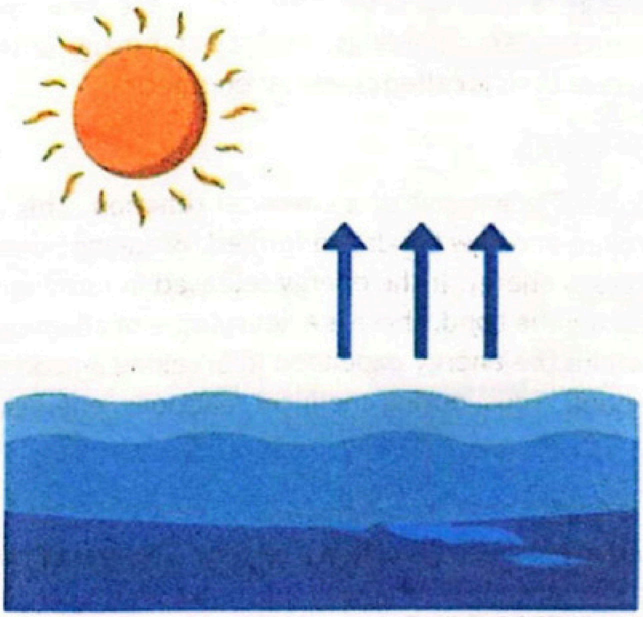
UNIT 08



ENERGETICS

Student Learning Outcomes (SLOs)

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

- Explain the idea of a chemical system and its connections with its surroundings influences energy transfer during a chemical reaction.
- Differentiate between exothermic and endothermic reactions giving examples.
- State that thermal energy is called enthalpy change and recognize its sign as negative for exothermic and positive for endothermic reactions.
- Define activation energy as minimum energy that colliding molecules must have for a successful collision.
- Explain that activation energy depends on reaction pathway which can be changed using catalyst or enzyme (detailed pathways not required).
- Draw, label and interpret reaction pathway diagram for exothermic and endothermic reaction which includes enthalpy change, activation energy (uncatalyzed and catalyzed), reactants and products.
- Recognize that bond breaking is endothermic and bond making is exothermic processes.
- Explain that enthalpy change is sum of energies absorbed and released in bond breaking and bond forming.
- Calculate enthalpy change of a reaction from given bond energy values.
- Explain how respiration(aerobic and anaerobic), an exothermic process, provides energy for biological systems and lipids as reserve stores of energy.

Introduction

Every process in this universe, whether it is in living cells, test tubes, atmosphere or water, etc., involves a change in energy. Some processes release energy, others require energy. Many chemical reactions produce huge amounts of energy, which is used to produce new raw materials such as iron, steel, copper, aluminum, etc. Energy is also used to transform these new raw materials into useful products such as trains, trucks, cars, buildings, bridges and many other objects. The study of energy changes in chemical reactions is called chemical energetics.

8.1 ENERGY IN CHEMICAL REACTIONS

Energy in the form of heat is developed or absorbed as a result of a chemical reaction. This is because in a chemical reaction old bonds are broken and new bonds are formed. Breaking bonds always consumes energy and binding always releases energy. If the energy released in forming a bond is greater than the energy expended in breaking the bond, there is a net release of chemical energy. On the other hand, energy is absorbed when the energy expended in breaking a bond is greater than the energy released in forming the bond. Thus, during chemical reactions, energy is exchanged with the surroundings.

8.1.1 System and Surroundings

The part of the universe that we want to focus our attention on is called a system. The rest of the universe is called the environment. In chemistry, a system is usually a substance that changes physically or chemically. For example, when studying the reaction of limestone and hydrochloric acid solution in a test tube, limestone and hydrochloric acid solution form a system. The test tube and everything around the test tube is the environment. Similarly, when studying the thermal decomposition of a compound, the sample of the compound would be the system. While the beaker, heat source, and everything else would be the environment.

8.2 THERMOCHEMICAL REACTIONS

When a chemical change takes place, energy is exchanged between system and its surroundings. Energy has many forms such as heat, light, work etc. A chemical reaction which proceeds with the evolution or absorption of heat is called a thermochemical reaction. **A balanced chemical equation which also shows heat change of a chemical reaction is called thermochemical equation. The branch of chemistry which deals with the heat or thermal energy changes in chemical reactions is called thermochemistry.**

For example

$$C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)} \qquad \Delta H^\circ = -393.5kJ$$

There are two types of thermochemical reactions.

8.2.1 Exothermic Reactions

A chemical reaction that proceeds with the evolution of heat is called an exothermic reaction. In an exothermic reaction the chemical system transfers energy to the surroundings as the reactants are converted to products e.g. burning of fuels is a highly exothermic reaction. The energy released can be used to heat a room, or to drive an engine or to cook food. Examples of exothermic reactions are given below:

(i) $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$ $\Delta H^\circ = -393.5kJ$

(ii) $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(g)}$ $\Delta H^\circ = -571.6kJ$

(iii) $C_{(s)} + \frac{1}{2} O_{2(g)} \longrightarrow CO_{(g)}$ $\Delta H^\circ = -110.5kJ$

8.2.2 Endothermic Reactions:

A chemical reaction that proceeds with the absorption of heat is called an endothermic reaction. In these reactions heat is transferred from surrounding to the system. Examples of endothermic reactions are given below:

(i) $H_{2(g)} + I_{2(g)} \longrightarrow 2HI_{(g)}$ $\Delta H^\circ = +53.8kJ$

(ii) $C_{(s)} + H_2O_{(g)} \longrightarrow CO_{(g)} + H_{2(g)}$ $\Delta H^\circ = +131.4kJ$

(iii) $N_{2(g)} + O_{2(g)} \longrightarrow 2NO_{(g)}$ $\Delta H^\circ = +180.5kJ$

CONCEPT ASSESSMENT EXERCISE 8.1

Classify the following processes as exothermic or endothermic.

(a) Freezing of water
(b) Combustion of methane
(c) Sublimation of dry ice
(d) $H_2O_{(g)} \longrightarrow H_2O_{(l)}$
(e) decomposition of limestone.

8.3 ENTHALPY OF REACTION

The amount of heat or thermal energy evolved or absorbed in a chemical reaction is called enthalpy of reaction. Its sign is negative for exothermic and positive for endothermic reactions.

Enthalpy of reaction measured at 25°C (or 298K) and one atmospheric pressure is known as standard enthalpy change. It is denoted by ΔH°.

(i) $C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$ $\Delta H^\circ = -393.5k\ J$

(ii) $H_{2(g)} + I_{2(g)} \longrightarrow 2HI_{(g)}$ $\Delta H^\circ = +53.8kJ$

Which of the above reaction is endothermic?

8.4 BOND ENERGY AND BOND DISSOCIATION ENERGY

When a chemical reaction occurs, old bonds are broken and new bonds are formed. Breaking bonds always requires energy, and forming a bond always releases energy. The amount of energy required to break one mole of a particular bond to form neutral atoms is called the bond dissociation energy. In contrast, the amount of energy released when neutral atoms form one mole of a bond is called bond energy. The difference between the bond dissociation energy and the bond energy determines whether the reaction absorbs or releases energy.

The enthalpy change in a chemical reaction is the sum of energies absorbed and released in bond breaking and bond forming.

ΔH° = Sum of bond dissociation energies of reactants — Sum of bond energies of products

Example 8.1: Calculate the enthalpy of the reaction between hydrogen and iodine to form hydrogen iodide from the given bond energy data. Bond energy of H—H, I—I, H—I bonds are 436kJ/mol, 151kJ/mol and 299kJ/mol respectively

Problem solving strategy:

1. Write the balanced chemical equation.
2. Show all the reactant and the products in the gaseous state.
3. Substitute the relevant bond energy values in the formula and solve.

ΔH° = Sum of bond dissociation energies of reactants — Sum of bond energies of products

Solution:

$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$ $\Delta H^\circ = ?$

$$\Delta H^\circ = [\text{B.E of H—H} + \text{B.E. of I—I}] - [2 \times \text{B.E of H—I}]$$
$$= [436 + 151] - [2 \times 299]$$
$$= 587 - 598$$
$$= -11 \text{ kJ/mol}$$

Note that the enthalpy of reaction calculated using bond energy data are often different from values determined experimentally.

CONCEPT ASSESSMENT EXERCISE 8.2

Example: Calculate the enthalpy of the following reaction from the given bond energy data. Bond energy of H—H, F—F, H—F bonds are 436kJ/mol, 155kJ/mol and 567kJ/mol respectively.

8.5 ACTIVATION ENERGY

Chemical reactions involve the breaking and forming of chemical bonds. These changes are accompanied by changes in energies. Collision theory was proposed to explain the observed reaction kinetics. For a chemical reaction to occur, the bonding atoms or molecules must collide with each other. These collisions can be effective or ineffective depending on the energy and direction of the colliding particles. An effective collision can only occur if the energy of the colliding particles is high enough to overcome the repulsion between the electrons around the reacting particles. The correct orientation means that at the moment of collision, the atoms needed to form new bonds must collide with each other. The minimum amount of energy that, in addition to the average kinetic energy, particles must have an effective collisions is called the activation energy. No reaction occurs if the energy of the reacting particles is lower than the activation energy. Thus, the speed of a reaction depends on

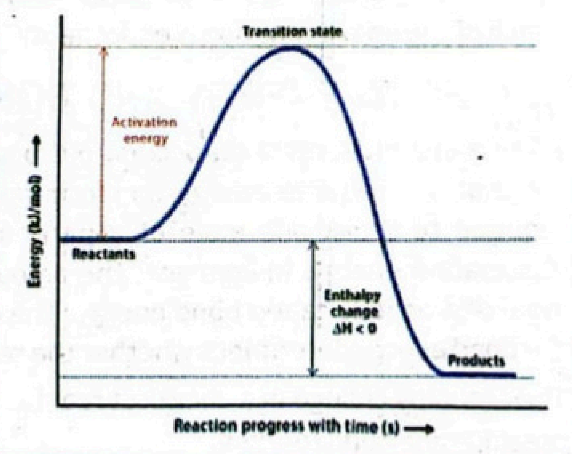
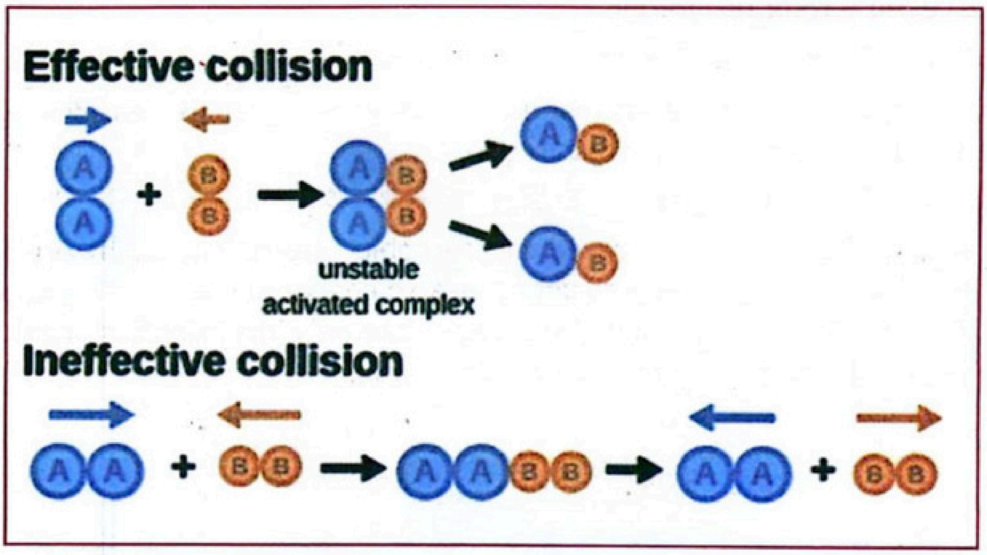


Figure 8.1: Activation energy

its activation energy. The higher the activation energy, the lower the reaction rate. For example, the reaction between A_2 and B_2 molecules.



8.6 CATALYST

Many industrial reactions are carried out at high temperatures over a period of time to maximize the amount of product that can be synthesized. High temperature reactions cause safety problems and many chemicals are not stable at high temperatures. So it would be useful to use another method to increase the speed of chemical reactions. Another way to increase the reaction rate is to change this mechanism in a way that lowers the activation energy. This can be done by adding a catalyst. **A substance that accelerates a chemical reaction, but remains chemically unchanged at the end of the reaction, is called a catalyst,** and the phenomenon is called catalysis. The catalyst provides a new mechanism for the reaction with low activation energy (Figure 8.3). Thus, a catalyst increases the rate of a reaction by lowering its activation energy. The catalyst does not affect the overall thermodynamics or enthalpy of the reaction.

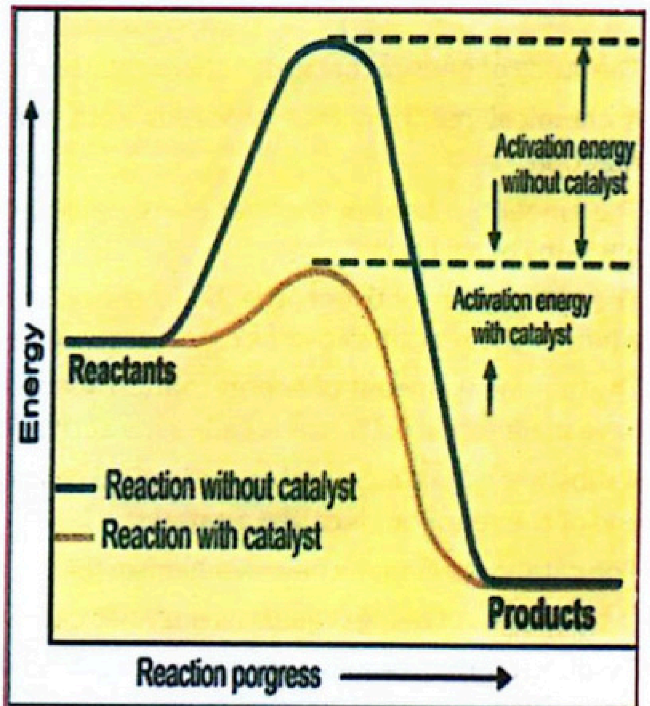


Figure 8.3: Effect of Catalyst on energy of activation

In the bodies of living organisms enzymes catalyze chemical reactions.

8.7 RESPIRATION

Where do we get energy for our body? Respiration is a biochemical process in which energy is released from food in a biological system. During this process, glucose is oxidized in the body of living organisms and energy is released. Therefore, respiration is an exothermic reaction. There are two types of respiration processes.

1. Aerobic respiration: Respiration that requires oxygen to break down glucose to release energy is called aerobic respiration.

   Glucose + Oxygen → Carbon dioxide + water + Energy

2. Anaerobic respiration: Respiration that does not require oxygen to break down glucose to release energy is called anaerobic respiration.

   Glucose → Lactic acid + Energy

Aerobic respiration releases more energy than anaerobic respiration. Lipids are important substances for building our body. They also act as reserve energy sources. Lipids can store very large amounts of energy in our body. When you exercise intensely, the oxidation of glucose is not enough for energy. At this stage, lipids are oxidized for energy.

KEY POINTS

- The study of energy changes in chemical reactions is called chemical energetics.
- A chemical reaction that proceeds with the evolution of heat is called an exothermic reaction.
- The amount of heat or thermal energy evolved or absorbed in a chemical reaction is called enthalpy of reaction.
- The difference between the bond dissociation energy and the bond energy determines whether the reaction absorbs or releases energy.
- The minimum amount of energy that, in addition to the average kinetic energy, particles must have in effective collisions is called the activation energy.
- A substance that accelerates a chemical reaction, but remains chemically unchanged at the end of the reaction, is called a catalyst.
- The catalyst provides a new mechanism for the reaction with low activation energy.
- In the bodies of living organisms enzymes catalyze chemical reactions.
- Respiration that requires oxygen to break down glucose to release energy is called aerobic respiration.
- Respiration that does not require oxygen to break down glucose to release energy is called anaerobic respiration.
- Lipids acts as reserve energy sources.

References for additional information

- Zumdahl, Introductory Chemistry.
- Raymond Chang, Essential Chemistry.

REVIEW QUESTIONS

1. **Encircle the correct answer.**

(i) If the ΔH value is negative than reaction will be

(a) Exothermic (b) Endothermic

(c) May or may not be Exothermic or Endothermic

(d) None of these

(ii) All chemical reactions involve

(a) Catalysts (b) Enzymes

(c) Energy changes (d) All of these

(iii) Which is not released in an aerobic respiration?

(a) Carbon dioxide (b) Water

(c) Energy (d) Lactic acid

(iv) A catalyst increases the rate of a chemical reaction by

(a) increasing activation energy

(b) increasing the enthalpy of reaction

(c) Decreasing the enthalpy of reaction

(d) None of these

(v) Activation energy of a chemical reaction must be _________ the average kinetic energy of reacting molecules

(a) Lower than (b) greater than

(c) equal to (d) None of these

2. **Give short answer.**

(i) Define exothermic and endothermic reactions.

(ii) Define enthalpy of a chemical reaction.

(iii) What is anaerobic respiration?

(iv) Define activation energy.

(v) What is the role of a catalyst in a chemical reaction.

(vi) Differentiate between aerobic and anaerobic respiration.

3. How can you determine the enthalpy of a chemical reaction?

4. Explain, how does the process of respiration provides us energy?

5. Draw labeled reaction pathway diagram for an exothermic and an endothermic reaction.

6. Calculate the enthalpy of reaction between hydrogen and chlorine to form hydrogen chloride from the given bond energy data. Bond energy of H-H, Cl-Cl, H-Cl are 436kJ/mol, 243kJ/mol and 432kJ/mol respectively.

7. Justify the statement that the process of respiration is crucial for us.

PROJECT

Create a chart showing pathway diagram for exothermic and endothermic reactions, which includes enthalpy change, activation energy (catalyzed and uncatalyzed), reactants and products.