2.1

# Chemical Bonds and Reactions

The climber, the mountain, the moon, and even the air are all made up of matter.

## CAN YOU EXPLAIN IT?

**FIGURE 1:** A cheeseburger is placed into hydrochloric acid. Over several hours, the acid breaks down much of the cheeseburger.

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**Gather Evidence** Record evidence that the matter in the hamburger is undergoing a chemical reaction.

When you eat food, chemical reactions in your digestive tract help break down that food. You can see changes in the hamburger as it is placed into the beaker of hydrochloric acid (HCl) in Figure 1. Hydrochloric acid is a strong acid that is present in your stomach. It can break down matter very quickly; it can even break down metals such as aluminum and zinc!

Digestion takes place through the interactions of stomach acid, hormones, and other chemicals, along with a network of nerves and muscles in the digestive system. Each organ contributes to breaking down food. For example, salivary glands in your mouth secrete an enzyme that helps to digest starches. During digestion, your stomach lining secretes gastric juice containing hydrochloric acid and a protein called pepsin. Gastric juice and pepsin work together to break down food very quickly.

**Predict** When the food you eat encounters the gastric juice in your stomach, chemical reactions help break down the food. Draw a diagram showing what you think happens to matter such as a food when it undergoes a chemical reaction.

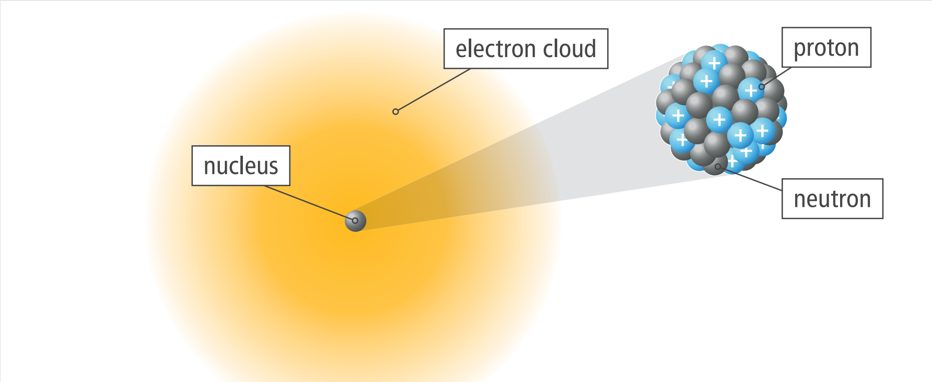
# Atoms, Elements, and Compounds

Living systems require complex interactions, some of which you can observe on a large, or macroscopic, scale every day. To understand these interactions on a deeper level, we need to take a closer look and explore the composition of living things at a molecular level. All organisms depend on different chemicals and chemical reactions. The study of living things relies on a basic understanding of chemistry.

## Atoms and Elements

Every physical thing you can think of, living or not, is made of incredibly small particles called atoms. An atom is the smallest basic unit of matter. Trillions of atoms could fit in a space the size of the period at the end of this sentence. Although there is a huge variety of matter on Earth, all atoms share the same basic structure.

**FIGURE 2:** Atoms consist of three types of particles. Protons have a positive charge, electrons have a negative charge, and neutrons have no charge.




An element is a substance made up of one type of atom and cannot be broken into simpler substances by ordinary chemical means. All the atoms of a given element have a specific number of protons. This number never varies. Atoms of different elements have different numbers of protons. For example, all hydrogen (H) atoms have one proton, and all carbon (C) atoms have six protons. Because the proton number never varies, we often identify an element by the number of protons in its nucleus. Scientists refer to the number of protons in the atoms of any given element as that element's atomic number. The elements are organized in a table called the periodic table.

**Engineering**

Some elements occur naturally and are abundant on Earth. Other elements are very rare or synthesized in laboratories. Research the processes scientists and engineers use to synthesize or isolate rare elements. What types of elements have only been found in a laboratory? Why don't we see these elements in nature? Create an infographic detailing your findings.

## Chemical Bonds

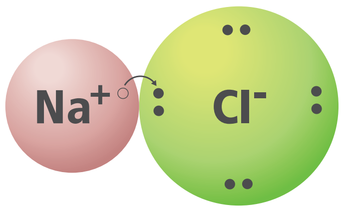
The electrons of an atom orbit the nucleus, occupying different energy levels. An atom is most stable when its outer energy levels are filled with electrons. The atoms of some of the elements, such as neon (Ne) and helium (He), have full outer energy levels and are rather unreactive. These elements rarely form bonds because they are already stable. The atoms of most other elements become more stable by bonding with other atoms, which is why atoms rarely exist alone in nature. For example, sodium (Na) and chlorine (Cl) atoms can bond to form sodium chloride (NaCl), also known as table salt.

**FIGURE 3:** Table salt is formed by a chemical bond.

### Ionic Bonds

One way that some atoms become more stable is by gaining or losing electrons. Atoms that have gained or lost electrons are known as ions. Atoms that gain electrons become negatively charged ions. Atoms that lose electrons become positively charged ions. Positive and negative ions are attracted to one another. Ionic bonds form through this attraction. Ionic bonds are a very strong type of chemical bond.

**FIGURE 4:** Sodium chloride is an example of ionic bonding.

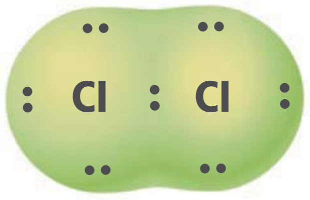



Sodium chloride (NaCl), or table salt, is an example of an ionic bond. A sodium atom (Na) transfers one electron to a chlorine atom (Cl). When it loses its one outer electron, the sodium atom becomes a positively charged sodium ion ($Na^+$). When it gains an electron the chlorine atom becomes a negatively charged chloride ion ($Cl^-$). The attraction between the $Na^+$ and $Cl^-$ ions forms NaCl, shown in Figure 4.

### Covalent Bonds

Not all chemical bonds form by the transfer of electrons. Some atoms become more stable by sharing one or more pairs of electrons with other atoms, known as covalent bonding. Covalent bonds are generally weaker than ionic bonds but are still very strong. Depending on the number of electrons an atom has, two atoms may form several covalent bonds, or share several pairs of electrons.

**FIGURE 5:** Two chlorine atoms form a covalent bond.




A molecule is two or more atoms held together by covalent bonds. A chlorine molecule ($Cl_2$), shown in Figure 5, shares a pair of electrons in a covalent bond. Covalent bonding is what makes it possible for atoms to form very large molecules, often with very complex shapes. Many substances in living things are composed of large, complex molecules.

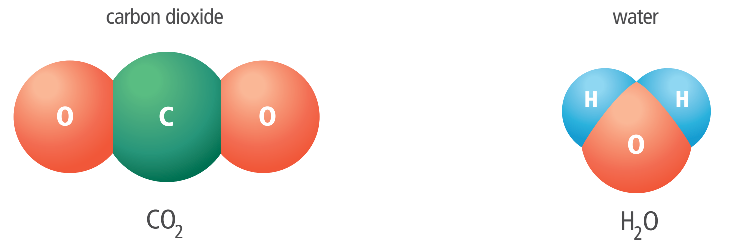
**Analyze** Create a Venn diagram to compare and contrast ionic and covalent bonds in terms of electrons and stability.

## Compounds

Compounds are substances composed of atoms of two or more different elements bonded together in specific ratios. Common compounds in living things include water ($H_2O$) and carbon dioxide ($CO_2$).

**Model** The chemical formula for carbon dioxide is $CO_2$. According to the model of this molecule in Figure 6, what does the 2 represent?

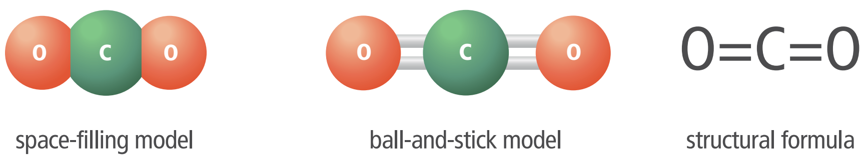
**FIGURE 6:** Carbon dioxide is made of two oxygen atoms each bonded to a carbon atom. Water is made of two hydrogen atoms each bonded to an oxygen atom.




The diagrams of the $CO_2$ and $H_2O$ molecules use one type of model, known as a space-filling model, to represent molecules. Space-filling models are three-dimensional diagrams that show atoms as spheres attached to one another. Atoms of different elements are usually represented by different colors.

A space-filling model is only one type of model scientists use to conceptualize molecules. Another type of model, called a ball-and-stick model, also uses spheres but uses sticks to represent the bonds between the atoms. A third, much simpler model, is a structural formula. This model uses letters to represent atoms and lines to represent bonds. Figure 7 shows carbon dioxide using three different molecular models.

**FIGURE 7:** Types of Molecular Models




**Analyze** Although different kinds of models are useful for understanding phenomena, all models have limitations. Describe one strength and one limitation for each of these types of models.

The properties of a compound are often very different from the properties of the elements that make up the compound. For example, at 25 °C (77 °F), hydrogen and oxygen are extremely flammable gases. Tanks containing either gas often bear warning symbols to prevent accidental explosions. When bonded together, however, these flammable elements form water. At room temperature, water is a liquid, not a gas, and—far from being flammable—it is often used to put out fires caused when other compounds react with oxygen!

**FIGURE 8:** The flammable gases oxygen and hydrogen combine to make a nonflammable liquid essential to life on Earth—water.


When examining the chemical formulas for compounds, look closely at the ratios of the atoms of the elements in the compound. For example, water ($H_2O$) has two hydrogen atoms for each oxygen atom. If the ratio of oxygen to hydrogen changes, a new compound with new properties results. Hydrogen peroxide ($H_2O_2$), for example, has two hydrogen atoms and two oxygen atoms. The same elements are present but in a different ratio, so this compound has different properties than water.

**Explain** Think back to the hamburger that was placed in the acid. Answer these questions about the matter in the hamburger:

1. How can matter be arranged? Draw a diagram to illustrate the difference between atoms, elements, and compounds.
2. How are atoms held together? Explain the differences between the two main types of bonding.
3. How do you think the arrangement of matter, such as the matter in the hamburger, changes in chemical reactions?

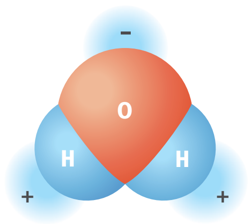
# Properties of Water

**Gather Evidence** As you read, record evidence to answer this question: What characteristics of a water molecule make it unique?

When you're thirsty, you need to drink something that is mostly water. Why is water so necessary for life? Your cells, and those of every other living thing on Earth, are mostly water. The composition and structure of the water molecule gives it unique properties essential to living things.

## Polar Molecules

**FIGURE 9:** In water molecules, the oxygen atom has a slightly negative charge, and the hydrogen atoms have slightly positive charges.



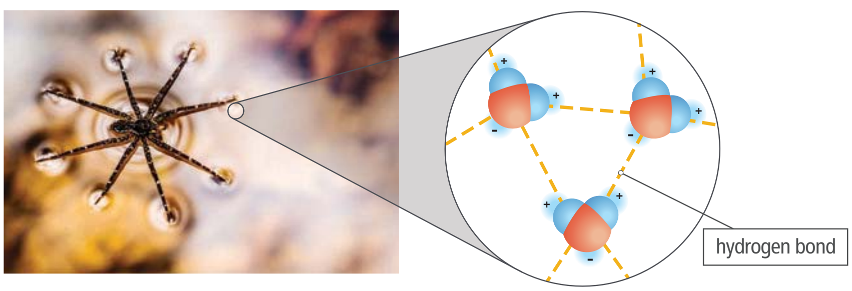

A water molecule has two covalent bonds. A water molecule is an example of a polar molecule. You can think about polar molecules similarly to how you think about the poles of a magnet. Just as magnets have a north and a south pole, polar molecules have a region with a slightly positive electric charge and a region with a slightly negative electric charge. Just like poles of magnets repel one another and opposite poles attract one another, so do the poles in polar molecules.

Polar molecules form when atoms in the molecule have unequal pulls on the electrons they share. In a molecule of water, the greater number of protons in the nucleus of an oxygen atom attracts the shared electrons more strongly than does the single proton in a hydrogen atom. Because electrons carry a negative charge, the oxygen atom gains a slight negative charge, and the hydrogen atoms gain slight positive charges. The more equally charged the atoms in chemical bond are, the less polar a bond is, because the atoms share the electrons more equally.

## Hydrogen Bonds

When a hydrogen atom is part of a polar molecule, the hydrogen atom has a slight positive charge. This slightly positive atom is attracted to a slightly negative atom, often oxygen or nitrogen, forming a hydrogen bond. Life depends on hydrogen bonds. For example, hydrogen bonds are part of the structures of proteins and DNA molecules. Hydrogen bonding is important in other ways, as shown in Figure 10.

**FIGURE 10:** Water's surface tension comes from hydrogen bonds that cause water molecules to stick together, allowing this spider to walk across the surface of water.




**Analyze** How are hydrogen bonds similar to ionic bonds?

### Properties of Hydrogen Bonds

Individual hydrogen bonds are about 20 times weaker than typical covalent bonds, but they are strong enough to have an influence on water molecules. As a result, a large amount of energy is needed to overcome the interactions among water molecules. Water is a liquid at the temperatures that support most life on Earth because of hydrogen bonding among the water molecules. Without hydrogen bonds, water would boil at a much lower temperature than it does, because less energy would be needed to change liquid water into water vapor. Hydrogen bonds are responsible for other important properties of water.

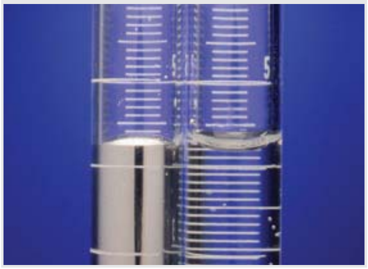
**High Specific Heat** Hydrogen bonds give water an abnormally high specific heat. This means that water resists changes in temperature. This property is very important in cells. The processes that produce usable chemical energy in cells release a great deal of heat. Water absorbs the heat, which helps to regulate cell temperatures and maintain homeostasis.

**Cohesion** The attraction among molecules of a substance is called cohesion. Cohesion from hydrogen bonds makes water molecules "stick" to each other and produces surface tension.

**Adhesion** The attraction among molecules of different substances is called *adhesion*. For example, water molecules can stick to each other or to the sides of a glass tube. Adhesion helps plants transport water from their roots to their leaves, because water molecules stick to the sides of the tissues through which water passes.

**Explain** As shown in Figure 11, water sticks to the sides of a glass tube, but mercury forms a rounded, bubble-like surface at the top of the liquid. Which is probably greater in mercury—cohesion or adhesion? Explain your answer.

**FIGURE 11:** When water and mercury are placed in glass tubes, the water adheres to the sides of the tube. The mercury, by contrast, forms a rounded surface at the top of the liquid.



## Water as a Solvent

Many substances dissolve in the water in your body. When one substance dissolves in another, a solution forms. A solution has two parts: the solvent and the solute. The substance in a solution that is present in the greater amount and that dissolves another substance is the solvent. A solute is a substance that dissolves in a solvent. The amount of solute dissolved in a certain amount of solvent is a solution's concentration.

Although water is known as the "universal solvent," not all substances dissolve in water. For example, nonpolar molecules, such as oil, will not dissolve in water. Substances that are similar in structure mix more readily. This phenomenon is also known as "like dissolves like." For example, nonpolar molecules will dissolve in nonpolar solvents. Some vitamins, such as vitamin E, are nonpolar. They do not dissolve in water in the body, but they do dissolve in nonpolar substances such as the lipids that make up body fat. This is why vitamin E is classified as a fat-soluble vitamin.

**Analyze** The liquid part of blood, called plasma, is about 95% water. Molecules such as sugars and proteins are dissolved in the water of blood plasma. What is the solute and what is the solvent in blood plasma?

**Predict** Why is the ability to dissolve many substances important for a solvent that is found in living things?

## Acids and Bases

Some compounds separate into ions when they dissolve in water. An acid is a compound that releases a proton—a hydrogen ion ($H^+$)—when it dissolves in water. An acid increases the concentration of $H^+$ ions in a solution. Bases are compounds that remove $H^+$ ions from a solution. When a base dissolves in water, the $H^+$ concentration decreases. A solution's acidity, or $H^+$ concentration, is measured by the pH scale.

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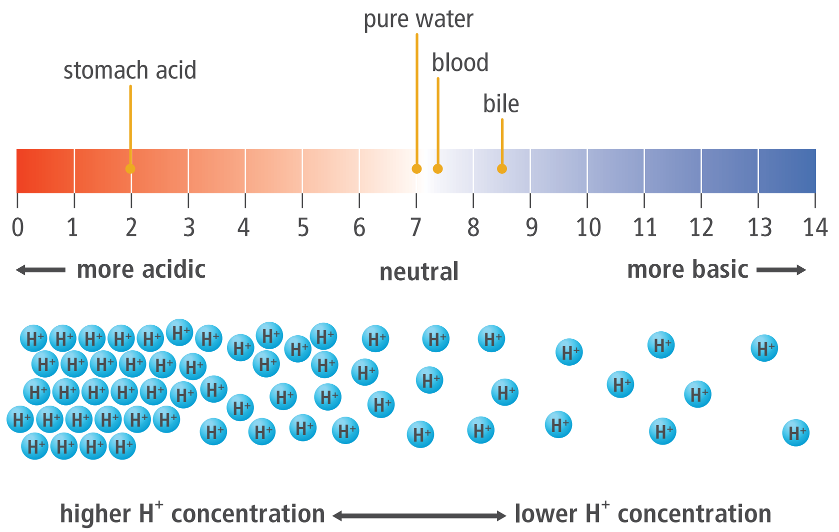
**Hands-On Lab**

**Investigating Acids and Bases** Use different tools to measure the pH of various substances including foods and cleaning products.

**FIGURE 12:** The pH of a solution depends on the concentration of $H^+$ ions.




**Analyze** Lemon juice has a high hydrogen ion concentration. Where would you expect to find it on the pH scale?

In order to maintain homeostasis, most organisms need to keep their pH within a very narrow range around neutral (pH 7.0). However, some organisms require a pH outside this range. For example, the azalea plant thrives in acidic (pH 4.5) soil, and a microorganism called *Picrophilus* survives best at an extremely acidic pH of 0.7.

For all of these different organisms, pH must be regulated. One way pH is regulated in organisms is by substances called buffers. A buffer is a compound that can bind to an $H^+$ ion when the $H^+$ concentration increases, and can release an $H^+$ ion when the $H^+$ concentration decreases. The buffer maintains a more constant level of $H^+$ ions and helps to maintain homeostasis.

**Explain** Construct an explanation for how hydrogen bonds between water molecules contribute to the properties important for the survival of living things. In your explanation, discuss the structure of the water molecule, and explain how this structure contributes to the unique properties of water. Finally, explain how these properties are related to the proper functioning and survival of living things.

# 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

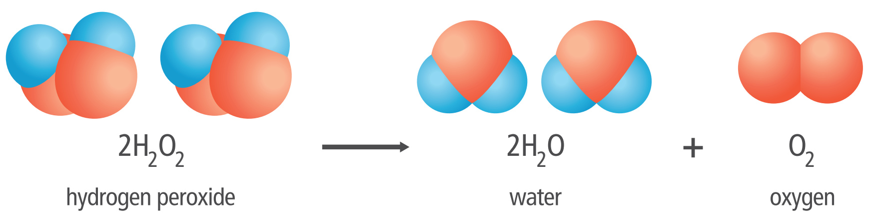
To understand chemical reactions, we need to know the inputs and outputs. Reactants are the initial substances in a chemical reaction. As the reaction proceeds, the bonds of the reactants are broken and rearranged to form the products of the reaction. The products of a chemical reaction are different 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 ($O_2$).

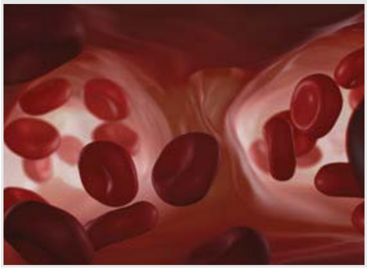



**Analyze** Answer these questions about the chemical reaction in Figure 13:

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.

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

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.

## 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.

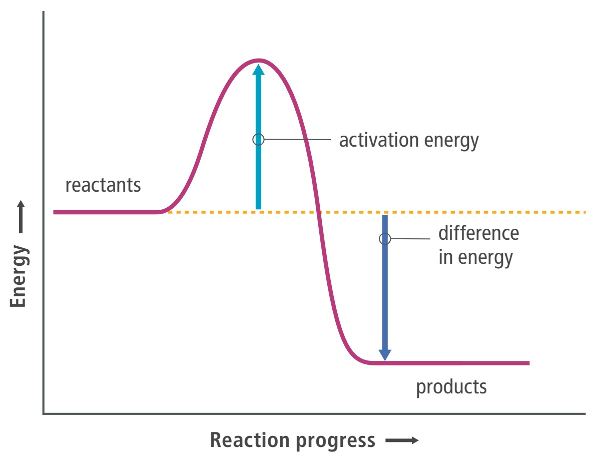
Some energy must be absorbed to start a chemical reaction. Activation energy is the amount of energy that needs to be absorbed to start, or activate, a chemical reaction.

**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.

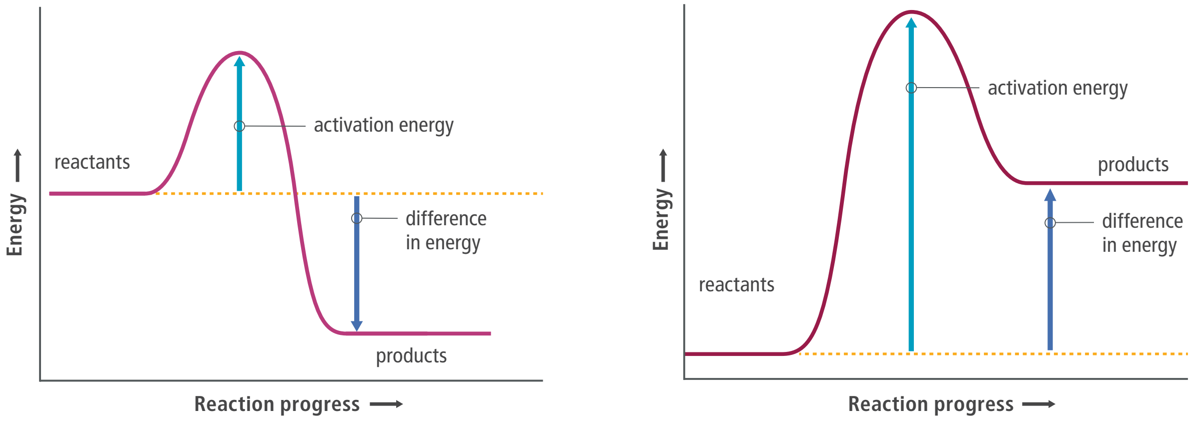
**FIGURE 16:** A chemical reaction in a firefly releases light energy.

**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

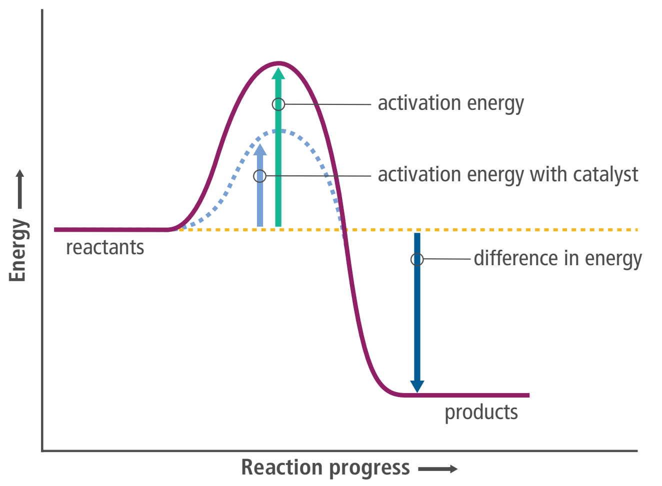
Chemical reactions in living things often need to happen quickly, but some have a high activation energy that makes this not possible. Remember that the activation energy is the amount of energy a chemical reaction needs to absorb before it can begin. Often, that activation energy comes from an increase 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.

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**Hands-On Lab**

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

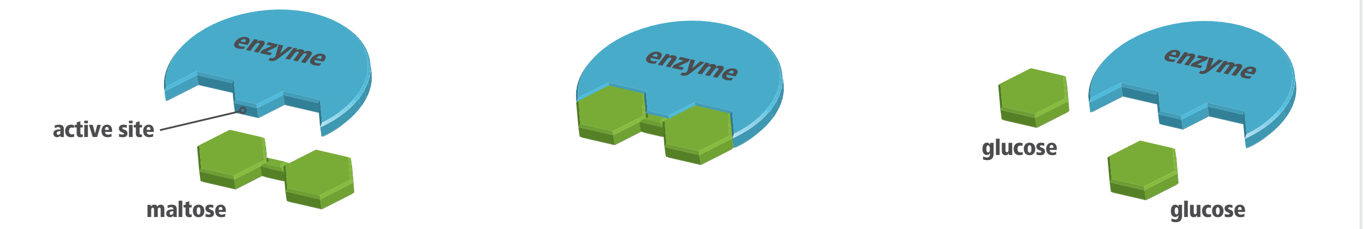
## Enzymes

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.

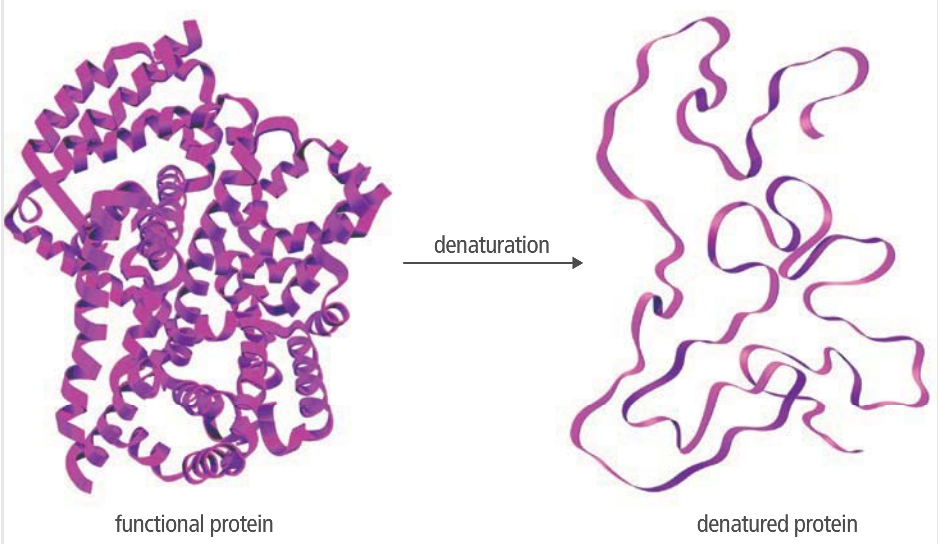
3 The enzyme allows a chemical reaction to occur that breaks the maltose molecule into two glucose molecules.

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?

# Hands-On Lab

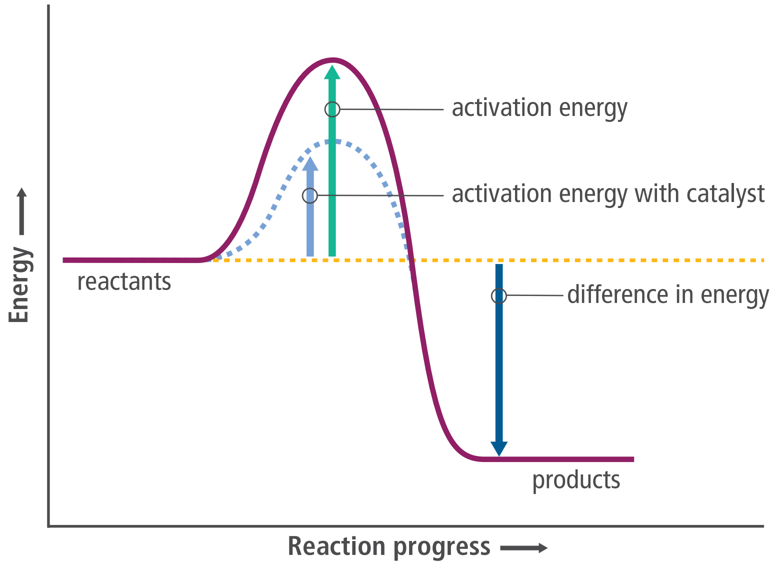
## Experimenting with Catalase

Many chemical reactions take place in the cells of living things. Some of these reactions break down molecules from nutrients to obtain energy. Other reactions synthesize all the compounds that cells need to survive. Together, these two categories of reactions are called metabolism. Metabolism is the total of all the chemical reactions that take place in a living organism.

Catalysts are substances that help speed up chemical reactions by lowering the activation energy required to start the reaction. Within living organisms, these substances are called enzymes. Enzymes are proteins. The reactants that enzymes work on are called substrates, and the resulting substances are called products. We would not survive without enzymes, because the essential reactions that keep us alive would take far too long.

**Activation Energy with a Catalyst**

**FIGURE 22:** A catalyst lowers the activation energy for a chemical reaction.




Many factors influence how well an enzyme functions. Temperature, pH, and the presence of inhibitors such as heavy metals can affect the ability of an enzyme to catalyze a reaction.

One important enzyme is catalase. Catalase is found in many cells, and it is highly concentrated in the human liver. Catalase speeds up the decomposition, or breakdown, of hydrogen peroxide ($H_2O_2$) in the body. Hydrogen peroxide is a toxic byproduct of cellular respiration. Too much hydrogen peroxide in the body can result in death. Catalase is able to speed up the decomposition of hydrogen peroxide into harmless water and oxygen. This chemical reaction is shown below.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

## SAFETY

Hydrochloric acid and sodium hydroxide are corrosive to the skin. Use caution when pouring these chemicals. Raw liver can carry *E. coli*, so be sure to wear gloves or use forceps when handling the liver and wash your hands thoroughly.

## MATERIALS

- beaker
- beef liver
- forceps, scalpel, and tongs
- graduated cylinder, 10 mL
- hot plate
- hydrochloric acid, diluted (1.0 M HCl)
- hydrogen peroxide, 3%
- ice
- pH paper and pH probe
- ruler and scissors
- sodium hydroxide, diluted (1.0 M NaOH)
- test tubes and test tube rack
- thermometer
- water, distilled

Choose a factor, such as temperature or pH, and investigate how it affects the activity of the catalase enzyme.

**Predict** How do you think changes in this factor will affect the activity of the catalase enzyme? Give reasoning to support your claim.

## PROCEDURE

Design a procedure to investigate how the factor you chose affects catalase activity. Use the following questions to guide you in writing your procedure. If there is time, you may investigate more than one factor.

- Which variable will you be changing, and how will you change it?
- Which variables will be kept constant?
- How many experimental setups will you need? Which setup will serve as your control?
- How will you measure the activity of the enzyme?
- How many times will you run your test, and what safety considerations need to be made?

Have your teacher check your procedure before moving on. Before carrying out the experiment, create one or more data tables for your measurements and observations.

## ANALYZE

Answer the following questions in your Evidence Notebook:

1. How did you know when the activity of the catalase enzyme had increased or decreased?
2. Make a graph of your data, and show any calculations you completed. What patterns can you identify in the data?

## EXPLAIN

Write a conclusion explaining how the factor you tested affected enzyme activity. Include each of the sections below in your explanation.

**Claim** Was your prediction correct? What conclusion can your make based on the data?

**Evidence** Give specific examples from your data to support your claim.

**Reasoning** Explain how the evidence you gave supports your claim.

## REFINE

Explain how you would improve this investigation if you were to do it again.

**Precision and Accuracy** Did the equipment used provide the level of precision needed to make a valid conclusion?

**Propose Changes** What improvements would you make in this procedure to obtain more precise data? Why would you make these changes?

ENZYMES AND ATHLETES

INVESTIGATING ACIDS AND BASES

**Go online to choose one of these other paths.**

# Lesson Self-Check

## CAN YOU EXPLAIN IT?

Explore Online

**FIGURE 23:** Hydrochloric acid is highly acidic. It is present in your stomach and can break down food matter very quickly.

In the digestive system, several organs work together to break down food into simpler molecules. Digestion begins in the mouth, continues in the stomach, and is completed in part of the small intestine. In the mouth, mechanical digestion begins as you start chewing. Your teeth shred and grind the food into smaller pieces. As you chew your food, salivary glands secrete the enzyme amylase that begins the breakdown of complex starch molecules into glucose.

Once food has been chewed and mixed with saliva, the tongue pushes it to the back of the mouth to swallow. The food moves down to the stomach where digestion continues. In the stomach, your stomach lining secretes gastric juice containing hydrochloric acid (HCl) and the digestive enzyme pepsin. Proteins are digested in the stomach and small intestine, but fats and sugars are digested only in the small intestine where other enzymes, including maltase, continue the process.

Whenever you eat, your stomach produces hydrochloric acid. This acid has a pH of about 1.5. Cells in the stomach lining produce a layer of mucus that protects the cells from damage by the acid.

**Explain** Refer to the notes in your Evidence Notebook to explain how matter, such as a hamburger, is changed in a chemical reaction. Use evidence and models to support your claim, and address the following questions:

1. How can matter be arranged, and how do we model the arrangement of matter?
2. How does matter and energy change in chemical reactions, and how can these changes be modeled?
3. How do the properties of water and the ability to modify the rates of chemical reactions enable living things to carry out functions necessary for life, such as digesting food?

## CHECKPOINTS

### Check Your Understanding

1. What does all matter have in common?
   - **a.** It is liquid at room temperature.
   - **b.** It is made up of atoms.
   - **c.** It is visible.
   - **d.** It is neutral.

2. Which statement best describes compounds?
   - **a.** Compounds are collections of several atoms of the same element.
   - **b.** Compounds are made up of atoms of one or more elements bonded together.
   - **c.** Compounds rarely occur in nature and are often synthesized by humans.
   - **d.** Compounds are composed of atoms that are not likely to react with one another.

3. Which of the following are examples of matter? Select all correct answers.
   - **a.** heat
   - **b.** sunlight
   - **c.** water
   - **d.** grass
   - **e.** air

4. An animal's stomach contains enzymes that break down food into smaller molecules that the animal's cells can use. Enzymes perform this function by
   - **a.** participating in chemical reactions
   - **b.** increasing the reaction temperature
   - **c.** decreasing the activation energy
   - **d.** lowering the pH

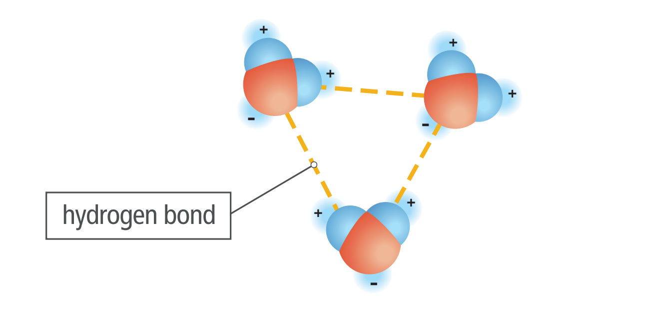
5. A chemical reaction proceeds until it reaches an equilibrium. Which statement is true when the reaction is at equilibrium?
   - **a.** All the reactants are used up.
   - **b.** The reaction is completed and will not change.
   - **c.** One reactant is used up, but one or more of the other reactants are still present.
   - **d.** Both products and reactants are present.

6. How do the properties of elements compare to the properties of the compounds they form?
   - **a.** The properties of the elements may differ from the properties of the compounds they form.
   - **b.** The properties of the compound are always the same as the elements that are in the compound.
   - **c.** The properties of the compound will change only if the elements in the compound are exposed to heat.
   - **d.** The properties of the compound are the same as the properties of the individual atoms in the compound.

7. Which of the following is *not* a property of water?
   - **a.** high specific heat
   - **b.** cohesion
   - **c.** relatively low boiling point
   - **d.** adhesion

8. How do temperature and pH affect an enzyme that a chemical reaction depends on?
   - **a.** They can break down the reactants.
   - **b.** They can break down the products.
   - **c.** They can change the shape of the enzyme.
   - **d.** They can cause the chemical reaction to reverse.

**FIGURE 24:** Hydrogen bonds form between water molecules.

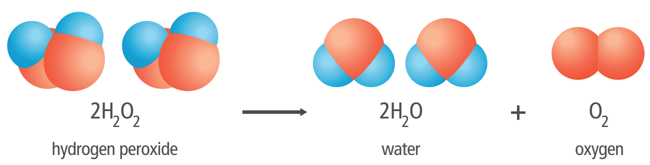



9. How does the structure of a water molecule result in hydrogen bonding? Use evidence from Figure 24 to support your answer.

10. You may have noticed that water sticks to surfaces such as glass. Which property of water is responsible for this phenomenon?

11. Explain why the formation of hydrogen bonds between water molecules is important for the survival of living things.

FIGURE 25: Hydrogen peroxide breaks down into water and oxygen.

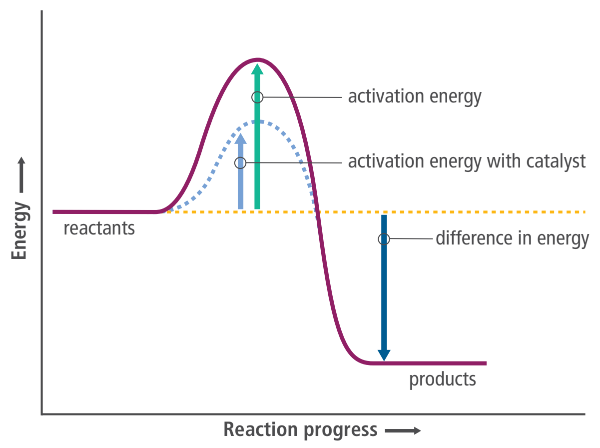



Use Figure 25 to answer questions 12–13.

**12.** Describe what is happening in terms of atoms and bonds in this chemical reaction.

**13.** Explain how this model of a chemical reaction demonstrates that matter is conserved.

FIGURE 26: A reaction progresses with the help of a catalyst.




Use Figure 26 to answer questions 14–15.

**14.** Which statement is true regarding a catalyst?

**a.** A catalyst increases the activation energy for a chemical reaction.

**b.** A catalyst decreases the difference in energy for a chemical reaction.

**c.** A catalyst allows the reactants to start at a higher energy level.

**d.** A catalyst lowers the activation energy for a chemical reaction.

**15.** Is this graph depicting an exothermic or endothermic chemical reaction? Use evidence to support your answer.

**16.** Which of these statements about enzymes is true? Select all correct answers.

**a.** Enzymes can help break chemical bonds.

**b.** Enzymes always change their shape when they bind to a molecule.

**c.** Enzymes can break down a variety of different substances.

**d.** An enzyme's shape is related to the shape of the substrate it binds to.

## MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

**Living things and the nonliving materials they use are all made of matter.**

**In chemical reactions, bonds are broken and new bonds are formed. Atoms are rearranged, but not created or destroyed.**

**Changes in matter keep living things alive and help them maintain homeostasis.**

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how matter changes during chemical reactions and how external conditions affect these changes.