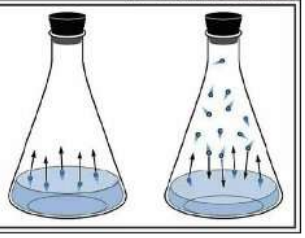
6 CHAPTER EQUILIBRIA



Student Learning Outcomes

After studying this chapter, students will be able to:

- Recognize that reversible reactions are shown by symbol and may not go to completion
- Describe how changing the physical conditions of a chemical equilibrium system can redirect reversible reactions (Some examples can include:

  a. effect of heat on hydrated compounds

  b. addition of water to anhydrous substances in particular copper (Il) sulfate and cobalt (Il)chloride
- State that reversible reactions can achieve equilibrium in a closed system when rate of forward and backward reactions are equal.

INTRODUCTION

Q.3 What are chemical reactions? ***(Knowledge Base)***

Ans:

CHEMICAL REACTION

Definition:

"The process in which chemical change occurs in nature and composition of substances is called chemical reaction".

Examples:

- Rusting of iron
- $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$

Q.4 Differentiate between reactants and products. ***(Understanding Base)*** **(MTN 2016 G-I, FSD 2016 G-II)**

Ans:

DIFFERENTIATION

The differences between reactants and products are as follows:

Reactants	Products
Definition	
• In a chemical reaction the substances that combine are called reactants.	• The new substances formed during a chemical reaction are called products.
Example	
• In a reaction $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$ H_2 and O_2 are reactants.	• In a reaction $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$ H_2O is product.

Q.5 What is complete reaction? How it is represented? ***(Understanding Base)*** **(LHR 2018)**

Ans: A reaction in which **all** the **reactants** are **converted** into **products** is called complete reaction.

Representation: It is represented by single arrow " $\longrightarrow$ "

Example: $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$

Q.6 Write down an example of equilibrium in nature. ***(Knowledge Base + Understanding Base)***

Ans:

EQUILIBRIUM IN NATURE

Following examples describe the phenomenon of equilibrium in nature:

(i) Between O_2 and CO_2:

We owe our existence to equilibrium phenomenon taking place in atmosphere. We inhale oxygen and exhale carbon dioxide, while plants consume carbon dioxide and release oxygen. This natural process is responsible for the existence of life on the Earth.

Q.1 Describe types of chemical reactions on the basis of direction. ***(Knowledge Base + Understanding Base)***

Ans:

TYPES OF CHEMICAL REACTION

Types of chemical reaction (on the basis of direction)

1. **Irreversible reaction**

In most of the reactions the products do not recombine to form reactants, are called irreversible reactions and such reactions proceed in one direction only.

OR

In a chemical reaction, the reactants react to give the products. The reaction will continue until all the reactants or one of the reactants is converted into product.

Example

Representation:

It is represented by single arrow " $\longrightarrow$

Examples:

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$$

The following reaction takes place immediately in an aqueous solution to give the products.

$$NaCl_{(aq)} + AgNO_{3(aq)} \longrightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

The reaction goes to completion and if stoichiometric amounts of the reactants are used then no reactant species are present at the end of the reaction. Such a reaction is called an irreversible reaction.

Direction

It moves in the forward direction.

2. Reversible reaction

Definition:

"*The reactions in which the **products** can **recombine** to **form reactants** are called reversible reactions".*

In the majority of chemical reactions, however, the reaction does not go to completion. The products of the reaction react among themselves to give back the reactants under the same conditions. Such a reaction moves in both the forward and backward directions under the same conditions. The reactants react to give the products and the products, in turn, react to give back the reactants. The reaction is called a reversible reaction.

Representation

It is denoted by a double arrow.

Examples

(i) Reaction between N_2 and H_2:

$$N_{2(g)} + 3H_{2(g)} \underset{Fe}{\overset{400°C,\ 200\ atm}{\rightleftharpoons}} 2NH_{3(g)}$$

In this reaction, one mole of nitrogen gas reacts with three moles of hydrogen gas under the conditions of reaction in a closed container to give two moles of ammonia gas. After its formation, the ammonia gas decomposes to give the reactants back. The reaction never goes to completion. At any time, all the three species are simultaneously present in the reaction mixture.

Completion of reversible reaction

A reversible reaction, however, goes to completion if either one of the products is withdrawn from the reaction mixture or being a gas, it escapes into the atmosphere.

Example $\longrightarrow$

Calcium carbonate is decomposed by heating at a particular temperature. $\longrightarrow$

$$CaCO_3(s) \underset{}{\overset{Heat}{\rightleftharpoons}} CaO(s) + CO_2(g)$$

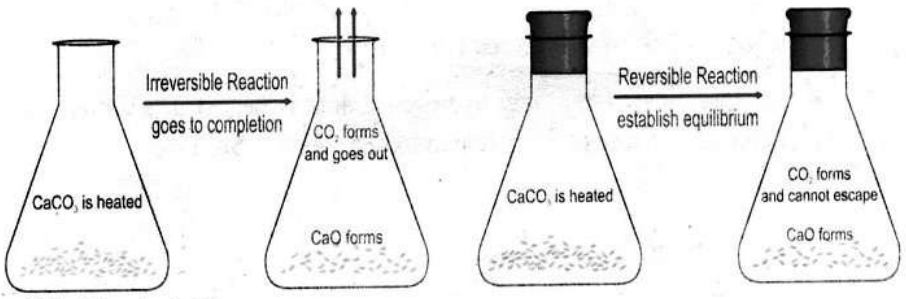
(ii) Thermal decomposition of $CaCO_3$

(a) In open container

If the above reaction is carried out in an open container, the carbon dioxide gas will escape into the atmosphere as soon as it is formed and the reaction is forced to go to completion.

(b) In closed container

If, on the other hand, the reaction is performed in a closed container, the carbon dioxide will react with calcium oxide to give back the reactants.



Reversible Physical Change

(iii) Heating of copper sulphate pentahydrate ($CuSO_4$, $5H_2O$)

Like chemical changes, physical changes may also be reversible in nature. Copper sulphate pentahydrate ($CuSO_4.5H_2O$) is an important salt which is blue in coiour. When this salt is heated strongly, its colour changes to white. This physical change involves the following equilibrium.

$$\underset{\text{Hydrated Copper sulphate}}{CuSO_4\ 5\ H_2O} \xrightleftharpoons{\text{Heat}} \underset{\text{Anhydrous Copper sulphate}}{CuSO_4} + 5\ H_2O$$

When white anhydrous copper sulphate absorbs moisture from the atmosphere, it will turn blue again.

(iv) Heating of cobalt chloride hexa-hydrate ($CoCl_2.6H_2O$)

Similar to this, when cobalt chloride hexa-hydrate ($CoCl_2.6$ HO), which is pink in colour, is heated it is converted to anhydrous $CoC1_2$ which is blue in colour.

$$\underset{\text{Hydrated Cobalt chloride (Pink)}}{CoCl_2\ 6\ H_2O} \xrightleftharpoons{\text{Heat}} \underset{\text{Anhydrous Cobalt chloride (Blue)}}{CoCl_2} + 6\ H_2O$$

In the reverse reaction, the anhydrous cobalt chloride absorbs less moisture, it is first converted into a di-hydrate which is purple in colour. This di-hydrate then further absorbs four more water molecules to become a hexa-hydrate which is pink in colour.

ACTIVITY

Take a few grams of coloured copper sulphate in a dry test tube.
First heat it gently and strongly for some time.
Note down the observation.
Let the test tube cool down.
Again note down the observation.

Answer:

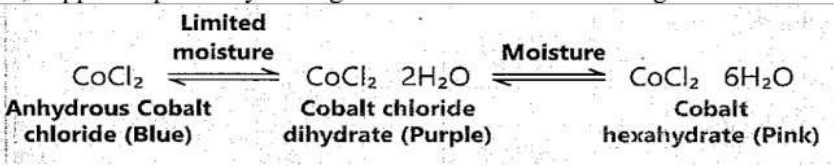
Observations:

(a) After heating gently and strongly

After heating gently, the colour of the copper sulphate will be blue whereas after heating strongly for some time the colour of the crystals will become white due to loss of water of crystallization.

(b) After cooling down the test tube

When cooled, copper sulphate crystals again turn blue after absorbing moisture.



SHORT QUESTIONS

Q.1 Differentiate between reversible and irreversible reactions. ***(Understanding Base)***

Ans:

DIFFERENTIATION

The differences between reversible and irreversible reactions are as follows:

Reversible Reaction	Irreversible Reaction
Definition	
• *Reactions in which products recombine to form reactants are called reversible reactions and such reactions proceed in both directions.*	• *In most of the reactions the products do not recombine to form reactants, are called irreversible reactions and such reactions proceed in one direction only.*
Completion	
• They never go to completion.	• They go to completion.
Representation	
• These are represented by a double arrow (⇌) between reactants and products.	• These are represented by a single arrow (→) between reactants and products.

Q.2 Write down macroscopic characteristics of forward reactions. ***(Knowledge Base)***

(LHR 2019, MTN 2016 G-I, BWP 2017, DGK 2017)

Ans:

CHARACTERISTICS OF FORWARD REACTIONS

Following are the characteristics of forward reactions:

- It is reaction in which reactants react to form products.
- It takes place from left to right.
- At initial stage the rate of forward reaction is very fast.
- It slows down gradually.

Q.3 Write down macroscopic characteristics of reverse reactions. ***(Knowledge Base)***

(GRW 2017, DGK 2017, SWL 2017, LHR 2013, 2014, 2015, GRW 2014)

Ans:

CHARACTERISTICS OF REVERSE REACTIONS

Following are the characteristics of reverse reactions:

- It is reaction in which products react to produce reactants.
- It takes place from right to left.
- In the beginning the rate of reverse reaction is negligible.
- It speeds up gradually.

Q.4 Why reaction does not stop during equilibrium condition? ***(Understanding Base)***

(SGD 2016 G-I)

Ans: **REACTION AT EQUILIBRIUM**

The reaction does not stop during equilibrium condition because **products recombine** to form **reactants** again i.e. the forward and reverse reactions keep on occurring continuously.

$$A + B \underset{R_f}{\overset{R_r}{\rightleftharpoons}} C + D$$

Reactants Products

Q.5 **Write down macroscopic characteristics of forward and reverse reactions.** ***(Knowledge + Understanding Base)***

Ans: **DIFFERENTIATION (LHR 2017, SGD 2017, FSD 2017)**

The differences between forward and reverse reaction are as follows:

Forward Reaction	Reverse Reaction
Definition	
• It is reaction in which reactants react to form products.	• It is reaction in which products react to produce reactants.
Direction	
• It takes place from left to right.	• It takes place from right to left.
Rate of Reaction in the beginning	
• At initial stage the rate of forward reaction is very fast.	• In the beginning the rate of reverse reaction is negligible.
Rate of Reaction at later stage	
• It slows down gradually.	• It speeds up gradually.

MULTIPLE CHIOICE QUESTIONS

4. **In chemical reactions the substances that combine are called:** ***(K.B)*** **(FSD 2017 G-I)**

(A) Products (B) Reaction intermediates
(C) Reactants (D) Both A and C

5. **Name the reactants in the equation,** $2H_{2(q)} + O_{2(g)} \xrightarrow[Heat]{Pt} 2H_2O_{(l)}$ **:** ***(K.B)***

(A) Water (B) Hydrogen and oxygen
(C) Oxygen (D) None of these

6. **The reactions in which all the reactants have been converted into products are known as:** ***(K.B)***

(A) Incomplete reactions (B) Complete reactions
(C) Continuous reactions (D) Reversible reactions

7. **A complete reaction is one in which:** ***(U.B)*** **(LHR 2016)**

(A) All the reactants convert into products
(B) All the reactants do not convert into products
(C) Half of the reactants convert into products
(D) Only 10% reactants convert into products

8. **Name the products in the equation,** $2H_{2(q)} + O_{2(g)} \xrightarrow[Heat]{Pt} 2H_2O_{(l)}$ **:*(K.B)***

(A) Water (B) Hydrogen and oxygen
(C) Oxygen (D) None of these

9. **The reaction in which the products do not recombine to form reactants is known as:** ***(K.B)***

(A) Reversible reaction (B) Decomposition reaction
(C) Addition reaction (D) Irreversible reaction

10. **The reactions in which the products recombine to form reactants are called:** ***(K.B)*** **(SGD 2016 G-II, FSD 2017 G-II)**

(A) Forward reactions (B) Reversible reactions
(C) Irreversible reactions (D) Backward reactions

11. Reversible reactions take place in: ***(U.B)***

(A) One direction (B) Both directions
(C) Left to right (D) Right to left

12. The characteristics of reversible reactions are the following except: ***(U.B)***

(A) They never complete
(B) Products never recombine to form reactants
(C) They have a double arrow between reactants and products
(D) They proceed in both ways

13. An irreversible reaction consists of: ***(U.B)***

(A) Forward reaction (B) Reverse reaction
(C) Both forward and reverse reactions (D) None of these

14. Which reaction is irreversible? ***(U.B)*** **(MTN 2016 G-II)**

(A) $N_2+3H_2 \longrightarrow 2NH_3$ (B) $H_2+I_2 \longrightarrow 2HI$
(C) $2H_2+O_2 \longrightarrow 2H_2O$ (D) None of these

15. Reversible reaction is represented by: ***(K.B)*** **(FSD 2017-G-I)**

(A) $\longrightarrow$ (B) $\rightleftharpoons$
(C) $\longleftarrow$ (D) $\rightleftharpoons$

6.1 DYNAMIC EQUILIBRIUM

LONG QUESTIONS

Q.1 Define dynamic equilibrium. How dynamic equilibrium is established?

(Understanding+Application Base)

Ans:

DYNAMIC EQUILIBRIUM

Definition

"When reaction does not stop only the ***rates of forward and reverse reaction*** *become equal to each other but take place in* ***opposite directions****. This is called dynamic equilibrium state."*

Note: Dynamic means reaction is still continuing at dynamic equilibrium state.

Example:

$$CaCO_3 \rightleftharpoons CaO+CO_2$$

At equilibrium:

Rate of forward reaction = Rate of reverse reaction

Example

Establishment of dynamic equilibrium

i. If a reversible reaction is started by mixing the reactants, the reaction moves in the forward direction only.
ii. After some time when enough concentrations of the products are built up, they react to give back the reactants in the reverse reaction.
iii. The reaction will keep on going in both the directions until the rate of forward reaction becomes equal to the rate of reverse reaction.
iv. In other words, the number of reactant molecules which will disappear as a result of forward reaction becomes equal to the number of reactant molecules which will form as a result of the reverse reaction. The same will be true for the product molecules.
v. At this stage, the reaction is said to be in a state of chemical equilibrium. It appears as if nothing is going on in the reaction vessel as the concentrations of both reactant and product molecules do not undergo any change at this stage.

vi. Since the reaction did not cease at this state of equilibrium, rather it keeps on going in both the directions, this state is called dynamic equilibrium.

vii. The concentrations of reacting species (reactants and products) remain constant at equilibrium.

INTERESTING INFORMATION

FORMATION OF METHANE FROM COAL

Vast deposit of coal are available in Thar, Sindh. This coal can be used to generate electricity. When coal is made to react with steam, Co and H_2 are produced. These products then react by a reversible reaction called catalytic methanation to yield methane.

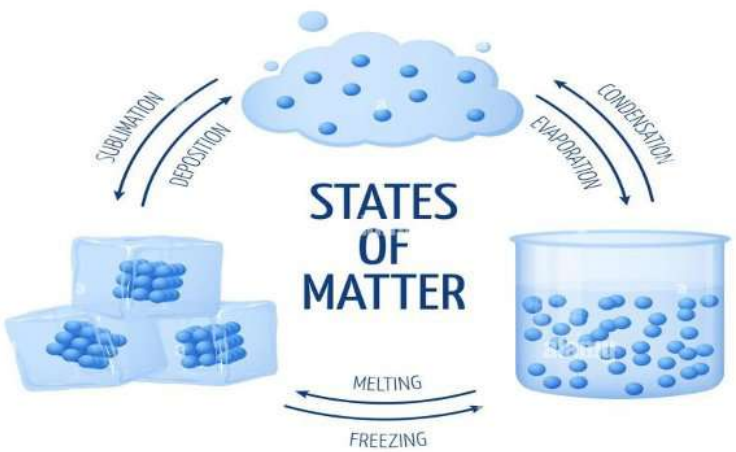
$$C_{(s)} + H_2O_{(g)} \longrightarrow \underbrace{CO_{(g)} + H_{2(g)}}_{\text{Water gas}}$$

$$CO_{(g)} + 3H_{2(g)} \overset{\text{Catalyst}}{\rightleftharpoons} CH_{4(g)} + H_2O_{(g)}$$

EXERCISE

1. Elaborate an example of dynamic equilibrium which exist in this world between three physical states of water.

Ans:



2. Dinitrogen tetra oxide (Na_2O_4) is a colourless gas. It slowly changes to brown coloured nitrogen dioxide (NO_2) at 100°C. Predict how the colour of mixture will change if N_2O_4 is kept in a sealed flask at 100°C.

$$\underset{\text{Colourless}}{N_2O_4} \overset{100°C}{\rightleftharpoons} \underset{\text{Brown}}{2NO_2(g)}$$

Ans: The colour of the mixture will turn brown.

Q.2 Describe dependence of time to attain the state of dynamic equilibrium.

(Understanding+Application Base)

Ans: **DEPENDENCE OF TIME TO ATTAIN DYNAMIC EQUILIBRIUM**

The time a reaction will take to attain the state of dynamic chemical equilibrium depends upon

- The nature of the reaction
- The conditions at which the given reversible reaction is performed.

(a) For very slow reaction

For a dynamic equilibrium to be set up, the rate of the forward reaction must be equal to the rate of backward reaction. This does not happen instantly and for very slow reaction, it may take years.

(b) For moderate speed reaction

Both the rates of formation and the decomposition of ammonia are reasonably fast at around 400^0C in the presence of a catalyst. This reaction will reach the equilibrium state within minutes of the start of reaction.

(c) For very fast reaction

The following equilibrium reaction takes 4-5 seconds to reach at the point of equilibrium.

SHORT QUESTIONS

Q.1 What is chemical equilibrium? Explain its types with examples. ***(Knowledge Base)***

Ans:

CHEMICAL EQUILIBRIUM

Definition:

"When the rate of the forward reaction takes place at the rate of reverse reaction, the ***composition*** *of the* ***reaction mixture remains constant****, is called chemical equilibrium state".*

Types:

There are two types of chemical equilibrium:

(i) Static Equilibrium:

"When a body is at rest position, it is called static equilibrium.

Example:

A building remains standing rather than falling down because all the forces acting on it are balanced. This is an example of static equilibrium.

(ii) Dynamic Equilibrium:

"*When reaction does not stop only the* ***rates of forward and reverse reaction*** *become equal to each other but take place in* ***opposite directions****. This is called dynamic equilibrium state."*

Note: Dynamic means reaction is still continuing at dynamic equilibrium state.

Example:

$$CaCO_3 \rightleftharpoons CaO + CO_2$$

At equilibrium:

Rate of forward reaction = Rate of reverse reaction

Q.2 Explain graphical representation of dynamic equilibrium.

(Understanding+Application Base)

Ans:

GRAPHICAL REPRESENTATION

In a reversible reaction, dynamic equilibrium is established before the completion of reaction.

At initial stage the rate of forward reaction is very fast and reverse reaction is taking place at a negligible rate. But gradually forward reaction slows down and reverse reaction speeds up. Eventually, both reactions attain the same rate; it is called a dynamic equilibrium state.

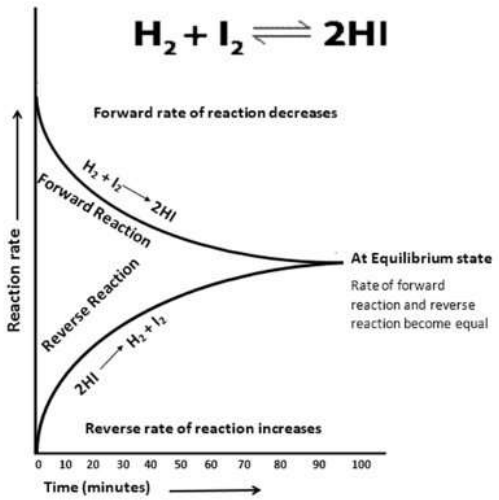


Figure: Graph Showing the Rate of Forward and Reverse Reactions and Establishment of Equilibrium State

Example:

In case of reaction between hydrogen and iodine vapors, some of the molecules react with each other to give hydrogen iodide.

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

At the same time, some of the hydrogen iodide molecules decompose back to hydrogen and iodine.

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

Speed of Reaction:

In the Beginning:

In the beginning, as the concentration of the reactants is higher than that of the products, the rate of the forward reaction is fast than the reverse reaction.

At Later Stage:

As the reaction proceeds, the concentration of reactants will gradually decrease while that of products will increase, consequently the rate of the forward reaction will go on decreasing and the reverse reaction will go on increasing and ultimately the two rates will become equal to each other. Thus, the equilibrium will set up and concentration of various species (H_2, I_2, HI) becomes constant. It is represented as:

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

Q.2 Write down macroscopic characteristics of forward reactions. ***(Knowledge Base)***

(LHR 2019, MTN 2016 G-I, BWP 2017, DGK 2017)

Ans: **CHARACTERISTICS OF FORWARD REACTIONS**

Following are the characteristics of forward reactions:

- It is reaction in which reactants react to form products.
- It takes place from left to right.
- At initial stage the rate of forward reaction is very fast.

- It slows down gradually.

Q.3 Write down macroscopic characteristics of reverse reactions. ***(Knowledge Base)***
(GRW 2017, DGK 2017, SWL 2017, LHR 2013, 2014, 2015, GRW 2014)

Ans: **CHARACTERISTICS OF REVERSE REACTIONS**

Following are the characteristics of reverse reactions:

- It is reaction in which products react to produce reactants.
- It takes place from right to left.
- In the beginning the rate of reverse reaction is negligible.
- It speeds up gradually.

Q.4 Why reaction does not stop during equilibrium condition? ***(Understanding Base)***
(SGD 2016 G-I)

Ans: **REACTION AT EQUILIBRIUM**

The reaction does not stop during equilibrium condition because **products recombine** to form **reactants** again i.e. the forward and reverse reactions keep on occurring continuously.

$$A + B \underset{R_f}{\overset{R_r}{\rightleftharpoons}} C + D$$

Reactants Products

Q.5 Why reversible reactions never complete? ***(Understanding Base)*** **(LHR 2013, SWL 2017)**

Ans: **COMPLETION OF REVERSIBLE REACTIONS**

The reversible reactions never complete because products recombine to form reactants again. The forward and reverse reactions keep on occurring continuously. e.g.

$$A + B \underset{R_f}{\overset{R_r}{\rightleftharpoons}} C + D$$

Reactants Products

Q.6 What is a static equilibrium? Explain with an example. ***(Knowledge Base)***
(LHR 2015, GRW 2015)

Ans: Answer given on page # 164

Q.7 Why the amounts of reactants and products do not change in reversible reaction? ***(Understanding Base)***
(GRW 2013)

Ans: **AMOUNTS OF REACTANTS AND PRODUCTS**

The amounts of reactants and products do not change in a reversible reaction because a state of **dynamic equilibrium** is established in reversible reaction. In dynamic equilibrium state the **rate of forward and reverse reaction** becomes **equal** and take place in **opposite direction** but amounts of reactants and products remain the same.

MULTIPLE CHOICE QUESTIONS

1. Dynamic means reaction: ***(K.B)***
(A) Stops (B) Is still continuing
(C) In opposite direction (D) Both A and B

2. When reaction ceases to proceed it is called: ***(K.B)*** **(SGD G-II 2016)**
(A) Dynamic equilibrium (B)Static equilibrium
(C) Chemical equilibrium (D) None of these

3. Reaction in which reactants react to form products is called: ***(K.B)***
(A) Forward reaction (B) Reverse reaction
(C) Reversible reaction (D) Backward reaction

4. At initial stage the rate of forward reaction is: ***(K.B)***
(A) Low (B) Very low
(C) Very fast (D) All of these

5. **Reverse reactions _____ gradually.** ***(U.B)***
   (A) Speed up (B) Negligible
   (C) Slow down (D) Do not speed up
6. **Forward reaction takes place from:** ***(K.B)***
   (A) Left to right (B) Right to left
   (C) Both A and B (D) All of these
7. **When CaO reacts with CO_2 they produce:** ***(U.B)***
   (A) $CaCO_3$ (B) $CaCO_2$
   (C) CaC_2 (D) CaO
8. **In the beginning reverse reaction:** ***(K.B)*** **(FSD 2017 G-I)**
   (A) Is fast (B) Stops
   (C) Is slow (D) Is very fast
9. **When rate of forward reaction takes place at the rate of reverse reaction and the composition of the reaction mixture remains constant is called:** ***(K.B)***
   (A) Static equilibrium (B) Neutral equilibrium
   (C) Chemical equilibrium state (D) None of these
10. **When a system is at equilibrium state then?** ***(U.B)*** **(GRW 2015)**
    (A) The concentration of reactants and products becomes equal
    (B) The opposing reactions (forward and reverse) stop
    (C) The rate of reverse reaction becomes very low
    (D) The rate of forward reaction becomes equal to the rate of reverse reaction

6.2 CHANGING THE PHYSICAL CONDITIONS OF A CHEMICAL REACTION

LONG QUESTIONS

Q.1 What are the possible ways to disturb a reversible chemical system? ***(Understanding Base)*** **(GRW 2013)**

Ans: **WAYS TO DISTURB A REVERSIBLE CHEMICAL SYSTEM**

If a given reversible reaction has attained the state of dynamic equilibrium, it will remain in this state for infinite time unless it is somehow disturbed.

A reversible chemical system may be distributed in the following possible ways.

1. Adding or withdrawing one or more of the reacting species
2. Adding or withdrawing one or more ofthe product species
3. Changing the temperature of the reaction
4. Effect of the presence of a catalyst on a reversible reaction
5. Changing the pressure of the reaction if it involves reactants or the products in the gaseous state

Example

Consider the following reversible reaction at equilibrium.

$$N_{2(g)} + 3H_{2(g)} \underset{\text{Catalyst}}{\overset{400^\circ C}{\rightleftharpoons}} 2NH_{3(g)}$$

The concentrations of all the participating chemicals will be constant at the state of equilibrium.

(i) Addition of N_2 gas

At this stage if we add more N_2 gas in the mixture, its concentration will increase and the reaction will no longer maintain its state of equilibrium. To restore the equilibrium state again, nitrogen will react with hydrogen to produce more ammonia. This change will go on until a new state of equilibrium is reached at which the concentration of all the species will again become constant.

(ii) New concentration at new state of equilibrium

These new concentrations will, however, be different from the concentrations of the earlier equilibrium state.

(iii) **Withdrawing of NH_3 gas**

Now let us disturb the equilibrium again by withdrawing some of the ammonia gas formed. As a result, its concentration will decrease. To restore the equilibrium state, more nitrogen and hydrogen will react to produce ammonia. When the state of equilibrium is reached again, the concentrations of all the species shall again become constant.

SHORT QUESTIONS

Q.1 How we can increase formation of ammonia in the reaction?

$$N_{2(g)} + 3H_{2(g)} \underset{\text{Catalyst}}{\overset{400^\circ C}{\rightleftharpoons}} 2NH_{3(g)}$$

Ans:

WITHDRAWING OF NH_3 GAS

Now let us disturb the equilibrium again by withdrawing some of the ammonia gas formed. As a result, its concentration will decrease. To restore the equilibrium state, more nitrogen and hydrogen will react to produce ammonia. When the state of equilibrium is reached again, the concentrations of all the species shall again become constant.

Q.2 Why the reversible reactions do not go to completion? *(Understanding Base)*

Ans:

COMPLETION OF REVERSIBLE REACTIONS

The reversible reactions do not go to completion because products recombine to form reactants and reaction occurs in both directions i.e. forward and reverse. At this state, the composition of reaction mixture remains constant.

$$A + B \underset{K_r}{\overset{K_f}{\rightleftharpoons}} C + D$$

Reactants *Products*

MULTIPLE CHOICE QUESTIONS

1. When H_2 and O_2 combine they form: *(K.B)*

(A) H_2O (B) H and O

(C) HO_2 (D) None of these

2. When H_2 and N_2 combine they form: *(K.B)*

(A) H_2O (B) NH_3

(C) I_2 (D) H_2 and I_2

6.3 EFFECT OF CHANGING THE TEMPERATURE ON THE STATE OF EQUILIBRIUM

LONG QUESTIONS

Q.1 Describe the effect of changing the temperature on the state of equilibrium. *(Understanding Base)* (GRW 2013)

Ans:

EFFECT OF CHANGING TEMPERATURE ON EQUILIBRIUM

Example (Formation of Ammonia)

The formation of ammonia is exothermic in the forward direction and hence this reaction will be endothermic in the reverse direction.

$$N_{2(g)} + 3H_{2(g)} \underset{\text{Heat}}{\rightleftharpoons} 2NH_{3(g)} \quad \Delta H = -92.4 \text{ kJ/mole}$$

Heat

If this reaction is at equilibrium and its temperature is increased, the state of the equilibrium will be disturbed again.

The ΔH

The ΔH of this reaction is negative. This means the total energy of the system containing N_2 and H_2 is higher than that of ammonia.

(a) Effect of increase in temperature

The increase in temperature of this reaction at equilibrium will push the reaction in the backward direction i.e. the reactants side.

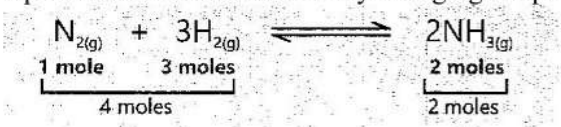
(b) Effect of decrease in temperature

Decreasing the temperature will drive the equilibrium to the forward direction.

Effect of change of pressure on the reaction at equilibrium

Principle

Change of pressure will disturb the equilibrium state of only those gaseous reactions in which the number of moles of the reacting gases will be different from the number of moles of the gases being produced. Since the formation of ammonia gas meets such a condition, the state of its equilibrium will be disturbed by changing the pressure exerted on the reaction mixture.



(a) Effect of increase in pressure

The increase in pressure shifts the reaction to that side in which he number of moles are less

Effect of decrease in pressure at Equilibrium

The decrease in pressure shifts the reaction to that side in which number of moles are more.

In this reaction:

4 moles of reacting gases are producing two moles of product gas

4 moles of gases at say S.T.P will occupy 4 x 22.414 = 89.656 dm^3 of volume

2 moles of NH_3 will occupy 2 x 22.414 = 44.828 dm^3 of volume

Effect of increase in Pressure at Equilibrium

If this reaction is at equilibrium and the pressure is increased, the equilibrium will be disturbed. To restore this, the reaction will move to that side in which the number of moles are less i.e. forward direction. The formation of ammonia gas is thus favoured at high pressure.

Effect of presence of a catalyst on the reversible reaction

At the stage of dynamic equilibrium, the rates of both forward and backward reactions are equal.

Principle

A catalyst increases both the rates of forward and back reactions of a reversible reaction. So if a reversible reaction is carried out in the presence of a catalyst it will decrease the time taken by the reaction to attain the state of equilibrium.

Example

Let us consider another example of a reversible reaction at equilibrium. Phosphorous pentachloride decomposes according to the following equation.

$$PCl_{5(g)} \rightleftharpoons PCl_3 + Cl_2$$

According to the equation one mole of the gaseous reactant is giving two moles of the product gases. The reaction is an endothermic reaction. Keeping in view the above description of the reaction, answer the following questions.

i. What will happen if the gas mixture is compressed?

Ans:

The reaction will move towards the backward direction with less number of moles of PCl_5.

ii. What will happen if we add $C1_2$ gas to the equilibrium mixture?

Ans:

If we add Cl_2 gas to the equilibrium mixture the reaction will move towards the backward direction to achieve equilibrium state again.

iii. What will happen if the temperature of the reaction is increased?

Ans:

The reaction will move towards the forward direction.

INTERESTING INFORMATION

100% conversion of N_2 and H_2 to NH_3 in Haber's process

Industrial: production of ammonia in Haber Process is a very useful application Of the Phenomenon of chemical equilibrium. Ammonia gas leads to the formation of an important fertilizer urea. The ability of ammonia gas to be converted into its liquid form easily is used to drive the reaction to completion. In this way, practicably 100% conversion of N_2 and H_2 to NH_3 is

achieved.

EXERCISE

Q. The preparation of ethyl acetate is commercially very important because it is used as a thinner in paint industry. dil. H2S04

$$\underset{\text{Ethyl alcohol}}{C_2H_5OH_{(l)}} + \underset{\text{Acetic acid}}{CH_3COOH_{(l)}} \overset{\text{dil. } H_2SO_4}{\rightleftharpoons} \underset{\text{Ethyl acetate}}{CH_3COOC_2H_{5(l)}} + H_2O_{(l)}$$

One way to get the better yield of the product ethyl acetate is to remove water from the reaction mixture as soon as it is formed. Suggest a suitable method to withdraw water from the reaction mixture.

Ans: **METHOD TO WITHDRAW WATER**

Using vapour permeation/pervaporization at the boiling point of the reaction mixture is a suitable method to withdraw water from the reaction mixture.

SHORT QUESTIONS

Q.1 What is the effect of presence of a catalyst on the reversible reaction? (SGD 2017)

Ans: **EFFECT OF PRESENCE OF A CATALYST**

At the stage of dynamic equilibrium, the rates of both forward and backward reactions are equal.

Principle

A catalyst increases both the rates of forward and back reactions of a reversible reaction. So if a reversible reaction is carried out in the presence of a catalyst it will decrease the time taken by the reaction to attain the state of equilibrium.

Q.2 Name the possible ways to disturb a reversible chemical system.

Ans: **WAYS TO DISTURB REVERSIBLE SYSTEM**

A reversible chemical system may be distributed in the following possible ways.

(i) Adding or withdrawing one or more of the reacting species
(ii) Adding or withdrawing one or more ofthe product species
(iii) Changing the temperature of the reaction
(iv) Effect of the presence of a catalyst on a reversible reaction
(v) Changing the pressure of the reaction if it involves reactants or the products in the gaseous state

Q.3 Point out the coefficients of each in the following hypothetical reactions:
(Understanding Base)

a. 2A + 3B ⇌ 4C + 2D **b. 4X ⇌ 2Y + 3Z** **c. 2M + 4N ⇌ 5O**

Ans: **COEFFICIENTS OF HYPOTHETICAL REACTIONS**

(a) 2A + 3B ⇌ 4C + 2D

Reacting substances	A	B	C	D
Coefficients	2	3	4	2

(b) 4X ⇌ 2Y + 3Z

Reacting substances	X	Y	Z
Coefficients	4	2	3

(c) 2M + 4N ⇌ 5O

Reacting substances	M	N	O

Coefficients	2	4	5

MULTIPLE CHOICE QUESTIONS

1. What will happen if the rates of forward and reverse reactions are very high?
(A) The equilibrium point will reach very soon.
(B) The equilibrium point will reach very late.
(C) The reaction will not attain the state of dynamic equilibrium.
(D) The reaction will be practically irreversible.

2. Predict which components of the atmosphere react in the presence of lightening?
(A) N_2 and H_2O
(B) O_2 and H_2O
(C) CO_2 and O_2
(D) N_2 and O_2

3. An inorganic chemist places one mole of CI_2 in a container A and one mole of each Cl_2 and $PC1_3$ in container B. Both the containers were sealed and heated to the same temperature to reach the state of equilibrium. Guess about the composition ofmixtures in both the containers.
(A) Both the containers will have the same composition of mixtures.
(B) Container A will have more concentration of PCl_3 than B.
(C) Container A will have less concentration of $PC1_3$ than B.
(D) Both the containers will have zero concentration of its reactants.

4. CaO or lime is used extensively in steel, glass and paper industries. It is produced in an exothermic reversible reaction by the decomposition of lime ($CaC0_3$). Choose the conditions to produce maximum amount of lime.
(A) Heating at high temperature in a closed vessel
(B) Heating at high temperature in an open vessel
(C) Cooling it in a closed vessel
(D) Cooling it in an open vessel

5. What condition should be met for the reversible reaction ta achieve the state of equilibrium?
(A) All the reactants should be converted into the products.
(B) 50% of the reactants should be converted into products.
(C) The concentration of all the reactants and the product should become constant.
(D) One of the products should be removed from the reaction mixture.

6. Why the gas starts coming out when you open a can of fizzy drink?
(A) Because the solubility of the gas increases
(B) Because the gas is insoluble in water
(C) Because the gas is dissolved under pressure hence it comes out when pressure is decreased
(D) Because the solubility of the gas decreases at high pressure

7. The following reaction is performed in a closed vessel.
CaCO3 CaO + CO2
How the equilibrium will be affected if you increase the pressure?
(A) The forward reaction will be favoured
(B) The backward reaction will be favoured
(C) No effect on backward reaction
(D) No effect on forward or backward reaction

8. When a reaction will become a reversible one?
(A) If the activation energy of the forward reaction is comparable to that of backward reaction
(B) if the activation energy of the forward reaction is higher than that of backward reaction

(C) If the activation energy of the forward reaction is lower than that of backward reaction
(D) If the enthalpy change of both the reactions is zero.

9. Is reversible reaction useful for preparing compounds on large scale?
(A) No
(B) Yes
(C) They are useful only when equilibrium lies far to the right side
(D) They are useful only when equilibrium lies far to the left side

10. What will happen to the concentrations of the products if a reversible reaction at equilibrium is not disturbed?
(A) They will remain constant
(B) They will keep on increasing
(C) They will keep on decreasing
(D) They will remain constant for some time and then start decreasing

ANSWER KEY

MULTIPLE CHOICE QUESTIONS

INTRODUCTION

1	C	**2**	B		B	**4**	A	5	A
6	D	**7**	B	**8**	B	**9**	B	10	A
11	C	**12**	B						

6.1 DYNAMIC EQUILIBRIUM

1	B	**2**	B	**3**	A	**4**	C
5	A	**6**	A	**7**	A	**8**	C
9	C	**10**	D				

6.2 CHANGING THE PHYSICAL CONDITIONS OF A CHEMICAL REACTION

1	A	**2**	B		

6.3 EFFECT OF CHANGING THE TEMPERATURE ON THE STATE OF EQUILIBRIUM

1		**2**		**3**		**4**	

EXERCISE SOLUTION

MULTIPLE CHOICE

1. Tick (v) the correct answer.

1. What will happen if the rates of forward and reverse reactions are very high?

(A) The equilibrium point will reach very soon.
(B) The equilibrium point will reach very late.
(C) The reaction will not attain the state of dynamic equilibrium.
(D) The reaction will be practically irreversible.

2. Predict which components of the atmosphere react in the presence of lightening.

(A) N_2 and H_2O
(B) O_2 and H_2O
(C) CO_2 and O_2
(D) N_2 and O_2

3. An inorganic chemist places one mole of CI_2 in a container A and one mole of each Cl_2 and $PC1_3$ in container B. Both the containers were sealed and heated to the same temperature to reach the state of equilibrium. Guess about the composition of mixtures in both the containers.

(A) Both the containers will have the same composition of mixtures.
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(B) Heating at high temperature in an open vessel
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(C) Because the gas is dissolved under pressure hence it comes out when pressure is decreased
(D) Because the solubility of the gas decreases at high pressure

7. The following reaction is performed in an open vessel.

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

How the equilibrium will be affected if you increase the pressure?

(A) The forward reaction will be favoured
(B) The backward reaction will be favoured
(C) No effect on backward reaction
(D) No effect on forward or backward reaction

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(A) If the activation energy of the forward reaction is comparable to that of backward reaction
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(A) They will remain constant
(B) They will keep on increasing
(C) They will keep on decreasing
(D) They will remain constant for some time and then start decreasing

ANSWER KEY

1	A	**2**	D	**3**	A	**4**	C	**5**	C
6	C	**7**	B	**8**	A	**9**	B	10	A

QUESTIONS FOR SHORT ANSWER

2. Questions for Short Answers.

Q.1 How is dynamic equilibrium different from the static equilibrium?

Ans: **DIFFERENTIATION**

The differences between dynamic equilibrium and static equilibrium are as follows:

Dynamic Equilibrium	Static Equilibrium
Definition	
*"When reaction does not stop only the **rates of forward and reverse reaction** become equal to each other but take place in **opposite directions**. This is called dynamic equilibrium state."* ***Note: Dynamic means reaction is still continuing at dynamic equilibrium state.***	• *"When the system is at rest position, it is called static equilibrium. This happens mostly in physical phenomenon".*
Example:	
• $CaCO_3 \rightleftharpoons CaO+CO_2$ At equilibrium: **Rate of forward reaction = Rate of reverse reaction**	• A building remains standing rather than falling down because all the forces acting on it are balanced. This is an example of static equilibrium. •

Q.2 How the following reversible reaction will be affected if its temperature is increased?

$$2H_2O_{(l)} \rightleftharpoons 2H_{2(g)} + O_{2(}$$

Ans: **EFFECT OF TEMPERATURE INCREASE**

An increase in temperature will increase the rate of reaction in the above mentioned example because this is an endothermic reaction.

Q.3 How can you get the maximum yield in a reversible reaction?

Ans: **TO GET MAXIMUM YIELD IN REVERSIBLE REACTION**

We can get the maximum yield in a reversible reaction by:

- removing products continuously from the reaction mixture
- increasing temperature if the reaction is endothermic
- decreasing pressure if the number of moles of reactants is less than number of moles of products.

Q.4 How can you decrease the time to attain the position of equilibrium in a reversible reaction?

Ans: **TO DECREASE TIME TO ATTAIN EQUILIBRIUM**

We can decrease the time to attain the position of equilibrium in a reversible reaction by adding a catalyst to the reaction mixture. As the catalyst speeds up both the forward and reverse reactions equally thus equilibrium will be achieved earlier.

Q.5 What is the effect of increasing pressure on the following reaction?

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$$

Ans: **EFFECT OF INCREASING PRESSURE**

There will be no effect of increasing pressure on the given reaction because the number of moles of reactants is equal to the number of moles of products.

CONSTRUCTED RESPONSE QUESTIONS

3. Constructed Response Questions.

Q.1 Why are some reactions irreversible while others are reversible?

Ans: **IRREVERSIBLE AND REVERSIBLE REACTIONS**

Some of the reactions are irreversible because the products formed are sufficiently stable under the reaction conditions and are not converted back into the reactants while others are reversible because the products formed are unstable under the reaction conditions and are thus converted back into the reactants again.

Q.2 Why are combustion reactions generally irreversible?

Ans: **COMBUSTION REACTIONS AS IRREVERSIBLE**

Combustion reactions are generally irreversible because once the fuel is burnt due to reaction with oxygen to produce carbon dioxide, water and heat energy, it becomes quite difficult to use that energy to reverse the reaction and reform the oxygen and original fuel.

Q.3 Can you make an irreversible reaction reversible and vice versa?

Ans: **IRREVERSIBLE REACTION**

No, we cannot make an irreversible reaction reversible and vice versa because the reversible reaction can proceed in one direction only.

Q.4 How do you know if a reaction is reversible or irreversible?

Ans: **REVERSIBLE OR IRREVERSIBLE REACTION**

Irreversible Reaction

A reaction is irreversible chemical reactions if it can occur in only one direction. The reactants can change to the products, but the products cannot change back to the reactants.

Reversible Reaction

Reversible chemical reactions can occur in both directions. The reactants can change to the products, and the products can also change back to the reactants

Q.5 Do the phase changes in water (solid to liquid, liquid to vapour) reversible or irreversible?

Ans: **PHASE CHANGE IN WATER**

Phase changes in water (solid to liquid, liquid to vapor) are reversible. It means we can change the water back to its original state by altering the temperature conditions.

DESCRIPTIVE QUESTIONS

4. Descriptive Questions.

Q.1 How can you derive the reversible reaction at equilibrium?
(a) in the forward direction (b) in the backward direction

Ans: **DERIVATION OF REVERSIBLE REACTION**

(a) In the Forward direction

We can derive the reversible reaction in the forward direction by adding more reactant, withdrawing products, increasing or decreasing pressure accordingly or increasing or decreasing temperature etc. according to the reaction.

(b) In the Backward direction

We can derive the reversible reaction in the backward direction by removing reactant, adding products, increasing or decreasing pressure accordingly or increasing or decreasing temperature etc. according to the reaction.

Q.2 Explain how the forward and backward reactions change when the system approaches equilibrium.

Ans: **FORWARD AND BACKWARD REACTIONS AT EQUILIBRIUM**

When the system approaches equilibrium the rates of forward and backward reactions become equal. Since the forward and reverse rates are equal, the concentrations of the reactants and products are constant at equilibrium.

Q.3 Describe the effect of a catalyst on the reversible reaction.

Ans: **EFFECT OF CATALYST ON REVERSIBLE REACTION**

CATALYST

Definition

A catalyst is defined as a substance that increases the rate of a chemical reaction without itself undergoing any permanent chemical change.

Examples

- Ni acts as a catalyst in the hydrogenation of oil to give banaspati ghee
- Platinum acts as a catalyst in the production of H_2SO_4

Chlorine acts as a catalyst promoting the breakdown of ozone

Principle

A catalyst increases both the rates of forward and back reactions of a reversible reaction. So if a reversible reaction is carried out in the presence of a catalyst it will decrease the time taken by the reaction to attain the state of equilibrium.

Effect of Catalyst on rate of Reaction

An addition of the catalyst in a reaction increases the rate of reaction

Reason

It changes the path adopted by the reactants whereby the activation energy value of the reaction is substantially decreased. As a result, more reactants are now able to be converted into product molecules and hence the rate of reaction will increase Fig (5.6).

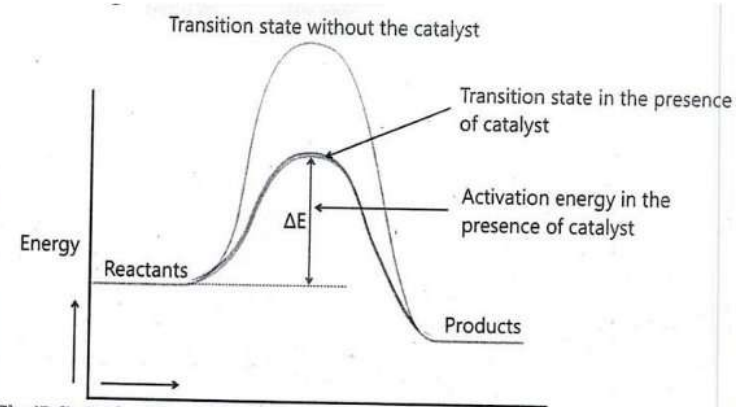

Fig (5.6) Path of Reaction in the absence and presence of a catalysist

Q.4 How can a reversible reaction be forced to go to completion?

Ans: **REVERSIBLE REACTION TO COMPLETE**

A reversible reaction be forced to go to completion by continuously removing one of the products from the reaction mixture. It will disrupt the equilibrium and forces the reaction to produce more products.

Q.5 How does change in temperature affect the reaction at equilibrium?

Ans: **EFFECT OF TEMPERATURE ON EQUILIBRIUM**

EFFECT OF CHANGING TEMPERATURE ON EQUILIBRIUM

Example (Formation of Ammonia)

The formation of ammonia is exothermic in the forward direction and hence this reaction will be endothermic in the reverse direction.

$$N_{2(g)} + 3H_{2(g)} \underset{\text{Heat}}{\rightleftharpoons} 2\,NH_{3(g)} \quad \Delta H = -92.4\ kJ/mole$$

Heat

If this reaction is at equilibrium and its temperature is increased, the state of the equilibrium will be disturbed again.

The ΔH

The ΔH of this reaction is negative. This means the total energy of the system containing N_2 and H_2 is higher than that of ammonia.

(c) Effect of increase in temperature

The increase in temperature of this reaction at equilibrium will push the reaction in the backward direction i.e. the reactants side.

(d) Effect of decrease in temperature

Decreasing the temperature wilt drive the equilibrium to the forward direction.

INVESTIGATIVE QUESTIONS

5. Investigative Questions.

Q.1 Study the effect of heat on hydrated $CuSO_4.5H_2O$. Why does this salt look coloured and why does it lose colour upon heating?

Ans: **EFFECT OF HEAT ON HYDRATED $CuSO_4.5H_2O$**

Hydrated copper sulfate, **$CuSO_4.5H_2O$** has 5 molecules of water as water of crystallization. It looks blue coloured due to the presence of water of crystallization. When it is heated it loses these water molecules and becomes anhydrous which is colorless.

Q.2 Synthesis of ammonia gas is very important industrially because it is used in the preparation of urea fertilizer. Explain the conditions you will use to get the maximum yield of ammonia.

Ans: Answer given on page #

TERMS TO KNOW

Terms	Definitions
Reversible reaction	Majority of chemical reactions are reversible reactions. Reactants react to give the products and the products, in turn, react or decompose to give back the reactants
Completion of reversible reaction	A reversible reaction never goes to completion. However, it may be forced to go to completion if one or all the products are withdrawn from the reaction mixture as soon as they are formed
Physical changes as reversible	Physical changes may also be reversible in nature.
State of chemical equilibrium	A reversible reaction will keep on going in both the directions until the rate of forward reaction becomes equal to the rate of reverse reaction. At this point the reaction is said to be at a state of chemical equilibrium.
Dynamic equilibrium	Since both the forward and reverse reactions keep on going at the state of chemical equilibrium, it is called a dynamic equilibrium. The concentrations of at the reacting species remain constant at equilibrium.
Time to attain dynamic equilibrium	The time a reaction takes to attain the state of dynamic equilibrium depends upon the nature of reaction and the conditions at which the reversible reaction is performed.
Disturbance in equilibrium state	A reversible chemical system may be disturbed either by adding or withdrawing the reactants or the products and by changing the conditions of temperature, pressure and catalyst.