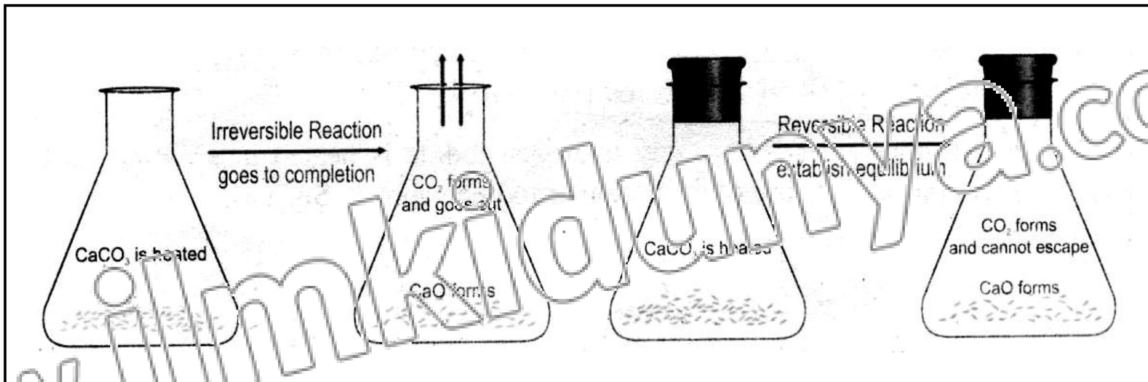
(ii) In Closed Container:

When calcium carbonate is heated in a **closed flask** so that **CO_2 cannot escape out,** following reaction takes place.

At Equilibrium:

In the beginning, **forward reaction is fast and reverse reaction is slow.** But eventually, the reverse reaction speeds up and both reactions go on at the same rate. At this stage decomposition and combination take place at the same rate but in opposite directions, as a result amounts of $CaCO_3$, CaO and CO_2 do not change. It is written as:

$$CaCO_3 \rightleftharpoons CaO + CO_2$$



$CaCO_{3(s)} \xrightarrow{\text{Decomposition}} CaO_{(s)} + CO_{2(g)}$ $\quad$ $CaCO_{3(s)} \underset{\text{Combination}}{\overset{\text{Decomposition}}{\rightleftharpoons}} CaO_{(s)} + CO_{2(g)}$

Figure: Showing Establishment of Reversible Reaction

Q.2 What is chemical equilibrium? Explain its types with examples. ***(Knowledge Base)***

Ans:

CHEMICAL EQUILIBRIUM

Definition:

"When the rate of the forward reaction takes place at the rate of reverse reaction, the ***composition*** *of the* ***reaction mixture remains constant****, is called chemical equilibrium state".*

Types:

There are two types of chemical equilibrium:

(i) Static Equilibrium: ***(Test Yourself 9.1 Q(ii))***

"When reaction ***ceases*** *to proceed, it is called static equilibrium. This happens mostly in physical phenomenon".*

Example:

- A building remains standing rather than falling down because all the forces acting on it are balanced. This is an example of static equilibrium.

(ii) Dynamic Equilibrium:

"*When reaction does not stop only the* ***rates of forward and reverse reaction*** *become equal to each other but take place in* ***opposite directions****. This is called dynamic equilibrium state."*

Note: Dynamic means reaction is still continuing at dynamic equilibrium state.

Example:

- $CaCO_3 \rightleftharpoons CaO + CO_2$

At equilibrium:

Rate of forward reaction = Rate of reverse reaction

Q.3 Explain graphical representation of dynamic equilibrium.

(Understanding+Application Base)

GRAPHICAL REPRESENTATION

In a reversible reaction, dynamic equilibrium is established before the completion of reaction. At initial stage the rate of forward reaction is very fast and reverse reaction is taking place at a negligible rate. But gradually forward reaction slows down and reverse reaction speeds up. Eventually, both reactions attain the same rate; it is called a dynamic equilibrium state.

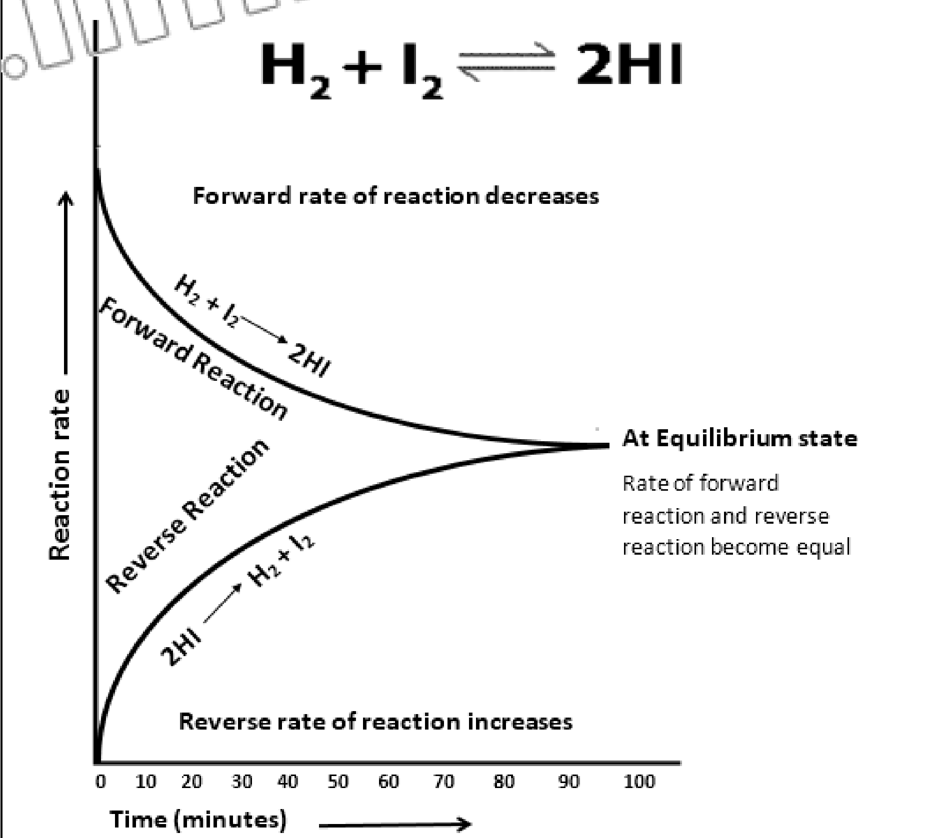


Figure: Graph Showing the Rate of Forward and Reverse Reactions and Establishment of Equilibrium State

Example:

In case of reaction between hydrogen and iodine vapors, some of the molecules react with each other to give hydrogen iodide.

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

At the same time, some of the hydrogen iodide molecules decompose back to hydrogen and iodine.

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

Speed of Reaction:

In the Beginning:

In the beginning, as the concentration of the reactants is higher than that of the products, the rate of the forward reaction is fast than the reverse reaction.

At Later Stage:

As the reaction proceeds, the concentration of reactants will gradually decrease while that of products will increase, consequently the rate of the forward reaction will go on decreasing and the reverse reaction will go on increasing and ultimately the two rates will become equal to each other. Thus, the equilibrium will set up and concentration of various species (H_2, I_2, HI) becomes constant. It is represented as:

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

Q.3 Write down macroscopic characteristics of forward and reverse reactions. ***(Knowledge + Understanding Base)***

Ans: **DIFFERENTIATION** **(LHR 2016-2017, SGD 2017, FSD 2017)**

The differences between forward and reverse reaction are as follows:

Forward Reaction	Reverse Reaction
Definition	
• It is reaction in which reactants react to form products.	• It is reaction in which products react to produce reactants.
Direction	
• It takes place from left to right	• It takes place from right to left.
Rate of Reaction in the beginning	
• At initial stage the rate of forward reaction is very fast.	• In the beginning the rate of reverse reaction is negligible.
Rate of Reaction at later stage	
• It slows down gradually.	• It speeds up gradually.

Q.4 Write down macroscopic characteristics of dynamic equilibrium.

(Knowledge+Understanding Base)

(Ex-Q.2) (LHR 2014-16-17, SGD 2014, MTN 2016 G-II, 17, SWL 2017, FSD 2017, DGK 2016 G-II, BWP 2016, G-I)

Ans: **MACROSCOPIC CHARACTERISTICS**

Characteristics:

A few important characteristic features of dynamic equilibrium are given below:

(i) Closed System:

An equilibrium is achievable only in a closed system (in which substances can neither leave nor enter).

(ii) $R_f = R_r$:

At equilibrium state a reaction does not stop. Forward and reverse reactions keep on taking place at the same rate but in opposite direction.

(iii) Concentration of Substances:

At equilibrium state, the amounts (concentrations) of reactants and products do not change. Even physical properties like colour, density, etc. remain the same.

(iv) Attaining of Chemical Equilibrium:

An equilibrium state is attainable from either way, i.e. starting from reactants or from products.

(v) Re-establishment of Equilibrium after Disturbance:

An equilibrium state can be disturbed and again achieved under the given conditions of concentration, pressure and temperature.

9.1 REVERSIBLE REACTION AND DYNAMIC EQUILIBRIUM

SHORT QUESTIONS

Q.1 Differentiate between reversible and irreversible reactions. ***(Understanding Base)***

(LHR 2015-18-19)

Ans: **DIFFERENTIATION**

The differences between reversible and irreversible reactions are as follows:

Reversible Reaction	Irreversible Reaction
Definition	
• Reactions in which products recombine to form reactants are called reversible reactions and such reactions proceed in both directions.	• In most of the reactions the products do not recombine to form reactants, are called irreversible reactions and such reactions proceed in one direction only.
Completion	
• They never go to completion.	• They go to completion.
Representation	
• These are represented by a double arrow ($\rightleftharpoons$) between reactants and products.	• These are represented by a single arrow (→) between reactants and products.

Q.2 Write down macroscopic characteristics of forward reactions. ***(Knowledge Base)***

(LHR 2019, MTN 2016 G-I, BWP 2017, DGK 2017)

Ans: **CHARACTERISTICS OF FORWARD REACTIONS**

Following are the characteristics of forward reactions:

- It is reaction in which reactants react to form products.
- It takes place from left to right.
- At initial stage the rate of forward reaction is very fast.
- It slows down gradually.

Q.3 Write down macroscopic characteristics of reverse reactions. ***(Knowledge Base)***

(GRW 2017, DGK 2017, SWL 2017, LHR 2013, 2014, 2015, GRW 2014)

Ans: **CHARACTERISTICS OF REVERSE REACTIONS**

Following are the characteristics of reverse reactions:

- It is reaction in which products react to produce reactants.
- It takes place from right to left.
- In the beginning the rate of reverse reaction is negligible.
- It speeds up gradually.

Q.4 Why reaction does not stop during equilibrium condition? ***(Understanding Base)***

(SGD 2016 G-I)

Ans: **<u>REACTION AT EQUILIBRIUM</u>**

The reaction does not stop during equilibrium condition because **products recombine** to form **reactants** again i.e. the forward and reverse reactions keep on occurring continuously.

$$A + B \underset{R_f}{\overset{R_r}{\rightleftharpoons}} C + D$$

Reactants Products

9.1 REVERSIBLE REACTION AND DYNAMIC EQUILIBRIUM

MULTIPLE CHIOICE QUESTIONS

1. The reaction in which the products do not recombine to form reactants is known as: ***(K.B)***
(A) Reversible reaction (B) Decomposition reaction
(C) Addition reaction (D) Irreversible reaction

2. The reactions in which the products recombine to form reactants are called: ***(K.B)***
(SGD 2016 G-II, FSD 2017 G-II)
(A) Forward reactions (B) Reversible reactions
(C) Irreversible reactions (D) Backward reactions

3. Reversible reactions take place in: ***(U.B)***
(A) One direction (B) Both directions
(C) Left to right (D) Right to left

4. The characteristics of reversible reactions are the following except: ***(U.B)***
(A) They never complete
(B) Products never recombine to form reactants
(C) They have a double arrow between reactants and products
(D) They proceed in both ways

5. Irreversible reactions are represented by a ________ between reactants and products. ***(K.B)***
(A) Single arrow (B) K_c
(C) Double arrow (D) Single line

6. An irreversible reaction consists of: ***(U.B)***
(A) Forward reaction (B) Reverse reaction
(C) Both forward and reverse reactions (D) None of these

7. Which reaction is irreversible? ***(U.B)*** **(MTN 2016 G-II)**
(A) $N_2+3H_2 \longrightarrow 2NH_3$ (B) $H_2+I_2 \longrightarrow 2HI$
(C) $2H_2+O_2 \longrightarrow 2H_2O$ (D) $N_2+O_2 \longrightarrow 2NO$

8. Reversible reaction is represented by: ***(K.B)*** **(FSD 2017-G-I)**
(A) $\longrightarrow$ (B) [illegible]
(C) $\longleftarrow$ (D) $\rightleftharpoons$

9. The colour of hydrogen iodide (HI) is: ***(K.B)*** **(GRW 2014, FSD 2017 G-II)**
(A) Blue (B) Grey
(C) Purple (D) Colourless

10. The colour of iodine (I_2) is: ***(K.B)*** **(LHR 2014, FSD G-I 2016, SWL 2016 G-I, 17, BWP 201 G-I)**
(A) Purple (B) Green
(C) Yellow (D) None of these

11. Dynamic means reaction: *(K.B)*
(A) Stops (B) Is still continuing
(C) In opposite direction (D) Both A and B

12. When reaction ceases to proceed it is called: *(K.B)* **(SGD G-II 2016)**
(A) Dynamic equilibrium (B) Static equilibrium
(C) Chemical equilibrium (D) None of these

13. Reaction in which reactants react to form products is called: *(K.B)*
(A) Forward reaction (B) Reverse reaction
(C) Reversible reaction (D) Backward reaction

14. At initial stage the rate of forward reaction is: *(K.B)*
(A) Low (B) Very low
(C) Very fast (D) All of these

15. Reverse reactions _________ gradually. *(U.B)*
(A) Speed up (B) Negligible
(C) Slow down (D) Do not speed up

16. Forward reaction takes place from: *(K.B)*
(A) Left to right (B) Right to left
(C) Both A and B (D) All of these

17. When CaO reacts with CO_2 they produce: *(U.B)*
(A) $CaCO_3$ (B) $CaCO_2$
(C) CaC_2 (D) CaO

18. In the beginning reverse reaction: *(K.B)* **(FSD 2017 G-I)**
(A) Is fast (B) Stops
(C) Is slow (D) Is very fast

19. When rate of forward reaction takes place at the rate of reverse reaction and the composition of the reaction mixture remains constant is called: *(K.B)*
(A) Static equilibrium (B) Neutral equilibrium
(C) Chemical equilibrium state (D) None of these

20. There are ________characteristics of dynamic equilibrium. *(K.B)*
(A) One (B) Two
(C) Three (D) Five

21. When a system is at equilibrium state then? *(U.B)* **(GRW 2015)**
(A) The concentration of reactants and products becomes equal
(B) The opposing reactions (forward and reverse) stop
(C) The rate of reverse reaction becomes very low
(D) The rates of forward and reverse reactions become equal

9.1 TEST YOURSELF

i. Why reversible reactions never complete? *(Understanding Base)* **(LHR 2013, SWL 2017)**

Ans: **<u>COMPLETION OF REVERSIBLE REACTIONS</u>**

The reversible reactions never complete because products recombine to form reactants again. The forward and reverse reactions keep on occurring continuously. e.g.

$$A + B \underset{R_f}{\overset{R_f}{\rightleftharpoons}} C + D$$

Reactants Products

ii. What is a static equilibrium? Explain with an example. ***(Knowledge Base)***

(LHR 2015, GRW 2015)

Ans: Answer given on Page # 5

iii. Why the amounts of reactants and products do not change in reversible reaction? ***(Understanding Base)***

(GRW 2013)

Ans: **AMOUNTS OF REACTANTS AND PRODUCTS**

The amounts of reactants and products do not change in a reversible reaction because a state of **dynamic equilibrium** is established in reversible reaction. In dynamic equilibrium state the **rate of forward and reverse reaction** becomes **equal** and take place in **opposite direction** but amounts of reactants and products remain the same.

9.2 LAW OF MASS ACTION

LONG QUESTION

Q.1 State the Law of Mass Action and derive an expression for equilibrium constant for a general reaction. ***(Understanding Base + Application Base)*** **(Ex-Q.3)**

(DGK 2016 G-I, 17, RWP 2017, LHR 2015,2016,2017,2019, GRW 2015, 17, BWP 2017, SWL 2016 G-I, 17, SGD 2016 G-II, FSD 2016 G-I, 17)

Ans: **LAW OF MASS ACTION**

Introduction:

Law of Mass Action was given by C.M. Guldberg and P.Waage in 1869. They studied a lot of reversible reactions and put forward this law.

Definition:

"*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".*

Active Mass:

Generally, an active mass is considered as the molar concentration in units of mol dm^{-3}, expressed as square brackets [ ].

DERIVATION OF EXPRESSION FOR EQUILIBRIUM CONSTANT

Consider a reversible reaction

$$A + B \underset{k_r}{\overset{k_f}{\rightleftharpoons}} C + D$$

Suppose [A], [B], [C] and [D] are the molar concentrations (mol dm^{-3}) of A, B, C and D respectively.

According to the Law of Mass Action:

Forward Reaction:

The rate of the forward reaction $\propto$ [A] [B]

$$R_f = k_f [A] [B] \quad \textbf{......(i)}$$

Similarly

Reverse Reaction:

The rate of the reverse reaction $\propto$ [C] [D]

$$R_r = k_r [C] [D] \quad \textbf{......(ii)}$$

Where k_f and k_r are the proportionality constant called specific rate constants of the forward and the reverse reactions respectively.

At Equilibrium State:

The rate of forward reaction = The rate of reverse reaction

$$R_f = R_r \quad \text{.......(iii)}$$

$$k_f[A][B] = k_r[C][D] \quad \textbf{By putting values of eq (i) and (ii) in (iii)}$$

$$\frac{k_f}{k_r} = \frac{[C][D]}{[A][B]}$$

$$\left(K_c = \frac{k_f}{k_r}\right)$$

Where,

K_c is called equilibrium constant. It is represented as:

$$K_c = \frac{[C][D]}{[A][B]}$$

Significance:

Law of Mass Action describes the relationship between active masses of the reactants and the rate of a reaction.

DERIVATION OF THE EXPRESSION FOR EQUILIBRIUM CONSTANT FOR GENERAL REACTION

Consider a general reaction.

$$aA + bB \rightleftharpoons cC + dD$$

This reaction consists of two reactions i.e. forward and backward.

According to Law of Mass Action:

*"The **rate** of a chemical reaction is **directly proportional** to the **product** of the **molar concentrations** of its **reactants** raised to power equal to their number of moles in the balanced chemical equation of the reaction".*

Derivation:

Forward Reaction:

In forward reaction A and B are the reactants whereas 'a' and 'b' are their number of moles. The rate of forward reaction is:

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

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

Where k_f is the rate constant for the forward reaction while square brackets represent concentration in mol dm^{-3}.

Reverse Reaction:

The rate of the reverse reaction R_r is directly proportional to the product of $[C]^c[D]^d$, where 'c' and 'd' are the number of moles as given in the balanced chemical equation.

Thus,

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

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

Where k_r is the rate constant for the reverse reaction

At Equilibrium State:

Rate of forward reaction = Rate of reverse reaction

Such as: $R_f = R_r$

By putting the values of R_f and R_r

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

By taking the constants on one side and the variables on other side of the equation, the above equation becomes:

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

Where,

$$\left[K_c = \frac{k_f}{k_r}\right]$$

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

Where K_c is called equilibrium constant.

<u>Example 1:</u>

When nitrogen reacts with oxygen to form nitrogen monoxide, the reversible reaction is as follows:

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

The rate of forward reaction $R_f = k_f\,[N_2]\,[O_2]$

The rate of reverse reaction $R_r = k_r\,[NO]^2$

The equilibrium constant expression for this reaction is:

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

<u>Example 2:</u>

For the reaction of nitrogen with hydrogen to form ammonia, the balanced chemical equation is:

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

For the reaction

The rate of forward reaction $R_f = k_f\,[N_2]\,[H_2]^3$

The rate of reverse reaction $R_r = k_r\,[NH_3]^2$

The expression for the equilibrium constant for this reaction is:

$$K_c = \frac{[NH_3]_2}{[N_2][H_2]^3}$$

9.2 LAW OF MASS ACTION

SHORT QUESTIONS

Q.1 What is significance of Law of Mass Action? *(Knowledge Base)* **(BWP 2016 G-II)**

Ans: **<u>SIGNIFICANCE OF LAW OF MASS ACTION</u>**

Law of Mass Action describes the relationship between active masses of the reactants and the rate of a reaction.

Q.2 Define specific rate constant. *(Knowledge Base)*

Ans: **<u>SPECIFIC RATE CONSTANT</u>**

<u>Definition:</u>

"The rate constants at which concentrations of reactants and products are unity, are called specific rate constant".

Q.3 Find Kc for the reaction of nitrogen and hydrogen to form Ammonia?

Ans: See **Example 2** on Page # 13.

9.2 LAW OF MASS ACTION

MULTIPLE CHIOICE QUESTIONS

1. For the reaction $2A_{(g)} + B_{(g)} \rightleftharpoons 3C_{(g)}$ the expression for the equilibrium constant is: ***(U.B)*** **(BWP 2017)**

(A) $\frac{[2A][B]}{[3C]}$ (B) $\frac{[A]^2[B]}{[C]^3}$

(C) $\frac{[3C]}{[2A][B]}$ (D) $\frac{[C]^3}{[A]^2[B]}$

2. Which statement is not correct about active mass? ***(U.B)***

(A) Rate of reaction is directly proportional to active masses

(B) Active mass is taken in molar concentration

(C) Active mass means total mass of substances

(D) Active mass expressed in square brackets

3. Name the scientist who presented Law of Mass Action: ***(K.B)*** **(GRW 2013)**

(A) Guldberg and Waage (B) Boyle

(C) Newton (D) Lavoisier

4. Point out the coefficients in the following hypothetical reaction: ***(U.B)***

$$2A + 3D \longrightarrow 4C + 8D$$

(A) 2,3,4,5 (B) 2,3,4,3

(C) A, b, c, d (D) 2,3,4,8

5. An active mass is considered as the molar concentration in units of: ***(K.B)***

(A) mol dm^{-3} (B) mol^{-3} dm

(C) mol^{-2} dm (D) mol^{-2} dm

6. The units of molar concentration: ***(K.B)*** **(LHR 2013, 17, GRW 2016)**

(A) mol dm^{-2} (B) mol dm^{-1}

(C) mol dm^{3} (D) mol dm^{-3}

7. Kc is always equal to: ***(K.B)*** **(LHR 2015, DGK 2017)**

(A) $\frac{R_f}{R_r}$ (B) $\frac{k_r}{k_f}$

(C) $\frac{k_f}{k_r}$ (D) $\frac{R_r}{R_f}$

8. Specific rate constant for forward reaction is represented by: ***(K.B)*** **(GRW 2017)**

(A) k_f (B) k_c

(C) k_r (D) k_b

9. Molar concentration (mol dm^{-3}) is expressed as: ***(K.B)*** **(GRW 2017)**

(A) { } (B) ( )

(C) [ ] (D) ϕ

9.2 TEST YOURSELF

i. Define the Law of Mass Action. ***(Knowledge Base)***
(LHR 2014-17-18, GRW 2014, MTN 2016 GII, 17, SWL 2016 G-II, 17, RWP 2017, FSD 2016 G-I, SGD 2016 G-II, DGK 2016 G-II)

Ans: **LAW OF MASS ACTION**

Definition:

*"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."*

Rate of reaction ∝ active masses of reacting substances

$$A + B \underset{K_r}{\overset{K_f}{\rightleftharpoons}} C + D$$

$$K_C = \frac{[C][D]}{[A][B]}$$

ii. How the active mass is represented? ***(Knowledge Base)*** **(SGD 2017)**

Ans: **REPRESENTATION OF ACTIVE MASS**

An active mass is considered as the molar concentration in units of mol dm^{-3}. It is represented in square brackets, as [ ].

iii. What do you mean by equilibrium constant? (LHR 2015, BWP 2017, MTN 2017, SWL 2017)

Ans: **EQUILIBRIUM CONSTANT**

Definition:

"***Ratio*** *of the product of* ***concentration of products*** *raised to the power of coefficients to the product of* ***concentration of reactants*** *raised to the power of coefficients as expressed in the balanced chemical equation is called equilibrium constant."*

$$Kc = \frac{\text{Product of concentration of products raised to the power of coefficients}}{\text{Product of concentration of reactants raised to the power of coefficients}}$$

Importance of Kc:

- Equilibrium constant helps to predict the direction of a reaction and extent of a reaction.

iv. Point out the coefficients of each in the following hypothetical reactions: ***(Understanding Base)***

a. $2A + 3B \rightleftharpoons 4C + 2D$ **b.** $4X \rightleftharpoons 2Y + 3Z$ **c.** $2M + 4N \rightleftharpoons 5O$

Ans: **COEFFICIENTS OF HYPOTHETICAL REACTIONS**

(a) $2A + 3B \rightleftharpoons 4C + 2D$

Reacting substances	A	B	C	D
Coefficients	2	3	4	2

(b) $4X \rightleftharpoons 2Y + 3Z$

Reacting substances	X	Y	Z
Coefficients	4	2	3

(c) $2M + 4N \rightleftharpoons 5O$

Reacting substances	M	N	O
Coefficients	2	4	5

v. Write the equilibrium constant expressions for the following reactions:

(Understanding Base)

a. $2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$ **b.** $PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$

c. $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$

Ans: **EQUILIBRIUM CONSTANT EXPRESSIONS**

(a) $2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$ **(SWL 2016 G-I, DGK 2017)**

For this reaction

Rate of forward reaction = $R_f = k_f [NO_2]^2$

Rate of reverse reaction = $R_r = k_r [N_2O_4]$

Equilibrium constant expression

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

(b) $PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$ **(RWP 2017)**

For this reaction

Rate of forward reaction = $R_f = k_f [PCl_3] [Cl_2]$

Rate of reverse reaction = $R_r = k_r [PCl_5]$

Equilibrium constant expression

$$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]}$$

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

For this reaction

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

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

Equilibrium constant expression

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

9.3 EQUILIBRIUM CONSTANT AND ITS UNITS

LONG QUESTIONS

Q.1 What is equilibrium constant? Explain its units. *(Knowledge +Understanding Base)*

(BWP 2016 G-II)

Ans: **EQUILIBRIUM CONSTANT**

Definition:

"*Equilibrium constant is* ***ratio*** *of the* ***product of concentration*** *of* ***products*** *raised to the power of coefficients to the* ***product of concentration*** *of* ***reactants*** *raised to the power of coefficients as expressed in the balanced chemical equation".*

Formula:

$$K_c = \frac{\text{Product of concentration of products raised to the power of coefficients}}{\text{Product of concentration of reactants raised to the power of coefficients}}$$

Representation of Equilibrium Expression:

It is conventional to write the products side numerator and reactants denominator. By knowing the balanced chemical equation for reversible reaction we can write the equilibrium expression.

Determination of K_c Value:

We can calculate the numerical values by putting actual equilibrium concentrations of the reactants and products into equilibrium expression.

Dependence of Kc Value:

The value of **Kc depends only on temperature**, it does not depend on the initial concentrations of the reactants and the products.

UNITS OF K_c

There are two possibilities for units of K_c.

(i) No Unit of K_c: **(BWP 2017)**

Number of moles of reactants = Number of moles of products.

In a balance chemical equation.

This is because concentration units cancel out in the expression for K_c for the reaction.

Example:

$$H_2 + I_2 \rightleftharpoons 2HI$$

$$\text{Units} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})} = \text{no unit}$$

(ii) Some Unit of K_c:

Number of moles of reactants ≠ Number of moles of products.

In a balance chemical equation.

Example:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$K_c = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})^3} = \text{mol}^{-2}\text{dm}^6$$

NUMERICAL EXAMPLES

EXAMPLE 9.1

When hydrogen reacts with iodine at 25^0C to form hydrogen iodide by a reversible reaction as follows: *(U.B +A.B)*

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

The equilibrium concentrations are:

$[H_2] = 0.05\,moldm^{-3}$; $[I_2] = 0.06\,moldm^{-3}$.

$[HI] = 0.49\,moldm^{-3}$

Calculate the equilibrium constant for this reaction.

Solution:

Given Data:

Given equilibrium concentrations are:

$[H_2] = 0.05\,moldm^{-3}$

$[I_2] = 0.06\,moldm^{-3}$

$[HI] = 0.49\,moldm^{-3}$

To Find:

Equilibrium constant Kc = ?

Calculations:

Write the equilibrium constant expression as:

$$Kc = \frac{[HI]^2}{[H_2][I_2]}.$$

Now put the equilibrium concentration values in Kc. expression

$$Kc = \frac{[0.49]^2}{[0.05][0.06]} = \frac{0.2401}{0.0030} = 80$$

Result:

Thus equilibrium constant for the reaction= 80

EXAMPLE 9.2

For the formation of ammonia by Haber's process hydrogen and nitrogen react reversibly at 500 ^{0}C as follows: *(U.B +A.B)*

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

The equilibrium concentrations of these gases are: nitrogen 0.602 mol dm^{-3}; hydrogen 0.420 mol dm^{-3} and ammonia 0.113 mol dm^{-3}. What is value of K_c?

Solution:

Given data:

The equilibrium concentrations are:

$[N_2] = 0.602\,moldm^{-3}$

$[H_2] = 0.420\,moldm^{-3}$

$[NH_3] = 0.113\,moldm^{-3}$

To Find:

Equilibrium constant Kc = ?

Calculations:

The equilibrium constant expression for this reaction is

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

No put the equilibrium concentration values into the equilibrium expression.

$$Kc = \frac{[0.113]^2}{[0.602][0.420]^3} = 0.286\,mol^{-2}dm^6$$

Result:

Thus equilibrium constant for the reaction = 0.286 mol^{-2}dm^6

EXAMPLE 9.3

For a reaction between PCI_3 and CI_2 to from PCI_5, the equilibrium constant is 0.13 mol^{-1} dm^3 at a particular temperature. When the equilibrium concentrations of PCI_3 and CI_2 are 10.0 and 9.0 mol dm^{-3} respectively, what is the equilibrium concentration of PCI_5? *(U.B +A.B)*

Solution:

Given data:

The equilibrium concentrations are:

$[PCl_3] = 10\,moldm^{-3}$ $[Cl_2] = 9.0\,moldm^{-3}$

$Kc = 0.13\,mol^{-1}dm^3$

To Find:

$[PCl_5] = ?$

Solution:

Now write the balanced chemical equation and equilibrium constant expression:

$$PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$$

$$Kc = \frac{[PCl_5]}{[PCl_3][Cl_2]}$$

Now put the known values in above equation and rearrange.

$$0.13 = \frac{[PCl_5]}{[10.0][9.0]}$$

$$[PCl_5] = 0.13 \times 10.0 \times 9.0 = 11.7\,moldm^{-3}.$$

Result:

Thus molar concentration of PCl_5 = 11.7 moldm^{-3}

9.3 EQUILIBRIUM CONSTANT AND ITS UNITS
SHORT QUESTIONS

Q.1 What are the units of Kc? ***(Understanding Base)***

Ans:

UNITS OF Kc

There are two possibilities for units of K_c.

i. No Unit of K_c: **(BWP 2017)**

Number of moles of reactants = Number of moles of products.

In a balance chemical equation.

This is because concentration units cancel out in the expression for K_c for the reaction. e.g.

$$H_2 + I_2 \rightleftharpoons 2HI$$

$$\text{Units} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})} = \text{no unit}$$

ii. Some Unit of K_c:

Number of moles of reactants ≠ Number of moles of products.

In a balance chemical equation.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$K_c = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})^3} = \text{mol}^{-2}\text{dm}^6$$

9.3 EQUILIBRIUM CONSTANT AND ITS UNITS
MULTIPLE CHIOICE QUESTIONS

1. **For a reaction between PCl_3 and Cl_2 to form PCl_5 the units of Kc are:** ***(U.B)***
(GRW 2017, DGK 2017, MTN 2017)
(A) mol dm^{-3} (B) mol^{-1} dm^{-3}
(C) mol^{-1} dm^{3} (D) mol dm^{3}

2. **When H_2 and O_2 combine they form:** ***(K.B)***
(A) H_2O (B) H and O
(C) HO_2 (D) None of these

3. **When H_2 and N_2 combine they form:** ***(K.B)***
(A) H_2O (B) NH_3
(C) I_2 (D) H_2 and I_2

4. **The ratio of product of concentration of products raised to power of coefficients to the product of concentration of reactants raised to the power of coefficients in a balanced chemical equation at equilibrium is known as:** ***(U.B)***
(A) Kc (B) Qc
(C) Kr (D) Kf

5. **Equilibrium constant is represented by:** ***(K.B)***
(A) Qc (B) Kc
(C) Kr (D) Kf

6. **What are units of Kc for the reaction?** $H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$ ***(K.B)***
(GRW 2015, SWL 2017, RWP 2017)
(A) No units (B) mol dm^{-3}
(C) mol^{2} dm^{6} (D) mol^{-1} dm^{3}

7. The units of equilibrium constant Kc for the reaction in the balanced chemical equation $N_2 + 3H_2 \rightleftharpoons 2NH_3$ are: *(K.B + U.B)*

(A) $mol^{-2}\ dm^{6}$ (B) $mol^{-1}\ dm^{-3}$

(C) $mol^{-1}\ dm^{3}$ (D) $mol\ dm^{3}$

8. For the reaction $H_2 + I_2 \rightleftharpoons 2HI$ the expression for the equilibrium constant: *(U.B)*

(SGD 2017)

(A) $Kc = \frac{[HI]^2}{[H_2][I_2]}$ (B) $Kc = \frac{[H_2][I_2]}{[HI]^2}$

(C) $Kc = \frac{[2HI]}{[H_2][I_2]}$ (D) $Kc = \frac{[H_2][I_2]}{[2HI]}$

9. The value of equilibrium constant Kc depends only on: *(K.B)*(BWP 2016 G-II, DGK 2016 G-II)

(A) Temperature (B) Pressure

(C) Concentration (D) Density

10. When number of moles of both sides are equal in a reaction then the unit of Kc: *(K.B)* (DGK 2016 G-II)

(A) No units (B) $mol\ dm^{-3}$

(C) $mol^{2}\ dm^{6}$ (D) $mol^{-1}\ dm^{3}$

9.4 IMPORTANCE OF EQUILIBRIUM CONSTANT

LONG QUESTIONS

Q.1 What is the importance of equilibrium constant? *(Application Base)* (Ex-Q.4)

(GRW 2014, LHR 2015, SGD 2014, 17, BWP 2017)

Ans: **IMPORTANCE OF EQUILIBRIUM CONSTANT**

The numerical value of equilibrium constant of a chemical reaction helps in:

- Predicting Direction of a Reaction
- Predicting Extent of a Reaction

(i) Predicting Direction of a Reaction: **(MTN 2016 G-I)**

Direction of a reaction can be predicted by performing following steps:

Determination of K_c (Equilibrium Constant):

Direction of a reaction at a particular moment can be predicted by inserting the concentration of the reactants and products at that particular moment in the equilibrium expression.

Example:

- The reaction of hydrogen with iodine

$$H_2 + I_2 \rightleftharpoons 2HI \qquad K_C = 57.0 \text{ at } 700 \text{ K}$$

Determination of Q_c (Reaction Quotient):

We withdraw the samples from the reaction mixture and determine the concentrations of H_2, I_2 and HI. Suppose concentrations of the components of the mixture are:

$[H_2]_t = 0.10\ mol\ dm^{-3}$ $[I_2]_t = 0.20\ mol\ dm^{-3}$ and $[HI]_t = 0.40\ mol\ dm^{-3}$

The subscript 't' with the concentration symbols means that the concentrations are measured at some time t, not necessarily at equilibrium. When we put these concentrations into the equilibrium constant expression, we obtain a value called the reaction quotient Q_c. The reaction quotient for this reaction is calculated as:

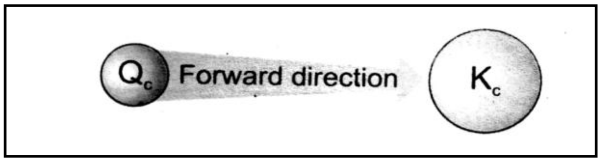
$$Q_c = \frac{[HI]_t^2}{[H_2]_t[I_2]_t} = \frac{(0.40)^2}{(0.10)(0.20)} = 8.0$$

As the numerical value of Q_c (8.0) is less than K_c (57.0), the reaction is not at equilibrium. It requires more concentration of products. Therefore, reaction will move in the forward direction. The reaction quotient Q_c is useful because it predicts the direction of the reaction by comparing the value of Q_c with K_c.

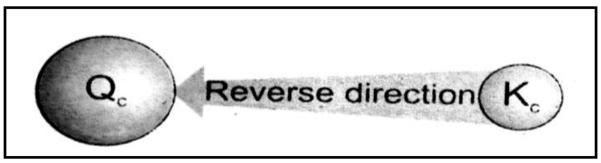
<u>Comparison of Q_c with K_c:</u>

Thus, we can make the following generalization about the direction of reaction.

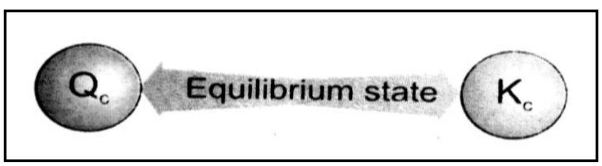
- If **$Q_c < K_c$;** the reaction goes from left to right, i.e., in **forward direction** to attain equilibrium.



- If **$Q_c > K_c$;** the reaction goes from right to left, i.e., in **reverse direction** to attain equilibrium.



- If **Qc = Kc;** forward and reverse reactions take place at equal rates i.e., **equilibrium** has been **attained**.



(ii) <u>Predicting Extent of a Reaction:</u> **(MTN 2017)**

*"**Numerical value** of the equilibrium constant **predicts the extent of a reaction**. It indicates to which extent reactants are converted to products"*

OR

*"It **measures how far a reaction proceeds** before establishing equilibrium state".*

<u>Possibilities:</u>

In general, there are three possibilities of predicting extent of reaction as explained below.

<u>Large Numerical Value of K_c:</u>

The large value of Kc indicates that at equilibrium position the reaction mixture consists of **almost all products** while **reactants are negligible.** The reaction has **almost gone to completion.**

Example:

Oxidation of carbon monoxide goes to completion at 1000 K.

$$2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)} \qquad Kc = 2.2 \times 10^{22}$$

Small Numerical Value of K_c:

The small value of kc indicates that the equilibrium has established with a very **small conversion of reactants to products**. At equilibrium position almost all reactants are present but amount of product is negligible. Such type of reaction **never goes to completion**.

Example:

$$2NH_{3(g)} \rightleftharpoons N_{2(g)} + 3H_{2(g)} \qquad Kc = 3.0 \times 10^{-9}$$

Numerical Value of Kc is Neither Small Nor Large:

The moderate value of Kc indicates that at equilibrium position the reaction mixture consists of **comparable amounts of reactants and products.**

Example:

$$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)} \qquad Kc = 0.211$$

9.4 IMPORTANCE OF EQUILIBRIUM CONSTANT

SHORT QUESTIONS

Q.1 Define reaction quotient. ***(Understanding Base)***

Ans: **REACTION QUOTIENT**

Definition:

"The ratio of product of concentration of products raised to the power of coefficients to the product of concentration of reactants raised to the power of co-efficients in a balanced chemical equation ***at any moment of the reversible reaction*** *is known as reaction quotient".*

Importance:

The reaction quotient Q_c is useful because it predicts the direction of the reaction by comparing the value of Q_c with K_c.

Q.2 Describe use of atmospheric gases in the manufacture of chemicals. ***(Knowledge Base)***

(Science, Technology and Society Pg. # 14)(LHR 2013, BWP 2017, RWP 2017)

Ans: **USES OF ATMOSPHERIC GASES**

The two major components of atmosphere are nitrogen and oxygen gases. Both of these gases constitute 99% of the atmosphere.

- **Nitrogen:**
  Nitrogen is **used** to prepare **ammonia**, which is further used to manufacture nitrogenous fertilizers.
- **Oxygen:**
  Oxygen is used to prepare **sulphur dioxide** which is further used to manufacture **king of chemicals sulphuric acid.**

Q.3 Which chemical is called king of chemicals? *(Knowledge Base)*

(Science, Technology and Society Pg. # 14)

Ans: **KING OF CHEMICALS**

Sulphuric acid (H_2SO_4) is called king of chemicals because it is used in almost all chemical industries directly or indirectly.

Q.4 Write the names of two major gases of atmosphere. *(Knowledge Base)*

(Science, Technology and Society Pg. # 14)(GRW 2013)

Ans: **MAJOR GASES OF ATMOSPHERE**

The two major gases of atmosphere are:

- Nitrogen 78%
- Oxygen 21%

Both constitute 99% of the atmosphere.

Q.5 Write the importance of equilibrium constant. *(Application Base)* **(LHR 2014)**

Ans: **IMPORTANCE OF EQUILIBRIUM CONSTANT**

The importance of equilibrium constant is as follows:

- It is used to predict the direction of reaction i.e. forward or reverse
- It is used to predict the extent of reaction which means how much of the reactants are converted into products.

Q.6 Write the names of two chemicals in which nitrogen is used. *(Knowledge Base)*

Ans: **CHEMICALS INVOLVING NITROGEN**

Following are the chemicals in which nitrogen is used:

- Urea (H_2NCONH_2)
- Nitric acid (HNO_3)

9.4 IMPORTANCE OF EQUILIBRIUM CONSTANT

MULTIPLE CHOICE QUESTIONS

1. In direction of a reaction, if reaction proceeds forward then: *(K.B)*

(A) Qc < Kc (B) Qc > Kc
(C) Qc = Kc (D) None of them

2. In direction of a reaction, if reaction proceeds reverse then: *(K.B)*

(A) Qc < Kc (B) Qc > Kc
(C) Qc = Kc (D) All of these

3. In direction of a reaction, if reaction is at equilibrium then: *(K.B)*

(A) Qc < Kc (B) Qc > Kc
(C) Qc = Kc (D) Both a & b

4. In extent of reaction, the reaction which almost goes to completion has: *(U.B)*

(A) Very large Kc value (B) Very small Kc value
(C) Moderate Kc value (D) None of these

5. In extent of reaction, the reaction never goes to completion has: *(U.B)*

(A) Very large Kc value (B) Very small Kc value
(C) Moderate Kc value (D) Qc = Kc

6. There are _________ possibilities of predicting extent of a reaction. *(K.B)* **(MTN 2017)**

(A) 1 (B) 2
(C) 3 (D) 4

7. There are _________ major components of atmosphere. *(K.B)*

(A) 1 (B) 2
(C) 3 (D) 4

8. The two major components of atmosphere are: *(K.B)* **(MTN 2017)**

(A) Nitrogen and hydrogen gases (B) Oxygen and hydrogen gases
(C) Nitrogen and carbon dioxide gases (D) Nitrogen and oxygen gases

9. Nitrogen and oxygen constitute _____ of the atmosphere. *(K.B)* **(GRW 2013)**

(A) 99% (B) 98%
(C) 92% (D) 97%

10. Nitrogen is used to prepare: *(K.B)*

(A) Carbon dioxide (B) Ammonia
(C) Hydrogen (C) Sulphuric acid

11. Oxygen is used to prepare: *(K.B)*

(A) Ammonia (B) Nitrogen gas
(C) Oxygen (D) Sulphur dioxide

12. The percentage of nitrogen in atmosphere is: *(K.B)*

(A) 21 % (B) 78%
(C) 99% (D) 0.93%

13. Ammonia is used to manufacture: *(U.B)*

(A) Sulphuric acid (B) Hydrogen gas
(C) Nitrogenous fertilizers (D) Chlorine gas

14. Sulphur dioxide is used to manufacture: *(U.B)*

(A) Sulphuric dioxide (B) Ammonia
(C) Sulphuric acid (D) Nitrogenous fertilizers

15. Which is the king of chemicals? *(K.B)* **(MTN 2017)**

(A) Sulphur dioxide (B) Ammonia
(C) Nitrogen (D) Sulphuric acid

16. The value of Kc for the reaction $N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$ is: *(U.B)*

(A) 2.2×10^{22} (B) 0.211
(C) 3.5×10^{1} (D) None of these

17. The oxidation of carbon monoxides goes to completion at: *(K.B)*

(A) 2000K (B) 1000K
(C) 100K (D) 200K

18. The reaction quotient is useful because it predicts the direction of reaction by comparing the values of *(K.B)*

(A) Qc (B) Qc with Kc
(C) k_c (D) None of these

19. As the numeric value of Qc (3.0) is less than K_C (57.0) the reaction is: *(U.B)*

(A) In forward direction (B) At equilibrium
(C) In reverse direction (D) All of these

20. When $Qc < Kc$, then reaction goes in: *(U.B)* **(SWL 2016 G-II, LHR 2016, SWL 2017)**

(A) Forward (B) Reverse
(C) Equilibrium (D) None of these

9.3 TEST YOURSELF

i. What do you mean by the extent of reaction? *(Knowledge Base)*

Ans: **EXTENT OF REACTION**

The extent of a reaction means the extent to which reactants are converted into products. In fact, it measures how far a reaction proceeds before establishing equilibrium state.

ii. Why the reversible reactions do not go to completion? *(Understanding Base)*

Ans: **COMPLETION OF REVERSIBLE REACTIONS**

The reversible reactions do not go to completion because products recombine to form reactants and reaction occurs in both directions i.e. forward and reverse. At this state, the composition of reaction mixture remains constant.

$$\underset{Reactants}{A + B} \underset{K_r}{\overset{K_f}{\rightleftharpoons}} \underset{Products}{C + D}$$

iii. If a reaction has large value of K_c will it go to completion and why? *(Understanding Base)* **(SWL 2016)**

Ans: **LARGE K_c VALUE**

If a reaction has large value of K_c it indicates that reaction has almost gone to completion because at the equilibrium position the reaction mixture consists of almost all products and reactants are negligible.

Example:

$$2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)} \qquad K_c = 2.2 \times 10^{22}$$

iv. Which type of reactions do not go to completion? *(Knowledge Base)* **(RWP 2016 G-I)**

Ans: **REACTIONS WHICH DO NOT COMPLETE**

Reversible reactions do not go to completion. These reactions have very small value of K_c.

Examples:

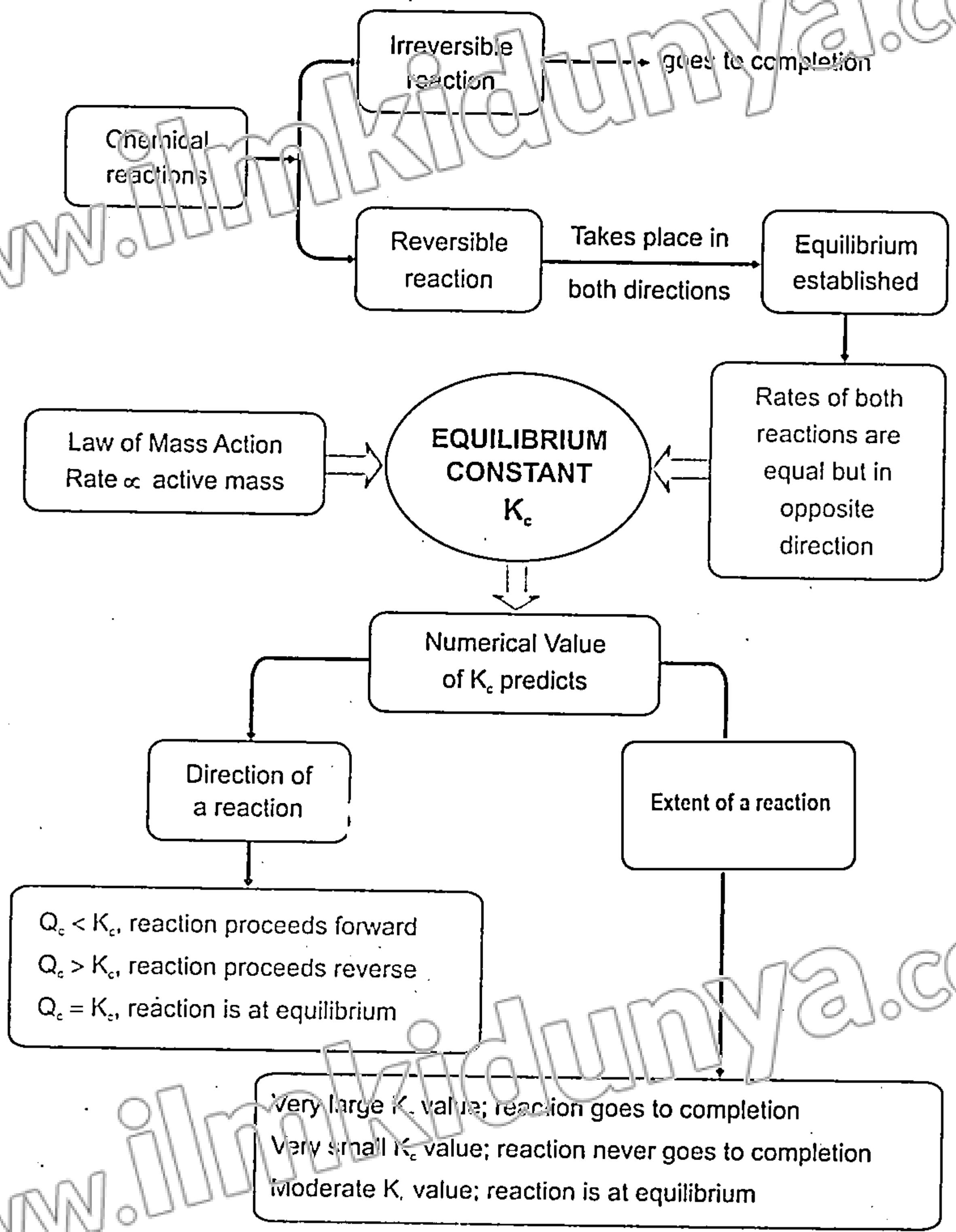
$$2NH_3 \rightleftharpoons N_2 + 3H_2 \qquad K_c = 3.0 \times 10^{-9}$$

v. Why the reaction mixture does not have 50% reactants and 50% products at equilibrium position? *(Understanding Base)*

Ans: **50% REACTANTS AND 50% PRODUCTS**

The reaction mixture does not have 50% reactants and 50% products at equilibrium position because equilibrium **does not depend upon concentration** rather it is a state at which rate of forward and reverse reactions must be equal. So it is not necessary that reaction mixture contains 50% reactants and 50% products.

CONCEPT DIAGRAM



ANSWER KEY

MULTIPLE CHOICE QUESTIONS

INTRODUCTION

1	C	6	C
2	B	7	A
3	B		
4	A		
5	A		

9.1 CHEMICAL EQUILIBRIUM AND REVERSIBLE REACTIONS

1	D	6	A	11	B	16	A	21	D
2	B	7	C	12	B	17	A		
3	B	8	B	13	A	18	C		
4	B	9	D	14	C	19	C		
5	A	10	A	15	A	20	D		

9.2 LAW OF MASS ACTION

1	D	6	D
2	C	7	C
3	A	8	A
4	D	9	C
5	A		

9.3 EQUILIBRIUM CONSTANT AND ITS UNITS

1	C	6	A
2	A	7	A
3	B	8	A
4	A	9	A
5	B	10	A

9.4 IMPORTANCE OF EQUILIBRIUM CONSTANT

1	A	6	C	11	D	16	B
2	B	7	B	12	B	17	B
3	C	8	D	13	C	18	B
4	A	9	A	14	C	19	A
5	B	10	B	15	D	20	A

EXERCISE SOLUTION

MULTIPLE CHOICE QUESTIONS

1. **The characteristics of reversible reactions are the following except: *(K.B)***
   (a) Products never recombine to form reactants
   (b) They never complete
   (c) They proceed in both ways
   (d) They have a double arrow between reactants and products

2. **In the lime kiln, the reaction $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$ goes to completion because: *(U.B)* (GRW 2013, 16, LHR 2015, SGD 2014, BWP 2017, MTN 2016 G-I, DGK 2016 G-I)**
   (a) Of high temperature
   (b) CaO is more stable than $CaCO_3$
   (c) CO_2 escapes continuously
   (d) CaO is not dissociated

3. **For the reaction, $2A_{(g)} + B_{(g)} \rightleftharpoons 3C_{(g)}$ the expression for the equilibrium constant is: *(K.B)***
   (LHR 2013, 14, BWP 2017, RWP 2016 G-II, FSD 2017 G-II)
   (a) $\frac{[2A][B]}{[3C]}$
   (b) $\frac{[A]^2[B]}{[C]^3}$
   (c) $\frac{[3C]}{[2A][B]}$
   (d) $\frac{[C]^3}{[A]^2[B]}$

4. **When a system is at equilibrium state: *(K.B)***
   (a) The concentration of reactants and products becomes equal
   (b) The opposing reactions (forward and reverse) stop
   (c) The rate of the reverse reaction becomes very low
   (d) The rates of the forward and reverse reactions become equal

5. **Which one of the following statement is not correct about active mass? *(K.B)***
   (a) Rate of reaction is directly proportional to active mass
   (b) Active mass is taken in molar concentration
   (c) Active mass is represented by square brackets
   (d) Active mass means total mass of substances

6. **When the magnitude of K_c is very large it indicates: *(U.B)***
   (RWP 2017, SGD 2016 G-I, MTN 2016 G-I)
   (a) Reaction mixture consists of almost all products
   (b) Reaction mixture has almost all reactants
   (c) Reaction has not gone to completion
   (d) Reaction mixture has negligible products

7. **When the magnitude of K_c is very small it indicates: *(U.B)***
   (a) Equilibrium will never establish
   (b) All reactants will be converted to products
   (c) Reaction will go to completion
   (d) The amount of products is negligible

8. Reactions which have comparable amounts of reactants and products at equilibrium state have: *(U.B)* **(RWP 2016 G-II, 17)**

(a) Very small K_c value (b) Very large K_c value
(c) Moderate K_c value (d) None of these

9. At dynamic equilibrium: *(K.B)* **(SGD 2016 G-I, II)**

(a) The reaction stops to proceed
(b) The amounts of reactants and products are equal
(c) The speeds of the forward and reverse reactions are equal
(d) The reaction can no longer be reversed

10. In an irreversible reaction dynamic equilibrium: *(K.B)* **(BWP 2016 G-II)**

(a) Never establishes
(b) Establishes before the completion of reaction
(c) Establishes after the completion of reaction
(d) Establishes readily

11. A reverse reaction is one that: *(K.B)*
(LHR 2013,2016, GRW 2016, DGK 2017, RWP 2016 G-I, MTN 2016 G-II, DGK 2016 G-I, II)

(a) Which proceeds from left to right
(b) In which reactants react to form products
(c) Which slows down gradually
(d) Which speeds up gradually

12. Nitrogen and hydrogen were reacted together to make ammonia: *(K.B + U.B)*
(GRW 2017, RWP 2017)

$$N_2 + 3H_2 \rightleftharpoons 2NH_3 \qquad K_c = 2.86\ mol^{-2}dm^{6}$$

What will be present in the equilibrium mixture?

(a) NH_3 only (b) N_2, H_2 & NH_3
(c) N_2 & H_2 (d) H_2 only

13. For a reaction between PCl_3 and Cl_2 to form PCl_5 the units of K_c are: *(U.B)*
(GRW 2014, SGD 2016 G-I, 17, SWL 2016 G-I, RWP 2016 G-I, II)

(a) $mol\ dm^{-3}$ (b) $mol^{-1}\ dm^{-3}$
(c) $mol^{-1}\ dm^{3}$ (d) $mol\ dm^{3}$

ANSWER KEY

1	a	6	a	11	d
2	c	7	d	12	b
3	d	8	c	13	c
4	d	9	c		
5	d	10	a		

EXERCISE SHORT QUESTIONS

1. What are irreversible reactions? Give a few characteristics of them?
(Knowledge+Understanding Base) **(LHR 2013, RWP 2015, 2017, SGD 2017)**

Ans: **IRREVERSIBLE REACTIONS**

Definition:

"The reactions, in which the products ***do not recombine*** *to form reactants are called irreversible reactions".*

Examples:

- $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$
- $2Na + 2H_2O \longrightarrow 2NaOH + H_2$

Characteristics:

Following are the characteristics of irreversible reactions:

- These reactions proceed in one direction only.
- They are represented by single arrow ($\rightarrow$) between reactants and products.
- Reactants are completely converted into products at end of reaction.
- These reactions are generally fast.

2. Define chemical equilibrium state. ***(Knowledge Base)***
(LHR 2013, BWP 2017, DGK 2016 G-II)

Ans: **CHEMICAL EQUILIBRIUM STATE**

Definition:

"When the rate of the forward reaction takes place at the rate of reverse reaction, the ***composition*** *of the* ***reaction mixture remains constant.*** *It is called a chemical equilibrium state".*

Types:

- Static equilibrium
- Dynamic equilibrium

3. Give the characteristics of reversible reaction. ***(Knowledge+Understanding Base)***
(MTN 2017, RWP 2016 G-II, BWP 2016 G-II)

Ans: **REVERSIBLE REACTIONS**

Definition:

"The reactions in which ***products can recombine*** *to form* ***reactants*** *are called reversible reactions".*

Example:

- $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ $K_c = 2.86\ mol^{-2}dm^6$

Characteristics:

- They are represented by double arrow ($\rightleftharpoons$) between reactants and products.
- They proceed in both ways.
- A reversible reaction never goes to completion.

4. How dynamic equilibrium is established? ***(Understanding Base)***
(SGD 2016 G-II, 17, FSD 2017, GRW 2013, MTN 2016 G-II)

Ans: **ESTABLISHMENT OF DYNAMIC EQUILIBRIUM**

In a **reversible reaction,** dynamic equilibrium is established before the completion of reaction. At initial stage the rate of **forward reaction is very fast** and **reverse reaction** is taking place at a **negligible rate.** But gradually slows down and reaction speeds up. Eventually, **both reactions** attain the **same rate,** it is called a **dynamic equilibrium state.**

Example:

- $N_2 + 3H_2 \rightleftharpoons 2NH_3$ $K_c = 2.86\ mol^{-2}dm^6$

5. Why at equilibrium state reaction does not stop? ***(Understanding Base)*** **(BWP 2016 G-I, 17, MTN 2017)**

Ans: **REACTION AT EQUILIBRIUM**

At equilibrium state, a reaction does not stop because forward and reverse reactions keep on taking place at the same rate but in opposite direction. Products recombine to from reactants.

Example:

$$H_2 + I_2 \rightleftharpoons 2HI \qquad K_c = 57.0 \text{ at } 700\ K$$

6. Why equilibrium state is attainable from either way? ***(Understanding Base)*** **(FSD 2016 G-I)**

Ans: **ATTAINING OF EQUILIBRIUM STATE**

An equilibrium state is attainable from either way because it may start from reactants to give products or products can recombine to give reactants again.

$$\text{Reactants} \rightleftharpoons \text{Products}$$

$$A + B \rightleftharpoons C + D$$

Equilibrium state is established in a reversible reaction which proceeds in two direction.

7. What is relationship between active mass and rate of reaction? ***(Knowledge Base)*** **(SGD 2016 G-I, II)**

Ans: **RELATIONSHIP**

According to Guldberg and Waage's Law of Mass Action, the rate of a reaction is **directly proportional** to the product of the active masses of reacting substances.

Rate of Reaction $\propto$ active masses of reacting substances.

8. Derive equilibrium constant expression for the synthesis of ammonia from nitrogen and hydrogen. ***(Application Base)*** **(GRW 2014)**

Ans: **EQUILIBRIUM CONSTANT EXPRESSION**

For the synthesis of ammonia from nitrogen and hydrogen the balanced chemical equation is:

$$N_{2(g)} + 3H_{2(g)} \underset{R_r}{\overset{R_f}{\rightleftharpoons}} 2NH_{3(g)}$$

The rate of forward reaction: $R_f = k_f[N_2][H_2]^3$

The rate of reverse reaction: $R_r = k_r[NH_3]^2$

At equilibrium state:

$$R_f = R_r$$

$$k_f[N_2][H_2]^3 = k_r[NH_3]^2$$

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

The equilibrium expression for this reaction is

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

9. Write the equilibrium constant expression for the following reactions:
(Application+Understanding Base) **(GRW 2014, SWL 2017, RWP 2017, FSD 2017)**

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

(ii) $CO_{(g)} + 3H_{2(g)} \rightleftharpoons CH_{4(g)} + H_2O_{(g)}$

Ans: **EQUILIBRIUM CONSTANT EXPRESSIONS**

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

The rate of forward reaction $R_f = k_f [H_2][I_2]$

The rate of reverse reaction $R_r = k_r [HI]^2$

The equilibrium constant expression:

$$K_c = \frac{[\text{Products}]}{[\text{Reactants}]}$$

$$\mathbf{K_c} = \frac{[HI]^2}{[H_2][I_2]}$$

(ii) $CO_{(g)} + 3H_{2(g)} \rightleftharpoons CH_{4(g)} + H_2O_{(g)}$:

The rate of forward reaction $R_f = k_f [CO] [H_2]^3$

The rate of reverse reaction $R_r = k_r [CH_4] [H_2O]$

The equilibrium constant expression:

$$K_c = \frac{[CH_4][H_2O]}{[CO]\,[H_2]^3}$$

10. How direction of a reaction can be predicted? *(Knowledge+Understanding Base)*
(SWL 2017, RWP 2017, SGD 2016 G-II, 17, LHR 2013)

Ans: **PREDICTION OF DIRECTION OF REACTION**

Direction of a reaction at particular moment can be predicted by comparing the value of Q_c (reaction quotient) with K_c (equilibrium constant) of a chemical reaction.

$$K_c = \frac{[\text{Molar concentration of product}]}{[\text{Molar concentration of reactatnt}]}$$

- **If $Q_c < K_c$;** the reaction goes from left to right, i.e., in **forward direction** to attain equilibrium.
- **If $Q_c > K_c$;** the reaction goes from right to left, i.e., in **reverse direction** to attain equilibrium.
- **If Qc = Kc;** forward and reverse reactions take place at equal rates i.e., **equilibrium** has been **attained.**

11. How can you know that a reaction has achieved an equilibrium state?
(Knowledge+Understanding Base)

Ans: **ACHIEVING OF EQUILIBRIUM STATE**

If $Q_c = K_c$, it indicates that forward and reverse reactions are taking place at equal rates i.e. equilibrium has been attained.

12. What are the characteristics of a reaction that establishes equilibrium state at once? *(Understanding Base)*

Ans: **CHARACTERISTICS OF A REACTION**

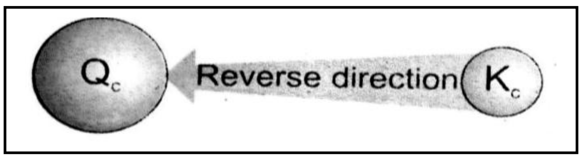
A reaction that establishes equilibrium state at once is called reversible reaction. Following are the characteristics of this type of reaction:

- These reactions never go to completion.
- These reactions are very fast.
- For these reactions the **value of K_c is small.**
- Closed flask $R_f = R_r$

13. If reaction quotient Qc of a reaction is more than Kc, what will be the direction of the reaction? *(Knowledge Base)* **(SGD 2013, BWP 2017, MTN 2017)**

Ans: **DIRECTION OF REACTION**

If reaction quotient, Q_c of a reaction is more than $\mathbf{K_c}$, the reaction proceeds from right to left i.e. in reverse direction to attain equilibrium.



14. An industry was established based upon a reversible reaction. It failed to achieve products on commercial level. Can you point out the basic reasons of its failure being a chemist? *(Application Base)*

Ans: **BASIC REASONS FOR FAILURE OF INDUSTRY**

An industry established based upon a reversible reaction failed to achieve products on commercial level due to the following reasons.

- Reaction is reversible so products recombine to form reactants and dynamic equilibrium is established.
- Equilibrium state is achieved at the initial stage of reaction and concentration of products is negligible.

EXERCISE LONG QUESTIONS

Q.1 Describe a reversible reaction with the help of an example and graph.

Ans: See LQ.1 (Topic 9.1)

Q.2 Write down the macroscopic characteristics of dynamic equilibrium.

Ans: See LQ.4 (Topic 9.1)

Q.3 State the Law of Mass Action and derive the expression for equilibrium constant for a general reaction

Ans: See LQ.1 (Topic 9.2)

Q.4 What is the importance of equilibrium constant?

Ans: See LQ.1 (Topic 9.4)

EXERCISE NUMERICALS

Q.1 For the decomposition of di-nitrogen oxide (N_2O) into nitrogen and oxygen reversible reaction takes place as follows

$$2N_2O \rightleftharpoons 2N_2 + O_2$$

The concentration of N_2O, N_2 and O_2 are 1.1 mol dm^{-3}, 3.90 mol dm^{-3} and 1.95 mol dm^{-3}, respectively at equilibrium. Find out K_c for this reaction.

Solution:

Given data:

The reversible reaction takes place as follows:

$$2N_2O \rightleftharpoons 2N_2 + O_2$$

The equilibrium concentration of:

$[N_2O]$ = 1.1mol dm^{-3}
$[N_2]$ = 3.90 mol dm^{-3}
$[O_2]$ = 1.95 mol dm^{-3}

The reversible reaction takes place as follows:

$$2N_2O \rightleftharpoons 2N_2 + O_2$$

To Find:

Equilibrium constant = K_c =?

Calculations:

The equilibrium constant expression for this reaction is

$$K_c = \frac{[N_2]^2[O_2]}{[N_2O]^2}$$

Putting the values

$$K_c = \frac{[3.90]^2[1.95]}{[1.1]^2}$$

$$= \frac{[15.21 \text{mol/dm}^3][1.95 \text{mol/dm}^3]}{[1.1 \text{moldm}^3]^2}$$

$$K_c = 24.51 \text{ mol dm}^{-3}$$

Result:

Thus equilibrium constant for the reaction= 24.51 mol dm^{-3}

Q.2 Hydrogen iodide decomposes to form hydrogen and iodine. If the equilibrium concentration of HI is 0.078 mol dm^{-3}, H_2 and I_2 is same 0.011 mol dm^{-3}. Calculate the equilibrium constant value for this reversible reaction:

Solution:

Given data:

The equilibrium concentration of:

$$[HI] = 0.078 \text{ mol dm}^{-3}$$

$$[H_2] = 0.011 \text{ mol dm}^{-3}$$

$$[I_2] = 0.011 \text{ mol dm}^{-3}$$

The reversible takes place as follows:

$$2HI \rightleftharpoons H_2 + I_2$$

To Find:

Equilibrium constant = K_c = ?

Calculations:

The equilibrium constant expression for this reaction is

$$K_c = \frac{[H_2][I_2]}{[HI]^2}$$

Putting the values

$$K_c = \frac{[0.011][0.011]}{[0.078]^2}$$

$$= \frac{0.000121}{0.006084}$$

$$K_c = 0.01989$$

Result:

Thus equilibrium constant for the reaction= 0.01989

Q.3 For the fixation of nitrogen following reaction takes place:

$$N_2 + O_2 \rightleftharpoons 2NO$$

When the reaction takes place at 1500 K, the K_c for this is 1.1 x 10^{-5}. If equilibrium concentrations of nitrogen and oxygen are 1.7 × 10^{-3} mol dm^{-3} and 6.4 × 10^{-3} mo1dm^{-3}, respectively, how much NO is formed?

Solution:

Given data:

Equilibrium concentrations of:

$[N_2] = 1.7 \times 10^{-3}$ mol dm^{-3}

$[O_2] = 6.4 \times 10^{-3}$ mol dm^{-3}

$K_c = 1.1 \times 10^{-5}$

The reversible takes place as follows:

$$N_2 + O_2 \rightleftharpoons 2NO$$

To Find:

Molar concentration of [NO] =?

Calculations:

The equilibrium constant expression for this reaction is

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

Putting the values

$$1.1 \times 10^{-5} = \frac{[NO]^2}{[1.7\times10^{-3}\,moldm^{-3}][6.7\times10^{-3}\,moldm^{-3}]}$$

$$[NO]^2 = (1.1 \times 10^{-5}) \times (1.7 \times 10^{-3} moldm^{-3}) \times (6.4 \times 10^{-3}\,moldm^{-3})$$

$$[NO]^2 = 11.96\times10^{-11}\,(moldm^{-3})^2$$
$$[NO]^2 = 1.96\times10^{-10}\,moldm^{-3}$$

Taking square root on both sides

$$\sqrt{[NO]^2} = \sqrt{1.1968\times10^{-10}}$$

$$[NO] = 1.09 \times 10^{-3}\,mol\,dm^{-3}$$

Result:

This molar concentration of NO = 1.09 × 10^{-3} mol dm^{-3}

Q.4 When nitrogen reacts with hydrogen to form ammonia, the equilibrium mixture contains 0.31 mol dm^{-3} and 0.50 mol dm^{-3} of nitrogen and hydrogen respectively. If the K_c is 0.50 mol dm^{-3} what is the equilibrium concentration of ammonia?

Solution:

Given data:

The equilibrium concentrations of:

$[N_2] = 0.31 mol\,dm^{-3}$

$[H_2] = 0.50$ mol dm^{-3}

$K_C = 0.5\,mol^{-2}dm^{6}$

The equilibrium constant expression for this reaction is

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

To Find:

Equilibrium concentration of ammonia= $[NH_3]$ = ?

Calculations:

The equilibrium constant expression for this reaction is

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

Putting the values

$$K_c = \frac{[NH_3]^2}{[0.31\,moldm^{-3}][0.50\,moldm^{-3}]^3}$$

$$[NH_3]^2 = (0.50\,mol^{-2}dm^{6}) \times (0.31\,moldm) \times (0.50\,moldm)^3$$

$$[NH_3]^2 = \sqrt{0.019375}$$

Taking square root on both sides

$$[NH_3]^2 = 0.1392\,mol\,dm^{-3}$$
$$[NH_3] = 0.14\,mol.dm^{-3}$$

Result:

Thus equilibrium concentration of NH_3 = 0.14 mol dm^3

ADDITIONAL CONCEPTUAL QUESTIONS

Q.1 Why is equilibrium achievable only in closed system?

Ans: Equilibrium is only achievable in close system because dynamic equilibrium is only attained in reversible reactions and reversible reaction can only take place in closed system.

Q.2 How can we determine the value of Kc?

Ans: We can calculate the numerical values by putting actual equilibrium concentrations of the reactants and products into equilibrium expression.

Q.3 Why reaction quotient Qc is useful?

Ans: Qc is useful because it predicts the direction of a reaction by comparing the value of Qc with Kc.

Q.4 Differentiate between Qc and Kc.

Ans:

Qc	Kc
Definition: Ratio of product of concentration of products raised to the power of co-efficient to the product of concentration of reactants raised to the power of co-efficient in a balanced chemical equation, **at any time interval 't'** of reversible reaction	**Definition:** Ratio of product of concentration of products raised to the power of co-efficient to the product of concentration of reactants raised to the power of co-efficient in a balanced chemical equation. At the time of equilibrium.
Value: Its value can be obtained **before equilibrium state.**	**Value:** Its value can be obtained **only** at **equilibrium state.**
Formula: $Qc = \frac{[Product]_t}{[Reactant]_t}$	**Formula:** $Kc = \frac{[Product]}{[Reactant]}$

Q.5 Differentiate between Reverse and Reversible Reaction.

Ans:

Reverse Reaction	Reversible Reaction
Definition: It is reaction in which products react to produce reactants.	**Definition:** It is a reaction in which reactants react to produce products and products react to give reactants.
Direction: It takes place in one direction, i.e from right to left.	**Direction:** It takes place in both directions.

Q.6 Why at large numerical value of Kc concentration of products are high and reactants are low?

Ans: As we know

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

Which means **Kc** is **directly proportional** to concentration of **products** and inversely proportional to centration of reactants. If numerical value of Kc is large it means concentration of products are high as Kc is directly proportional to product and reaction has **almost** gone to completion.

Q.7 Why at small numerical value of Kc concentration of reactants are high and products are negligible?

Ans: As we know

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

Which means **Kc** is **directly proportional** to concentration of **products** and inversely proportional to centration of reactants. If numerical value of Kc small it means concentration of reactants are high as Kc is inversely proportional to the reactants and reaction will never go to completion.

Q.8 Explain why does the concentration of reactants decrease in forward reaction and increase in reverse reaction?

Ans: **In forward reaction reactants react and concentration of reactants decreases gradually** as they form products, as concentration decreases rate of forward reaction also decreases. On the other hand rate of reverse reaction increases and concentration of reactants also increases with time as products react to form reactants in reverse reaction. Therefore we can say that rate and concentration are directly proportional to each other.

Rate of reaction $\propto$ Concentration of reactants

TERMS TO KNOW

Terms	Definitions
Chemical Reactions	The process in which chemical change occurs in nature and composition of substances is called chemical reaction.
Complete Reaction	A reaction in which all the reactants are converted into products is called complete reaction.
Irreversible Reactions	In most of the reactions the products do not recombine to form reactants, are called irreversible reactions and such reactions proceed in one direction only.
Reversible Reactions	Reactions in which products recombine to form reactants are called reversible reactions and such reactions proceed in both directions.
Chemical Equilibrium	When the rate of the forward reaction takes place at the rate of reverse reaction, the composition of the reaction mixture remains constant, is called chemical equilibrium state.
Static Equilibrium	When reaction ceases to proceed, it is called static equilibrium. This happens mostly in physical phenomenon.
Dynamic Equilibrium State	When reaction does not stop only the rates of forward and reverse reaction become equal to each other but take place in opposite directions. This is called dynamic equilibrium state.
Law of Mass Action	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.
Active Mass	An active mass is considered as the molar concentration.
Equilibrium Constant	Ratio of the product of concentration of products raised to the power of coefficients to the product of concentration of reactants raised to the power of coefficients as expressed in the balanced chemical equation is called equilibrium constant.
Extent of a Reaction	Numerical value of the equilibrium constant predicts the extent of a reaction. It indicates to which extent reactants are converted to products. OR It measures how far a reaction proceeds before establishing equilibrium state.
Reaction Quotient	The ratio of product of concentration of products raised to the power of coefficients to the product of concentration of reactants raised to the power of co-efficients in a balanced chemical equation at any moment of the reversible reaction is known as reaction quotient.

CUT HERE

SELF TEST

Time: 35 Minutes **Marks: 25**

Q.1 Four possible answers (A), (B), (C) and (D) to each question are given, mark the correct answer. **(6×1=6)**

1. When the magnitude of K_c is very large it indicates:

(A) Equilibrium will never establish
(B) Reaction mixture has almost all products
(C) Reaction has not gone to completion
(D) Reaction mixture has negligible products

2. A reverse reaction is one that:

(A) Proceeds from left to right
(B) In which reactant react to form product
(C) Slows down gradually
(D) Speeds up gradually

3. The colour of hydrogen iodide is:

(A) Colourless
(B) Black
(C) Red
(D) Pink

4. Which gas is used to manufacture king of chemicals (sulphuric acid)?

(A) N_2
(B) O_2
(C) Cl_2
(D) CO_2

5. The units of molar concentration:

(A) $mol.dm^{-2}$
(B) $mol.dm^{-1}$
(C) mol.dm
(D) $mol.dm^{-3}$

6. If $Q_c < K_c$, the reaction goes in:

(A) Forward
(B) Reverse
(C) At equilibrium state
(D) None of the above

Q.2 Give short answers to the following questions. **(5×2=10)**

(i) Why reversible reactions never complete?
(ii) Define irreversible reaction.
(iii) Write use of atmospheric gases in manufacture of chemicals.
(iv) Define k_c and give its formula.
(v) How can you predict the direction of reaction?

Q.3 Answer the following questions in detail. **(5+4=9)**

(a) State law of mass action and explain derivation of expression for equilibrium constant for general reaction. **(5)**

(b) When nitrogen reacts with hydrogen to form ammonia, the equilibrium mixture contains 0.31 and 0.50 $mol.dm^{-3}$ of nitrogen and hydrogen respectively. If the K_c is 0.50 mol^{-2} dm^6, what is the equilibrium concentration of ammonia? **(4)**

NOTE: Parents or guardians can conduct this test in their supervision in order to check the skill of students.