Chemical Reactions and Enzymes

Chemical reactions are important to all living things. Plant cells make compounds by linking simple sugars together. Plant and animal cells break down sugars to get usable energy. These are just a few of the chemical reactions in living things. Chemical reactions change substances into different substances by breaking chemical bonds and forming new chemical bonds, rearranging atoms in the process.

Explain Think about the last food you ate. How do you know the chemical bonds in your food were broken?

Modeling Chemical Reactions

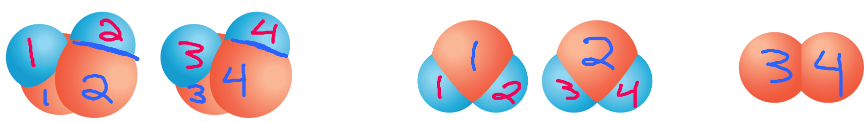
To understand chemical reactions, we need to know the inputs and outputs. Reactants are the initial substances in a chemical reaction. As the reaction proceeds, the bonds of the reactants are broken and rearranged to form the products of the reaction. The products of a chemical reaction are different from the reactants—all the same atoms are still present, but their rearrangement produces substances with properties that are different from those of the starting materials.

For example, hydrogen peroxide, shown in Figure 13, is a very reactive compound. You may have used a hydrogen peroxide solution to clean a cut or scrape. When this compound comes into contact with certain proteins in your blood, bubbles are produced. The foamy substance you see is made up of oxygen gas and water. The properties of these molecules are very different than those of hydrogen peroxide.

Chemical equations model what happens in a chemical reaction. In a chemical equation, the reactants are on the left side of the equation, and the products are on the right side. Chemical reactions also model the conservation of matter. This means that in chemical reactions, atoms are not created or destroyed, only rearranged. All the atoms from the reactants will still be present in the products once the reaction is complete.

Energy and Matter

FIGURE 13: This chemical reaction shows that two molecules of hydrogen peroxide (H_2O_2) break apart to form two molecules of water (H_2O) and one molecule of oxygen (O_2).



$2H_2O_2 \longrightarrow 2H_2O + O_2$

hydrogen peroxide — water — oxygen

Reactant
input

Product
output

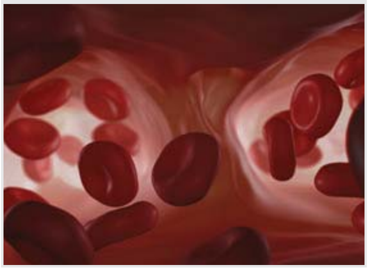
Law of Conservation of Matter

Analyze Answer these questions about the chemical reaction in Figure 13:

1. How does the arrangement of atoms and bonds change?
2. What are the inputs and outputs of the reaction?
3. How can you tell that matter is conserved in this reaction?

Chemical Equilibrium

FIGURE 14: Carbonic acid dissolves in the blood so that carbon dioxide can be transported to the lungs.



Some chemical reactions go from reactants to products until all the reactants are consumed. This is like a one-way street. The reaction can only proceed in one direction and is irreversible. These types of chemical reactions have an arrow pointing toward the products. Other chemical reactions are like a two-way street. They can proceed in either direction, meaning they are reversible. These chemical reactions go in one direction or the other depending on the concentrations of the reactants and the products. Arrows pointing in each direction indicate a reversible chemical reaction. One such reversible reaction lets blood carry carbon dioxide. Carbon dioxide reacts with water in your blood to form a compound called carbonic acid. Some of the carbonic acid breaks down into water and carbon dioxide, which exits the body via the respiratory system.

In an irreversible chemical reaction, the reaction proceeds in one direction until at least one reactant is completely consumed. In a reversible chemical reaction, the reaction proceeds to an equilibrium point. At the equilibrium point, both reactants and products are present. The chemical reaction does not stop but continues in both directions at equal rates, so that the net concentrations of each reactant and product do not change. If some of the products of one reaction are removed, the chemical reaction proceeds in the direction required to restore the reactants and products to equilibrium again. A reversible reaction will always maintain an equilibrium as long as there are reactants and products.

Analyze In terms of homeostasis, why it is important for some reactions to be reversible?

Activation Energy

All chemical reactions involve changes in energy. The reactants must absorb energy in order to break their chemical bonds. When new bonds form to make the products, energy is released. During a chemical reaction, energy is both absorbed and released. Some chemical reactions absorb more energy than they release, while other reactions release more energy than they absorb. Whether a chemical reaction absorbs or releases more energy depends on the bond energy of the reactants and products. Bond energy is the amount of energy needed to break a specific chemical bond.

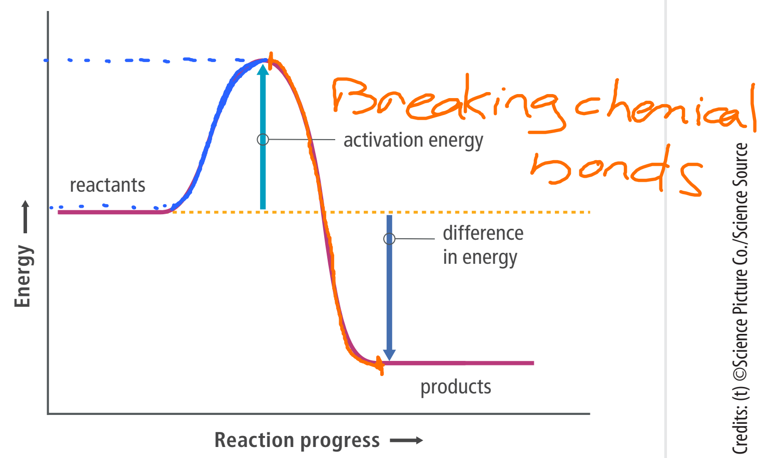
Some energy must be absorbed to start a chemical reaction. Activation energy is the amount of energy that needs to be absorbed to start, or activate, a chemical reaction.

Language Arts Connection

One analogy used to describe activation energy compares it to the energy needed to push a rock up a hill. Once the rock is at the top of the hill, it rolls down the other side by itself. Write your own analogy describing activation energy.

Activation Energy

FIGURE 15: The peak on the graph indicates the activation energy. This is the amount of energy reactants must absorb in order to break their chemical bonds so the reaction can proceed.



Endothermic and Exothermic Reactions

Chemical reactions may be classified by whether or not energy is absorbed or released during the reaction overall. The total energy of the reaction is the difference between the energy absorbed when bonds break and the energy released when bonds form. When a chemical reaction releases more energy than it absorbs, it is called an exothermic reaction. In an exothermic reaction, the products have lower bond energies than the reactants. The excess energy—the difference in bond energy between the reactants and the products—is often given off as heat or light. The prefix *exo-* means "outside." In an exothermic reaction, energy is an output.

When a chemical reaction absorbs more energy than it releases, it is called an endothermic reaction. In an endothermic reaction, the products have higher bond energies than the reactants. Energy must be absorbed to make up the difference. The vessel that contains an endothermic reaction in progress usually feels cold to the touch because it is absorbing energy from its surroundings—which includes your skin if you are touching the container. The prefix *endo-* means "inside." In an endothermic reaction, energy is an input.

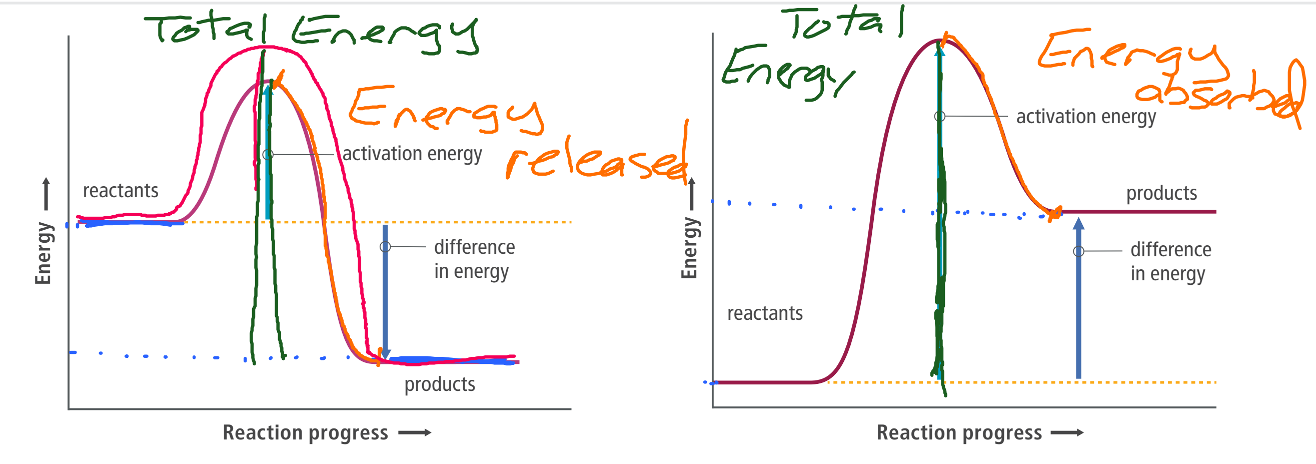
FIGURE 16: A chemical reaction in a firefly releases light energy.

Explain In this firefly's body, chemical reactions take place that allow the firefly to give off light to attract a mate. Is this light most likely the result of endothermic or exothermic reactions? Explain your answer.

Data Analysis

Exothermic and Endothermic Reactions

FIGURE 17: Energy is released in exothermic reactions and absorbed in endothermic reactions.



a Exothermic reaction

b Endothermic reactions

Explain Use the graphs in Figure 17 to answer the following questions:

1. How do endothermic and exothermic reactions differ in terms of energy?
2. Is activation energy part of the overall difference in energy for a chemical reaction?
3. Why do exothermic reactions feel warm to the touch, while endothermic reactions feel cold? Use evidence from the graphs to support your answer.

A huge number of chemical reactions take place at any given time in a living organism. Survival of the organism depends on some reactions proceeding as rapidly as possible despite a restrictive environment and high activation energies.

Catalysts

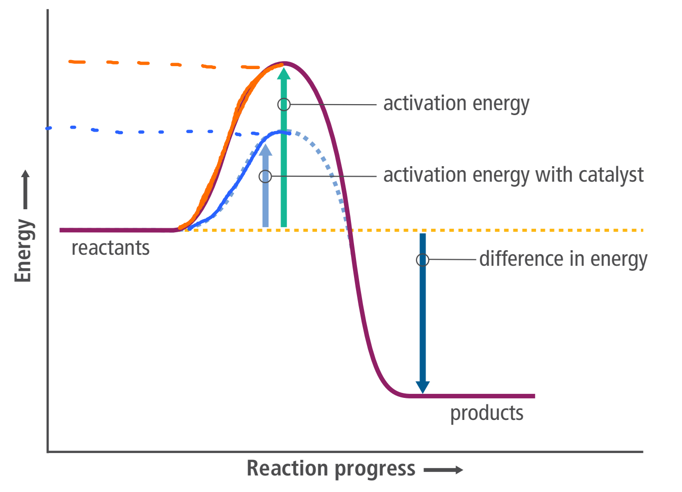
Chemical reactions in living things often need to happen quickly, but some have a high activation energy that makes this not possible. Remember that the activation energy is the amount of energy a chemical reaction needs to absorb before it can begin. Often, that activation energy comes from an increase in temperature. Once the reaction starts, however, it still might proceed slowly. For any reaction to take place, the reactant molecules need to collide with enough force and in a specific orientation. Especially if the concentration of reactants is low, collisions with the necessary force and orientation are much less frequent.

However, the activation energy, and thereby the rate of the chemical reaction, can be changed with a catalyst. A catalyst is a substance that increases the rate of the reaction. Catalysts are neither changed nor consumed during a reaction, so they are not part of the equation. Catalysts provide an alternate way for the reaction to occur that requires less activation energy.

Analyze According to the graph, how does a catalyst increase the rate of a chemical reaction?

Activation Energy with Catalyst

FIGURE 18: This graph shows how a catalyst changes the activation energy of a reaction. Note that the overall difference in energy does not change as a result of adding a catalyst.



Explore Online

Hands-On Lab

Experimenting with Catalase Design and conduct an investigation of how a factor affects the activity of the catalase enzyme.

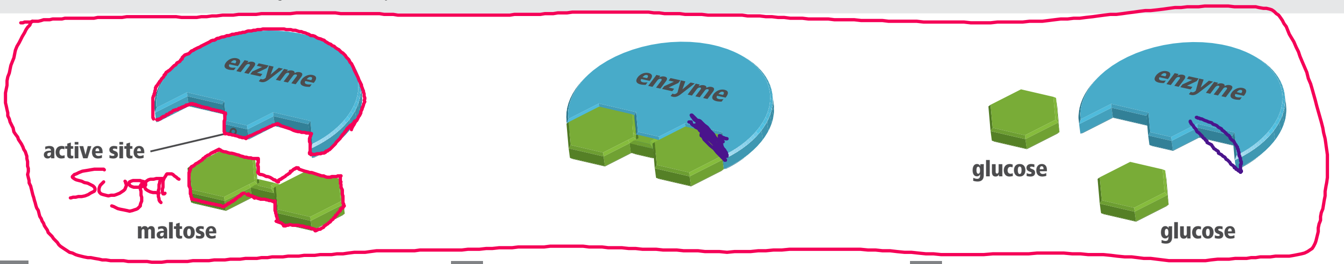
Enzymes

One way to provide the necessary activation energy for a reaction is to increase the temperature of the system. However, chemical reactions in organisms must take place at the organism's body temperature, which must remain within a narrow range. In addition, the reactants are often present in low concentrations. To lower the activation energy and help molecular collisions be more efficient, cells use biological catalysts.

The catalysts used in living organisms are called enzymes. Enzymes, like other catalysts, lower the activation energy and increase the rate of chemical reactions. This is true in both reversible and irreversible reactions. Enzymes are involved in almost every process in organisms, from breaking down food to building proteins. For example, during digestion, an enzyme called amylase in your saliva begins to break down starches in your food. In the intestines, another enzyme called maltase breaks down the sugar maltose into individual glucose molecules.

Enzyme structure is important because each enzyme's shape allows only certain reactants to bind to the enzyme. The specific reactants that an enzyme acts on are called substrates. In the same way that a key fits into a lock, substrates fit the active sites of enzymes. This is why, if an enzyme's structure changes, it may not work at all. This model of enzyme function is called the lock-and-key model.

FIGURE 19: The maltase enzyme is shaped to fit a molecule of maltose.



1 The sugar maltose is the substrate for this enzyme. Maltose is made up of two glucose molecules bonded together.

2 The maltase enzyme is shaped so that only the maltose molecule fits into the active site of the enzyme.

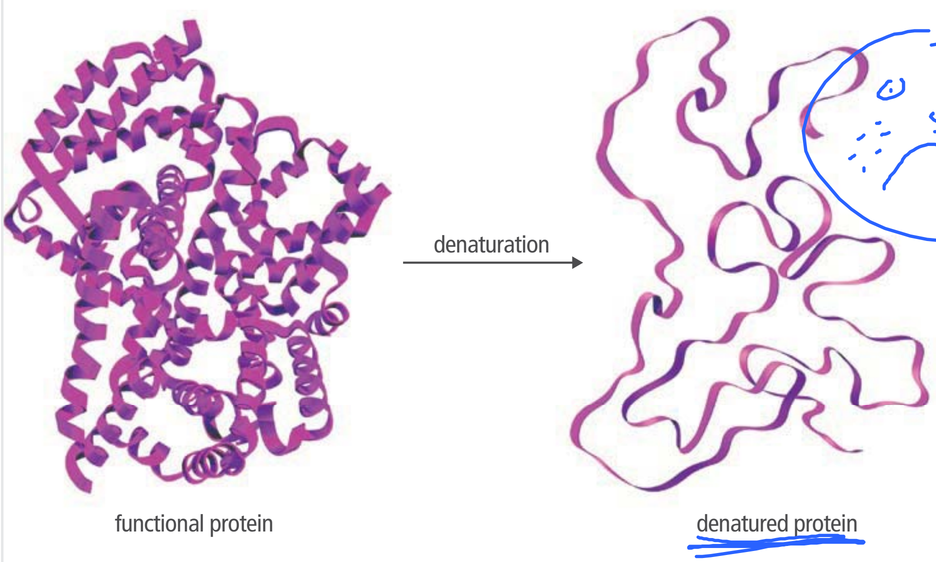
3 The enzyme allows a chemical reaction to occur that breaks the maltose molecule into two glucose molecules.

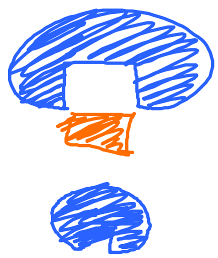
The lock-and-key model is a good starting point for understanding enzyme function. However, scientists have found that the structures of enzymes are not fixed in place. Instead, enzymes actually bend slightly when they are bound to their substrates. In terms of a lock and key, it is as if the lock bends around the key to make the key fit better. The bending of the enzyme is one way in which bonds in the substrates are weakened. This explanation is known as the induced-fit model.

Model Make a diagram to illustrate how an enzyme would break down a substrate according to the induced-fit model.

Almost all enzymes are proteins. Interactions between different parts of the protein cause it to form a complex 3D structure. This 3D structure enables an enzyme to function properly as a catalyst. Changes in conditions such as temperature and pH can affect the shape and function of a protein. Enzymes work best in a limited temperature range that is around the organism's normal body temperature. At only slightly higher temperatures, the hydrogen bonds in an enzyme may begin to break apart. The enzyme begins to unravel and unfold, or denature, as shown in Figure 20.

FIGURE 20: A change in temperature or pH can cause an enzyme to become denatured.





Explain Why is having a very high fever dangerous for humans? Cite evidence related to enzyme structure and function.

A change in pH can also affect the hydrogen bonds in enzymes and so cause denaturation. Many enzymes work best at the nearly neutral pH that is maintained within the body's cells. If the fluid becomes more acidic or basic as the pH changes, the reactions slow down. If the fluid becomes very acidic or basic, enzymes may stop working altogether. Not all enzymes have the same pH requirements. For example, enzymes in the stomach work best in acidic conditions. Alternately, some enzymes in the small intestine work best under slightly basic conditions.

Predict At the beginning of the lesson, you saw hydrochloric acid breaking down a hamburger. Hydrochloric acid is present in the stomach. How do you think enzymes in the stomach might resist being denatured by such an acidic environment?

You can see denaturation occur when you cook an egg. As the egg starts cooking, the proteins in the egg white extend as they unravel and unfold. The protein molecules then begin linking to other protein molecules to form a network.

Collaborate Certain chemicals can be used to change hair from straight to curly. With a partner, discuss how this might be related to chemical bonds and the denaturation of proteins.

In some cases, denatured proteins can become renatured or regain their normal shape. However, many proteins are not able to regain normal function once they are denatured. In the case of the egg white, the proteins form new bonds that cause the white to develop the characteristic white gel of the cooked egg.

FIGURE 21: The changes that occur in an egg white as it cooks involve the denaturation of proteins.

Because enzymes are proteins, changes in pH and adding heat can cause them to become denatured. For a catalyst to work properly, it must maintain the proper shape to accept the substrate molecule. Denaturation alters that shape and the catalyst no longer works properly.

Explain Answer these questions to construct an explanation for how matter changes during chemical reactions:

1. What happens in terms of atoms and bonds in chemical reactions?
2. How are energy inputs and outputs related to chemical reactions?
3. How do enzymes help living things carry out chemical reactions?