Chapter = 01

Chemical Equilibrium

Q 1. What is a chemical reaction? Discus it in brief.

CHEMICAL REACTION

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

$$2NaHCO_3 \rightleftharpoons Na_2CO_3 + CO_2 + H_2O$$

Q 2. Define chemical equilibrium with example.

CHEMICAL EQUILIBRIUM

Chemical equilibrium refers to the state of a system in which the concentration of the reactant and the concentration of the products do not change with time and the system does not display any further change in properties

$$N_2O_4 \rightleftharpoons 2NO_2$$
$$PCl_5 \rightleftharpoons PCl_3 + PCl_2$$
$$N_2 + H_2 \rightleftharpoons 2NH_3$$

Q 3. Describe dynamic equilibrium with two examples.

DYNAMIC EQUILIBRIUM

Any reaction will be in dynamic equilibrium if it's reversible and the rates of the forward and reverse reactions are equal.

Rate of forward reaction = Rate of reverse reaction

EXAMPLE # 1

If you prepare a solution that is saturated with an aqueous solution of NaCl. If you then add solid crystals of NaCl, the NaCl will be simultaneously dissolving and recrystallizing within the solution. The reaction, $NaCl(s) \rightleftharpoons Na^+(aq) + Cl^-(aq)$, will be in dynamic equilibrium when the rate of the dissolution of the NaCl equals the rate of recrystallization.

EXAMPLE # 2

Dynamic equilibrium is $NO_2(g) + CO(g) \rightleftharpoons NO(g) + CO_2(g)$ (again, as long as the two rates are equal). Nitrogen dioxide (NO_2) reacts with carbon monoxide (CO) to form nitrogen oxide (NO) and carbon dioxide (CO_2), and, in the reverse reaction, nitrogen oxide and carbon dioxide react to form nitrogen dioxide and carbon monoxide.

Q 4. Define Reverse reaction and forward reaction.

REVERSE REACTION

A reaction in which product change in to reactant is known as reverse reaction

FORWARD REACTION

A reaction in which reactant change in to product is known as reverse reaction.

Q 5. What are the characteristics of Reversible reaction, forward reaction and dynamic equilibrium?

CHARACTERISTICS OF FORWARD REACTION

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

CHARACTERISTICS OF REVERSE REACTION

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

CHARACTERISTICS OF IN DYNAMIC EQUILIBRIUM

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

Q 6. Distinguished between reversible and irreversible reaction.

REVERSIBLE REACTION	IRREVERSIBLE REACTION
Products are converted back to reactants.	Products are not converted back to reactants.
The reaction appears to have stopped but does not undergo completion.	The reaction stops completely and almost goes to completion.
It is generally carried out in a closed vessel.	It can be carried out in an open or closed vessel
It takes place in both directions. It is represented by e.g. $N_2 + O_2 \rightleftharpoons 2NO$	It takes place only in one direction. It is represented by e.g. $C + O_2 \rightarrow CO_2$

Q 7. State law of mass action How is the active mass is represented?

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.

REPRESENTATION

The unit of active mass Mol/dm^3 and its value is expressed in square brackets.

Q 8. Derive an expression for equilibrium constant.

DERIVATION

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

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

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

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

$$Rf = kf [A]^a [B]^b$$

Where Kf is the rate constant for forward reaction.

Likewise, rate of reverse reaction is directly proportional to product of molar concentration Of C and D whereas “c” and “d” are number of moles needed to balance a chemical reaction

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

$$Rr = kr [C]^c [D]^d$$

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

$$Rf = Rr$$

Putting the values of Rt ana Rr, we have

$$kf [A]^a [B]^b = kr [C]^c [D]^d$$

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

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

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

$$OR \quad Kc = \frac{Kf}{Kr}$$

Hence

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

Q 9. **Why equilibrium constant may or may not have unit? Justify with example**

Since the kc is the ratio of product and reactant, therefore when the number of moles of an equation are equal the kc will have no unit. When the number of moles is unequal then it will have the unit

EXAMPLE # 1 **$2HI \rightleftharpoons H_2 + I_2$**

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

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

$$unit = \frac{[mole/dm^3]\,[mole/dm^3]}{[mole/dm^3]^2}$$

$$unit = \frac{\frac{mole}{dm^3} \times \frac{mole}{dm^3}}{\frac{mole^2}{dm^6}}$$

Unit = 1

EXAMPLE # 1 **$PCl_5 \rightleftharpoons PCl_3 + Cl_2$**

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

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

$$unit = \frac{\frac{mole}{dm^3} \times \frac{mole}{dm^3}}{\frac{mole}{dm^3}}$$

Unit = $mole/dm^3$

Q 10. **How direction of a reaction can be predicted if Kc is known to you.**

DIRECTION OF REACTION

1. If Qc = Kc, the actual product and reactant concentrations are equal to equilibrium concentrations, and the system is stable.
2. If Qc <Kc increase in product concentration for equilibrium. So, the Reaction occurs, forming additional products.
3. If Qc > Kc, there is decrease in product concentration. As, the process Reverses, forming more reactants.

Q 11. Discus the extent of chemical reaction on the basis of Kc

Kc IS VERY SMALL

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

$F_2 \rightleftharpoons 2F$ $Kc = 7.4 \times 10^{-13}$ at 227°C

Kc IS VERY LARGE

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

$2H_2 + O_2 \rightleftharpoons 2H_2O$ $Kc = 2.4 \times 10^{47}$ at 227°C

Kc IS NEITHER VERY SMALL NOR VERY LARGE

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

FOR EXAMPLE:

$N_2O_4 \rightleftharpoons 2NO$ $Kc = 0.36$ at 25°C

Q 12. How con you predict the following stages of a reaction by comparing the values Of Kc and Qc.

1) Net reaction proceeds in forward direction.
2) Net reaction proceeds in reverse direction

1. **Net reaction proceeds in forward direction.**

The value of Kc will be very large

2. **Net reaction proceeds in reverse direction**

The value of Kc will be very small

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Numerical Problems

Numerical 01

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

$$2NO+0_2 \rightleftharpoons 2NO_2$$

At equilibrium at 230 °C, the concentrations are measured to be : [NO] =0.0542 mol.dm^{-3} , [O_2] = O.127 mol.dm^{-3}, and [NO_2] = 15.5 mol.dm^{-3} Calculate the equilibrium constant at this temperature.

Numerical 02

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

$$Fe^{+3} + 4Cl^- \rightleftharpoons FeCl_4^-$$

At equilibrium, the concentrations are measured to be (Fe^{+3}) is 0.2 mol.dm^{-3}, Cl^- is 0.28mol.dm^{-3} and $FeCl_4^-$ is 0.95x 10^{-4} mol.dm^{-3}. Calculate equilibrium constant Kc for given reaction.

Numerical 03

Nitrogen oxides are air pollutants produced by the reaction of nitrogen and oxygen at high temperature.

At 2000 °C, the value of the equilibrium constant for the given reaction is 4.1 x 10^{-4}

$$N_2 + 0_2 \rightleftharpoons 2NO$$

Find the concentration of NO in an equilibrium mixture at 1 atm pressure at 2000°C. In air, [N_2] = 0.036 mol/L and [0_2) = 0.0089 mol/L.

Book Numerical

1. Dinitrogen tetra oxide N_2O_4 decomposed into nitrogen dioxide NO_2 in a reversible reaction. Derive equilibrium constant expression for the reaction of decomposition. Also interpret unit of Kc for balanced chemical reversible reaction.

2. PCl_5, PCl_3, and Cl_2 are at equilibrium at 500K in a closed container and their concentrations are 0.8 x 10^{-3} mol dm^{-3}, 1.2 x 10^{-3} mol dm^{-3} and 1.2 x 10^{-3} mol dm^{-3} respectively. Calculate the value of Kc for the reaction along with unit.

3. The value of Kc for the reaction is 1x10^{-4} $\quad 2HI \rightleftharpoons H_2 + I_2$

At a given temperature, the molar concentration of reaction mixture is HI = 2x10^{-5} mol dm^{-3}, H_2=1x10^{-5} mol dm^{-3} and I_2 = 1 x10^{-5}mol dm^{-3}. Predict the direction of the reaction.