Chapter: Chemical Equilibrium

Important Question Answers:

Q1): Define active mass?

Ans): The active mass of a substance is the mass that develops or dissolves in a solvent, dissociates into ions, and carries an electric charge. Or

The quantity of reactants wholly engaged in the reaction is known as the active mass.

Q2): Describe the law of mass action?

Ans): The rate of the reaction is directly proportional to the active mass of the reactant that is actively participating in the reaction, according to this law, which was put forth by C.M. Gulberg and P. Waage. We may therefore conclude that the rate of reaction is directly proportional to the product of the active masses of the reactants if there are several reactants on the left side.

Q3): Define irreversible reaction?

Ans): Irreversible reactions are those in which all of the reactants on the left are entirely consumed, transformed into products, and then converted back into reactants. A single-headed arrow is used to depict an irreversible reaction that moves in one direction, or from forward left to right.

Q4): How would you explain reversible reaction?

Ans): The process in which the reactants on the left side of the equation combine to form products, which are then broken down and changed back into reactants on the right. The double-headed arrow used to depict the reversible reaction moves in both the forward and backward directions (left to right and right to left).

Q5): What is meant by chemical equilibrium?

Ans): Chemical equilibrium is the condition of a system at which the rates of forward and reverse reactions are equal. As soon as the concentration of the reactants and products is equal, the reactants and products will be in equilibrium.

Q6): Write at least three examples of irreversible changes which you can see in your daily life.

Ans): Following are some instances of irreversible changes:

• **Burning**

When we burn wood or any other material, it turns into ash and cannot be changed back into the wood.

• **Cooking**

When we cook a meal, for instance, when we boil an egg, we cannot turn it back into an uncooked state.

• **Roughening of iron**

We are unable to restore the piece of iron to its original, un-rusted state once it has become rusted.

Q7): Write at least three examples of reversible changes which you can see in your daily life.

Ans): The following are instances of reversible changes:

• **Melting**

As we have observed in our daily life, when the ice melts, we can then turn that liquid back into a solid form (ice).

• **Freezing**

We have been accustomed to the idea that freezing turns a liquid into ice, which eventually melts back into a liquid form.

• **Boiling**

We have been accustomed to boiling water in our daily lives, causing the water to turn into vapour. Therefore, the process of condensation allows for the return of these vapours to a liquid condition.

Q8): Point out the conditions of equilibrium.

Ans): When forward and reverse reaction rates become equal it means that reactants and products concentration is balanced. And this state of a system is called the state of equilibrium. There are some conditions of equilibrium that are given below.

- Reactants and products concentration will be the same/balanced/constant
- Three factors of a system namely; temperature, pressure and volume of the system will also not change (balanced/constant).

Q9): State the ways with the help of which we can recognize that the system is at equilibrium.

Ans): We know that in a state of equilibrium forward and reverse reaction rates become equal which means that reactants and products concentration become balanced. So how we will find physically and chemically that yes now reactants and product concentration become balanced.

We can find out the state of equilibrium by the most commonly used methods:

1) Titration 2) Spectroscopy

Q10) Define Kc.

Ans): Kc can be defined as the product of the ratio of reactants and products molar concentration. Kc does not ∝ initial concentration of reactants. It is ∝ to temperature. Or

Kc may have a unit or have no unit both conditions are possible depending upon the reactants and products molar concentration.

Q11): What is the importance of Kc?

Ans): The equilibrium constant can help us understand some crucial facts about a reaction. When we don't know the equilibrium concentration of the equilibrium mixture, Kc uses the initial concentration of the reactants to determine the equilibrium concentration of the equilibrium mixture.

When a reaction is underway and we are unsure of its direction—whether it will move ahead or backward—Kc will decide the reaction's course.

When a reaction is underway and we are unsure of its magnitude or the rate at which it is progressing, Kc will determine the reaction's size or velocity.

When a reaction is in equilibrium, any changes that take place at this point in the reaction will have an impact on the reaction depending on Kc. Industrial chemists also determine the impact of changes in concentration, temperature, pressure, and other variables before determining the impact of changes that take place at equilibrium.

Q12): State Le Chatellier's principle.

Ans): According to Le Chatellier's principle, a reaction will migrate its equilibrium to either the left or the right side of the reaction when its concentration, temperature, or pressure are changed while it is in an equilibrium condition. Therefore, to synthesize more and more products, we will make the kinds of adjustments that cause the equilibrium to shift in favor of the product side.

Q13): According to Chatellier's principle when the reaction is endothermic then how we can increase the yield of product in terms of temperature?

Ans): According to this theory, when a reaction is endothermic, it means that it will absorb energy. As a result of the system's increased temperature as a result of the energy absorption, the reaction will then prefer the product side.

Q14): According to Chatellier's principle when the reaction is exothermic then how we can increase the yield of product in terms of temperature?

Ans): When a reaction is exothermic, however, it indicates that energy will be released; as a result, the system's temperature will drop and the equilibrium will shift to the product side.

Q15): Observe the below reaction and explain that by increasing pressure the equilibrium will shift in which direction? And also explain the reason.

$$N_2 + 3H_2 \underset{400\,^{\circ}C,\ 200\ atm}{\overset{Fe}{\rightleftharpoons}} 2NH_3$$

$$\Delta H = -92.4\ kJ$$

Ans): In this reaction, we can see that the number of moles are greater on the left side (reactants side) and fewer on the right side (products side). So, by increasing pressure we know that the reaction will go towards less volume side means towards product side and in this way, the yield of ammonia can be increased. This is because we know that pressure and volume are inversely proportional to each other. When pressure increases then volume decreases and vice versa.

Q16): Observe the reaction below and explain that by decreasing pressure the equilibrium will shift towards which direction? And also explain the reason.

$$2SO_2 + O_2 \xrightarrow[400\,^{\circ}C,\ 200\ atmp]{V_2O_5} 2SO_3$$

$$\Delta H = -196$$

Ans): In this reaction, we can see that the number of moles are greater on the left side (reactant side) while lesser on the right side (product side) so, when the pressure will decrease or low pressure will be supplied to this reaction then the reaction will favor towards reactant side (greater volume) and the yield of the product will decreases. This is because as we know that pressure and volume are inversely proportional to each other. When the pressure decreases then volume increases and vice versa.

Q17): Differentiate between forward and reverse reactions.

Ans): When a reaction proceeds from left to right then this is called forward reaction. In this reaction synthesis of the product is favored. While a reaction that proceeds from the right to the left side is called a reverse reaction and in this reaction synthesis of reactants is favored. e.g.

Example :

$$2N_{2(g)} + O_{2(g)} \underset{\text{Spark}}{\overset{\text{Electric}}{\rightleftharpoons}} 2NO_{2(g)}$$

Forward Reaction:

$$2N_{2(g)} + O_{2(g)} \xrightarrow[\text{Spark}]{\text{Electric}} 2NO_{2(g)}$$

Backward Reaction:

$$2NO_{2(g)} \xrightarrow[\text{Spark}]{\text{Electric}} 2N_{2(g)} + O_{2(g)}$$

Q18): Following reaction can occur during lightning storms

$$3O_2 \rightleftharpoons 2O_3$$

For this reaction write

- **Expression of the equilibrium constant**
- **Determine the units of the equilibrium constant**
- **Forward and reverse reactions**

Ans): (I)

$$Kc = \frac{[O_2]^3}{[O_3]^2}$$

(II)

$$Kc = \frac{[mol/dm_3]^2}{[mol/dm_3]^{2+1}}$$

$$Kc = mol^{-1}.dm^3$$

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(III)

Forward Reaction:

$$3O_2 \longrightarrow 2O_3$$

Reverse Reaction:

$$2O_3 \longrightarrow 3O_2$$

Q19): To form CO and H_2 coal reacts with hot steam. In the presence of a catalyst, these substances react further to give methane and water vapour.

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O$$

- **Write forward and reverse reactions for it**
- **Derive the expression of Kc for the reaction**
- **Determine units for Kc**

Ans): (I)

Forward Reaction:

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$

Reverse Reaction:

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

(II)

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

(III)

$$Kc = \frac{\cancel{[mol/dm_3]}\ \cancel{[mol/dm_3]}}{\cancel{[mol/dm_3]}\ [mol/dm_3]^{2+\cancel{1}}}$$

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

Q20): Derive the expression of Kc for each of the following reactions.

(I) $H_2O \rightleftharpoons H_2 + 1/_2\, O_2$

(II) $CO + 2H_2 \rightleftharpoons CH_3OH$

(III) $COCl_2 \rightleftharpoons CO + Cl_2$

(IV) $4HCl + O_2 \rightleftharpoons 2Cl_2 + 2H_2O$

Ans): (I)

$$Kc = \frac{[H_2]\,[O_2]^{1/2}}{[H_2O]}$$

(II)

$$Kc = \frac{[CH_3OH]}{[CO]\,[H_2]^2}$$

(III)

$$Kc = \frac{[CO]\ [Cl_2]}{[COCl_2]}$$

(IV)

$$Kc = \frac{[Cl_2]^2\ [H_2O]^2}{[HCl]^4\ [O_2]}$$

Q21) Find out the units of Kc for the following reactions.

$$COCl_2 \rightleftharpoons CO + Cl_2$$

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

$$N_2 + 2O_2 \rightleftharpoons 2NO_2$$

$$2H_2 + O_2 \rightleftharpoons 2H_2O$$

Ans):

$$Kc = \frac{[CO]\ [Cl_2]}{[COCl_2]}$$

$$Kc = \frac{[mol / dm_3]\ [mol / dm_3]}{[mol / dm_3]}$$

$$Kc = mol/dm^3$$

$$Kc = \frac{[HI]^2}{[H_2]^1\ [I_2]^1}$$

$$Kc = \frac{[mol/dm^3]^2}{[mol/dm^3]^1\ [mol/dm^3]^1}$$

$$Kc = mol/dm^3$$

$$Kc = \frac{[NO_2]^2}{[N_2]\ [O_2]^2}$$

$$Kc = \frac{[mol/dm^3]^2}{[mol/dm^3]\ [mol/dm^3]^2}$$

$$Kc = mol^{-1}.dm^3$$

$$Kc = \frac{[H_2O]^2}{[H_2]^2\ [O_2]}$$

$$Kc = \frac{[mol/dm^3]^2}{[mol/dm^3]^2\ [mol/dm^3]}$$

$$Kc = mol^{-1}.dm^3$$

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Q22): What is meant by catalyst? Give examples of some catalysts used in chemical reactions.

Ans): Catalyst is a substance that when added to the reaction then it speeds up the reaction. Catalyst does not affect the state of equilibrium it only speeds up the rate of a reaction.

Examples of catalysts are:

Fe (iron), Ni (Nickel), V_2O_5 (Vanadium pentoxide), Pt (platinum), Pd (palladium) etc.

Q23): State and explain the law of mass action in detail?

Ans): Law of Mass Action:

In 1864, C.M. Gulberg and P. Waage proposed the concept of the law of mass action. To demonstrate how this law works, add some sugar to a glass of water, shake it vigorously, or stir it with a spoon. Observation will reveal that a sugar crystal's surface molecules are in direct contact with water, and the water molecules around it aid in their dissolution, causing them to break into ions that carry an electric charge.

The number of reactants that participate by dissociating into ions and carrying an electric charge may now be stated as the active mass of that sugar. The pace of any reaction depends on the active masses of the reactants involved in that reaction.

We can also define active mass as the molar concentration of the reactants and products, which we represented as mol/dm3. Square brackets [ ] are used to denote the active mass of material, whether it is a reactant or a product. Consider the following response.

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

In the light of the law of mass action;

Rate of forward reaction $\propto [H_2]^1 [I_2]^1$

Rate of forward reaction = $K_f [H_2]^1 [I_2]^1$

Rate of reverse reaction $\propto [HI]^2$

Rate of reverse reaction = $Kr [HI]^2$

The number 1 and 2 in this equation represent the number of moles of reactant and product, respectively, and [H2]1 [I2]1 is the concentration of H2 and I2 in terms of mol/dm3, while Kf and

Kr are proportionality constants for forward and reverse processes, respectively. We may set up the response as

Rate of forward reaction = Rate of reverse reaction

$K_f [H_2]^1 [I_2]^1 = Kr [HI]^2$

By rearranging,

$$\frac{K_f}{Kr} = \frac{[HI]^2}{[H_2]^1 [I_2]^1}$$

$$Kc = \frac{[HI]^2}{[H_2]^1 [I_2]^1}$$

So, we are aware that $Kc = K_f / Kr$, also known as the equilibrium constant, and that the c in front of K stands for the molar concentrations of the reactants and products in the equilibrium state.

Therefore, to define the Kc or equilibrium constant, we can state that it is the result of the molar ratio of the products and reactants. Initial reactant concentration is not affected by Kc. The temperature is.

Q24): Which one will cause a vigorous reaction 1) Addition of water in sulfuric acid or 2) Addition of sulfuric acid in water?

Ans): When we want to make sulfuric acid dilute and add water to sulfuric acid then it causes a vigorous reaction and can lead to a blast. So, always remember that the addition of water in sulfuric acid should be extremely avoided and if you want to make sulfuric acid dilute then add sulfuric acid in water not water in sulfuric acid.

Q25): Define and describe Le Chatellier's principle in detail with examples.

Ans): Le Chatellier's Principle:

According to Le Chatellier's principle, a reaction will migrate its equilibrium to either the left or the right side of the reaction when its concentration, temperature, or pressure are changed while it is in an equilibrium condition. Therefore, to synthesize more and more products, we will make the kinds of adjustments that cause the equilibrium to shift in favor of the product side.

According to this theory, when a reaction is endothermic, it means that it will absorb energy. As a result of the system's increased temperature as a result of the energy absorption, the reaction will then prefer the product side.

When a reaction is exothermic, however, it indicates that energy will be released; as a result, the system's temperature will drop and the equilibrium will shift to the product side.

When there are more moles on the reactant side and fewer on the product side, the equilibrium will move toward the product side when pressure is increased. This is because pressure and volume are known to be inversely related to one another. The volume reduces as pressure rises and vice versa.

The reaction will favor the product side as the concentration of the reactants side rises.

For Example:

$$N_2 + 3H_2 \xrightleftharpoons[400\,^{\circ}C,\ 200\ atm]{Fe} 2NH_3$$

$$\Delta H = -92.4\ kJ$$

In this response, we can observe that there are more moles on the left side and fewer on the right. Therefore, by raising the pressure, we know that the reaction will move from the volume side to the product side, increasing the yield of ammonia.

Furthermore, we would use a low temperature to produce more product because we know that the reaction is exothermic and will release heat or energy; otherwise, if we use a high temperature, the reaction will favor moving oppositely, producing reactants once more.

Example 2:

$$2SO_2 + O_2 \xrightarrow[400\,^{\circ}C,\ 200\ atmp]{V_2O_5} 2SO_3$$

$$\Delta H = -196\ KJ$$

We will use high pressure in this reaction because we can see that the number of moles is greater on the reactant side and lower on the product side. Since pressure and volume are inversely proportional, as pressure is increased, the equilibrium will move to the side with the smaller volume (the product side), giving us a high yield of Sulphur trioxide.

Furthermore, we would use a low temperature to produce more product because we know that the reaction is exothermic and will release heat or energy; otherwise, if we use a high temperature, the reaction will favor moving oppositely, producing reactants once more.

Q26): When we open the cork of Cold drinks or fizzy drinks then a gas comes out of the bottle which one gas is it, and what is its reaction during the manufacturing and on opening the bottle lid of fizzy drinks reactions happen?

$$CO_2 \rightleftharpoons CO$$

Ans): During the manufacturing of fizzy drinks the carbon dioxide gas is dissolved in it under high pressure and then the bottles are sealed with a lid. So when we open the lid of the bottle then it's the dissolved carbon dioxide gas that comes out of the bottle.

During the manufacturing of fizzy drinks forward reactions occur while during the opening of the lid of the bottle reverse reaction occur.

Q27): Explain the macroscopic characteristics of an equilibrium reaction.

Ans): The macroscopic characteristics of an equilibrium reaction are given below:

- At a state of equilibrium reactants and products, concentrations will become equal to each other.
- At the state of equilibrium forward and reverse reaction rates will become equal to each other.
- The addition of a catalyst does not affect the state of equilibrium it only speeds up the reaction.
-

Q28): Bromine chloride (BrCl) decomposes to form chlorine and bromine. For this reaction write

- **Chemical equation**
- **Kc expression**
- **Unit of Kc**

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Ans):

(I)

$$2BrCl \rightleftharpoons Br_2 + Cl_2$$

(II)

$$Kc = \frac{[Br_2]\ [Cl_2]}{[BrCl]^2}$$

(III)

$$Kc = \frac{\cancel{[mol/dm^3]}\ \cancel{[mol/dm^3]}}{\cancel{[mol/dm^3]^2}}$$

$$Kc = \text{no unit}$$

Q29): Kc expression for a reaction is given below

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

Choose reactant and product to derive the unit of Kc for this reaction.

Ans):

$$Kc = \frac{[mol/dm^3]^{1+\cancel{1}}}{\cancel{[mol/dm^3]}}$$

$$Kc = mol / dm^3$$

Q30): For which of the following reactions are both reactants and products likely to be found when the reaction appears to be complete. Justify.

$$(I)\ C + O_2 \longrightarrow CO_2$$

$$(II)\ 2HF \rightleftharpoons H_2 + F_2$$

Cobalt chloride forms pink crystals ($CoCl_3.6H_2O$). Water is evolved from ($CoCl_3.6H_2O$). upon heating and turns blue ($CoCl_3$). Can you use Cobalt chloride as a test for water, argue

$$CoCl_3.6H_2O \rightleftharpoons CoCl_3 + 6H_2O$$

Ans): The second reaction which is given below is reversible.

$$2HF \rightleftharpoons H_2 + F_2$$

We know that reversible reaction proceeds in both forward and reverse directions so, obviously yes both reactants and products would likely be found at the state of equilibrium when forward and reverse reaction rates become equal then equilibrium will be established and at the state of equilibrium reactants and products, concentration will become equal. While the first reaction (formation of CO_2) is a combustion reaction that is irreversible in nature and will proceed only in one direction (forward direction) means left to right and reactants will be completely consumed and will convert to the product.

Anhydrous cobalt (II) chloride is a blue substance. On reaction with water, it converted to pink color (hydrated cobalt (II) chloride). So, the change of color from blue to pink is a very useful thing and due to this color change, cobalt chloride can be used as a test for water.

Q31): State the reaction of preparation of ammonia and also write the catalyst used in this reaction and mention the temperature and pressure given to this reaction.

Ans):

$$N_2 + 3H_2 \underset{400\,^\circ C,\ 200\ atm}{\overset{Fe}{\rightleftharpoons}} 2NH_3$$

$$\Delta H = -92.4\ kJ$$

Ammonia reaction is an exothermic reaction and it is formed by the reaction of nitrogen and hydrogen gas at 400 $^\circ$C under 200 atmospheric pressure in the presence of Fe (Iron catalyst). This process is known as the Haber process.

Numerical Problems:

Self-Assessment Exercise 9.1:

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

Example 1:

$$N_2 + 3H_2 \underset{400\,^\circ C,\ 200\ atm}{\overset{Fe}{\rightleftharpoons}} 2NH_3$$

Forward Reaction:

$$N_2 + 3H_2 \xrightarrow[400\,^\circ C,\ 200\ atm]{Fe} 2NH_3$$

Reverse Reaction:

$$2NH_3 \xrightarrow[400\,^\circ C,\ 200\ atm]{Fe} N_2 + 3H_2$$

Macroscopic Characteristics:

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We know that the formation of ammonia is a reversible reaction and a reversible reaction favors both forward and reverse directions. So, when forward and reverse reaction rates become equal reaction then the equilibrium is established, and at this state reactants ($N_2 + 3H_2$) and product ($2NH_3$) concentration becomes equal. The addition of catalyst Fe does not affect the state of equilibrium it only speeds up the formation of the product.

Example 2:

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

Forward Reaction:

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

Reverse Reaction:

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

Macroscopic Characteristics:

We know the formation of hydrogen Iodide is a reversible reaction and reversible reaction favors two directions forward and reverse direction. So, when the rate of forward reaction will become equal to the rate of reverse reaction then equilibrium will be established and at this state, the concentration of reactants $H_2 + I_2$ will become equal to the concentration of product 2HI.

Self-Assessment Exercise 9.2:

- **The following reaction can occur during lightning storms.**

$$3O_2 \rightleftharpoons 2O_3$$

Derive equilibrium constant expression for this reaction.

Ans):

$$Kc = \frac{[O_2]^3}{[O_3]^2}$$

- **Find Kc expressions for the following reactions.**

(1) $4HCl + O_2 \rightleftharpoons 2H_2O + 2Cl_2$

(2) $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

(3) $2HF \rightleftharpoons H_2 + F_2$

(4) $2NO_2 \rightleftharpoons N_2O_4$

Ans):

(1) $$Kc = \frac{[H_2O]^2 [Cl]^2}{[HCl]^4 [O_2]}$$

(2) $$Kc = \frac{[CH_3COOC_2H_5]\ [H_2O]}{[CH_3COOH]\ [C_2H_5OH]}$$

(3) $$Kc = \frac{[H_2]\ [F_2]}{[HF]^2}$$

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

Self-Assessment Exercise 9.3:

Derive the Kc units for the following reactions.

$PCl_5 \rightleftharpoons PCl_3 + Cl_2$

$H_2 + CO_2 \rightleftharpoons H_2O + CO$

$N_2 + O_2 \rightleftharpoons 2NO_2$

$CO + 2H_2 \rightleftharpoons CH_3OH$

Ans) Solution:

$$Kc = \frac{[PCl_3]\ [Cl_2]}{[PCl_5]} \qquad Kc = \frac{[H_2O]\ [CO]}{[H_2]\ \ [CO_2]} \qquad Kc = \frac{[NO_2]^2}{[N_2]\ \ [O_2]}$$

$$Kc = \frac{\cancel{[mol/dm_3]}\ [mol/dm_3]}{\cancel{[mol/dm_3]}} \qquad Kc = \frac{\cancel{[mol/dm_3]}\ \cancel{[mol/dm_3]}}{\cancel{[mol/dm_3]}\ \cancel{[mol/dm_3]}} \qquad Kc = \frac{\cancel{[mol/dm_3]^2}}{\cancel{[mol/dm_3]}\ \cancel{[mol/dm_3]}}$$

$$Kc = [mol/dm_3] \qquad Kc = \text{No Unit} \qquad Kc = \text{No Unit}$$

$$Kc = \frac{[CH_3OH]}{[CO_2]\ [H_2]^2}$$

$$Kc = \frac{\cancel{[mol/dm^3]}}{\cancel{[mol/dm^3]}\ [mol/dm^3]^2}$$

$$Kc = mol^{-1}dm^3$$

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