Chemical Reactions and Energy

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CONCEPT 1 Chemical Reactions and Energy

Lesson Objectives

- Describe endothermic reactions.
- Describe exothermic reactions.
- Relate the law of conservation of energy to chemical reactions.
- Define activation energy.
- Identify factors that affect the rates of chemical reactions.

Lesson Vocabulary

- activation energy
- catalyst
- concentration
- endothermic reaction
- exothermic reaction
- law of conservation of energy
- reaction rate

Introduction

All chemical reactions involve energy. Energy is needed to break bonds in reactants. These bonds may be very strong. Energy is released when new bonds form in the products. That's because the atoms now have a more stable arrangement of electrons. Which energy is greater: that needed for breaking bonds in reactants or that released by bonds forming in products? It depends on the type of reaction. When it comes to energy, chemical reactions may be endothermic or exothermic.

Endothermic Reactions

In an **endothermic reaction**, it takes more energy to break bonds in the reactants than is released when new bonds form in the products. The word "endothermic" literally means "taking in heat." A constant input of energy, often in the form of heat, is needed in an endothermic reaction. Not enough energy is released when products form to break more bonds in the reactants. Additional energy is needed to keep the reaction going. The general equation for an endothermic reaction is:

$$\text{Reactants} + \text{Energy} \rightarrow \text{Products}$$

In many endothermic reactions, heat is absorbed from the surroundings. As a result, the temperature drops. The drop in temperature may be great enough to cause liquid products to freeze. That's what happens in the endothermic reaction at this URL: http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/chemreac/energychangesrev1.shtml.

One of the most important endothermic reactions is photosynthesis. In this reaction, plants synthesize glucose ($C_6H_{12}O_6$) from carbon dioxide (CO_2) and water (H_2O). They also release oxygen (O_2). The energy for photosynthesis comes from light (see **Figure** 1.1). Without light energy, photosynthesis cannot occur. The chemical equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

FIGURE 1.1

Plants can get the energy they need for photosynthesis from either sunlight or artificial light.

Exothermic Reactions

In an **exothermic reaction**, it takes less energy to break bonds in the reactants than is released when new bonds form in the products. The word "exothermic" literally means "turning out heat." Energy, often in the form of heat, is released as an exothermic reaction occurs. The general equation for an exothermic reaction is:

$$\text{Reactants} \rightarrow \text{Products} + \text{Energy}$$

If the energy is released as heat, an exothermic reaction results in a rise in temperature. That's what happens in the exothermic reaction at the URL below.

http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/chemreac/energychangesrev1.shtml

Combustion reactions are examples of exothermic reactions. When substances burn, they usually give off energy as heat and light. Look at the big bonfire in **Figure** 1.2. You can see the light energy it is giving off. If you were standing near the fire, you would also feel its heat.

Conservation of Energy

Whether a reaction absorbs energy or releases energy, there is no overall change in the amount of energy. Energy cannot be created or destroyed. This is the **law of conservation of energy**. Energy can change form — for example, from electricity to light — but the same amount of energy always remains.

FIGURE 1.2
The combustion of wood is an exothermic reaction that releases energy as heat and light.

If energy cannot be destroyed, what happens to the energy that is absorbed in an endothermic reaction? The energy is stored in the chemical bonds of the products. This form of energy is called chemical energy. In an endothermic reaction, the products have more stored chemical energy than the reactants. In an exothermic reaction, the opposite is true. The products have less stored chemical energy than the reactants. The excess energy in the reactants is released to the surroundings when the reaction occurs. The graphs in **Figure** 1.3 show the chemical energy of reactants and products in each type of reaction.

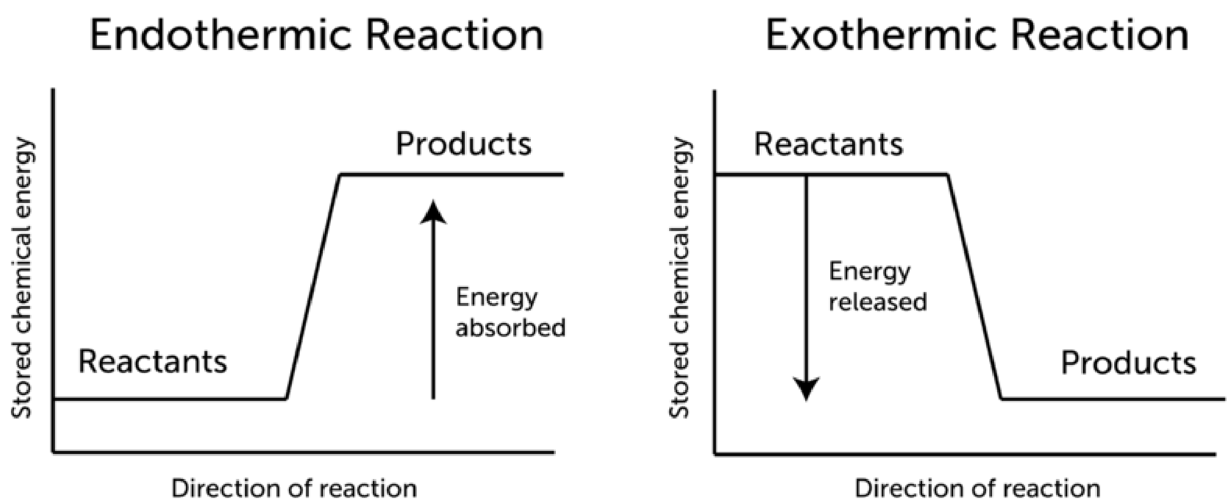

FIGURE 1.3
These graphs compare the energy changes in endothermic and exothermic reactions. What happens to the energy that is absorbed in an endothermic reaction?

Activation Energy

All chemical reactions, even exothermic reactions, need a certain amount of energy to get started. This energy is called **activation energy**. For example, activation energy is needed to start a car. Turning the key causes a spark that activates the burning of gasoline in the engine. The combustion of gas won't occur without the spark of energy to begin the reaction.

Why is activation energy needed? A reaction won't occur unless atoms or molecules of reactants come together.

This happens only if the particles are moving, and movement takes energy. Often, reactants have to overcome forces that push them apart. This takes energy as well. Still more energy is needed to start breaking bonds in reactants. The graphs in **Figure** 1.4 show the changes in energy in endothermic and exothermic reactions. Both reactions need the same amount of activation energy in order to begin.

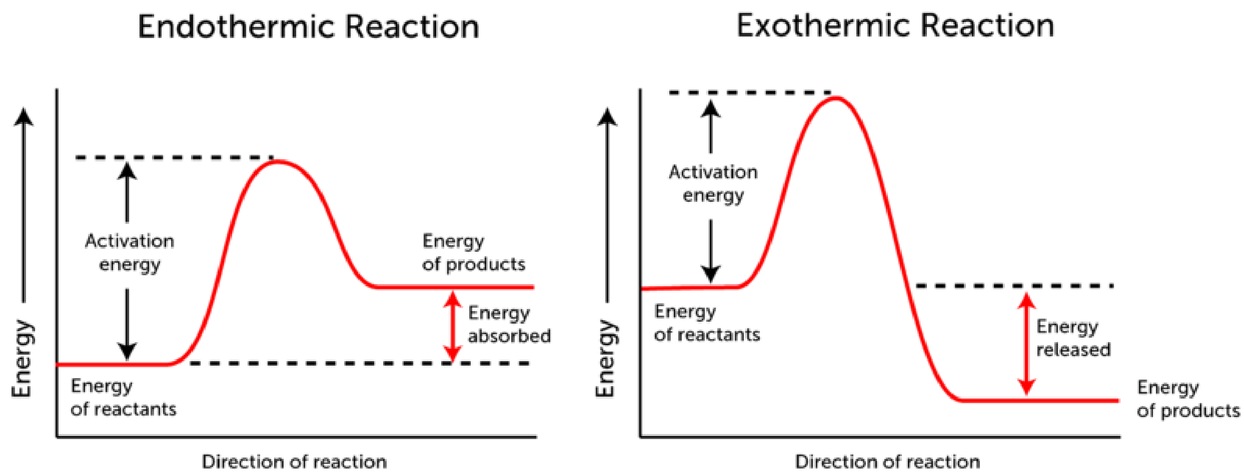

FIGURE 1.4

Even exothermic reactions need activation energy to get started.

You have probably used activation energy to start a chemical reaction. For example, if you've ever used a match to light a campfire, then you provided the activation energy needed to start a combustion reaction. Combustion is exothermic. Once a fire starts to burn, it releases enough energy to activate the next reaction, and the next, and so on. However, wood will not burst into flames on its own.

Reaction Rate

Any factor that helps reactants come together so they can react lowers the amount of activation energy needed to start the reaction. If the activation energy is lowered, more reactant particles can react, and the reaction occurs more quickly. How fast a reaction occurs is called the **reaction rate**. Factors that affect the reaction rate include:

- temperature of reactants
- concentration of reactants
- surface area of reactants
- presence of catalysts

Temperature of Reactants

When the temperature of reactants is higher, the rate of the reaction is faster. At higher temperatures, particles of reactants have more energy, so they move faster. They are more likely to bump into one another and to collide with greater force. For example, when you fry an egg, turning up the heat causes the egg to cook faster. The same principle explains why storing food in a cold refrigerator reduces the rate at which food spoils (see **Figure** 1.5). Both food frying and food spoiling are chemical reactions that happen faster at higher temperatures.

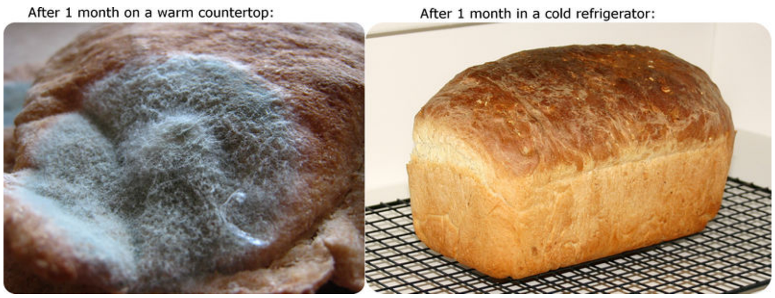

FIGURE 1.5
The chemical reactions that spoil food occur faster at higher temperatures.

Concentration of Reactants

Concentration is the number of particles of a substance in a given volume. When the concentration of reactants is higher, the reaction rate is faster. At higher concentrations, particles of reactants are crowded closer together, so they are more likely to collide and react. Did you ever see a sign like the one in **Figure** 1.6? You might see it where someone is using a tank of pure oxygen for a breathing problem. The greater concentration of oxygen in the air makes combustion rapid if a fire starts burning.

FIGURE 1.6
It's dangerous to smoke or use open flames when oxygen is in use. Can you explain why?

Surface Area of Reactants

When a solid substance is involved in a chemical reaction, only the matter at the surface of the solid is exposed to other reactants. If a solid has more surface area, more of it is exposed and able to react. Therefore, increasing the surface area of solid reactants increases the reaction rate. For example, crushing a solid into a powder exposes more of the substance to other reactants. This may greatly speed up the reaction. You can see another example in **Figure** 1.7. Iron rusts when it combines with oxygen in the air. The iron hammer head and iron nails will both rust eventually. Which will rust faster?

FIGURE 1.7
The nails have more surface area exposed to the air than the head of the hammer. How does this affect the rate at which they rust?

Presence of a Catalyst

Some reactions need extra help to occur quickly. They need another substance, called a catalyst. A **catalyst** is a substance that increases the rate of a chemical reaction but is not changed or used up in the reaction. The catalyst can go on to catalyze many more reactions.

Catalysts are not reactants, but they help reactants come together so they can react. You can see one way this happens in the animation at the URL below. By helping reactants come together, a catalyst decreases the activation energy needed to start a chemical reaction. This speeds up the reaction.

http://www.saskschools.ca/curr_content/chem30/modules/module4/lesson5/explainingcatalysts.htm

Living things depend on catalysts to speed up many chemical reactions inside their cells. Catalysts in living things are called enzymes. Enzymes may be extremely effective. A reaction that takes a split second to occur with an enzyme might take billions of years without it!

Lesson Summary

- In an endothermic reaction, it takes more energy to beak bonds in the reactants than is released when new bonds form in the products. Therefore, an endothermic reaction needs a constant input of energy to keep going.
- In an exothermic reaction, it takes less energy to break bonds in the reactants than is released when new bonds form in the products. Therefore, an exothermic reaction releases enough energy to keep going.
- In any chemical reaction, there is no overall change in the amount of energy. Energy cannot be created or destroyed. This is the law of conservation of energy.
- All chemical reactions, even exothermic reactions, need activation energy to get started. Activation energy is needed to bring reactants together so they can react.
- How fast a reaction occurs is called the reaction rate. Factors that affect the reaction rate include catalysts and the temperature, concentration, and surface area of reactants. A catalyst is a substance that increases the rate of a chemical reaction but is not changed or used up in the reaction.

Lesson Review Questions

Recall

1. What form of energy is needed for the endothermic reaction called photosynthesis?
2. What evidence shows that combustion reactions are exothermic?

3. What happens to the energy that is absorbed in an endothermic reaction?
4. In an exothermic reaction, which has more stored chemical energy: the reactants or the products?
5. Define activation energy.
6. List four factors that affect the rates of chemical reactions.

Apply Concepts

7. Suppose you put a whole antacid tablet in one glass of water and a crushed antacid tablet in another glass containing the same amount of water. Both tablets would start reacting and producing bubbles of gas. Use lesson concepts to predict which tablet would stop producing bubbles first. Explain your prediction. Then, with the permission of an adult, do the activity. Do your results agree with your prediction?
8. Sketch a simple graph to show how energy changes in an exothermic reaction. Include activation energy in your graph.

Think Critically

9. Compare and contrast endothermic and exothermic chemical reactions.

Points to Consider

You read in this chapter that most fuels contain carbon. In the next chapter, "Chemistry of Carbon," you will learn much more about carbon.

- What do you already know about carbon?
- Based on carbon's position in the periodic table, predict how it reacts and the type of bonds it forms.

References

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