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CHEMISTRY

Class 10th (KPK)

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Unit 9

CHEMICAL EQUILIBRIUM

Exercise: Short Questions.

Q1. Define chemical equilibrium with two examples.
Ans: Definition: "The state of a reversible chemical reaction in which the rate of forward reaction becomes equal to the rate of backward reaction in called chemical equilibrium/Dynamic equilibrium". OR The state in which both reactants and products are presents in concentration in which no further tendency to change with time.
Examples
i. Change of a liquid to gas in a closed container:
when liquid water is placed in a closed container at constant temperature, part of liquid evaporates. As water begins to evaporate, at the same time, some of the vapours also begin to condense. Although in the beginning rate of evaporation is faster than the rate of condensation but with the passage of time the rate of evaporation becomes equal to the rate of condensation and thus a state of equilibrium is established

$$\text{Water} \underset{condensation}{\overset{evaporation}{\rightleftarrows}} \text{Vapours}$$

Equilibrium state is also in the following chemical reactions
ii. Reaction of sulphur dioxide with oxygen: $2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2SO_{3(g)}$

iii. Reaction of hydrogen with iodine:
$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$.

Q2. How would you identify that dynamic equilibrium is established?
Ans: Chemical equilibrium/Dynamic equilibrium:
Definition:
"The state of a reversible chemical reaction in which the rate of forward reaction becomes equal to the rate of backward reaction and the concentrations of reactants and products remain constant is called chemical equilibrium/Dynamic equilibrium".
Explanation:
Consider a general chemical reaction in which reactant. A reacts with reactant B in gaseous state, in a closed container, to form products C and D.
$A_{(g)} + B_{(g)} \rightleftharpoons C_{(g)} + D_{(g)}$
The detail about this general reversible reaction is given below:
i. Concentrations at the start:
At the start of the reaction the concentrations of A and B are maximum while that C and D are zero.
ii. Concentrations after some time:
With the passage of time the concentrations of C and D gradually increase while that of A and B gradually decrease.
iii. Variation of rate of forward and backward reactions:
Change in concentrations of reactants or products per unit time is called rate of reaction.
In the beginning, the rate of forward reaction is maximum while rate of backward reaction is almost zero but as the time passes and sufficient amounts of C and D are formed then the rate of backward reaction increases while that of forward reaction decreases until rate of forward reaction becomes equal to the rate of backward reaction. Thus, a state of dynamic equilibrium is established.

iv. Concentration at equilibrium state:

The concentrations of reactants or products remain constant at equilibrium state. These concentrations are called equilibrium concentrations.

Q3. Compare the different macroscopic characteristics of forward and reverse reactions?

Forward reaction	Reverse reaction
It is defined as the conversion of reactants into products per unit time or the rate of chemical reaction taking place in forward rection,	It is defined as the conversion of products back into reactants per unit time or the rate of chemical reaction taking place in forward rection,
Characteristics	
i. It is a reaction in which reactants reacts to form product.	i. It is a reaction in which product reacts to orm reactants.
ii. It takes place from left to right	ii. It takes place from right to left.
iii. At the beginning, rate of forward reaction is very fast.	iii. At the beginning, rate of reverse reaction is ery slow.
iv. It slow down gradually	iv. It speeds up gradually...

Q4: **What information is required to predict the direction of chemical reaction?**

Ans: Prediction of direction of reaction:

The direction of reaction can be predicted by means of [product]/ [reactants] ratio.

$$Q_c = \frac{[initial\ concentration\ of\ products]}{[initial\ concentration\ reactions]}$$

By comparing the ratio with K_c we have three possibilities:

When the ratio is less than kc:

if the ratio is less then K_c. The system is not at equilibrium and more product is required to reach the equilibrium. Therefore, reaction will proceed in forward direction to form products.

When the ratio is greater than kc

If the ratio is greater than K_c The system is not at equilibrium and more reactant are required to reach the equilibrium. Therefore, the reaction will go in the reverse direction to form reactants.

When the ratio is equal to kc

If the ratio is equal to K_c then the reaction is at equilibrium i.e. rate of forward reaction is equal to the rate of reverse reaction.

Q5: Relate the active mass with the rate of chemical reaction?

Ans: Active mass:

Active masses are molar concentration of reacting substances. Molar concentration is the number of moles per dm^3 or litre.

Active mass and the rate of chemical reaction

The rate of a chemical reaction is directly proportional to the product of active masses of the reacting substances.

Which means when we increase the Molar concentration of reacting substances the rate of reaction also increases and vice versa.

Q6: At equilibrium a mixture of N_2, H_2, and NH_3 gas at 500°C is determined to consist of 0.602mol/dm³ of N_2, 0.420mol/dm³ of H_2 and 0.113mol/dm³ of NH_3. What is the equilibrium constant for the reaction for the reaction at this temperature?

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

Given: Concentrations of Nitrogen (N_2) = 0.602mol/ dm^3

Concentration of hydrogen (H_2) = 0.420mol/ dm^3

Concentrations of NH_3 = 0.113mol/ dm^3

Required:

Value of K_c =?

Solution:

Writing equilibrium constant expression for the above reaction:

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

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

$$= \frac{[0.012769 mol\ dm^{-3}]^2}{[0.602 mol\ dm^{-3}][0.074088 mol\ dm^{-3}]^3}$$

$$= \frac{[0.012769 mol\ dm^{-3}]^2}{[0.602 mol\ dm^{-3}][0.074088 mol\ dm^{-3}]^3} = \frac{[0.012769 mol\ dm^{-3}]^2}{[0.0446 mol\ dm^{-3}]^4}$$

$= 0{,}28630[mol/dm^{-3}]^{-2}$

$0.28630 mol^{-2}\ dm^6$

Q7: State conditions necessary for the chemical equilibrium.

Ans: Conditions necessary for equilibrium:

Followings are the conditions necessary for chemical equilibrium:

i. Closed container:

Equilibrium state can only be attained in closed container. It cannot be attained in open container because in open container the gaseous reactants and products will escape due to which there will be no possibility of equilibrium.

ii. Constant concentrations:

When equilibrium state is attained by a reaction in a closed container then the concentrations of various species in the reaction become constant. These concentrations are called equilibrium concentrations.

iii. Effect of catalyst on equilibrium:

A catalyst cannot change the equilibrium point, it only speedy up the rate forward and backward reactions. Thus, it helps to attain the equilibrium in short time.

Q8. Write equilibrium constant expression for the following reactions.

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

K_c for this reaction is

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

b. $2H_2\ (g) + O_2\ (g) \rightleftharpoons 2H_2O\ (g)$ K_c for this reaction is:

$$K_c = \frac{[H2O]^2}{H2]^2[O_2]}$$

c. $4NH_3 + 5O_2 \rightleftharpoons 4NO_{(g)} + 6H_2O_{(g)}$

K_c for this reaction is

$K_c = \frac{[NO]^4[H2O]^6}{[NH3]^4[O2]^5}$

Q9. A reaction between gaseous sulphur dioxide and oxygen gas to produce gaseous sulphur trioxide take place at 600^{0}C. At this temperature, the concentration of SO_2 is found to 1.50mol/dm$^{3.}$ Using the balanced chemical equation, calculate the equilibrium constant for this system. **Ans: balanced chemical equation:**

$2SO_{2(g)}$ + $O_{2(g)}$ $\rightarrow 2SO_3$

Solution:

Concentration of SO_2 =1.50mol/dm^3

Concentration of O_2 =1.250mol/dm^3

Concentration of SO_3 =3.50mol/dm^3

Find K_c =?

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

$= \frac{[3.50 mol\ dm^{-3}]^2}{[1.250 mol\ dm^{-3}][1.50 mol\ dm^{-3}]^2}$

$= \frac{12.25[mol\ dm^{-3}]^2}{2.8125[mol\ dm^{-3}]^3}$

4.353[mol/dm^3]$^{-1}$

Q10: Describe the effect of temperature on equilibrium constant?

Ans: Effect of equilibrium constant:

Equilibrium constant is changed if we change the temperature of the system. For example, when the forward reaction is exothermic then increasing the temperature decreases the value of equilibrium constant. When the forward reaction is endothermic then increasing the temperature increases the value of equilibrium constant.

LONG QUESTIONS:

1. $SO_{3\ (g)}$ decomposes to form SO_2 and $O_{2\ (g).}$ For this reaction write,

i. Chemical equation

$2SO_3 \rightarrow 2SO_{2\ (g)} + O_{2\ (g)}$

ii. **K_c expression:** $K_c = \frac{[SO_2]2\ [O_2]}{[SO_3]^2}$

iii. **Unit of K_c =** $\frac{[mol\ dm^{-3}]^2\ [mol\ dm^{-3}]}{[mol\ dm^{-3}]^2}$

= mol/dm^3

Q2.a. Describe equilibrium state with the help of graph and an example.

Ans: Equilibrium state:

History:

Chemical equilibrium was first discovered by a French chemist Claude Louis Berthollet in 1803.

Definition:

"The state of a reversible chemical reaction in which the rate of forward reaction becomes equal to the rate of backward reaction in called equilibrium state.

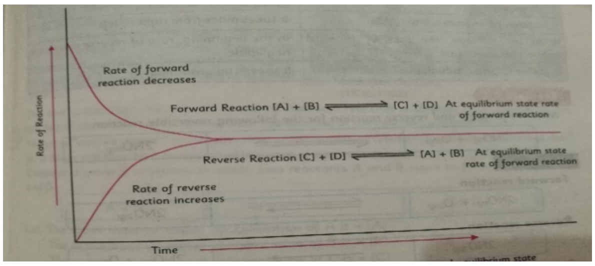
"The state of a reversible chemical reaction at which the reactants are continuously changing to products and the products are continuously changing to the reactants back but the concentrations of reactants and products remain constant is called chemical equilibrium/ equilibrium state.

Explanation:

i. Change of a liquid to gas in a closed container:

Consider a closed container which is partially filled with a liquid at a given temperature. At the start, and the vapour molecules are collected at the liquid surface. At the passage of time the collected gas molecules over the liquid surface converts to liquid back (condensation starts). In the beginning rate of evaporation is faster than the rate of condensation but with the passage of time the rate of evaporation becomes equal to the rate of condensation and thus a state of dynamic equilibrium is established.

v. Graphical representation:



b. Define law of mass action.

Ans: Law of mass action:

History:

This law was presented by two Norwegian chemists Cato Maximilian Guldberg and Peter Waage in 1864.

Definition/Statement:

"This law states that the rate of a chemical reaction is directly proportional to the product of active masses of the reacting substances".

Active masses:

The term active masses mean molar concentration of reacting substances. Molar concentration is the number of moles per dm^3 or litre. The molar concentration of reacting substances is expressed by enclosing their symbols or formulas in square brackets i.e. []

For example:

Consider the following general chemical equation.

$A+B \longrightarrow C+D$

Let, [A] and [B] = molar concentrations of A and B

And [C] and [C] = molar concentrations of C and D

Now according to law of mass action: rate of forward reaction is directly proportional to the concentration of the reactants A and B

$R_f \propto [A]\,[B]$ $\longrightarrow$ R_f = forward

$\Rightarrow R_f = K_f[A][B]$ ate

Where k_f is the rate constant for the forward rection.

Similarly, for rate of reverse *reaction*,

$R_r \propto [C]\,[D]$ R_r = reverse

$\Rightarrow R_r = K_r[C]\,[D]$

Where K_r *is* the rate constant for the reverse reaction.

At equilibrium state,

Rate of forward reaction = rate of reverse reaction

Therefore, we can write,

$$R_f = R_r$$

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

Thus, it is clear that rate of reaction is proportional to the concentration of the reactants.

Q3. Derive an expression for the equilibrium constant and explain its units.

Ans: equilibrium constant:

The ratio of the mathematical product of the concentration of reacting substances called equilibrium constant". OR

"The ratio of the product of the concentration of the products to the product of the concentration of reactants at equilibrium is called equilibrium constant

Denotation

It is denoted by K_c where the subscript c indicates the equilibrium concentrations of various species in term of mole/om^3 or litre.

Derivation of expression for the equilibrium constant:

Consider the following general reaction

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

Then K_c for this reaction will be

$$\frac{Kf}{Kr} = \frac{[C][D]}{[A][B]} \frac{Kf}{Kr} = Kc$$

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

For more general reaction K_c is written as:

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

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

Where [A], [B],[C] and [D] represents molar concentration of reactants and products while a,b,c and d represent the number of moles from the balanced chemical equation.

Units of equilibrium constant:

The unit of equilibrium constant is independent of pressure, concentration and catalyst depends the equilibrium constant expression.

Q3.b How Can you predict direction of reaction for the K_c value.

Ans: Prediction of direction of reaction:

The direction of reaction can be predicted by means of [product]/ [reactants] ratio.

$$Q_c = \frac{[initial\ concentration\ of\ products]}{[initial\ concentration\ reactions]}$$

By comparing the ratio with K_c we have three possibilities:

When the ratio is less than Kc:

if the ratio is less then K_c. The system is not at equilibrium and more product are required to reach the equilibrium. Therefore, reaction will proceed in forward direction to form products.

When the ratio is greater than Kc

If the ratio is greater than K_c The system is not at equilibrium and more reactant are required to reach the equilibrium. Therefore, the reaction will go in the reverse direction to form reactants.

When the ratio is equal to Kc

If the ratio is equal to K_c then the reaction is at equilibrium i.e. rate of forward reaction is equal to the rate of reverse reaction.

Q4.(a). K_c has different units in different reaction. Prove it with suitable examples.

Ans: Units of equilibrium constant:

The unit of equilibrium constant depends on the equilibrium constant expression. We have two cases regarding the units of equilibrium constant:

Case-1:

It may have no units if the number of moles of reactants and products are equal in the balanced chemical equation.

Example:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI\ (g)$$

K_c for this reaction is:

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{[mol\ dm^3]^2}{[mol\ dm^{-3}][mol\ dm^{-3}]} = \text{No units}$$

Case-2:

It may have units for the reaction in which the number of moles of product is greater than the reactants in a balanced chemical equation.

Example:

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

K_c for this reaction is:

$$K_c = \frac{[NO_2]^2}{[N_2O_4]} = \frac{[mol\ dm^{-3}]^2}{[mol\ dm^{-3}]}$$

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

Case-3:

It may have units for the reaction in which the number of moles of product is less than the reactants in a balanced chemical equation.

Example:

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

K_c for this reaction is:

$$K_c = \frac{[NH_3]^2}{[N_2][N_2]^3} = \frac{[mol\ dm^{-3}]^2}{[mol\ dm^{-3}][mol\ dm^{-3}]^3}$$

$$= \frac{[mol\ dm^{-3}]^2}{[mol\ dm^{-3}]^4} = \frac{1}{[mol\ dm^{-3}]^2} = \frac{1}{[mol^2\ dm^{-6}]}$$

Q4.(b). How can you predict the extent of reaction from the value of K_c value?

Ans: Extent of chemical reaction:

The value of K_c tells us about the extent of reaction from which quantities of reactants or products can also be predicted.

Consider the general reaction:

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

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

The extent of reaction depends upon the magnitude of K_c , so when

i. K_c value very small:

When the concentration of [A]and [B] is large and that of [C] and [D] is small, the equilibrium, mixture will contain large number of reactants and small number of products. It reflects that the reaction does not proceed appreciably in the forward direction.

ii. K_c value very large:

When the concentration of [A] and [B] is small and that of [C] and [D] is large, the equilibrium, mixture will contain large number of products and small number of reactants. It indicates that the reaction is completed in the forward direction

iii . K_c value neither very small nor very large (moderate):

If K_c value is neither very small nor very large then neither the forward nor the reverse reaction goes to completion. Thus, equilibrium mixture will contain appreciable amount of product and reactants.

Q5. (a). Kc expression for a reaction is given below,

K_c = $\frac{[H_2O]^2[Cl2]^2}{[HCl]^4[O_2]}$

For this reaction write,

i. Reactants and products   ii. Derive the units of K_c

Ans: Reactants and products:

Reactants: $HCl_4 + O_2$

Products: $2Cl_2 + 2H_2O$.

ii. The units of K_c

$K_c = \frac{[H_2O]^2[Cl2]^2}{[HCl]^4[O_2]}$

$K_c = \frac{[mol\ dm^{-3}]^2[mol\ dm^{-3}]^2}{[mol\ dm^{-3}]^4\ [mol\ dm^{-3}]}$

$K_c = \frac{1}{[mol\ dm^{-3}]}$

Q5. (b). Explain the importance on the importance of equilibrium constant, support your answer with examples and reasons?

Ans: Importance/applications of equilibrium constant:

The value of equilibrium constant is specific and remains constant at particular temperature. The equilibrium constant can be used to predict:

i. The direction of chemical reaction.

ii. The extent of chemical reaction.

iv. The effect of change in conditions upon a chemical reaction in equilibrium state.

The detail is given below

1. Prediction of direction of reaction:

The direction of reaction can be predicted by means of [product]/ [reactants] ratio.

$Q_c = \frac{[initial\ concentration\ of\ products]}{[initial\ concentration\ reactions]}$

By comparing the ratio with K_c we have three possibilities:

When the ratio is less than kc:

if the ratio is less then K_c. The system is not at equilibrium and more product are required to reach the equilibrium. Therefore, reaction will proceed in forward direction to form products.

When the ratio is greater than kc

If the ratio is greater than K_c The system is not at equilibrium and more reactant are required to reach the equilibrium. Therefore, the reaction will go in the reverse direction to form reactants.

When the ratio is equal to kc

If the ratio is equal to K_c then the reaction is at equilibrium i.e. rate of forward reaction is equal to the rate of reverse reaction.

2. Extent of chemical reaction:

The value of K_c tells us about the extent of reaction from which quantities of reactants or products can also be predicted.

Consider the general reaction:

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

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

The extent of reaction depends upon the magnitude of K_c, so when

i. K_c value very small:

When the concentration of [A} and [B] is large and that of [C] and [D] is small, the equilibrium, mixture will contain large number of reactants and small number of products. It reflects that the reaction does not proceed appreciably in the forward direction.

ii. K_c value very large:

When the concentration of [A} and [B] is small and that of [C] and [D] is large, the equilibrium, mixture will contain large number of products and small number of reactants. It indicates that the reaction is completed in the forward direction

iii. K_c value neither very small nor very large (moderate):

If K_c value is neither very small nor very large then neither the forward nor the reverse reaction goes to completion. Thus, equilibrium mixture will contain appreciable amount of product and reactants.

3. The effect of change in external conditions:

Once a system has attained the equilibrium it will remain in the same state indefinitely, if the condition does not change. However, the equilibrium state of a system is disturbed if external conditions are changed i.e. concentration, pressure, temperature. Changing these conditions will disturb the equilibrium. Whenever the equilibrium is disturbed by changes in the external conditions, the system always tends to restore equilibrium.

Topic wise questions

Q1. What are irreversible and reversible reactions?

Ans: Irreversible reactions:

"Those chemical reactions which proceed in forward direction only are called irreversible reactions". Or"Those chemical reactions in which reactants are changed into products only and products are not changed to reactants are called irreversible reactions".

Characteristics of irreversible reactions:

Irreversible reactions have the following characteristics:

i. These reactions proceed in one direction only.

ii. They are represented by a single arrow sign ($\longrightarrow$)

iii. No equilibrium state is established in irreversible reactions.

iv. These reactions go to completion.

Example:

A few examples of irreversible reactions are given below:

i. Reaction of carbon with oxygen:

$$C_{(S)} + O_{2(g)} \longrightarrow CO_{2(g)}$$

Ii.Reaction of magnesium with HCl:

$$Mg_{(g)} + HCl_{(g)} \longrightarrow MgCl_{2(s)} + H_{2(g)}$$

Reversible reactions:

Those chemical reactions which proceed both in forward and backward directions are called reversible reactions".

Characteristics of reversible reactions:

A reversible reaction has the following characteristics:

i. These reactions proceed in two directions i.e. forward and backward.

ii. These reactions never go to completion i.e. the reactants are not fully converted into products.

iii. Their reversibility can exist in closed containers only.

iv. A state of dynamic equilibrium is established in all reversible reactions.

v. These reactions are represented by double arrow sign ($\rightleftharpoons$).

Examples:

Following are a few examples of reversible reactions:

i. Reaction of nitrogen with hydrogen:

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

At the start reaction goes in forward direction but as soon as soon amount of ammonia is formed, the ammonia molecules dissociate to nitrogen and hydrogen. Thus, the reaction is reversed.

Some other examples are:

ii. Reaction of Sulphur dioxide with oxygen:

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

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

Q2.How can equilibrium constant be recognize:

Ans: in order to recognize the equilibrium constant of chemical reactions, following methods can be used:

I: Physical method: it includes Refractometry, polarimetry, Spectrophotometry **etc.**

ii. Chemical methods: such as titration.