Chapter 3: The Chemical Basis for Life
Lesson 3.3: Enzyme Regulation of Biochemical Reactions

What is a biological catalyst? This super-fast train can obviously reach great speeds. There's a lot of technology that helps this train go fast. Speaking of helping things go fast brings us to enzymes. Life could not exist without enzymes. Essentially, enzymes are biological catalysts that speed up biochemical reactions.

Lesson Objectives
- Describe what happens in chemical reactions.
- State the role of energy in chemical reactions.
- Explain the importance of enzymes to living organisms.
- Explain how enzymes regulate biochemical reactions within a cell.
- Describe the role of an enzyme as a catalyst in regulating a specific biochemical reaction.
- Explain how factors such as pH, temperature, and concentration levels can affect enzyme function.

Vocabulary
- activation energy
- biochemical reaction
- endothermic reaction
- enzyme
- exothermic reaction
- product
- reactant

INTRODUCTION
A general understanding of chemistry is necessary to understand biology. Essentially, our cells are just thousands of chemicals — made of elements like carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur — in just the right combinations. And these chemicals combine through chemical reactions. Energy is stored and released from these chemicals by cells through metabolic processes.

Hummingbirds, with their tiny bodies and high levels of activity, have the highest metabolic rates of any animals — roughly a dozen times that of a pigeon and a hundred times that of an elephant. The metabolic rate, or rate of metabolism, has to do with the amount of energy the organism uses to do work and to drive the chemical reactions in cells — or the biochemical reactions. And, of course, it is all the biochemical reactions that allow the cells to function properly, and maintain life.

So just how does the energy become available to do biological work. It comes from chemical reactions but chemical reactions need energy to get started. Some of the energy they need comes from
enzymes. Enzymes are magical proteins necessary for life. So how do enzymes work? How do they catalyze just one specific biochemical reaction? In a puzzle, only two pieces will fit together properly. Understanding that is one of the main steps in understanding how enzymes work.

**WHAT ARE CHEMICAL REACTIONS?**

The element chlorine (Cl) is a greenish poison. Would you eat chlorine? Of course not, but you often eat a compound containing chlorine. In fact, you probably eat this chlorine compound just about every day. Do you know what it is? It’s table salt. Table salt is sodium chloride (NaCl), which forms when chlorine and sodium (Na) combine in certain proportions. How does chlorine, a toxic green chemical, change into harmless white table salt? It happens in a chemical reaction.

A chemical reaction is a process that changes some chemical substances into others. A substance that starts a chemical reaction is called a reactant, and a substance that forms as a result of a chemical reaction is called a product. During a chemical reaction, the reactants are used up to create the products.

Another example of a chemical reaction is the burning of methane, which is shown in Figure 3.32. In this chemical reaction, the reactants are methane (CH₄) and oxygen (O₂), and the products are carbon dioxide (CO₂) and water (H₂O). A chemical reaction involves the breaking and forming of chemical bonds. When methane burns, bonds break in the methane and oxygen molecules, and new bonds form in the molecules of carbon dioxide and water.

![Figure 3.32](image)

**Chemical Equations**

A chemical reaction can be represented by a chemical equation. For example, the burning of methane can be represented by the chemical equation:

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

The arrow in a chemical equation separates the reactants from the products and shows the direction in which the reaction proceeds. If the reaction could occur in the opposite direction as well, two arrows pointing in opposite directions would be used. The number 2 in front of O₂ and H₂O shows that two oxygen molecules and two water molecules are involved in the reaction. (With no number in front of a chemical symbol, just one molecule is involved.)

**Conservation of Matter**

In a chemical reaction, the quantity of each element does not change; there is the same amount of each element in the products as there was in the reactants. This is because matter is always conserved. The conservation of matter is reflected in a reaction’s chemical equation. The same number of atoms of each element appears on each side of the arrow. For example, in the chemical equation above, there are four hydrogen atoms on each side of the arrow. Can you find all four of them on each side of this equation?
CHEMICAL REACTIONS AND ENERGY

Chemical reactions always involve energy. Energy is a property of matter that is defined as the ability to do work. When methane burns, for example, it releases energy in the form of heat and light. Other chemical reactions absorb energy rather than release it.

Exothermic Reactions

A chemical reaction that releases energy (as heat) is called an exothermic reaction. This type of reaction can be represented by a general chemical equation:

Reactants → Products + Heat

In addition to methane burning, another example of an exothermic reaction is chlorine combining with sodium to form table salt. This reaction also releases energy.

Endothermic Reactions

A chemical reaction that absorbs energy is called an endothermic reaction. This type of reaction can also be represented by a general chemical equation:

Reactants + Heat → Products

Did you ever use a chemical cold pack like the one in Figure 3.33? The pack cools down because of an endothermic reaction. When a tube inside the pack is broken, it releases a chemical that reacts with water inside the pack. This reaction absorbs heat energy and quickly cools down the pack.

Figure 3.33  This pack gets cold due to an endothermic reaction.

Activation Energy

All chemical reactions need energy to get started. Even reactions that release energy need a boost of energy in order to begin. The energy needed to start a chemical reaction is called activation energy. Activation energy is like the push a child needs to start going down a playground slide. The push gives the child enough energy to start moving, but once she starts, she keeps moving without being pushed again. Activation energy is illustrated in Figure 3.34.

Why do all chemical reactions need energy to get started? In order for reactions to begin, reactant molecules must bump into each other, so they must be moving, and movement requires energy. When reactant molecules bump together, they may repel each other because of intermolecular forces pushing them apart. Overcoming these forces so the molecules can come together and react also takes energy. An overview of activation energy can be viewed at: http://www.youtube.com/watch?v=VblaK6PlRM&feature=related
Biochemical reactions are chemical reactions that take place inside the cells of living things. The field of biochemistry demonstrates that knowledge of chemistry as well as biology is needed to understand fully the life processes of organisms at the level of the cell. The sum of all the biochemical reactions in an organism is called metabolism. It includes both exothermic and endothermic reactions.

Types of Biochemical Reactions

Exothermic reactions in organisms are called catabolic reactions. These reactions break down molecules into smaller units and release energy. An example of a catabolic reaction is the breakdown of glucose, which releases energy that cells need to carry out life processes. Endothermic reactions in organisms are called anabolic reactions. These reactions build up bigger molecules from smaller ones. An example of an anabolic reaction is the joining of amino acids to form a protein. Which type of reactions—catabolic or anabolic—do you think occur when your body digests food?

ENZYMES

Most biochemical reactions within organisms would be impossible under the conditions in cells. For example, the body temperature of most organisms is too low for reactions to occur quickly enough to carry out life processes. Reactants may also be present in such low concentrations that it is unlikely they will meet and collide. Therefore, the rate of most biochemical reactions must be increased by a catalyst. A catalyst is a substance that enables a chemical reaction to proceed at a usually faster rate or under different conditions (e.g., lower temperature) than otherwise possible without being changed by the reaction. In organisms, catalysts are called enzymes. Essentially, enzymes are biological or organic catalysts.

Like other catalysts, enzymes are not reactants in the reactions they control. They help the reactants interact but are not used up in the reactions. Instead, they may be used over and over again. Unlike other catalysts, enzymes are usually highly specific for particular chemical reactions. They
An enzyme is a protein that speeds up a biochemical reaction. An enzyme works by reducing the amount of activation energy needed to start the reaction. The graph in Figure 3.35 shows the activation energy needed for glucose to combine with oxygen. Less activation energy is needed when the correct enzyme is present than when it is not present.

**Figure 3.35** The reaction represented by this graph is a combustion reaction involving the reactants glucose ($C_6H_{12}O_6$) and oxygen ($O_2$). The products of the reaction are carbon dioxide ($CO_2$) and water ($H_2O$). Energy is also released during the reaction. The enzyme speeds up the reaction by lowering the activation energy needed for the reaction to start. Compare the activation energy with and without the enzyme.

Enzymes are involved in most biochemical reactions, and they do their job extremely well. A typical biochemical reaction could take several days to occur without an enzyme. With the proper enzyme, the same reaction can occur in just a split second! They can catalyze up to several million reactions per second. Without enzymes to speed up biochemical reactions, most organisms could not survive. The activities of enzymes depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments. Watch the animation “How to Speed Up Chemical Reactions (and Get a Date)” to get a better understanding of exactly how enzymes speed up chemical reactions at this link: http://www.ck12.org/biology/Biochemical-Reactions/enrichment/How-to-Speed-Up-Chemical-Reactions-%2528and-Get-a-Date%2529/.

**Importance of Enzymes**

Enzymes are involved in most of the chemical reactions that take place in organisms. About 4,000 such reactions are known to be catalyzed by enzymes, but the number may be even higher. In animals, an important function of enzymes is to help digest food. Digestive enzymes speed up reactions that break down large molecules of carbohydrates, proteins, and fats into smaller molecules the body can use. Without digestive enzymes, animals would not be able to break down food molecules quickly enough to provide the energy and nutrients they need to survive.
Enzyme Functions

Enzymes generally lower activation energy by reducing the energy needed for reactants to come together and react. For example:

- Enzymes bring reactants together so they don’t have to expend energy moving about until they collide at random. Enzymes bind both reactant molecules (called the substrate), tightly and specifically, at a site on the enzyme molecule called the active site (Figure 3.36). The active sites are specific to the reactants of the biochemical reaction the enzymes catalyze. Similar to puzzle pieces fitting together, the active sites can only bind certain substrates.
- By binding reactants at the active site, enzymes also position reactants correctly, so they do not have to overcome intermolecular forces that would otherwise push them apart. This allows the molecules to interact with less energy.
- Enzymes may also allow reactions to occur by different pathways that have lower activation energy.

![Enzyme Functions Diagram](image)

Figure 3.36 This enzyme model binds reactant molecule—called substrate—at its active site, forming an enzyme-substrate complex. This brings the reactant together and positions it correctly so the reaction can occur. After the reaction, the products are released from the enzyme’s active site. This frees up the enzyme so it can catalyze additional reactions.

The activities of enzymes also depend on the temperature, concentration levels, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.

- Digestive enzymes secreted in the acidic environment (low pH) of the stomach help break down proteins into smaller molecules. The main digestive enzyme in the stomach is pepsin, which works best at a pH of about 1.5. These enzymes would not work optimally at other pHs. Trypsin is another enzyme in the digestive system, which breaks protein chains in food into smaller parts. Trypsin works in the small intestine, which is not an acidic environment. Trypsin’s optimum pH is about 8.
- Biochemical reactions are optimal at physiological temperatures. For example, most biochemical reactions work best at the normal body temperature of 98.6°F. Many enzymes lose function at lower and higher temperatures. At higher temperatures, an enzyme’s shape deteriorates. Only when the temperature comes back to normal does the enzyme regain its shape and normal activity.

The animation at this link shows how enzymes work, a basic rundown of enzyme functions, and illustrates what enzymes do. [http://www.ryanshaw.com/Files/micro/Animations/Enzyme-Substrate/micro_enzyme-substrate.swf](http://www.ryanshaw.com/Files/micro/Animations/Enzyme-Substrate/micro_enzyme-substrate.swf)
Lesson Summary

• A chemical reaction is a process that changes some chemical substances into others. It involves breaking and forming chemical bonds. The reactants are used up to create the product.
• Chemical reactions always involve energy. A chemical reaction that releases energy is an exothermic reaction, and a chemical reaction that absorbs energy is an endothermic reaction. The energy needed to start a chemical reaction is the activation energy.
• Biochemical reactions are chemical reactions that take place inside the cells of organisms.
• Enzymes are biological catalysts.
• Enzymes are needed to speed up biochemical reactions in organisms. They speed up biochemical reactions by lowering the activation energy needed to start the biochemical reactions.
• Enzymes are involved in most of the chemical reactions that take place in organisms.
• The activities of enzymes depend on the temperature, concentration levels, and the pH of the surroundings.

References/ Multimedia Resources


Textbook resource granted through licensure agreement with the CK-12 Foundation at www.ck-12.org
CK-12 Foundation
3430 W. Bayshore Rd., Suite 101
Palo Alto, CA 94303
USA  http://www.ck12.org/saythanks

Except as otherwise noted, all CK-12 Content (including CK-12 Curriculum Material) is made available to Users in accordance with the Creative Commons Attribution/Non-Commercial/Share Alike 3.0 Unported (CC-by-NC-SA) License (http://creativecommons.org/licenses/by-nc-sa/3.0/), as amended and updated by Creative Commons from time to time (the “CC License”), which is incorporated herein by this reference. Complete terms can be found at http://www.ck12.org/terms.