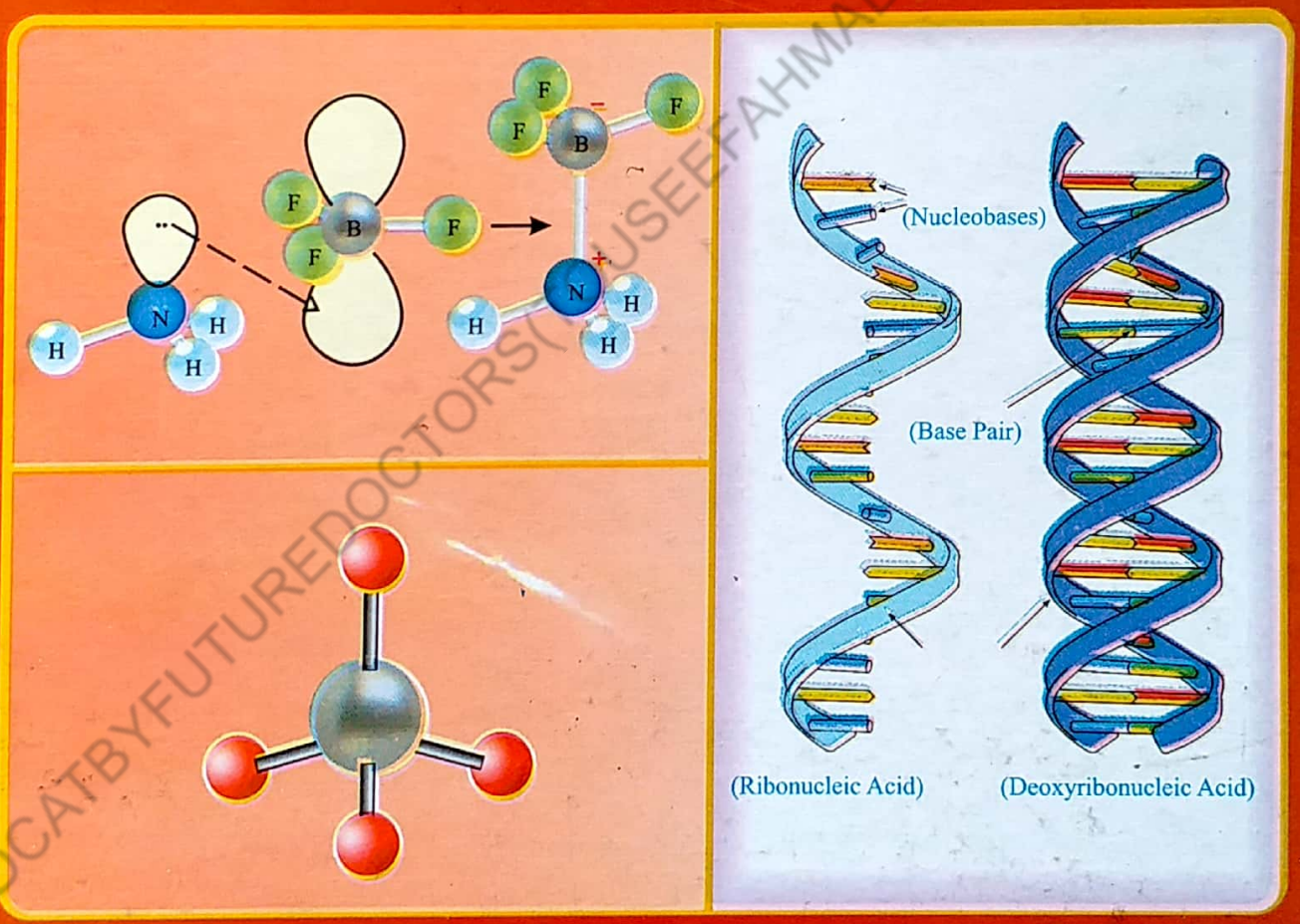
A Textbook of

CHEMISTRY X

For Class 10



Balochistan Textbook Board, Quetta.

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Chemistry 10

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Appeal,

Balochistan Textbook Board is a dedicated organization committed to undertake publication of quality textbooks in line with the curriculum. These books are the fruits of efforts by renowned educationists and experts. Despite our constant endeavours, chances of inadvertent mistakes cannot be ruled out, and there is always room for improvement. Therefore, we look forward to valuable suggestions to enhance the quality of the textbooks.

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Preface

In continuation of the developing new text books that have the challenge to accept new challenges of new and modern era, the Chemistry 10 is here which has been designed to meet the needs of this changing world. This again is in according to new curriculum for courses which has been set by the Ministry of Education in 2006;

The new curriculum offers a radical shift from the traditional curriculum is based upon the multi text book system, creating the students being able to think independently, asking questions and looking for the answers at their own. The understanding of subject must be more developed in them rather than the traditional remembering procedures,

This chemistry '10' book is also the part of new curricula system, and has been written in very simple language, so the learner feel easy in understanding the basic concepts of chemistry, and cope with the challenging demands of the todays world.

Some of the main aims of this book are:

(i) Writing the chemistry in an easy and approachable mannar so the students from the remote and backward areas feel easy to understand the important ideas, concepts of the subject.

(ii) An overview of the basic principles involved in the subject.

(iii) Knowledge of the practical approach in the subject, for this purpose many activities and interesting informations have been introduced in the book.

(iv) Most of the topics also explain the role of chemistry tools in our society so the reader be able to understand the importance of the subject and its role for improving the life standard of us.

(v) There are also solved examples to guide the students how to cope with the problems on the topic.

(vi) Each chapter is accompanied with an exercise at the end to check the learing ability of the students.

As it is obvious that a text book can do nothing alone and the most important part of studies is the role of Teachers and Instructors , so the teachers are requested to apply the aims of this book in the light of the SLOs (Students learning objectives) which are stated at the beginning of each chapter, that describes the time to be allotted to each chapter, tests and assignments of the chapter and the main areas that they should focus on. At the end we are thankful to all those0 who helped us in writing this book, and made it possible for us to try to bring a change in the traditional education system.

We also appreciate for further suggestions from readers and educators to improve the quality of this text in future,

Thanking you all in anticipation.

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Contents

Chapter 9

CHEMICAL EQUILIBRIUM

Conceptual Linkage

Before reading this chapter, the student must know the:

- Representation of chemical reactions and chemical equation.
- Balancing of chemical equations.
- Basic mathematics.

Time Allocation

Teaching periods	=08
Assessment periods	=03
Weightage	=05%

LEARNING OUTCOMES

Students will be able to:

- Define chemical equilibrium in terms of a reversible reaction. (Understanding)
- Write both the forward and the reverse reactions and describe the macroscopic characteristics of each. (Applying)
- Define law of mass action. (Understanding)
- Derive an expression for the equilibrium constant and its units. (Applying)
- State the necessary conditions for equilibrium and the ways that equilibrium can be recognized. (Understanding)
- Write the equilibrium constant expression of a reaction.

Introduction

The word "equilibrium" which is Latin origin literally means "balance of forces", This is the state when there seems no change in any system. e.g. a pencil which is kept on finger, when at rest is said to be in equilibrium state.

The equilibrium is generally of two types, the static equilibrium and the dynamic equilibrium. The static equilibrium is the type of equilibrium in which the different phases of equilibrium remain in the state of rest, e.g. in case of the fulcrum and fauna or the playground seesaw.

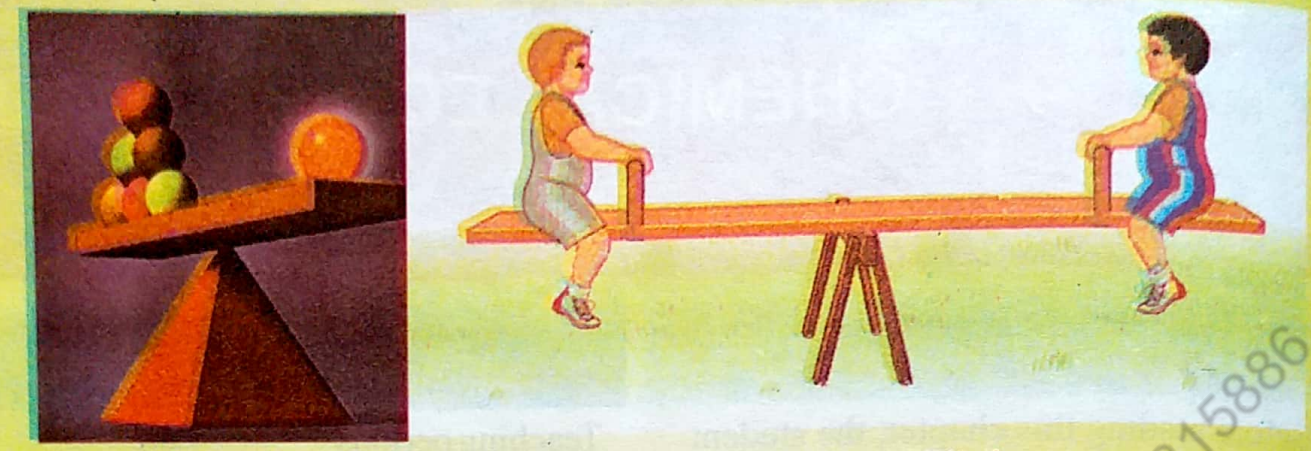


Fig.9.1: Common examples Static Equilibrium

The second type of equilibrium is the dynamic equilibrium which is the state of equilibrium in which the different phases readily interconvert in each other, for example during the vapour pressure the rate of evaporation and the rate of condensation remains equal so the net change in the system is zero and we say that the system is in equilibrium.

The chemical reactions are mostly reversible and the product of a chemical reaction can be transformed into the reactants through which they are formed. The general representation for such reversible chemical reactions is as:

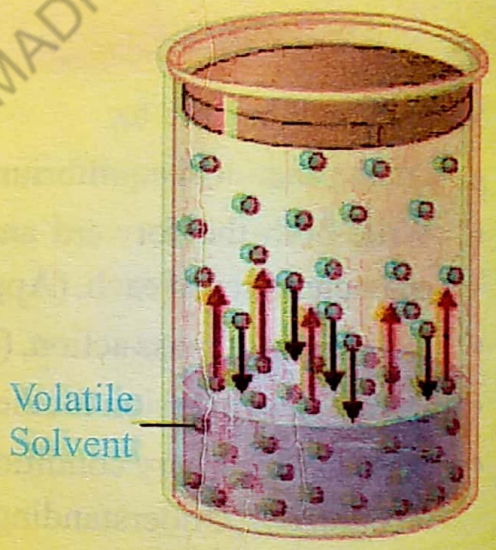


Fig. 9.2: Vapour Pressure of a volatile solvent, an example of dynamic equilibrium

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

Here 'A' and 'B' are initial reactants and 'C' and 'D' are the products. The double headed half arrow sign shows that change is taking place in both directions, such equilibrium where the rate at which the product C & D are produced is equal to the rate of reactants A & B are reproduced is called chemical equilibrium, e.g ammonia which is formed by the reaction between hydrogen and nitrogen, it can be again converted into its constituting elements i.e. the hydrogen and the nitrogen.

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

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

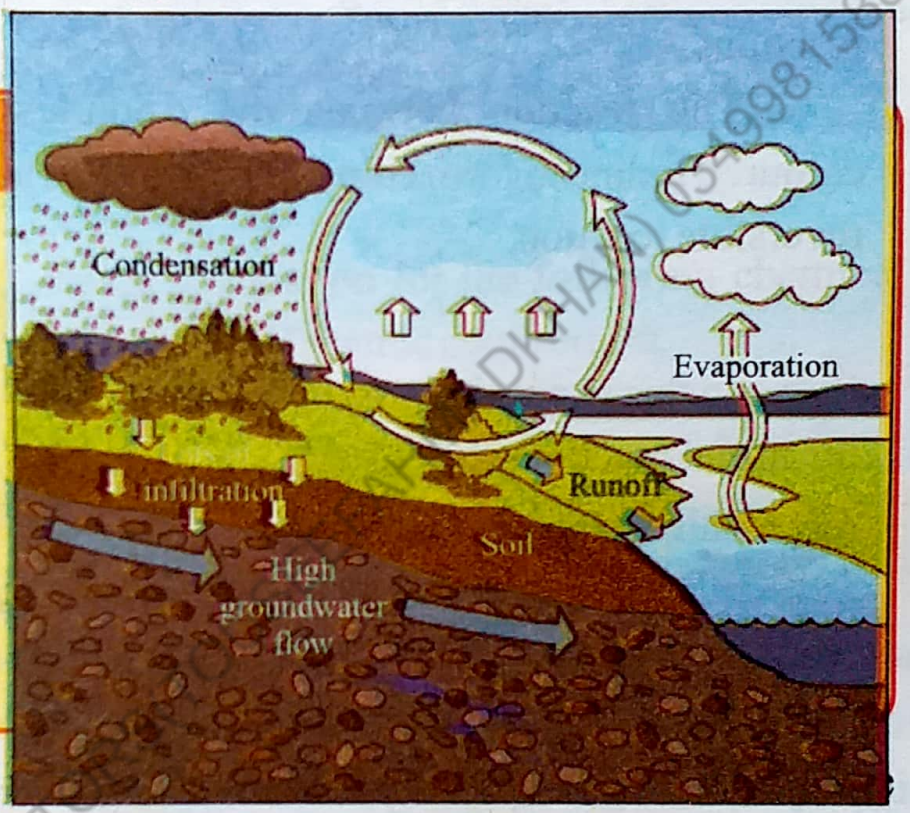
Collectively both these reactions are written as:

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

This special arrow sign " $\rightleftharpoons$ " indicates that the reaction can proceed in both directions. The NH_3 produced is an important constituent of urea fertilizer.

Interesting Information

This is interesting to know that different stages in the natural water cycle and the other natural processes like nitrogen cycle, Carbon dioxide cycle, Ozone cycle etc exist in dynamic equilibrium.



Many of the chemical reactions can be converted back into the initial reactants, and this is done by selecting suitable reaction conditions. There are many chemical reactions which can proceed in both the directions at almost the same conditions.

Another important example of such chemical reactions includes formation of NO_2 gas, which is reddish brown in colour from N_2O_4 gas (which is pale yellow).

$$\underset{\substack{\text{Pale Yellow}\\(\text{Liquid})}}{N_2O_{4(l)}} \underset{}{\overset{140^{\circ}C}{\rightleftharpoons}} \underset{\substack{\text{Reddish Brown}\\(\text{Gas})}}{2NO_{2(g)}}$$

Such reversible chemical reaction is actually do exist in dynamic manner and all the species involved in chemical reaction readily interconvert in a fashion that the net change remains zero, so the equilibrium establishes in all these cases. Such systems are called chemical equilibrium.

9.1 Reversible reactions and Dynamic Equilibrium

As already described, the chemical reactions involve a unique type of equilibrium where the concentration of reacting species that include both the initial reactants and the products remain unchanged in a dynamic manner. This means that the reactants and the product of the reaction reunite to yield the corresponding species of the reaction. This can be easily understood by considering the following examples of reversible dynamic chemical reactions.

The reaction between the colourless hydrogen gas with purple coloured Iodine to form colourless hydrogen iodide is a good example of such reversible reaction.

$$H_{2(g)} + I_{2(g)} \underset{\text{Reverse Reaction}}{\overset{\text{Forward Reaction}}{\rightleftharpoons}} 2HI_{(g)}$$

In this particular reaction the initial reactants the H_2 and I_2 react with each other to form HI. Subsequently, the product of this reaction decomposes and again converted into the initial used reactants i.e. the hydrogen and the Iodine. Hence this is the reversible reaction. A dynamic equilibrium establishes after a certain time. This can be seen in the graphical representation of the reaction in figure 9.3.

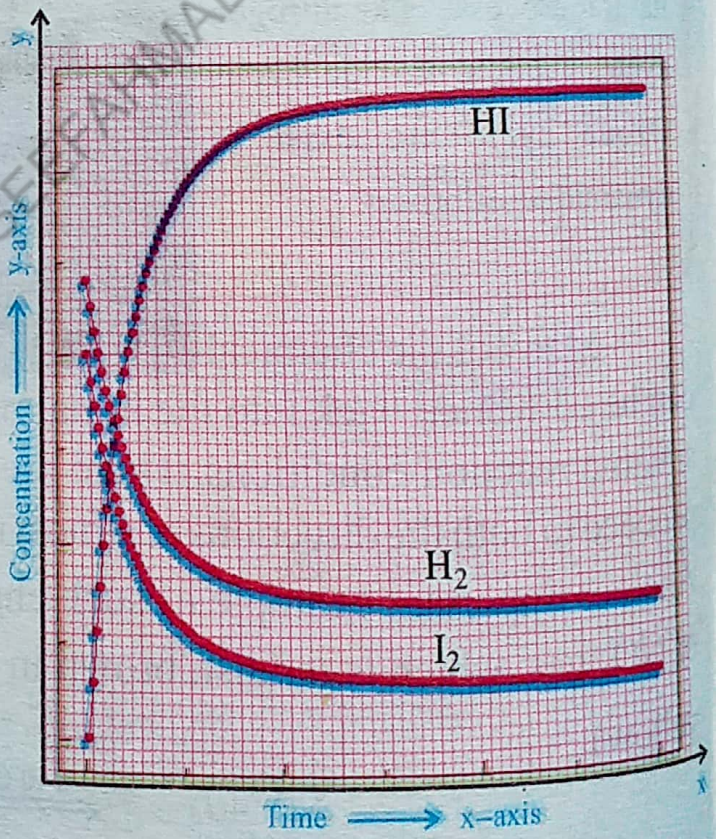


Fig. 9.3: Reaction between H_2 and I_2 showing equilibrium achievement

This is to be noted that at the point of equilibrium all three species of the reaction found in specific concentration. The reaction at this point does not stops but the all species of the reaction interconvert in a manner that their quantities remain unchanged and becaus

the rate of forward reaction is equal to the rate of reverse reaction that is why this is called dynamic equilibrium.

Important example of such reactions is the formation of SO_3 from the oxidation of SO_2 gas,

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

This should be clearly understood that the all chemical reactions are reversible but the extent of their reversibility varies greatly for each type, and all reversible reactions show dynamic equilibrium.

Activity 9.1

Write down the balanced chemical equation for the following chemical compounds when they attain the state of dynamic equilibrium.

N_2 and O_2 N_2 and H_2 H_2 and I_2 NO and O_2 CO_2 and H_2

9.2 Law of mass action and Derivation of the expression for the equilibrium constant

Uptill now you have learnt that there exists a dynamic equilibrium between reactants and products during reversible chemical reactions, in 1864 two scientists Guldberg and Waage studied the relation of dynamic equilibrium between the quantities or concentration and put forwarded their research work as law of mass action, according to the law of mass action.

"The rate of a chemical reaction is directly proportional to the product of active masses (or concentration) of reactants at constant temperature".

e.g for a general reaction.

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

Here, two reaction are included, one is the forward phase in which A and B changes into C and D.

$$A + B \longrightarrow C + D$$

The second reaction is the reverse phase of the process which is actually the conversion of the product of the initial reaction the C and D into

the reactants of the initial reaction, i.e. into A and B.

$$C + D \longrightarrow A + B$$

According to the law of mass action;

Rate of forward reaction = $(R_f) \alpha [A] [B]$

(Where sign "α" shows a direct relation among different species of the reaction, and [ ] shown the molar concentration.)

And the rate of reverse reaction = $(R_r) \alpha [C] [D]$

or it can be written as:

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

And

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

Where K_f and K_r are the proportionality constants.

At the dynamic equilibrium the rate of both the forward and the reverse reactions are equal.

$$R_f = R_r$$

or it can also be written as,

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

And by rearranging this:

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

Because K_f and K_r both are constant so they are combined to get one single constant, i.e.

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

Where K is the equilibrium constant and C is the molar concentration.

Therefore:

$$K_c = \frac{[C][D]}{[A][B]} \quad \ldots\ldots\ldots\ldots (i)$$

Where 'K_c' is called **equilibrium constant**.

For more general form, i.e.

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

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b} \quad \ldots\ldots\ldots\ldots (ii)$$

Where 'a, b, c' and 'd' are written at the top of the brackets, are the reaction coefficients.

The equation (ii) is a general form for describing chemical equilibrium. But remember, in gaseous systems partial pressure of gases is taken which describes of their concentration in solutions. For this reason we substitute 'K_p' rather than 'K_c' in such gaseous systems, hence for:

$$aA_{(g)} + bB_{(g)} \rightleftharpoons cC_{(g)} + dD_{(g)}$$

The

$$K_p = \frac{(pC)^c(pD)^d}{(pA)^a(pB)^b}$$

Coefficient

Coefficient

Where 'p' is the partial pressure of any gas and 'K_p' represents equilibrium constant for gaseous systems where concentration is measured using partial pressure of gases.

9.3 Equilibrium constant and its units

The equilibrium constant actually tells us the concentration of different species of the reaction at both the reactant and the product sides of the reaction, it is denoted by the symbol "K_c" and by some simple calculations we can get easily the information about the constitution of any chemical reaction at the time of equilibrium.

$$K_c = \frac{\text{Product of the concentration of products raised to the power of coefficient}}{\text{Product of the concentration of reactants raised to the power of coefficient}}$$

This not only helps us in calculating the concentration of species of a

chemical reaction but with some suitable applications we can enhance the quantity of the desired species of a reversible chemical reaction.

The equilibrium constant (K_c) depends upon the temperature, and if temperature is changed its value also changes, but its value does not depends upon the initial concentration of reactants or products.

Because the equilibrium constant (K_c) is a ratio and likewise all the other ratios, it also have no units, (as all the units in both the reactant(s) and the product(s) are same and are cancelled by each other in the expression). e.g. in the reaction between H_2 and I_2.

$$H_{2(g)} + I_{2(g)} \overset{450^\circ C}{\rightleftharpoons} 2HI_{(g)}$$

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

$$\text{Units} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})} = \text{No units}$$

Thus K_c has no units in this case.

In case when the number of moles of reactants and products are not equal then K_c has units. e.g. for the reaction between N_2 and H_2 to form NH_3.

$$N_{2(g)} + 3H_{2(g)} \overset{450^\circ C}{\rightleftharpoons} 2NH_{3(g)}$$

In this case, the units will be:

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

And

$$\text{Units} = \frac{(\text{mol dm}^{-3})^2}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})^3} = \frac{1}{(\text{mol dm}^{-3})^2} = (\text{mole dm}^{-3})^{-2}$$

Thus in this case it has some units too, it means that the units of K_c varies from case to case.

9.4 Importance of Equilibrium constant

The equilibrium constant has many applications in chemistry. The value of K_c is used to calculate many important phenomenon of the reversible reactions used in industries, e.g. it is used to calculate the amount of reactants or products of a reversible chemical reactions of industrially important compounds like sulphuric acid (H_2SO_4), nitric acid (HNO_3), urea or $CO(NH_2)_2$. For example in the preparation of NH_3 gas which is used in synthesis of urea fertilizer, the reaction is:

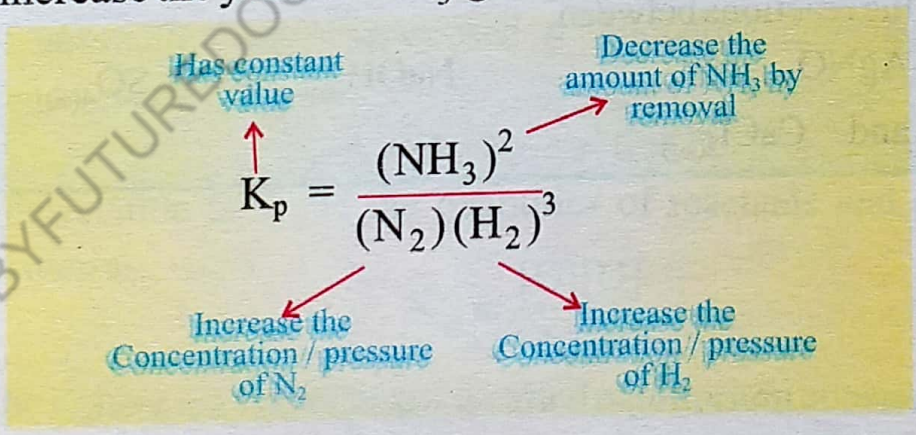
$$N_{2(g)} + 3H_2 \overset{450^\circ C}{\rightleftharpoons} 2NH_{3(g)}$$

to increase amount of NH_3 gas the knowledge of 'K_c' is used, according to which the concentrations of N_2 or H_2 or both has to be increased or concentration of NH_3 has to be decreased which result in the formation of more NH_3 and hence more urea can be formed.

In this process 'K_c' or more properly 'K_p' is:

$$K_p = \frac{(NH_3)^2}{(N_2)(H_2)^3}$$

So, to increase the yield of 'NH_3' gas we can do the following steps:



K_c is also used to predict the direction of a chemical reaction, and after a specific time period the extent of a chemical reaction. When the value of equilibrium constant is known which is done experimentally, it is used in many ways. For example, if the value of 'K_c' is very high for a reaction, it

means that the desired product can be easily made from this reaction, as the concentration of the products is very high at the time of equilibrium, which makes the 'K_c' very high.

Similarly, if the 'K_c' is very low for a given reaction, it means that the concentration of the initial reactants is high at the time of equilibrium of a reaction, so it means that the reaction is not feasible.

The knowledge of equilibrium constant expression is used to calculate and enhance the yield of products in the field of many of industrially important compounds like H_2SO_4, HNO_3, Urea etc are prepared through the chemical reactions which are reversible, in all such cases the application of some simple rules of Science increases the yield of these chemical reactions up to a great extent, and hence expenditure of the preparation decreases as a result of which the prices of the products can be controlled to a desired level.

The value of 'K_c' is also helpful in calculating the effect of changing the conditions upon a chemical reaction, and hence the yield of a chemical reaction can be controlled.

Activity 9.2

Write down the balanced chemical equation and equilibrium constant expression for the reactions between,

$NaCl_{(aq)}$ and $AgNO_{3(aq)}$ $\quad$ $NaOH_{(aq)}$ and $H_2SO_{4(aq)}$

$(NH_4)_2CO_{3(aq)}$ and $CaCl_{2(aq)}$

Summary of the Chapter

- A system is said to be in the state of equilibrium when there seems no change in that system.
- The Equilibrium is basically of two types, the static equilibrium and the dynamic equilibrium.
- When the different states or phases of an equilibrium established system do not move and remain constant at a place, such equilibrium is called static equilibrium e.g. Fulcrum and Fauna equilibrium and the equally balanced playground seesaw etc.
- A dynamic equilibrium is that type of equilibrium when different constituents of the system change in the manner that there occurs no change in the overall process.
- Most chemical reactions are reversible but tendency of reversibility varies for each system and equilibrium establishes in all these.
- The type of equilibrium in the chemical processes is of dynamic nature.
- In the state of dynamic equilibrium of a chemical reaction, there exists a simple relation between the concentration of reactants and the products, this relation can be represented by an equation.
- The Rate of a chemical reaction is directly proportional to the product of active masses (or concentration) of reactants, this statement is called Law of mass action and was proposed by Guldberg and Waage in 1864.
- For a general reaction

$$A + B \longrightarrow C + D$$

The relation between the quantities of reactants and products can be written as,

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

The K_c here is a constant and is called equilibrium constant.

- The Value of K_c can be used to predict the concentration of any reactant or product of a system which is at dynamic equilibrium.

Exercise

Q1: Fill in the blanks.

i) There are .... types of equilibrium.

ii) Vapour pressure is an important example of .... equilibrium.

iii) The equilibrium constant shows .... of products and reactants in a dynamic chemical process.

iv) All chemical reactions show .... type of equilibrium.

v) The Law of mass action was put forwarded by .... in ....

vi) All natural cycles show .... type of equilibrium.

vii) NH_3 gas is used for manufacture of .... fertilizer.

viii) In gaseous systems the .... is taken in consideration instead of concentrations.

ix) The value of K_c is .... of initial concentrations of reactants.

x) In the gaseous systems .... is replaced by K_p.

Q2: Tick the correct answer from the given list.

i) The types of equilibrium found in nature could be of

(a) 2 (b) 3 (c) 4 (d) 5

ii) The type of equilibrium found in fulcrum and fauna is

(a) Static (b) Dynamic

(c) Depends on conditions (d) Shows no equilibrium

iii) Most chemical reaction show

(a) Reversibility (b) Static equilibrium

(c) Heat energy (d) Pressure

iv) The value of K_c is dependent upon the

(a) Only on initial concentration of reactants

(b) Only on initial concentration of products

(c) Final concentration of reactants

(d) Does not depends upon initial concentration of reactants and products

v) The value of K_c can be used

(a) To increase the products of a chemical reaction.

(b) To predict the reaction pathway

(c) To reduce the heat supply of system

(d) To calculate the pressure of system

vi) The K_c is obtained by the data of

(a) initial concentration of reactants

(b) Initial concentration of products

(c) Concentration of both the reactants and the products at equilibrium state.

(d) Final concentration of products.

vii) The Value of K_c depends upon:

(a) Temperature of system

(b) Pressure of system

(c) Initial concentration of reactants

(d) Concentration of reactants and products at equilibrium

viii) Pressure of system effects the equilibrium of

(a) Liquids (b) Solids

(c) Gases (d) All of these

ix) The Carbon dioxide cycle involves

(a) Static equilibrium

(b) Dynamic equilibrium

(c) Does not related with equilibrium

(d) Related with atmospheric pressure

x) If for the general reaction

$A + B \rightleftharpoons C + D$

increase in concentration of D will result in the:

(a) Decrease in concentration of A

(b) Decrease in concentration of B

(c) Decrease in concentration of C

(d) Increase in the concentration of A and B.

Q3: Answer the following questions briefly.

i) What types of equilibrium are there in nature?

ii) Write down the equilibrium constant expression for the reaction.

$$NH_{3(g)} + HCl_{(g)} \rightleftharpoons NH_4Cl_{(s)}$$

iii) What are the units of K_c?"

iv) Explain the term Dynamic equilibrium?"

v) Define the term 'rate of a chemical reaction'.

Q4: What do you understand by the equilibrium?" Describe the types of equilibrium with examples.

Q5: Explain the reversible reaction with examples.

Q6: Describe the law of mass action and derive an expression for the equilibrium constant.

Q7: What do the K_c means? Explain its importance and applications.

Q8. In the reaction between:

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

How you can increase the production of So_3?