

Q: Differentiate between reversible and irreversible reaction.

Reversible reaction

The reaction in which products can react together to reform original reactants is called reversible reaction.

Definition

Irreversible reaction

The reaction in which products don't react together to reform original reactants is called irreversible reaction.

Direction

It proceeds in forward as well as reverse direction.

It proceed only in one direction.

Completion

It never goes completion.

It typically proceeds to completion.

Chemical Equation

In their chemical equation, reactants and products are separated by a double-headed arrow (\rightleftharpoons).

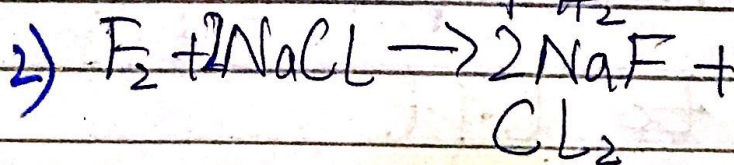
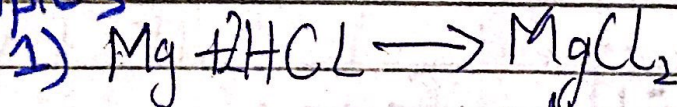
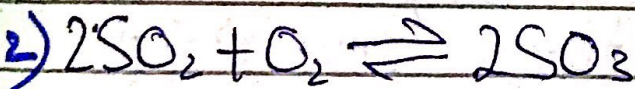
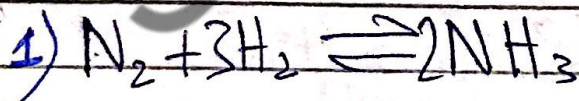
In their chemical equations, reactants and products are separated by a single-headed arrow (\rightarrow).

Equilibrium

They can reach state of equilibrium.

They are unable to reach equilibrium state because they typically go to completion.

Examples



Chemical Equilibrium:

Q: What type of molecules are present at equilibrium state?

Ans: At equilibrium, a mixture of reactants and products is present which is regarded as equilibrium mixture. Thus, both reactants and products are present at equilibrium state.

Q: Describe equilibrium state

Which reaction is called forward reaction?

Ans: Forward reaction:

In a reversible reaction, the reaction of reactants to form products is called forward reaction.

Written from:

It is written from ~~right~~ left to right.

Rate:

Its rate is fastest in the beginning (due to maximum concentration of reactants) and then \downarrow slows down gradually.

Which reaction is called reverse reaction?

Ans: Reverse reaction:

In a reversible reaction, the reaction of products to re-form original reactants is called reverse reaction.

Written from:

It is written from right to left.

Rate:

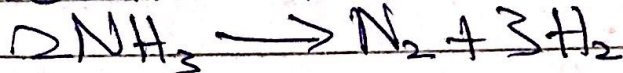
Its rate is ~~fastest~~ zero in the beginning (due to zero concentration of its reactants) and gradually speeds up.

Examples:

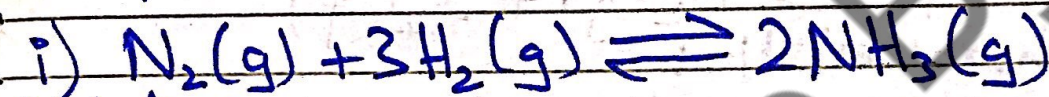
In reversible reaction,



reverse reaction is



Self-assessment - 9.1

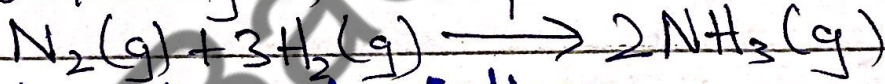


Solution:

Forward reaction:

As forward reaction is written

from left to right, therefore,



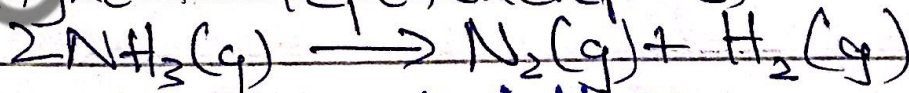
Macroscopic characteristics:

In this forward reaction, N_2 and H_2 gases react to form NH_3 .

Reverse reaction:

As reverse reaction is written

from right to left, therefore,



Macroscopic characteristics:

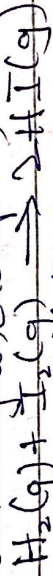
In this reverse reaction, NH_3 decomposes into N_2 and H_2 .



Solution:

Forward reaction:

As forward reaction is written from left to right, therefore,

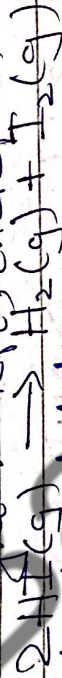


Macroscopic characteristic:

In this forward reaction H_2 and I_2 react and produce HI .

Reverse reaction:

As reverse reaction is written from right to left, therefore,



Macroscopic characteristic:

In this reverse reaction, HI decomposes to form H_2 and I_2 .

Law of Mass Action

Introduction:

Two chemists C.M. Guldberg and P. Waage in 1864 ~~experim~~ established the law of mass action to describe equilibrium state.

Statement:

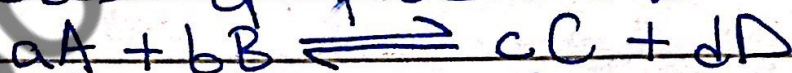
It states that "the rate at which a substance reacts is directly proportional to its active mass. The rate at which a reaction proceeds is directly proportional to the product of active masses of reactants".

Active mass:

The term active mass denotes the concentration of reactants and products at equilibrium in $\text{mol}\cdot\text{dm}^{-3}$. It is represented by square brackets $[\]$.

Derivation of K_c expression:

Consider a hypothetical reaction in which a moles of reactant A and b moles of reactant B react to give c moles of product C and d moles of product D .



According to Law of mass action,
Rate of forward reaction $\propto [A]^a [B]^b$
Rate of forward reaction = $k_f [A]^a [B]^b$

Rate of reverse reaction $\propto [C]^c [D]^d$
Rate of reverse reaction = $k_r [C]^c [D]^d$

At equilibrium state,

Rate of forward reaction = Rate of reverse reaction

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

Where k_f and k_r are rate constants for forward and reverse reactions respectively.

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

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

Where $k_e = \frac{k_f}{k_r}$ and is known as equilibrium constant expression and above expression is called equilibrium constant expression.

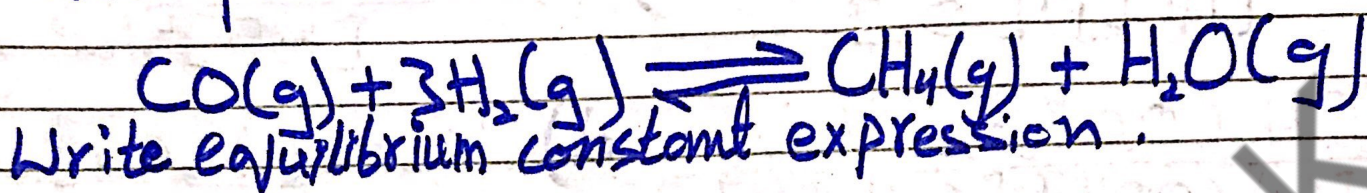
Equilibrium constant k_e :

Equilibrium constant k_e is defined as the ratio of the ~~conce~~ product of concentration of products to product of concentration of reactants at equilibrium. In k_e , subscript e ~~denote~~ denotes molar concentration at equilibrium.

Dependency:

Equilibrium constant k_e is independent of initial concentration of reactants but depends upon temperature.

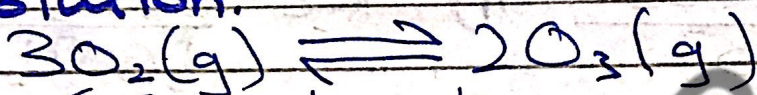
Example #9.2



$$K_c = \frac{[\text{CH}_4][\text{H}_2\text{O}]}{[\text{CO}][\text{H}_2]^3}$$

Self-assessment: 9.2

1: Solution:



Rate of forward reaction $\propto [\text{O}_2]^3$

Rate of forward reaction = $k_f[\text{O}_2]^3$

Rate of reverse reaction $\propto [\text{O}_3]^2$

Rate of reverse reaction = $k_r[\text{O}_3]^2$

At equilibrium state,

Rate of forward reaction = Rate of reverse reaction

$$k_f[\text{O}_2]^3 = k_r[\text{O}_3]^2$$

On-rearranging,

$$\frac{k_f}{k_r} = \frac{[\text{O}_3]^2}{[\text{O}_2]^3}$$

$$\left[K_c = \frac{[\text{O}_3]^2}{[\text{O}_2]^3} \right]$$

Where $k_c = \frac{k_f}{k_r}$ and is known as equilibrium

constant and above equation is called equilibrium constant expression.

2:

$$a) K_c = \frac{[H_2O]^2 [Cl_2]^2}{[HCl]^4 [O_2]}$$

$$c) K_c = \frac{[H_2][F_2]}{[HF]^2}$$

$$b) K_c = \frac{[CH_3COOC_2H_5][H_2O]}{[CH_3COOH][C_2H_5OH]}$$

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

Review Ex:

$$i) K_c = \frac{[H_2][O_2]^{1/2}}{[H_2O]}$$

$$ii) K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$$

$$iii) K_c = \frac{[Co][Cl_2]}{[CoCl_2]}$$

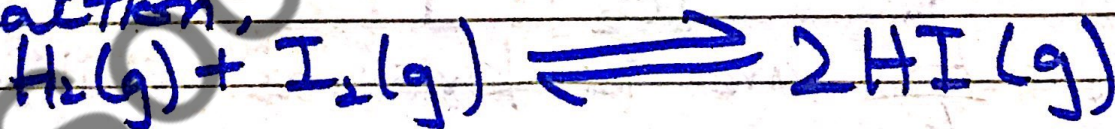
$$iv) K_c = \frac{[Cl_2]^2 [H_2O]^2}{[HCl]^4 [O_2]}$$

Peshawar Board
Finding values of K_c :

Example 9.3

Pg # 14

In the equilibrium mixture the concentration of hydrogen and iodine is 0.04 moles per dm^3 each while that of hydrogen iodide is 0.08 moles per dm^3 . Find K_c of following reaction,



Given data:

Active mass of $H_2 = [H_2] = 0.04 \text{ mol} \cdot \text{dm}^{-3}$

Active mass of $I_2 = [I_2] = 0.04 \text{ mol} \cdot \text{dm}^{-3}$

Active mass of $HI = [HI] = (0.08)^2 \text{ mol} \cdot \text{dm}^{-3}$

To find:

$$K_c = ?$$

Solution:

K_c expression for give reaction is

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

Putting values,

$$K_c = \frac{[0.08]^2}{[0.04][0.04]}$$

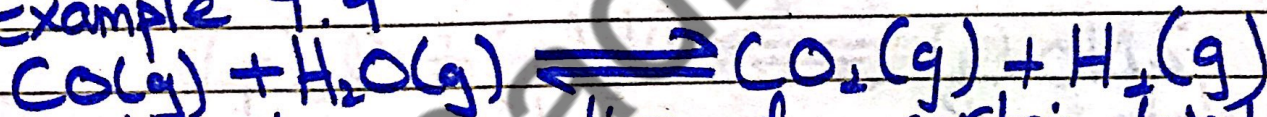
$$K_c = \frac{6.4 \times 10^{-3}}{1.6 \times 10^{-3}}$$

$$K_c = 4 \text{ mol} \cdot \text{dm}^{-3}$$

$$K_c = 4$$

(In this case, there are no units of K_c).

Example 9.4



For the above reaction, at a certain high temp. the concentrations in a particular equilibrium mixture of CO(g) is $0.0600 \text{ mol} \cdot \text{dm}^{-3}$, $\text{H}_2\text{O(g)}$ is $0.120 \text{ mol} \cdot \text{dm}^{-3}$, CO_2 is $0.150 \text{ mol} \cdot \text{dm}^{-3}$ and $\text{H}_2\text{(g)}$ is $0.3000 \text{ mol} \cdot \text{dm}^{-3}$. Calculate value of K_c at this temp.

Given data:

$$\text{Concentration of } \text{CO(g)} = [\text{CO}] = 0.0600 \text{ mol} \cdot \text{dm}^{-3}$$

$$\text{Concentration of } \text{H}_2\text{O(g)}$$

$$\text{Concentration of } \text{H}_2\text{O(g)} = [\text{H}_2\text{O}] = 0.120 \text{ mol} \cdot \text{dm}^{-3}$$

$$\text{Concentration of } \text{CO}_2\text{(g)} = [\text{CO}_2] = 0.150 \text{ mol} \cdot \text{dm}^{-3}$$

$$\text{Concentration of } \text{H}_2\text{(g)} = [\text{H}_2] = 0.3000 \text{ mol} \cdot \text{dm}^{-3}$$

To find: $K_c = ?$

Solution:

The K_c expression for this reaction is,

$$K_c = \frac{[CO_2][H_2]}{[CO][H_2O]}$$

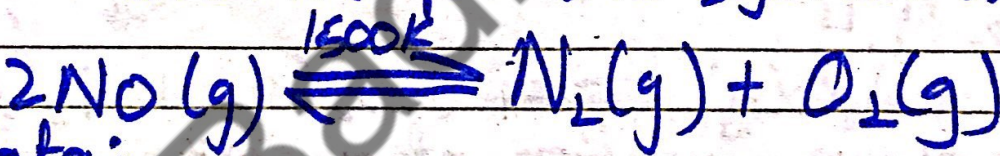
Putting values,

$$K_c = \frac{[0.150][0.300]}{[0.0600][0.120]}$$

$$K_c = 6.25 \text{ (There are no units of } K_c \text{ in this case)}$$

Practice problem 9.4

An equilibrium mixture of N_2 , O_2 and NO gases at 1500K is determined to consist of $6.4 \times 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$ of N_2 , $1.7 \times 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$ of O_2 and $1.1 \times 10^{-5} \text{ mol} \cdot \text{dm}^{-3}$ of NO . What is equilibrium constant for the system at this temp?



Given data:

Concentration of $N_2 = [N_2] = 6.4 \times 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$

Concentration of $O_2 = [O_2] = 1.7 \times 10^{-3} \text{ mol} \cdot \text{dm}^{-3}$

Concentration of $NO = [NO] = 1.1 \times 10^{-5} \text{ mol} \cdot \text{dm}^{-3}$

To find:

Equilibrium constant = $K_c = ?$

Solution:

The K_c expression for this reaction is,

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

Putting values,

$$K_c = \frac{[6.4 \times 10^{-3}][1.7 \times 10^{-3}]}{[1.1 \times 10^{-5}]^2}$$

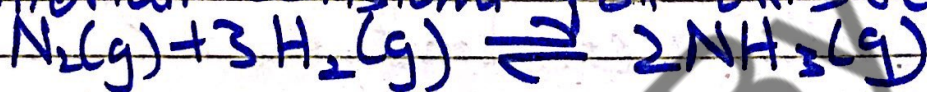
$$K_c = \frac{10.88 \times 10^{-6}}{1.21 \times 10^{-10}}$$

$$K_c = 8.99 \times 10^{-6+10}$$

$$K_c = 8.99 \times 10^4$$

Exercise (Peshawar Board)

6. At equilibrium, a mixture of N_2 , H_2 and NH_3 gas at $500^\circ C$ is determined to consist of $0.602 \text{ mol}\cdot\text{dm}^{-3}$ of N_2 , $0.420 \text{ mol}\cdot\text{dm}^{-3}$ of H_2 and $0.113 \text{ mol}\cdot\text{dm}^{-3}$ of NH_3 . What is the equilibrium constant for this reaction.



Given data:

$$\text{Concentration of } N_2 = [N_2] = 0.602 \text{ mol}\cdot\text{dm}^{-3}$$

$$\text{Concentration of } H_2 = [H_2] = 0.420 \text{ mol}\cdot\text{dm}^{-3}$$

$$\text{Concentration of } NH_3 = [NH_3] = 0.113 \text{ mol}\cdot\text{dm}^{-3}$$

To find:

$$\text{Equilibrium constant} = K_c = ?$$

Formula:

Solution:

The K_c expression for this reaction is given by,

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

Putting values,

$$K_c = \frac{[0.113]^2}{[0.602][0.420]^3}$$

$$K_c = \frac{0.012}{(0.602)(0.074)}$$

$$K_c = 0.281 \text{ dm}^6/\text{mol}^2$$

9: A reaction between gaseous SO_2 and $\text{O}_2(\text{g})$ to produce $\text{SO}_3(\text{g})$ takes place at 600°C . At this temp, the conc. of SO_2 is found to be 1.50 mol dm^{-3} , concentration of O_2 is 1.25 mol dm^{-3}

and concentration of SO_3 is 3.50 mol dm^{-3} . Using the balance chemical equation, calculate K_c for this system.

Given data:

Concentration of $\text{SO}_2(\text{g}) = [\text{SO}_2] = 1.50 \text{ mol dm}^{-3}$

Concentration of $\text{O}_2(\text{g}) = [\text{O}_2] = 1.25 \text{ mol dm}^{-3}$

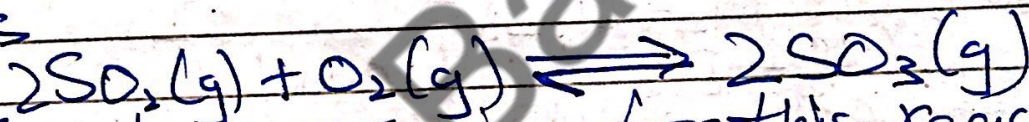
Concentration of $\text{SO}_3(\text{g}) = [\text{SO}_3] = 3.50 \text{ mol dm}^{-3}$

To find:

Equilibrium constant $K_c = ?$

Solution:

Balanced chemical equation for this reaction is



The K_c expression for this reaction is

$$K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$$

Putting values,

$$K_c = \frac{[3.50]^2}{[1.50]^2 [1.25]}$$

$$K_c = 4.36 \text{ dm}^3 \cdot \text{mol}^{-2}$$

Importance of Equilibrium constant K_c :

Equilibrium constant K_c can be used to:

1) predict the direction of chemical reaction.

Explanation:

Direction of a chemical reaction can be predicted by equilibrium constant K_c expression i.e.,

$$K_c = \frac{[\text{products}]}{[\text{reactants}]}$$

Direction of a reaction at any particular time can be predicted by comparing ratio $[\text{products}]/[\text{reactants}]$ to value of K_c . It leads to three possibilities.

1) If ratio $[\text{products}]/[\text{reactants}]$ is less than K_c then reaction isn't at equilibrium and more ~~reactants~~ ^{products} are required to reach equilibrium. Thus, reaction will move in forward direction until equilibrium is reached.

2) If ratio $[\text{products}]/[\text{reactants}]$ is greater than K_c , then reaction isn't at equilibrium and more ~~products~~ ^{reactants} are required to reach equilibrium. Thus, reaction will move in reverse direction until equilibrium is achieved.

3) If the ratio $[\text{products}]/[\text{reactants}]$ is equal to K_c , then reaction is at equilibrium.

2) predict extent of chemical reaction.

Explanation:

The extent of chemical reaction depends upon magnitude of K_c :

a) If $K_c < 1$, reaction lies towards reactants which means there are more reactants and less products in equilibrium mixture.

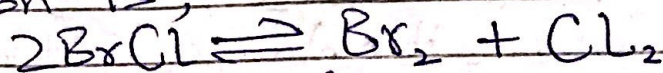
b) If $K_c > 1$, reaction lies towards products which means there are more products and less reactants in equilibrium mixture.

c) If $K_c = 1$, both reactants and products equilibrium lies midway between reactants and products.

Think - Tank :

1:

i) The ~~2~~ balanced chemical equation for this reaction is,



ii) K_c expression for this reaction is,

$$K_c = \frac{[\text{Br}_2][\text{Cl}_2]}{[\text{BrCl}]^2}$$

iii) From K_c expression

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

$$K_c = \text{no units}$$

For this reaction, K_c has no units because total number of moles of products is equal to total number of moles of reactant.

2:

ans: Chemical equation for this reaction is



K_c expression for this reaction is,

$$K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$$

$$\text{Thus, } K_c = \frac{[\text{mol}\cdot\text{dm}^{-3}]^2}{[\text{mol}\cdot\text{dm}^{-3}]}$$

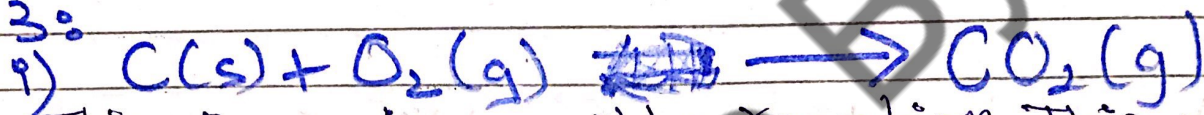
$$K_c = \text{mol}\cdot\text{dm}^{-3}$$

In this case, K_c has units because total number of moles of reactant ~~is~~ ^{are} not equal to total number of moles of product

4)

ans: Cobalt chloride (CoCl_2) can definitely be used as a test for water because both anhydrous cobalt chloride and hydrated cobalt chloride have different colors. If anhydrous cobalt chloride changes its blue color and turns into pink crystals, it indicates presence of water.

3:



This is an irreversible reaction. This means, in this reaction, products can't form original reactants. Thus, when reaction appears to be complete, only products will be found.



This is a reversible reaction which means that in this reaction products convert into reactants and reactants form products simultaneously. Thus when reactions appear to be complete, there will still be some reactant along with products.

PYQs

Long Qs: Write down macroscopic characteristics of a reversible chemical reaction.

Reversible reaction:

The reaction in which products can react together to reform original reactants is called reversible reaction.

Macroscopic characteristics:

A reversible reaction proceeds in forward as well as reverse direction. It never goes completion. It can reach equilibrium state under suitable conditions.

Macroscopic characteristics of forward reaction:

1: In forward reaction, reactants produce products.

2: ~~By~~ Its rate is fastest in beginning and

then slows down.

3: It is written from right to left to right.

Macroscopic characteristics of reverse reaction:

1: In reverse reaction, products produce reactants.

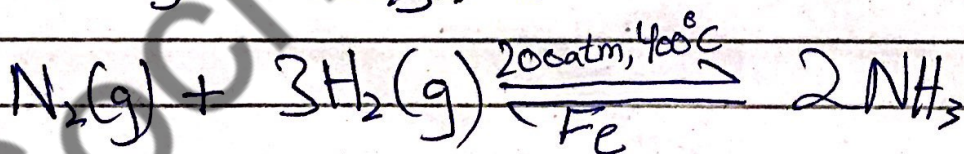
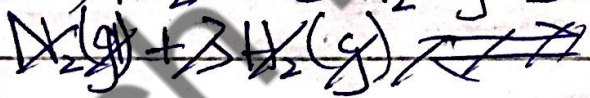
2: Its rate is zero in beginning and then speeds up.

3: It is written from right to left.

Model Paper Qs

How has Le-Chatelier's principle made it possible to get maximum amount of product from Haber's process? Write its three conditions.

Ans: Le-Chatelier's principle has enabled us to obtain maximum amount of products from reversible reactions. In the case of Haber's process, N_2 and H_2 gases react to produce NH_3 .



Under normal conditions, only 33% of NH_3 is produced at equilibrium. But by applying this principle, we can increase this yield to 98%. Temp. is decreased while pressure is increased which increases, yield of NH_3 .