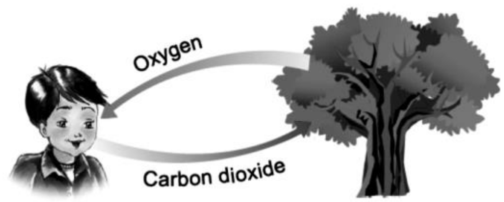
UNIT – 9

Chemical Equilibrium

INTRODUCTION:

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.



Many environmental systems depend for their existence on delicate equilibrium phenomenon. For example, concentration of gases in lake water is governed by the principles of equilibrium. The lives of aquatic plants and animals are indirectly related to concentration of dissolved oxygen in water.

Q.No. 9.1 Define chemical equilibrium in terms of a reversible reaction?

Ans. Chemical Equilibrium:

Definition:-

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

Reactants:-

"In a chemical reaction, the substances that combine are called reactants."

Products:-

"The new substances formed in a chemical reaction are called products."

Example:-

(Reactants)$2H_2+O_2 \rightarrow 2H_2O$(Products)

Irreversible Reaction:-

"The reaction, in which products do not recombine to form reactants".

Example:-

$2H_2+O_2 \rightarrow 2H_2O$

Representation:-

They are represented by single arrow **(→).**

Reversible Reaction:-

"The reaction in which products can recombine to form reactants".

Example:-

$H_2+I_2 \rightleftharpoons 2HI$

Representation:-

These reactions are represented by double arrow**(⇌)**

Forward reaction:-

"The reactions which goes from left to right is called as a forward reaction".

Explanation of Forward reaction:-

A reaction between hydrogen and iodine which are the reactants, Iodine is purple while the product hydrogen iodide is colourless. On heating the hydrogen and iodine vapours in a closed flask, hydrogen iodide is formed. As a result, purple colour of iodine fades as it reacts to form colorless hydrogen iodide.

$$H_2 + l_2 \xrightarrow{\Delta} 2Hl$$

This reaction is called as forward reaction.

Reverse reaction:-

"The reaction which goes from right to left is reverse reaction."

Example:-

$H_2+I_2 \rightleftharpoons 2HI$

Explanation of reverse reaction:

On the other hand, when only hydrogen iodide is heated in a closed flask purple colour appears because of formation of iodine vapours such as.

$$2Hl \xrightarrow{\Delta} H_2 + l_2$$

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

Q. No. 9.2 Show Graphical representation dynamic equilibrium.

Ans. In a reversible reaction, dynamic equilibrium is established before completion of reaction. At initial stage the rate of forward reaction is very fast and reverse reaction is at negligible rate. But gradually forward reaction slows and reverse reaction becomes fast.

Dynamic Equilibrium:-

"When both forward and reversible reactions take place at the same rate but take place in opposite direction this is called dynamic equilibrium".

Graphical Representation:-

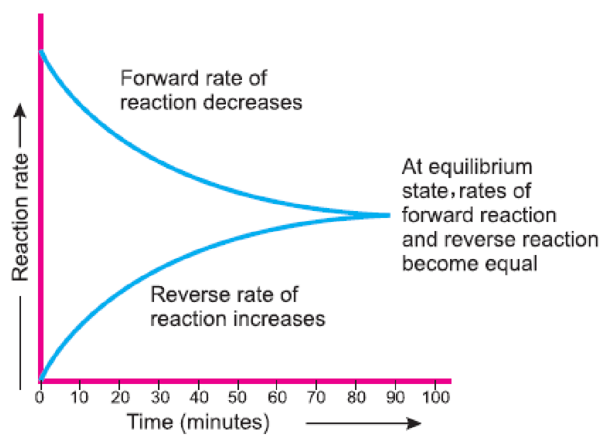


Fig. 9.3 Graph showing the rate of forward and reverse reactions and establishment

Explanation:

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

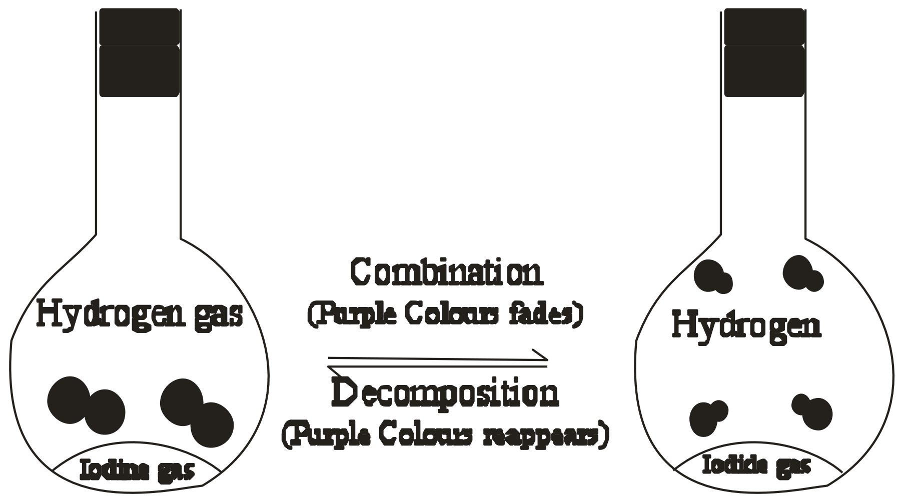
$H_{2(g)}+I_{2(g)} \longrightarrow 2HI_{(g)}$

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

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

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. As the reaction proceeds, the concentration of reactants will gradually decrease while that of product 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. No. 9.3: Define Chemical Equilibrium State and Decomposition of $CaCO_3$ is an example of reversible reaction. Explain and justify the statements.

Ans. Thus 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 there are two possibilities.

(i) When reaction ceases to proceed, it is called static equilibrium. This happens mostly in physical phenomenon for example, a building remains standing rather than falling down because all the forces acting on it are balance. This is an example of static equilibrium.

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

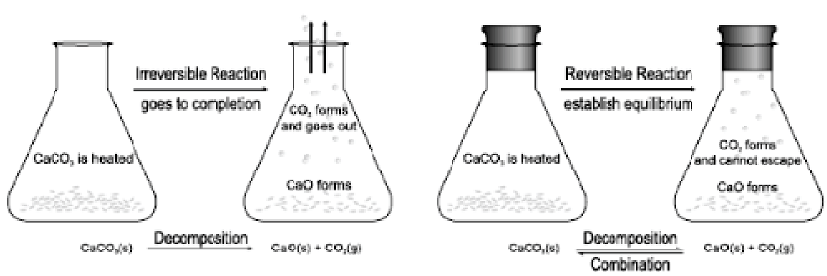
Decomposition of $CaCO_3$

When calcium oxide and carbon dioxide react, they produce calcium carbonate;

$$CaO_{(s)} + CO_{2\,(g)} \longrightarrow CaCO_{3(s)}$$

On the other hand, when $CaCO_3$ is heated in an open flask, it decomposes to form calcium oxide and carbon dioxide. CO escapes out and reaction goes to completion:

$$CaCO_{3(s)} \longrightarrow CaO_{(s)} + CO_{2(g)}\uparrow \quad \text{(decomposition)}$$



In these two reactions, decomposition is reverse to combination or vice versa. When calcium carbonate is heated in a closed flask, so that CO_2 can't escape out as shown in figure Initially only decomposition goes on (forward reaction), but after a while CO_2 starts combining with CaO to form $CaCO_3$ (reverse reaction). 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.

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

Forward Reaction	Reverse Reaction
1. It is a reaction in which reactants react to form products. 2. It takes place from left to right. 3. At initial stage, the rate of forward reaction is very fast. 4. It slows down gradually	1. It is a reaction in which products react to produce reactants. 2. It takes place from right to left. 3. In the beginning, the rate of reverse reaction is negligible. 4. It speeds up gradually.

Q. No. 9.4: Describe the Macroscopic characteristics of dynamic equilibrium.

Ans.

i. An equilibrium is achievable only in closed system.

ii- 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- At equilibrium state, the amount of reactants and products do not change, even physical properties like color, density etc remains same.

iv- An equilibrium state is attainable from either way, starting from reactants or from products.

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

Q. No:9.5: Describe "Law of Mass Action".

Ans. Introduction:-

"Guldberg " and "Waage" in 1869 put forward this law.

In a reversible reaction, dynamic equilibrium is established for completion of reaction. At initial stage the rate of forward reaction is very fast and rate of reverse reaction is negligible. But gradually forward reaction slows and reverse reaction becomes fast.

Statement:-

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

Active Mass:-

Definition:-

"An active mass is considered as a molar concentration its unit $moldm^{-3}$ expressed as square brackets[ ]."

Derivation of expression for equilibrium constant:-

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

Suppose [A], [B],[C]and [D] are molar concentration of A,B,C and D respectively.

According to law of Mass action:-

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

$$R_f = K_f [A][B]$$

Similarly,

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

$$R_r = K_r [C][D]$$

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

At equilibrium state:-

The rate of forward reaction= The rate of reverse reaction

$$K_f [A][B] = K_r [C][D]$$

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

$$Where\, K_c = \frac{K_f}{K_r}$$

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

K_c is called "chemical equilibrium constant".

Q.9.6: Derive the expression for equilibrium constant for general reaction:-

Definition:

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

Derivation:

Let us apply the law of mass action for a general reaction.

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

The rate of forward reaction according to law of mass action 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.

The rate of reverse reaction according to law of mass action is:

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

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

At equilibrium state:

The rate of forward reaction= The rate of reverse reaction.

$$\mathbf{R_f = R_r}$$

Putting values:-

$$K_f [A]^a[B]^b = K_r [C]^c[D]^d$$

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

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

$$K_c = \frac{K_f}{K_r}$$

Where k is called equilibrium constant.

Q. No. 9.7 Define equilibrium constant and also derive its units.

Ans. EQUILIBRIUM CONSTANT:

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

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

Explanation:

It is conventional to write the products as numerator and reactants as denominator. By knowing, the balanced chemical equation for a reversible reaction we can write the equilibrium expression. Thus, we can calculate the numerical value of by putting actual equilibrium concentrations of the reactants and products into equilibrium expression. The value of K_c depends only on temperature, it does not depend on the initial concentrations of the reactants and the products. A few problems have been solved to make the concept clear.

Units:

K_c has no units in reactions with equal number of moles on both sides of the equation. This is because concentration units cancel out in the expression for Kc, e.g., for the reaction:

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

$$K_c = \frac{[HI]^2}{[H_2][I_2]} \qquad \text{Units} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})} = \text{no units}$$

For reactions in which the number of moles of reactants and product are not equal in the balanced chemical equation, K of course, have units, e.g., for the reaction.

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

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})^3} = \frac{1}{(\text{mol dm}^{-3})^2} = \text{mol}^{-2}\,\text{dm}^6$$

Q. No. 9.8: What is the importance of equilibrium constant?

Ans. Knowing the numerical value of equilibrium constant of a chemical reaction, direction as well as extent of reaction can be predicted.

1- Predicting direction of a reaction:

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. Consider the gaseous reaction of hydrogen with iodine.

Example:-

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)} \qquad K_c = 57.0 \text{ at } 700\text{ K}$$

We withdraw the samples from the reaction mixture and determine the concentrations of $H_{2(g)}$, $I_{2(g)}$ and $HI_{(g)}$. Suppose concentrations of the components of the mixture are:

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

Explanation:

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 Qc. 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.

3. Conditions:-

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

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

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

2- Predicting extent of reaction:

Numerical value of the equilibrium constant predicts the extent of a reaction. It indicates to which extent reactants are converted to products. In fact, it measures how far a reaction proceeds before establishing equilibrium state. In general, there are three possibilities of predicting extent of reactions as explained below.

1- Large numerical value of K_c:

The large value of k_c indicates that at equilibrium Position the reaction mixture consist of almost all products and reactants are negligible. The reaction has almost gone to completion.

Example:-

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

2- Small numerical value of K_c:

The small value of K_c indicates the equilibrium has established with very small conversion of reactions into products. At equilibrium position almost all the reactants are presents but amount of products is negligible. Such type f reaction never goes to completion.

Example:

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

3- Numerical value of K_c is neither small nor large:

Such reactions have comparable amounts of reactants and products at equilibrium position

Example:

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

EXAMPLES

Problem 9.1

When hydrogen reacts with iodine at 25 °C to form hydrogen iodide by a reversible reaction as follows:

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

The equilibrium concentrations are:

$[H_2]$ = 0.05 mol dm^{-3}; $[I_2]$ = 0.06 mol dm^{-3}; and [HI] = 0.49 mol dm^{-3}

Find the equilibrium constant for this reaction.

Solution:

Given equilibrium concentrations are;

$[H_2]$ = 0.05 mol dm^{-3}; $[I_2]$ = 0.06 mol dm^{-3}; and [HI] = 0.49 mol dm^{-3}

Write the equilibrium constant expression as

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

Now, put the values of equilibrium concentrations in equilibrium expression:

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

Problem 9.2

For the formation of ammonia by Haber's process, hydrogen and nitrogen react reversibly at 500 °C as follows

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

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 $\mathbf{K_c}$.

Solution:

The equilibrium concentrations are:

$[N_2]$ = 0.602 mol dm^{-3}; $[H_2]$ = 0.420 mol dm^{-3}; and $[NH_3]$ = 0.113 mol dm^{-3}

The equilibrium constant expression for this reaction is:

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

Now put the equilibrium concentration values in the equilibrium expression

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

Problem 9.3

For a reaction between PCl_3 and Cl_2 to form PCl_5 , the equilibrium constant is 0.13 mol^{-1} dm^3 at a particular temperature. When the equilibrium concentrations of PCl_3 and Cl_2 are 10.0 and 9.0 mol dm^{-3}, respectively. What is the equilibrium concentration of PCl_5?

Solution:

$[PCl_3] = 10 \text{ mol dm}^{-3}$ $[Cl_2] = 9.0 \text{ mol dm}^{-3}$

$K_c = 0.13 \text{ mol}^{-1} \text{dm}^3$ $[PCl_5] = ?$

Now write the balanced chemical equation and equilibrium constant expression

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

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

Now put the known values in above equation and rearrange

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

$[PCl_5] = 0.13 \times 10.0 \times 9.0 = 11.7 \text{ mol dm}^{-3}$

Numericals

Q.No.1. For the decomposition of dinitrogen oxide into nitrogen (N_2O) and oxygen. Reversible reaction take place as follow $2N_2O \rightleftharpoons 2N_2+O_2$. The concentration of N_2O, N_2 and O_2 are 1.1 mol dm^{-3}, 3.90moldm^{-3} and 1.95 moldm^{-3}, respectively at equilibrium Find out K_c for this reaction.

Reaction :-

$2N_2O \rightleftharpoons 2N_2+O_2$

Give Data:-

$[N_2O]=1.1\text{mol dm}^{-3}$

$[N_2]=3.90 \text{ moldm}^{-3}$

$[O_2]=1.95\text{mol dm}^{-3}$

Required :-

$K_c=?$

Calculation:-

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

$$= \frac{[3.9 mol.dm^{-3}]^2 \times [1.95 mol.dm^{-3}]}{[1.1 mol.dm^{-3}]^2}$$

$$= \frac{15.21 \times 1.95}{1.21}$$

$$= \frac{29.65}{1.21}$$

$=24.5 \text{ moldm}^{-3}$

Results :-

The value of K_c at the following concentration is 24.5 moldm^{-3}

Q.No.2:- Hydrogen iodide decomposes to form hydrogen and iodine. If the equilibrium concentration of HI 0.078 mol dm^{-3}, H_2 and I_2 is same 0.011 mol dm^{-3}. Calculate the equilibrium constant value of for this reversible reaction.

Give Data:-

[HI]=0.078 mol dm^{-3}
$[I_2]$ =0.011 mol dm^{-3}
$[H_2]$ =0.011 mol dm^{-3}

Reaction :-

$2HI \rightleftharpoons I_2+H_2$

Required :-

K_c=?

Calculation:-

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

$$= \frac{[0.011 mol.dm^{-3}][0.011 mol.dm^{-3}]}{[0.078 mol.dm^{-3}]^2}$$

$$= \frac{1.21\times10^{-4}}{6.084\times10^{-3}}$$

$$= 0.19\times10^{-1}$$

$$= 0.019$$

Results :-

The value of K_c at the following concentration is 0.019

Q.No.3:- For the fixation of nitrogen following reaction take place:

$$N_2+O_2 \rightleftharpoons 2NO$$

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

Give Data:-

The value of Kc=1.1×10^{-5}

$[N_2]$=1.7×10^{-3}

$[O_2]$=6.4×10^{-3} mol dm^{-3}

Reaction :-

$N_2+O_2 \rightleftharpoons 2NO$

Required :-

[NO]=?

Solution:-

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

$$1.1\times10^{-5} = \frac{[NO]^2}{(1.7\times10^{-3}mol.dm^{-3})(6.4\times10^{-3}mol.dm^{-3})}$$

$$1.1\times10^{-5}\times(1.088\times10^{-5}) = [NO]^2$$

$$1.196\times10^{-10} = [NO]^2$$

$$\sqrt{1.196\times10^{-10}} = \sqrt{[NO]^2}$$

$$1.196\times10^{-10}moldm^{-3} = [NO]$$

Results:-

The concentration of [NO] in the following concentration is $1.093\times10^{-5}\,moldm^{-3}$

Q.No.4:- When nitrogen reacts with hydrogen to form ammonia, the equilibrium mixture contains 0.31mol dm^{-3} and 0.50 $moldm^{-3}$ of nitrogen and hydrogen respectively. If the K_c is 0.50 mol^{-2} dm^{-3}, what is the equilibrium concentration of ammonia?

1- Give Data:-

$[N_2]$=0.31 $moldm^{-3}$
$[H_2]$=0.50 $moldm^{-3}$
K_c =0.50 $moldm^{-3}$

Reaction :-

$N_2+3H_2 \rightleftharpoons 2NH_3$

Required :-

$[NH_3]$=?

Calculation:-

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

$$0.50 = \frac{[NH_3]^2}{(0.31mol.dm^{-3})(0.50mol.dm^{-3})^3}$$

$$0.50 = \frac{[NH_3]^2}{0.03875}$$

$$(0.50)(0.03875) = [NH_3]^2$$

Take square root on both side

$$\sqrt{[NH_3]^2} = \sqrt{(0.50)(0.03875}$$

$$\sqrt{[NH_3]^2} = \sqrt{0.019371}$$

$$[NH_3] = 0.14moldm^{-3}$$

SHORT QUESTIONS

1. What are irreversible reactions? Give a few characteristic of them.

Ans: Definition:-

"The reactions in which the products do not recombine to form the reactants"

Characteristics:-

(i) They are represented by single arrow (→).

(ii)They are supposed to be complete reactions.

Example:-

$$2H_{2(g)} + O_{2(g)} \xrightarrow[Heat]{Pt} 2H_2O$$

2. Define chemical equilibrium state.

Ans: Definition:-

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

3. Give the characteristics of reversible reaction.

Ans: Definition:-

"The reactions in which products recombine to produce the reactants are called reversible reaction".

Presentation:-

They are presented by double arrow (⇌).

These reactions proceed in both directions.

(i) Forward direction (ii) Reverse direction

Completion:-

They never go to completion.

Example:-

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

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

4. How dynamic equilibrium is established?

Ans: When the forward reaction become equal to the reverse reaction then dynamic equilibrium state is established.

Rate of forward reactions=Rate of Reverse reactions

Example:-

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

5. Why at equilibrium state reaction does not stop?

Ans: It is because the forward reaction take place at the same rate as of reverse but in opposite direction. So reactants convert into product and products convert into reactants and reaction does not stop.

6. Why equilibrium state reaction does not stop:

Ans: An equilibrium state is attainable from either way, starting from reactants or from products.

7. What is relationship between active mass and rate of reaction?

Ans:

Rate of Reaction	Active Mass
➢ The rate of reaction is directly proportional to the product of the active masses of the reacting substances." $A + B \underset{k_r}{\overset{k_f}{\rightleftharpoons}} C + D$ Rate of forward reaction $\propto$ [A][B] Rate of reverse reaction $\propto$ [C][D]	➢ While the rate at which a substance reacts is directly proportional to its products of active mass. ➢ It is represented by square brackets [ ]. Its units is "mol dm^{-3}"

8. Define drive equilibrium constant expression for the following reactions:

Ans:

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

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

9. Derive equilibrium constant expression for the synthesis of ammonia from nitrogen and hydrogen.

Ans: Chemical Equilibrium:-

It is because the forward reaction takes place at the same rate of reverse reaction but in opposite direction.

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

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

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

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

10. How direction of a reaction can be predicted?

Ans: The direction of a reaction can be predicted by inserting the concentration of the reactants and products at the particular moment in the equilibrium expression.

11. How can you know that a reaction has achieved an equilibrium state?

Ans: By knowing the value of K_c we can predict the equilibrium state. If the value of Q_c is equal to K_c" then indicate that a reaction has achieved an equilibrium state.

12. What are the characteristics of a reaction that established equilibrium state at once?

Ans: If a reaction has very small value of K_c will attain the equilibrium state at once.

13. If reaction quotient Q_c Of a reaction is more than K_c What will be the direction of the reaction?

Ans: If Q_c> Kc the reaction goes from right to left, i-e-, in reverse direction to attain equilibrium.

14. If industry was established based upon a reversible reaction. It failed achieve product on commercial level. Can you point out the basic reaction of its failure being a chemist?

Ans: **B**ecause this industry is based on reversible reaction so products convert into reactants again. As a result products cannot be achieve.

13. Write down the component of atmosphere and its % age ?

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

14. Why reversible reaction never complete?

Ans. As reversible reactions are those in which reactants combine to form products and products recombine to form the reactants that is why they never complete e.g. $I_2 + H_2 \rightleftharpoons 2HI$

15. What is static equilibrium, explain with example

Ans. Static equilibrium:- When reaction ceases to proceed it is called static equilibrium.

Example:-

A building remains standing rather than falling down because all of forces acting upon it are balanced. It is physical example of static equilibrium.

1. Why the amount of reactants and product do not change in reversible reaction?

Ans. In dynamic equilibrium Rate of forward reaction is always equal to Rate of reverse reaction as in reversible reaction dynamic equilibrium condition is appear that is why the amount will not change.

2. What is law of mass action?

Ans. Statement:-

"The rate at which a substance react is directly proportional to active mass and the rate of reaction is directly proportional to the product of the active masses of the reacting substance**"**

3. How the active mass is represented?

Active mass is represented by square brackets **[ ]**.

4. What do you mean by equilibrium constant?

Ans. Definition:-

"Ratio of the product of Concentration of product raised to the power of the coefficient to the product of Concentration of reactants raised to the power of co-efficient in a balanced chemical equation.**"**

Mathematically:-

It is expressed by the following:

$$K_c = \frac{\text{Product of concentration of produts raised to the power of co-effients}}{\text{Product of concentration of reactants raised to the poer of co-effients}}$$

5. Point out the coefficients in the following hypothetical reactions.

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

b. $4X \rightleftharpoons 2Y + 3Z$

c. $2M + 4N \rightleftharpoons 5O$

Ans.

coefficient in reactants	Coefficient in product
i- 2 and 3	4 and 2
ii- 4	2 and 3
iii- 2 and 4	5

6. Write equilibrium constant for the following.

a. $2NO_{2(g)} \rightleftharpoons N_2O_4$

b. PCl $_{2(g)}$ + $Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$

c. $2SO_{2(g)} + O_2(g) \rightleftharpoons 2SO_{3(g)}$

Ans. For $2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$

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

For $PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_5$

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

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

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

9. What is mean by extent of reaction?

Ans. It indicates how much reactants are converted into products and how far a reaction proceeds before the equilibrium state.

10. Why the reversible reactions do not go to completion?

Ans: It is because in reversible reactions products re-combine to form the reactants in a same rate as the reactants form the products.

11. If a reaction has large value of K_c will it go to completion and why?

Ans: The large values of K_c indicate that at equilibrium state reaction mixture consists of almost all product and reactants are negligible. It also shows that reaction has almost gone to completion reaction.

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

12. Which types of reactions do not go to completion?

Ans: Reversible reactions never go to completion. Because in it products recombine to form reactants again.

13. Write down the use of Nitrogen ?

Ans : These gases are being used to manufacture chemicals since the advent of 20th century**.** Nitrogen is used to prepare ammonia, which is further used to manufacture nitrogenous fertilizer.

14. Write down the use of oxygen ?

Ans: Oxygen is used to prepare sulphur dioxide which is further used to manufacture king of chemicals sulphuric acid.

MULTIPLE CHOICE QUESTIONS

1. **The characteristics of reversible reactions are the following except:**
(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.**
$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$
Goes to completion because.
(a) Of high temperature (b) CaO is more stable than $CaCO_3$
(b) 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:
(a) $\frac{[2A]\,[B]}{[3C]}$ (b) $\frac{[2A]^2\,[B]}{[3C]^3}$ (c) $\frac{[3C]\,[2A]}{[B]}$ (d) $\frac{[C]^3\,[A]^2}{[B]}$

4. **When a system is at equilibrium state:**
(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?**
(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 Kc is very large it indicates.**
(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.**
(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.**
(a) Very small K_c value (b) very large K_c value
(b) Moderate K_c value (d) none of these

9. **At dynamic equilibrium.**
(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.
(a) never establishes (b) establishes before the complete of reaction
(c) establishes after the completion of reaction
(d) establishes readily

11. A reverse reaction is one that.
(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;
$N_2 + 3H_2 \rightleftharpoons 2NH_3$ Kc = 2.86 $mol^{-2}dm^{6}$
What will be present in the equilibrium mixture?
(a) NH_3 only (b) N_2, H_2 , and NH_3 (c) N_2 and H_2 Only (d) H_2 Only

13. For a reaction between PCl_3 and Cl_2 to from PCl_5, the units of K_c are:
(a) Mol dm^{-3} (b) mol-1 dm^{3} (c) mol-1 dm^{3} (d) mol dm^{3}

14. In a chemical reaction the substances that combine are called________
(a) Products (b) Reactants (c) both a & b (d) None

15. In a chemical reaction the new substances formed known as________
(a) Products (b) Reactants (c) both a & b (d) None

16. Irreversible reactions are represented by_______
(a) $\rightarrow$ (b) $\rightleftharpoons$ (c) _____ (d) ---›

17. The reaction in which products do not recombine to form reactants are called_______
(a) Irreversible (b) Reversible (c) both a & b (d) None

18. The color of iodine is _______
(a) Pink (b) Green (c) Yellow (d) Purple

19. At dynamic equilibrium rate of forward reaction _______ to rate of reverse
(a) Equal (b) Unequal (c) More (d) Less

20. _______ reaction slows down gradually
(a) Forward (b) Reverse (c) both a & b (d) None

21. Active mass is expressed by _______
(a) $\rightarrow$ (b) $\leftarrow$ (c) [ ] (d) ( )

22. What is unit of molar concentration _______
(a) $moldm^{-3}$ (b) $mol^{-1}dm^{3}$ (c) $moldm^{2}$ (d) $mol^{-1}dm^{-3}$

23. Equilibrium Constant expression (Kc) is equal to _______ $A + B \rightleftharpoons C + D$
(a) $\frac{[C][D]}{[A][B]}$ (b) $\frac{[A][B]}{C[D]}$ (c) $\frac{[A][D]}{[B][C]}$ (d) None

24. Law of mass action put forward in _______
(a) 1859 (b) 1869 (c) 1969 (d) 1960

25. A reverse reaction is on that _______
(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

26. Nitrogen and hydrogen were reacted together to make ammonia
$N_2 + 3H_2 \rightleftharpoons 2NH_3$ K_c = 2.86 $mol^{-2}dm^{6}$
What will be present in equilibrium mixture
(a) NH_3 only (b) N_2,H_2 & NH_3 (c) N_2 and H_2 only (d) H_2 only

27. Reactions which have comparable amounts of reactants and products at equilibrium state have:
(a) very small K_c value (b) very large K_c value
(c) Moderate K_c value (d) None of these

28. For a reaction between PCl_3 and Cl_2 to form PCl_2 the unit of K_c are:
(a) mol dm^{-3} (b) mol^{-1} dm^{-3} (c) mol^{-1} dm^3 (d) mol dm^3

29. Two major components of atmosphere are _______
(a) Nitrogen & Oxygen (b) Oxygen & Carbon (c) Carbon & Nitrogen
(d) None of all these

30. In an irreversible reaction dynamic equilibrium
(a) Never establishes (b) establishes before the completion of reaction
(c) establishes after the completion of reaction (d) establishes readily

31. Nitrogen and hydrogen were reacted together to make ammonia _______
(a) Irreversible (b) Reversible (c) both a & b (d) None

32. Colour of HI is:
(a) orange (b) purple (c) red (d) colourless

33. If in a reaction Qc = Kc then.
(a) In forward (b) in reverse direction
(c) reaction in equilibrium (d) reaction is not in equilibrium

34. Qc < Kc then reaction will be.
(a) forward (b) Reverse (c) in state of quilibrium (d) none

35. Kc is always equal to:
(a) R_f/R_r (b) K_f/K_r (d) R_f/R_r (d) R_n/R_f

36. The Unit of K_c for following reaction
$H_{2(g)}\ I_{2(g)} \rightarrow 2HI_{(g)}$
(a) No Unit (d) $moldm^{-3}$ (c) mol^2dm^6 (d) $mol^{-1}dm^3$

37. Which reaction of rate constant K_f is of:
(a) forward reaction (d) Backward reaction (c) Upper reaction (d) Down reaction

38. The value of K_c depend upon.
(a) Temperature (d) Initial concentration (c) Both a,b (d) None of these

39. The colour of iodine is ……..
(a) Black (d) Yellow (c) Purple (d) Green

40. The reaction goes from left to right if.
(a) Qc = Kc (b) Qc > Kc (c) Qc < Kc (d) Qc = 0

MCQ's KEY

1	a	2	c	3	D	4	d	5	d	6	a	7	d	8	c
9	c	10	a	11	D	12	b	13	c	14	b	15	a	16	a
17	a	18	d	19	A	20	a	21	c	22	a	23	a	24	b
25	d	26	b	27	C	28	c	29	a	30	a	31	b	32	d
33	c	34	a	35	B	36	a	37	a	38	a	39	c	40	c