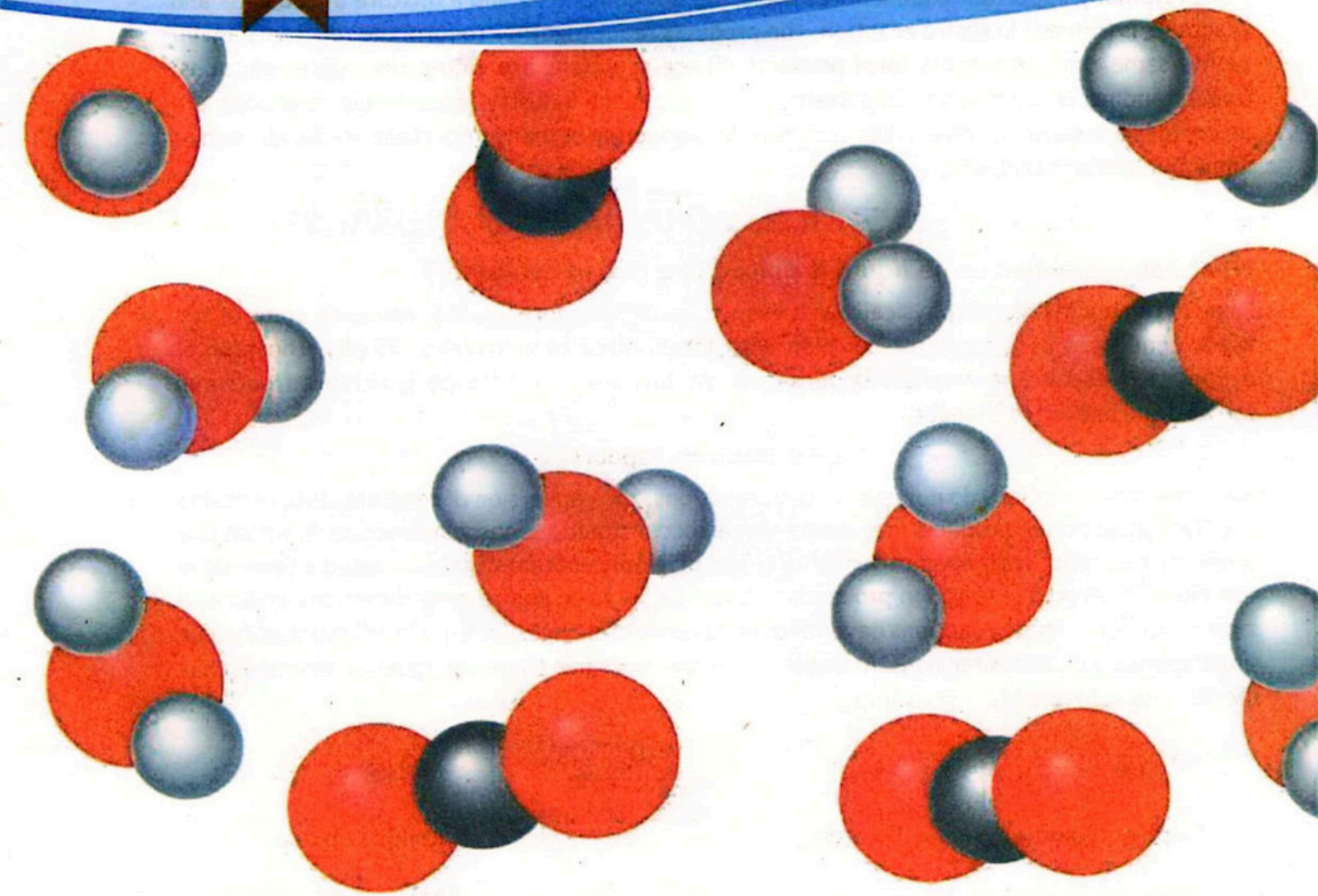
UNIT 09



CHEMICAL EQUILIBRIUM

Student Learning Outcomes (SLOs)

After completing this lesson, the student will be able to:

- Recognize that reversible reaction are shown by $\rightleftharpoons$ and may not go to completion.
- Describe how changing the physical conditions of a chemical equilibrium system can redirect reversible reactions (a) effect of heat on hydrated compounds (b) addition of water to anhydrous substances in particular copper (II) sulphate and cobalt (II) chloride.
- State that reversible reactions can achieve equilibrium in a closed system when rate of forward and backward reactions are equal

INTRODUCTION:

A complete reaction is a reaction in which all reactants have been converted to products. However, many important chemical reactions are not completed and a mixture of products and reactants is formed. In such a reaction, the products react together to form the reactants again. At the same time, reactants form products. These reactions are called reversible reactions. Understanding equilibrium is important in the chemical industry. Equilibrium reactions are involved in a number of steps in the commercial production of many important chemicals such as ammonia, sulfuric acid, etc.

9.1 REVERSIBLE REACTIONS AND DYNAMIC EQUILIBRIUM.

What happens when some liquid is placed in a closed container?

Some of the liquid changes physically as it evaporates. When more liquid evaporates, some of the vapor condenses as a result of collision with the surface of the liquid. Finally, the rate of evaporation equals the rate of condensation. At this stage, a balance is achieved between forward and backward changes.

$$\text{Liquid} \rightleftharpoons \text{Vapours}$$

Many chemical reactions do not end. In such reactions, the conversion of reactants into products and the conversion of products into reactants can occur simultaneously. **A reaction in which the products can react with each other to form the original reactants again is called a reversible reaction.** A reversible reaction proceeds in both the forward and reverse directions under the same conditions. These reactions never end. All reversible changes (physical and chemical) occur simultaneously in both directions. A double arrow $\rightleftharpoons$ in a chemical equation indicates that the reaction is reversible. For example:

$$2SO_{2(g)} + O_{2(g)} \underset{450^\circ C,\ 200\ atm}{\overset{V_2O_5}{\rightleftharpoons}} 2SO_{3(g)}$$

Sulphur dioxide — Oxygen — Sulphur trioxide

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

Nitrogen — Hydrogen — Ammonia

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

Nitrogen — Oxygen — Nitrogen dioxide

Consider what happens when SO_2 and O_2 gases are mixed in a sealed container (Figure 9.1)

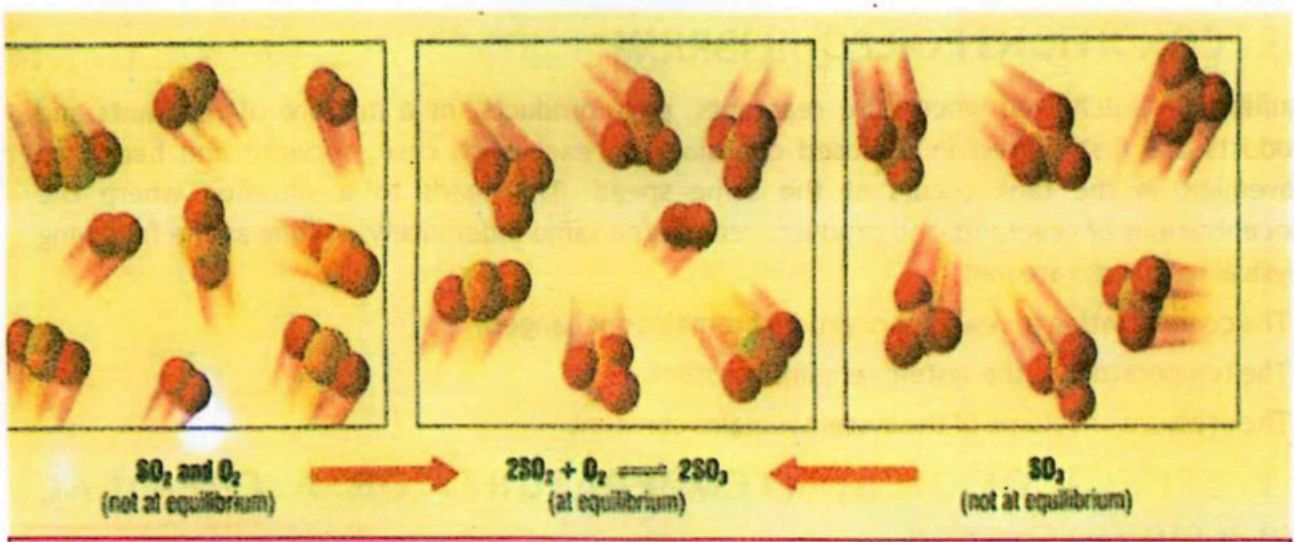


Figure 9.1: Reaction between SO_2 and O_2

So_2 and O_2 molecules react to form SO_3. SO_3 molecules break to give SO_2 and O_2. What types of molecules are in equilibrium? In the first reaction (from left to right), SO_2 and O_2 produce SO_3. In the second reaction (from right to left), SO_3 decomposes into SO_2 and O_2. Which reaction is called a forward reaction? Which reaction is called the reverse reaction? In the beginning, there is no SO_3. So the rate of the reverse reaction is zero. Due to the high concentration of the reactants, the speed of the forward reaction is the highest. As the reaction progresses, the concentration of the reactants gradually decreases and the speed of the forward reaction decreases accordingly. (figure)

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

As the concentration of SO_3 increases, a small amount of SO_3 slowly decomposes into SO_2 and O_2. This means that the reverse reaction has started. In this reaction, SO_3 acts as a reactant and produces SO_2 and O_2. That is, the opposite reaction

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

As the concentration of SO_3 increases, the reverse reaction accelerates. In the end, the two rates are equal. At this point, SO_3 decomposes into SO_2 and O_2 as fast as SO_2 and O_2 produce SO_3. At this point, the reaction has reached equilibrium. (Figure 9.1) **The state of a chemical reaction where the forward and reverse reactions occur at the same rate is called chemical equilibrium.** Chemical equilibrium is dynamic equilibrium. This is because reactions do not stop when they reach equilibrium. Individual molecules are constantly reacting. However, the actual quantities of reactants and products do not change. This means that the concentration of reactants and products becomes constant in the equilibrium state.

Science Titbits

When fizzy drinks are made, CO_2 is dissolved in the liquid drink under pressure and sealed. When you remove lid of the bottle, bubbles CO_2 of suddenly appear. When you put the lid back on the bottle, the bubbles stop. This is due to the following equilibrium.

$$CO_{2(g)} \rightleftharpoons CO_{2(aq)}$$

The forward reaction happens during manufacturing and the reverse reaction happens on opening

9.2 CONDITIONS FOR EQUILIBRIUM

Equilibrium is achieved when pure reactants, pure products, or a mixture of reactants and products are first placed in a closed container. In each such case, forward and backward movement in the tank occurs at the same speed. This leads to a situation where the concentrations of reactants and products remain the same indefinitely, as long as the following physical conditions are met:

1. The concentration of reactant or product remains unchanged.
2. The temperature of the system remains constant.
3. The pressure or volume of the system remains constant.

9.3 EFFECT OF HEAT (TEMPERATURE) ON A CHEMICAL EQUILIBRIUM SYSTEM

Activity:

Materials required Test tube, dropper, heating system, hydrated copper(ll)sulphate.

Procedure:

- Place 5 g of hydrated copper(ll) sulphate in a test tube. and heat slowly.
- Observe the colour change from blue to white.
- Allow the test tube and its contents to cool to room temperature.
- Add a few drops of water to the test tube using a dropper.
- Observe the colour change from white to blue again. When copper (II) sulphate is heated, the water in it is removed, forming anhydrous copper (II) sulphate, which is a white solid. This copper (II) sulphate changes back to the hydrated form on adding water.

NOTE:

Note: Copper sulphate is a harmful and toxic compound, so handle it with care. Wear safety glasses and gloves. Do this task in the presence of your teacher.

$$CuSO_4.5H_2O\ (\text{blue solid}) \rightleftharpoons CuSO_4(\text{white solid}) + 5H_2O$$

Likewise

Hydrated cobalt(II) chloride is a pink solid. When heated, it loses water and becomes anhydrous cobalt(II) chloride, a blue solid. So the equilibrium shifts towards right. But when water is added to it, it absorbs water and the equilibrium shifts to the left to form hydrated cobalt(II) chloride again

$$CoCl_2.6H_2O(\text{pink solid}) \rightleftharpoons CoCl_2(\text{blue solid}) + 6H_2O$$

KEY POINTS

- A reaction in which the products can react together to re-form the original reactants is called reversible reaction.
- A reversible reaction is shown by symbol .
- Anhydrous copper(ll)sulphate is a white solid.
- Hydrated copper(ll)sulphate is a blue solid.
- Anhydrous cobalt(ll)chloride is a blue solid.
- Hydrated cobalt(ll)chloride is a pink solid.
- A state of a chemical reaction in which forward and reverse reactions take place at the same rate is called chemical equilibrium.

References for additional information

- Chemistry, Roger Norris, Lawrie Ryen and David Acaster.
- Principals of chemical equilibrium, Kenneth Denbigh.

REVIEW QUESTIONS

1. Encircle the correct answer.

(i) Which is true about the equilibrium state?

(a) The forward reaction stops.

(b) The reverse reaction stops.

(c) Both forward and reverse reactions stop.

(d) Both forward and reverse reactions continue at the same rate.

(ii) When a mixture of and is sealed in a flask and temperature is kept at 25°C, following equilibrium is established.

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

Which substance or substances will be present in the equilibrium mixture?

(a) H_2 and I_2

(b) HI only

(c) H_2 only

(d) H_2 , I_2 and HI

(iii) Concentration of reactants and products at equilibrium remains unchanged if

(a) concentration of any reactant or product is not changed.

(b) temperature of the reaction is not changed.

(c) pressure or volume of the system is not changed.

(d) all of the above are observed

(iv) Which of the following does not happen, when a system is at equilibrium state?

(a) forward and reverse reactions stop.

(b) forward and reverse rates become equal.

(c) concentration of reactants and products stop changing.

(d) reaction continues to occur in both the directions.

(v) In an irreversible reaction equilibrium is

(a) established quickly

(b) established slowly

(c) never established

(d) established when reaction stops.

2. Give short answer.

(i) Differentiate between forward and reverse reactions.

(ii) What is chemical equilibrium?

(iii) Write two chemical equations of reversible reactions.

(iv) Write down the conditions for equilibrium.

3. Coal reacts with hot steam to form CO and H_2. These substances react further in the presence of a catalyst to give methane and water vapour.

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

Write forward and reverse reactions for it.

4. How does temperature affect cobalt chloride equilibrium?

THINK TANK

1. **Bromine chloride (BrCl) decomposes to form chlorine and bromine. Write reversible chemical reaction for this reaction.**